Acta reunión Comité Operativo Norma de Emisión para termoeléctricas
Miércoles 24 de junio 2009
Inicio: 10:00 hrs.
Término: 13:00 hrs.

Temas:

1. Hans Willumsen, Jefe del Dpto. Control de la Contaminación de CONAMA D.E., informa sobre ampliación de plazo para preparar el anteproyecto hasta diciembre 2009; e instruye al Comité Operativo sobre prioridad y urgencia para contar con el anteproyecto (Res. Ex. Nº 1005, del 25.02.09 que da plazo hasta el 26 de junio).

2. Hans Willumsen, Jefe del Dpto. Control de la Contaminación de CONAMA D.E., informa sobre gestión asociada al término anticipado de contrato con la consultora Ecofysvalgesta y al inicio de contratación Asociación KAS Ingeniería - P. Sanhueza.

3. Informa sobre actividades y avance en la formulación del anteproyecto. Se adjunta ppt realizada por Priscilla Ulloa, profesional de CONAMA D.E.

4. Exposición: Descripción del mercado eléctrico. Expositores: Samuel Jerardino, Carlos Barria. Consultores de KAS Ingeniería. Se adjunta exposición.

5. Próxima reunión miércoles 1º de julio. Temas: Evaluación de los beneficios de la norma de emisión para termoeléctricas. PhD Ingeniería Pedro Sanhueza.

Contacto en CONAMA D.E.:
Carmen Gloria Contreras Fierro
cgcontreras@conama.cl
fono:240 5772
..//

GOBIERNO DE CHILE
CONAMA

"COMITÉ OPERATIVO DE NORMA DE EMISION PARA TERMOELECTRICAS"

FECHA : 24/06/2009
HORA INICIO : _____
HORA TÉRMINO: _____
LUGAR : Sala de Reuniones 4° piso - Teatinos 258

N°	NOMBRE	INSTITUCION	DIRECCION	FONO	E-MAIL
1.	OLGA Espinoza M.	SAG	Paseo Bulnes 140 piso 5°	345-1535	olga.espinoza@sag.gob.cl
2.	PAULINO GONZALEZ	KAS	VESPUCIO NORTE 1101	2632090	pgonzalez@gmail.com
3.	Carmen G. Contreras	CONAMA			cgcontreras@conama.cl
4.	Carolina Gómez A	CNE	Alameda 1449 piso 14 Stgo Downtown II	3656876	cgomez@cne.cl
5.	Danilo Zurita	CNE	Alameda 1449 piso 13 Stgo Downtown II	3656854	DZURITA@CNE.CL
6.	Claudio Bonacic	Conama		2411880	cbonacic@conama.cl
7.	SANDRA BRICEÑO	CONAMA		2411878	sbriceno@conama.cl

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N°	NOMBRE	INSTITUCION	DIRECCION	FONO	E-MAIL
8.	HANS WILLUMSEN	CONAMA			
9.	Germán Oyola	CONAMA Biobío	Lincoyán 145	41-2791750	goyola.8@conama.cl
10.	Ingrid Henríquez	CONAMA		2405698	ihenriquez@conama.cl
11.	TEO SAAVEDRA	MINVU		3513633	tsaavedra@minvu.cl
12.	Camila Montes M.	CONAMA.		24056407	cmontes@conama.cl.
13.	Marcela Geraudino	KAS Ingeniería		2232346	marcela.geraudino@kasing.cl
14.	Priscilla Ulloa	CONAMA	Teatinos 258.	2405787	pulloa@conama.cl
15.	Marcela Fernández	KAS Ingen			marcela.fernandez.rojas@gmail.com
16.	Carlos Banú	KAS Ing.		2232346	carlos.banu@kasing.cl
17.	Saul Jerardino	KAS Ing			
18.	Mª PIA BAVO	KAS		2232346	
19.	WALTER FOLCH	MINSAL		5740787	wfolch@minsal.cl
20.	PEDRO SANTIBAÑEZ	GEOAINE		2093838	geoaine@gmail.com
21.	CRISTIAN UTHURTIA	CONAMA		41-2791750	curuntia.8@conama.cl

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Resumen de actividades realizadas a la fecha para apoyar el diseño regulatorio

CONAMA D.E. Dpto. Control de la Contaminación

Priscilla Andrea Ulloa Menares

Carmen Gloria Contreras Fierro

24 Junio, 2009

Actividades:

1. **Visitas técnicas a centrales termoeléctricas**
   - Guacolda
   - Renca – Nva. Renca
   - Ventanas
   - Petropower
   - Bocamina
   - Laguna Verde
   - Norgener (en el contexto de la formulación del PDA Tocopilla)
   - Electroandina (en el contexto la formulación del Tocopilla)

2. **Entrevistas técnicas con distribuidores de equipos de abatimiento**
   - MITSUBISHI (26.02.09).
   - ALSTOM. desulfurización con agua de mar (19.03.09).
   - PENTOL (30.03.09). Acondicionamiento del flujo de gas (FGC, sigla en inglés), reduce particulado al inyectar SO3, disminuyendo la resistividad de las partículas.
   - AEE Lentjes (18.06.09) abatimiento de SO2 (desulfurizador) y NOx (SCR).

3. **Entrevista y seminario a empresa Ambiente y Tecnología, presta servicios de medición de emisiones continuas en chimenea (22.05.09) (4 empresas en el mercado)**

Actividades:

4. Se ha establecido contacto con el Banco Mundial – IFC (Corporación Financiera Internacional del BM), con el fin de conocer fundamentos técnicos y financieros de la Guía para plantas de energía térmica (update dic.2008)

5. Se cuenta con minutas técnicas sobre (en elaboración):
   - Resumen de la normativa internacional
   - Análisis de proyectos presentados al SEIA (2006 al 2009)
   - Factibilidad y alternativas de regulación de metales: Hg – V - Ni

6. En proceso de elaboración de versión 03 de anteproyecto

Visita técnica Ventanas (V Región)

Priscilla Ulloa/Carmen Gloria Contreras (15.04.2009)

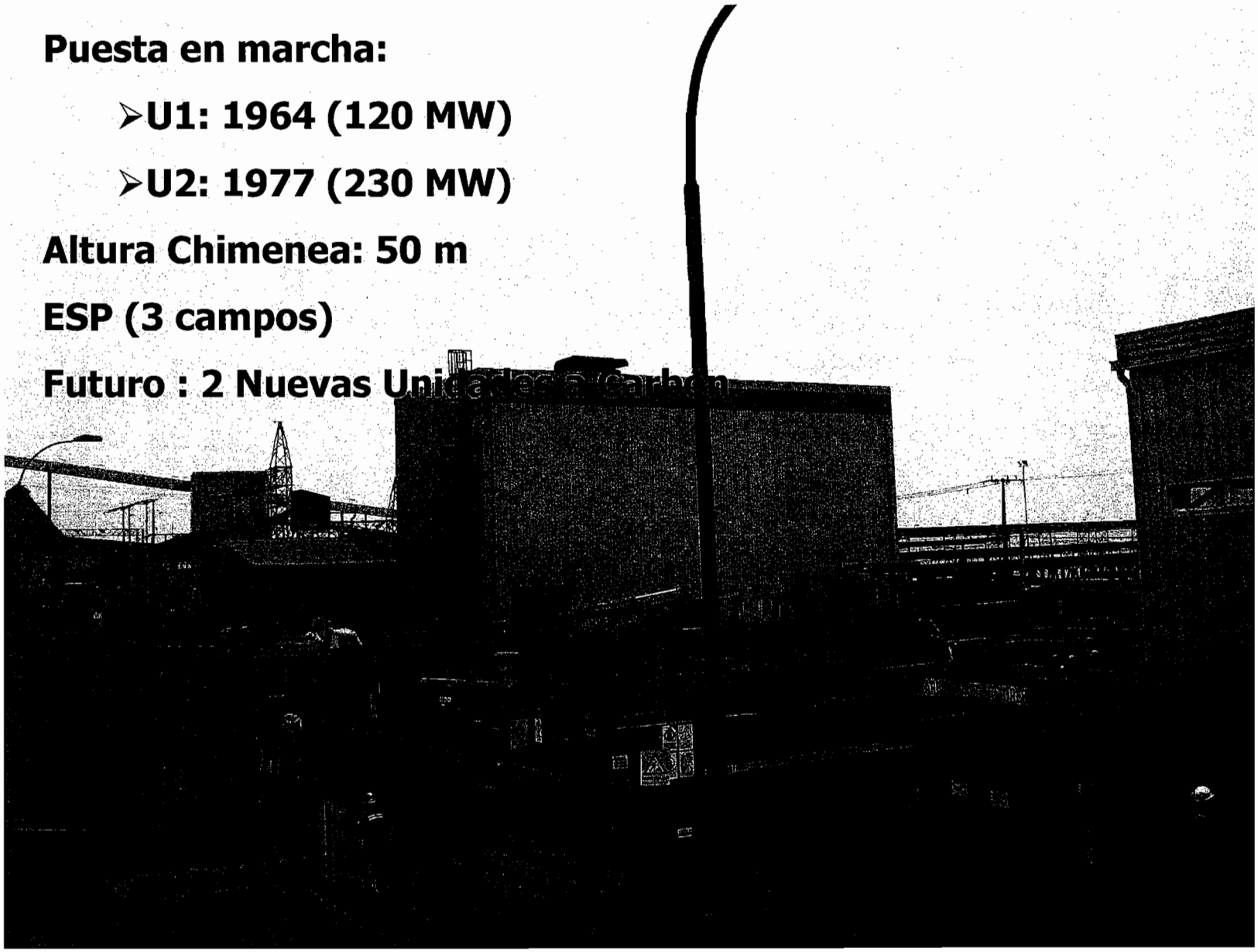
Puesta en marcha:

- **U1: 1964 (120 MW)**
- **U2: 1977 (230 MW)**

Altura Chimenea: 50 m

ESP (3 campos)

Futuro : 2 Nuevas Unidades a Carbón



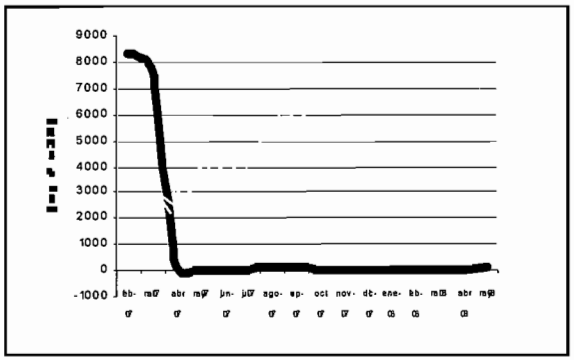
Visita Ventanas

Priscilla Ulloa/Carmen Gloria (15.04.2009)

Visita Bocam

Priscilla Ulloa/Carmen G. Contreras

- Puesta en marcha: Junio 1970
- Tecnología
  - Turbina a Vapor 128 MW
  - Incorpora quemador tangencial.
- 2 Unidades a Carbón (1 Construcción 350 MW - Costo Desulfurizador 50 a 60 MMUS)



Emisiones U1

MP: 50 mg/m3-N (antes sobre 7.000 mg/m3-N)

NOx: 300 mg/m3-N

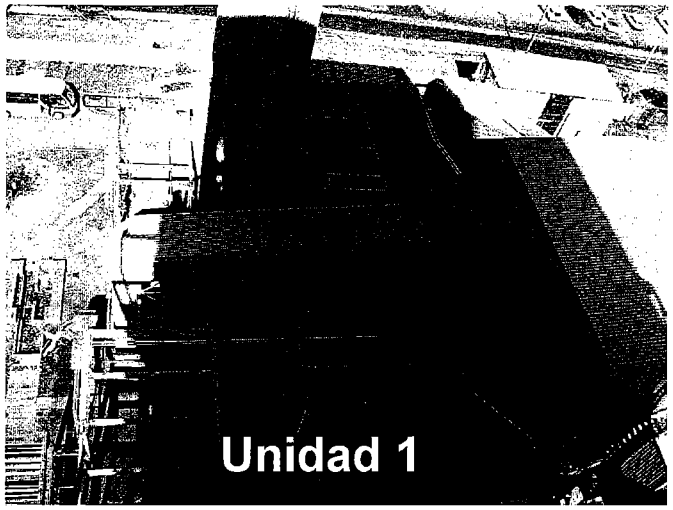
Altura Chimenea: 55 m

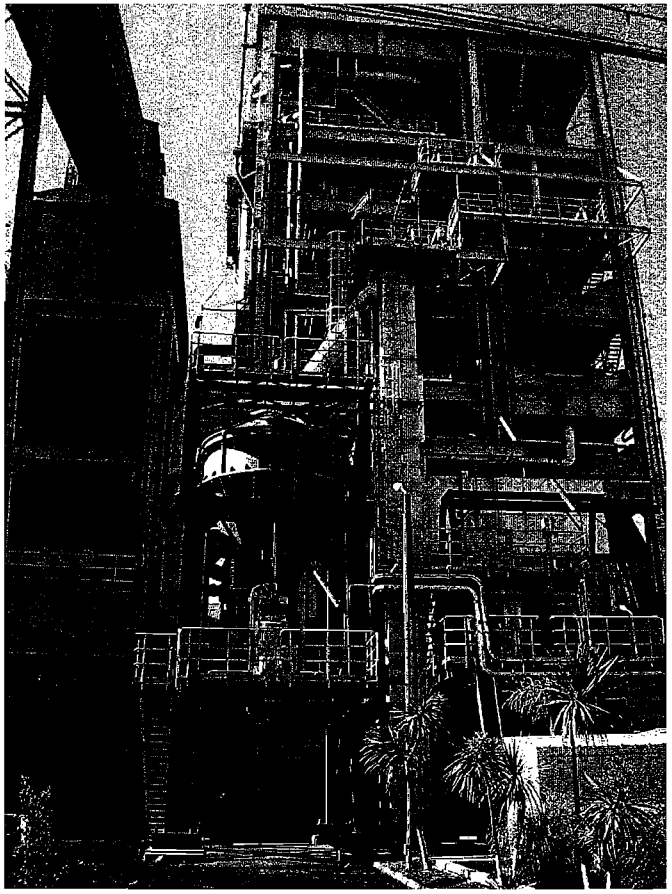
Filtro de mangas

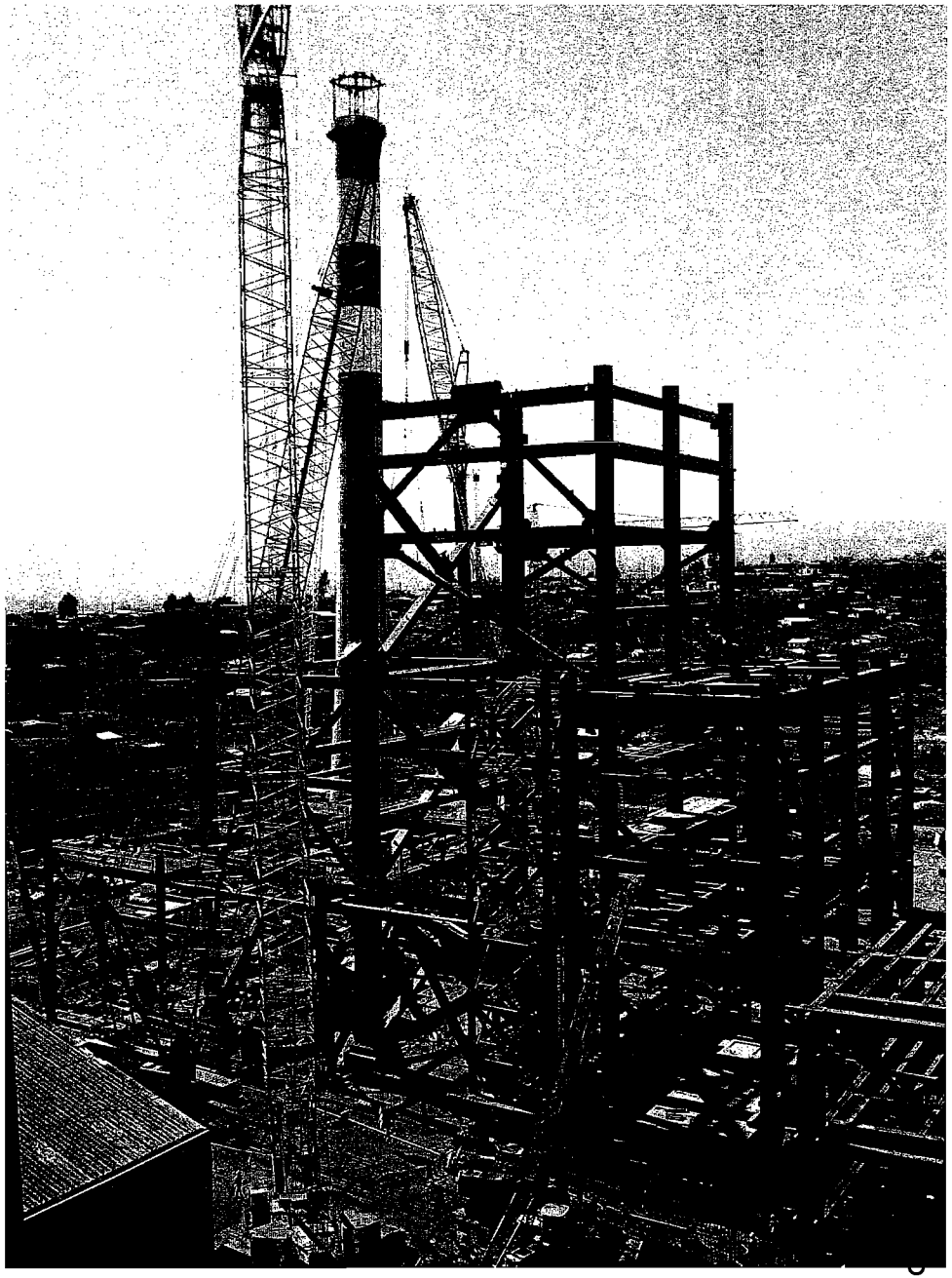
- **7 MM $US**
- **2.400 mangas (1 manga $US 85-90)**

Duración:

- **Proyecto de Ingeniería 7 meses**
- **Conexión 8 días**



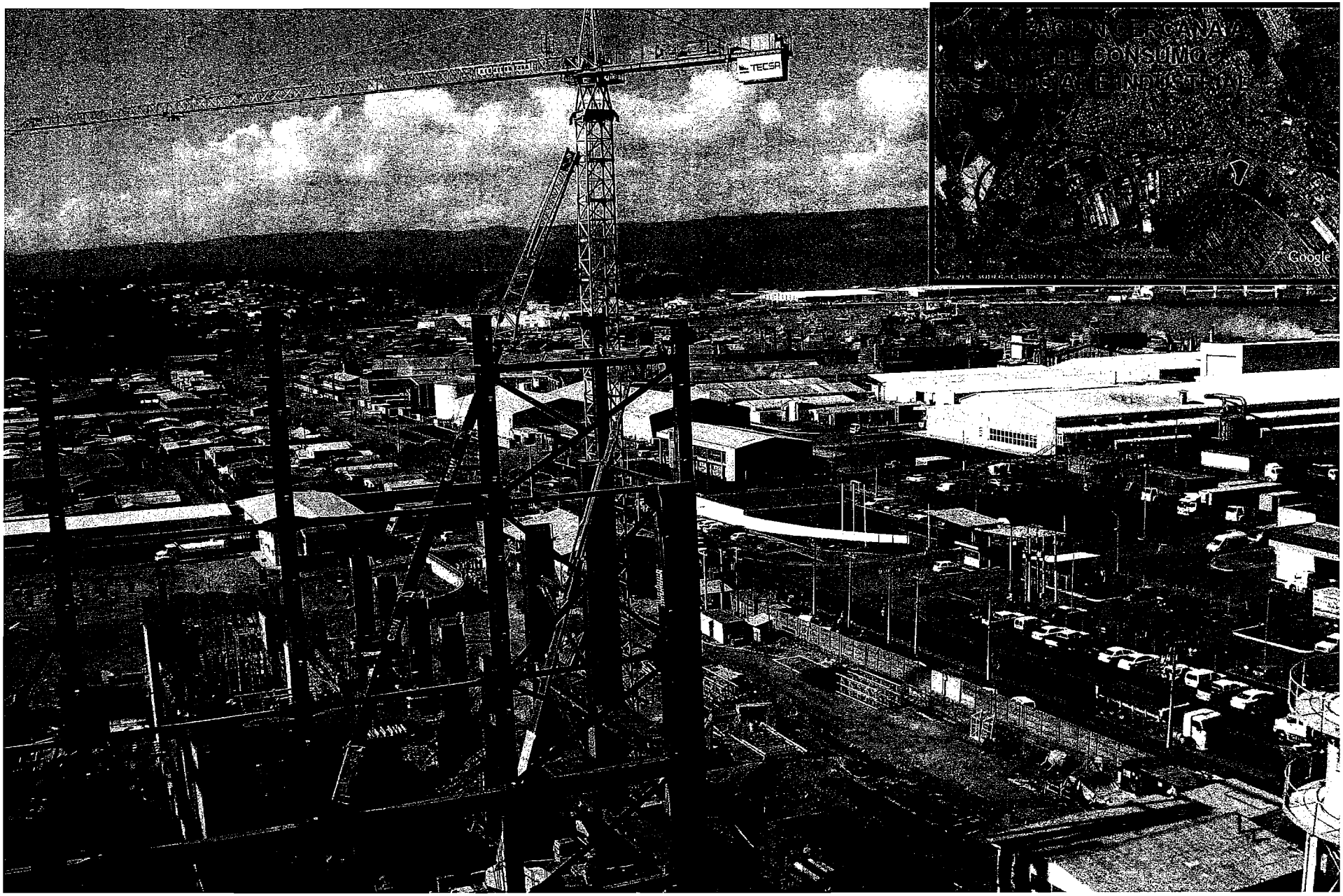




Construcción nueva unidad

Vista panorámica desde la Central:

La central se localiza cercana a centros de consumo (urbano y industrial)



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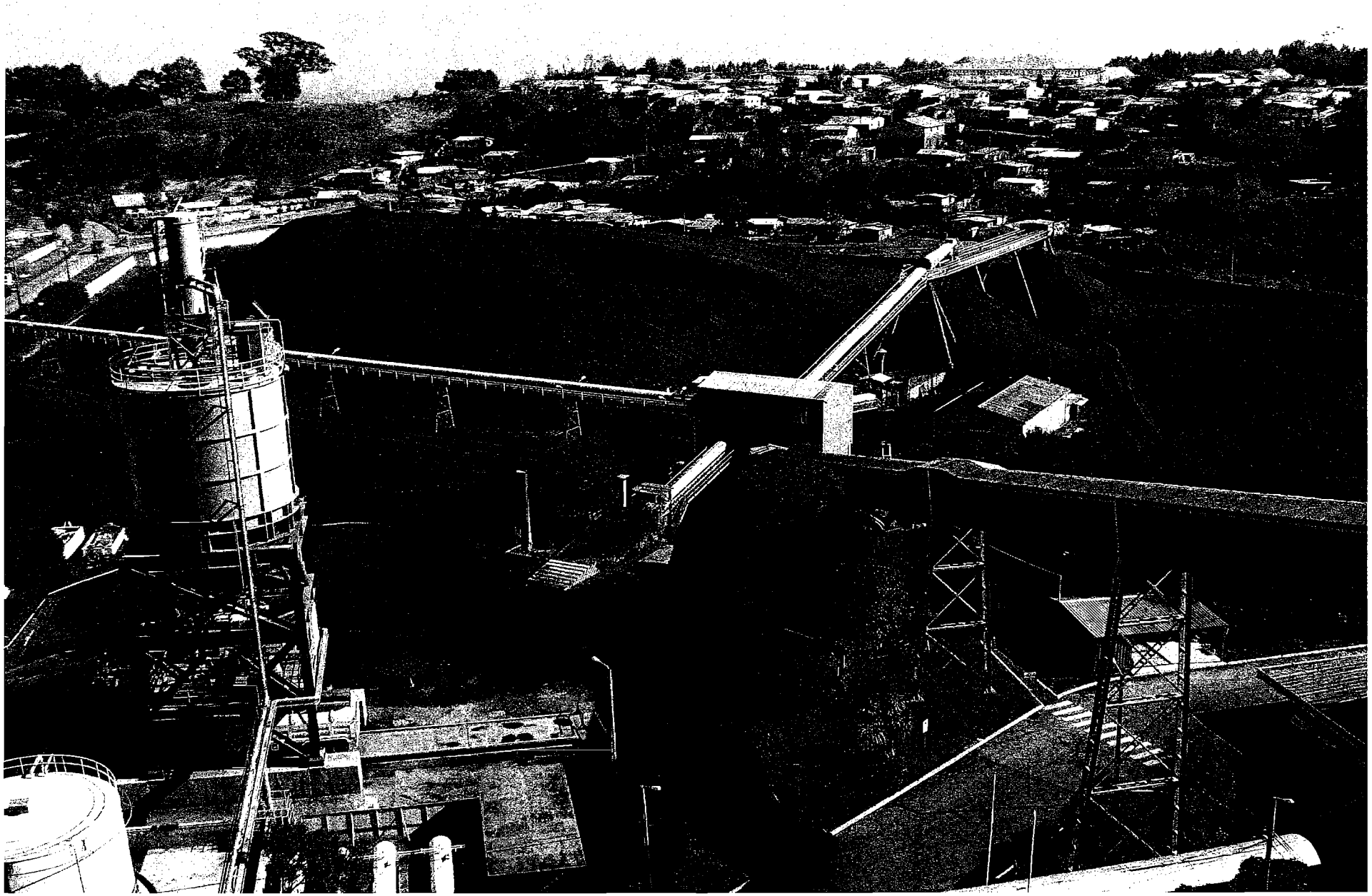


Petropower

Priscilla Ulloa/Carmen G. Contreras (23.04.2009)

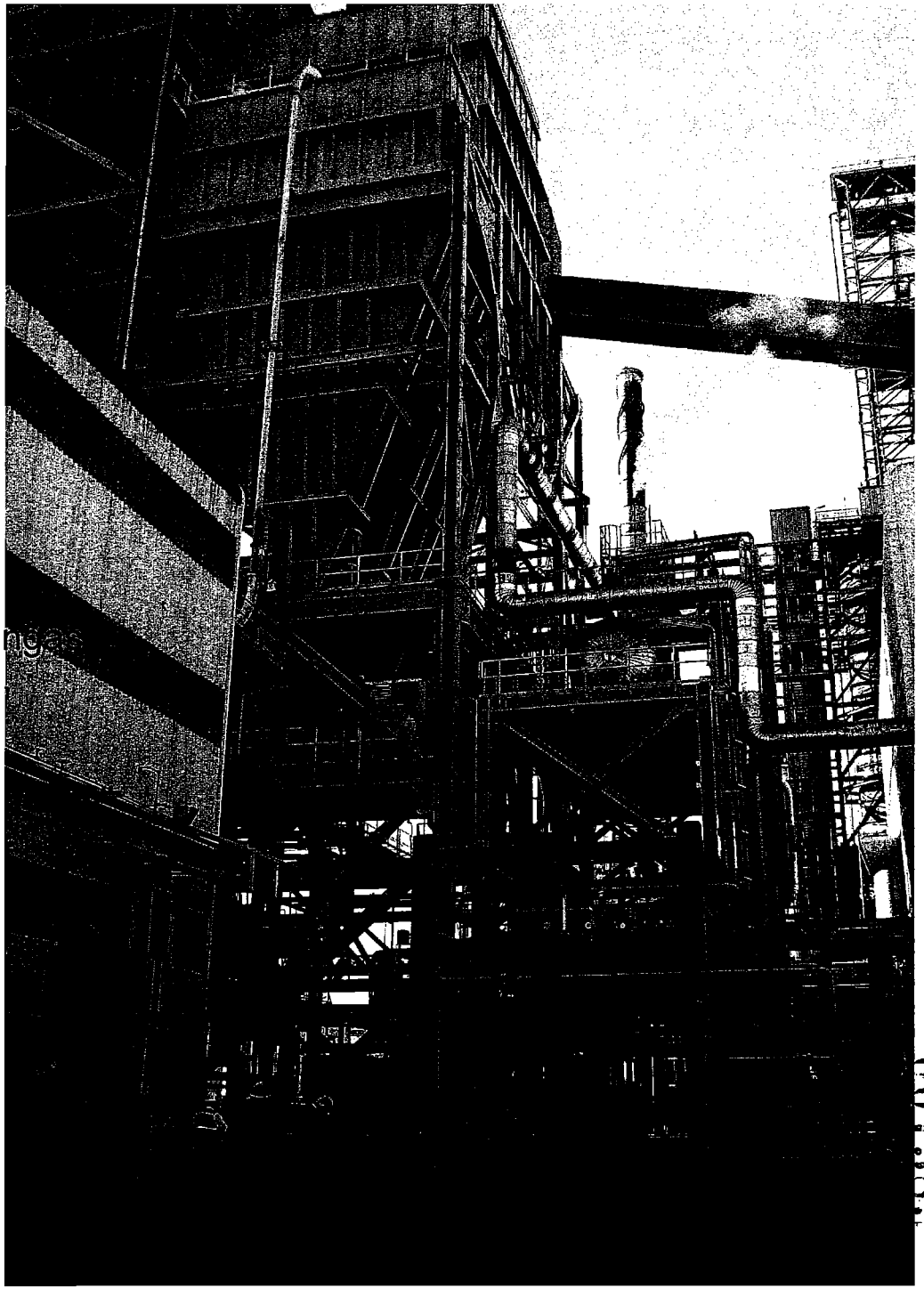
- Puesta en marcha: 1998
- Tecnología: Lecho Fluidizado
- Potencia Bruta: 74 MWe
- Unidad a PetCoke
- Equipo de Abatimiento
  - Filtro de Mangas, ŋ=99,6%, 3.240 mangas

Emisiones:

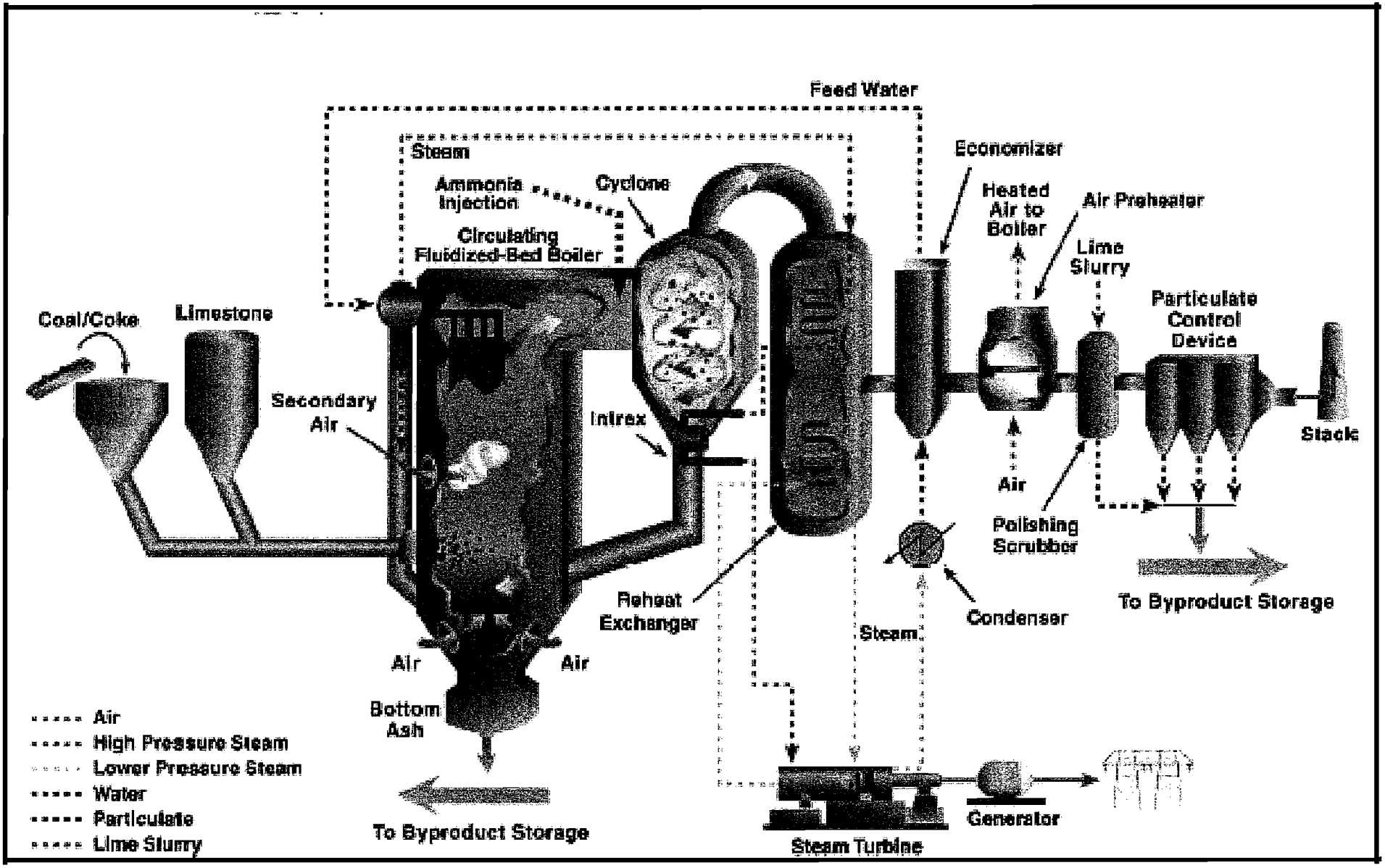
NOx: 30 ppm (máx. 50 ppm)

SO2: 0,4 mg/m3-N (máx. 150 mg/m3N)

MP : 2,9 mg/m3 (registrado en la visita s/normalizar)



Lecho Fluidizado Circulante



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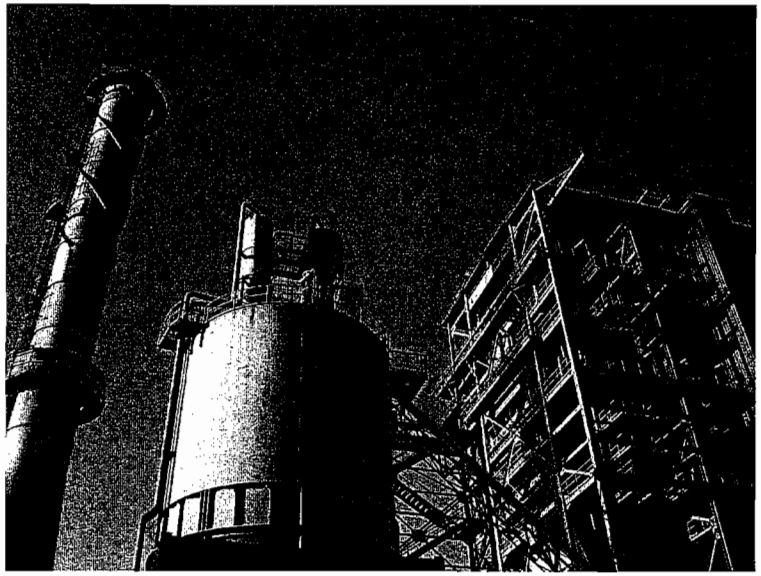
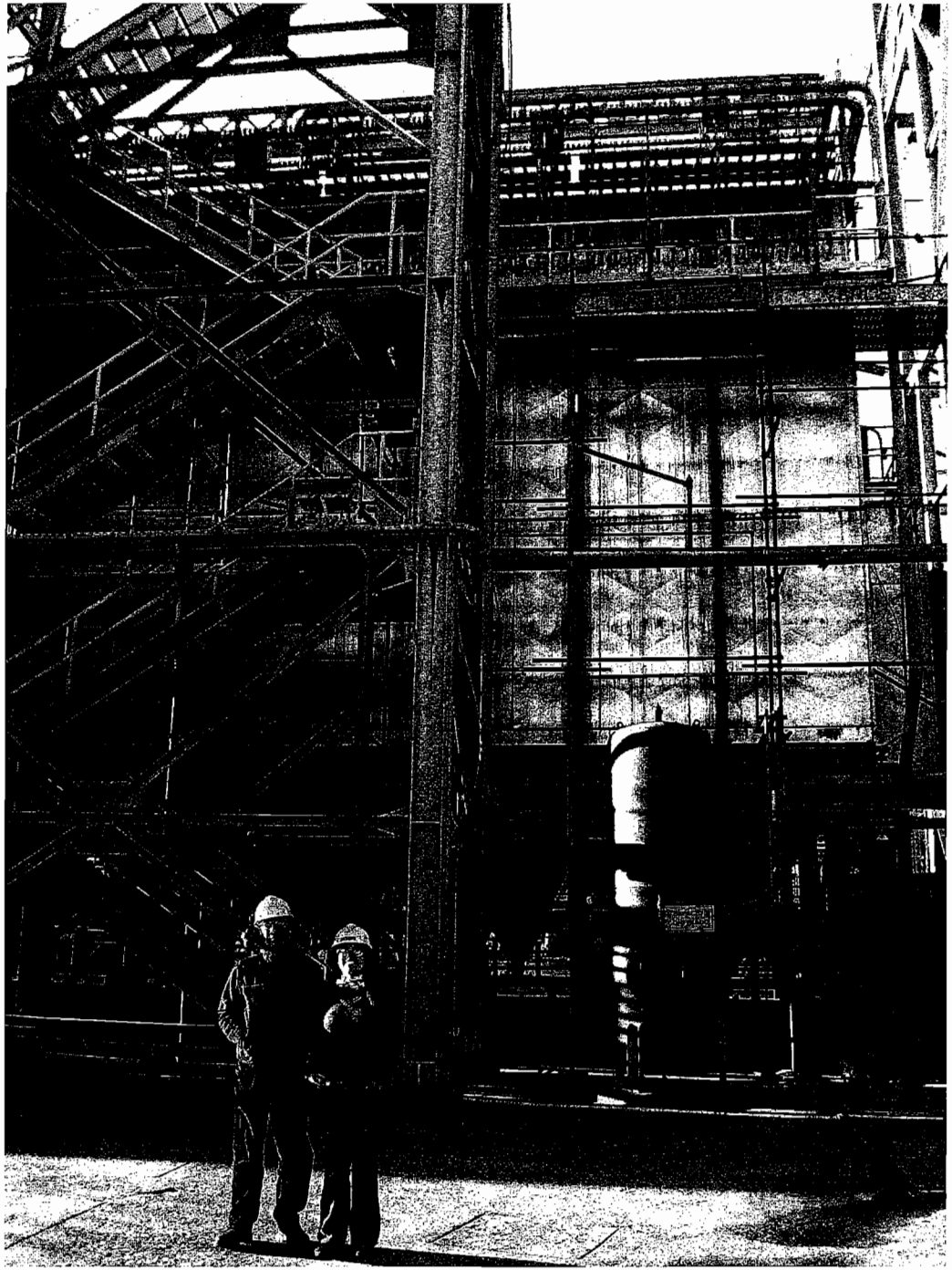
Petropower

Filtro de Manga

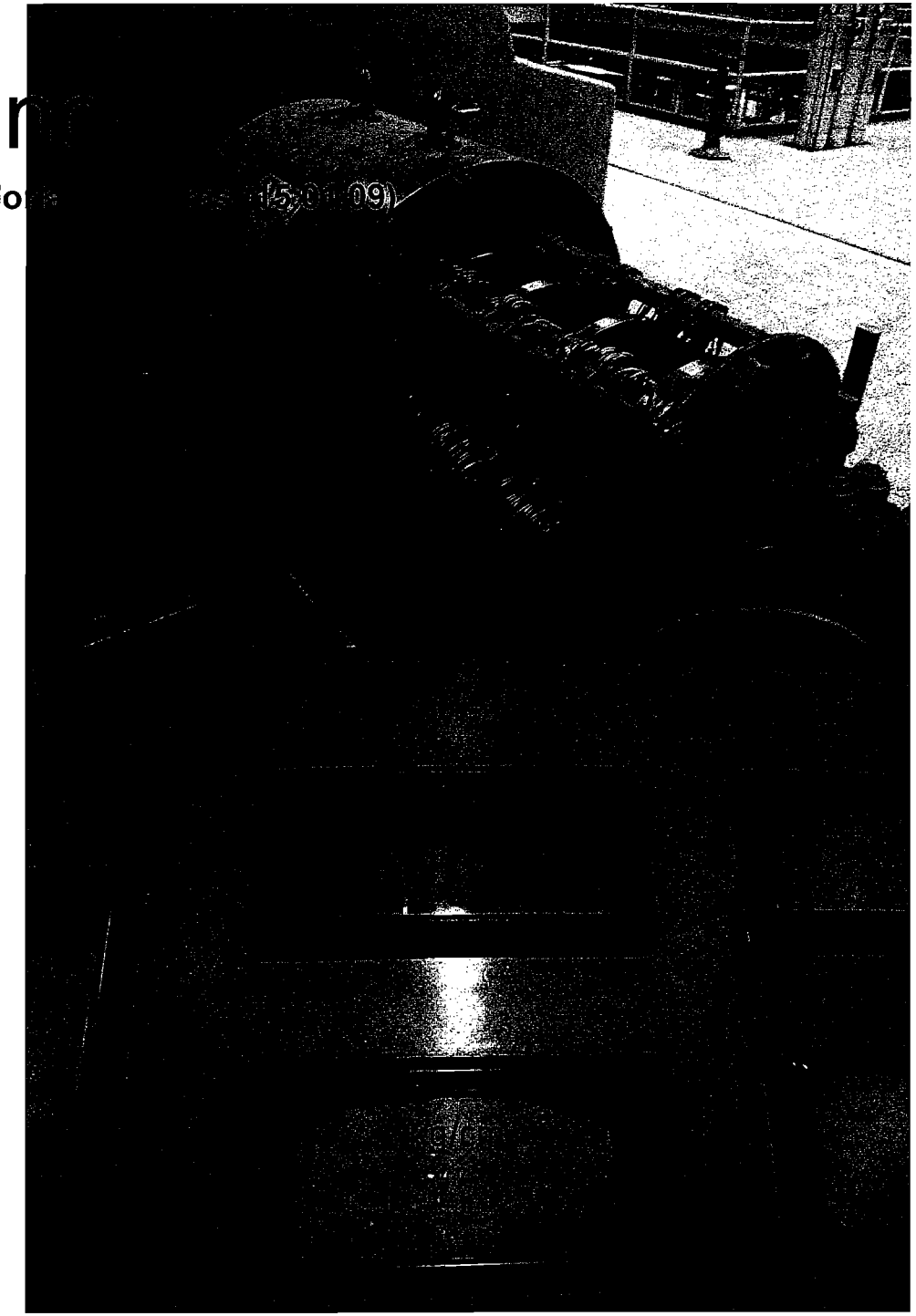




Visita Ren

Priscilla Ulloa (07.05.2009) - Carmen Glo

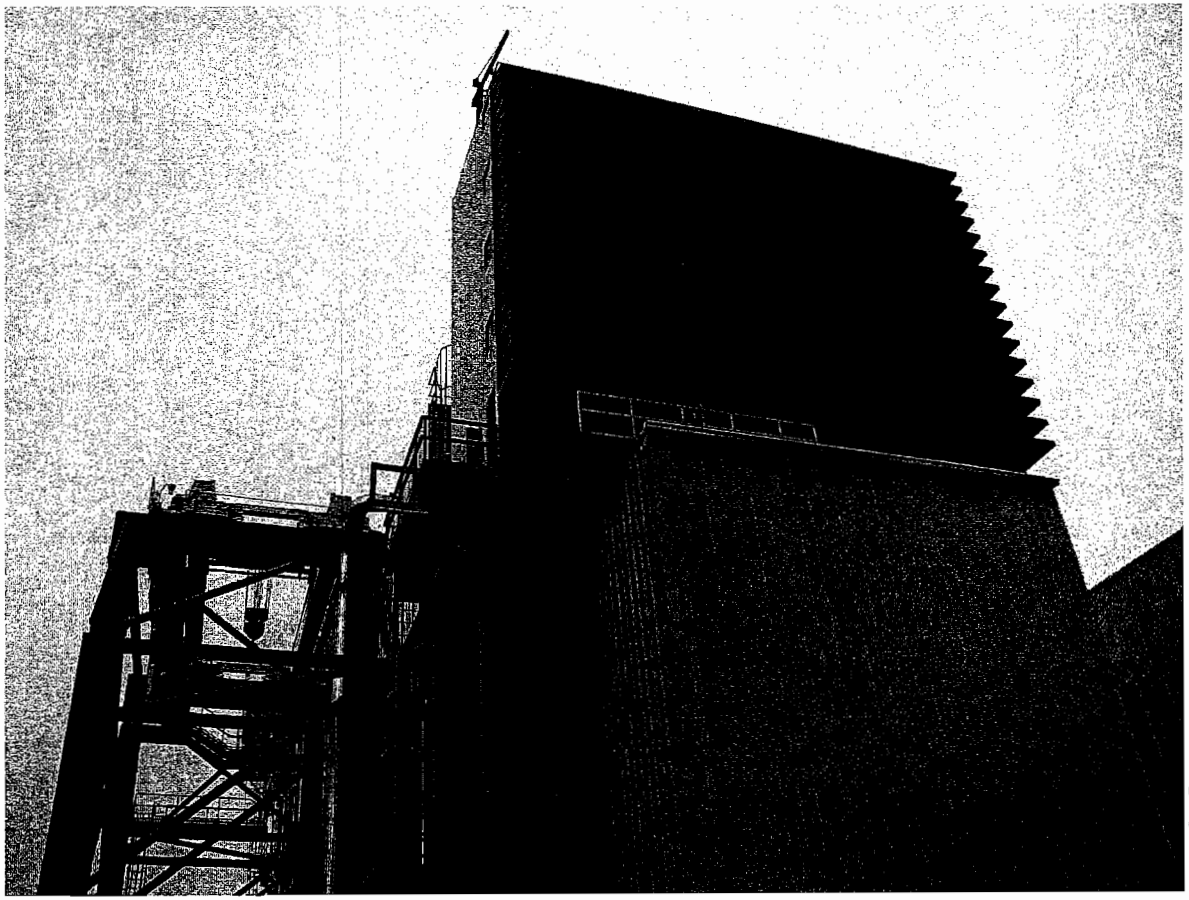
- Año puesta en servicio: 1962
- Turbina a Vapor
- Diesel Premium
- 2 unidades
- Potencia 100 MW
- Tiempo de Encendido: 24 horas



Visita Nueva Renca

Priscilla Ulloa (07.05.2009)- Carmen Gloria Contreras (15.01.09)

- Año puesta en servicio: 1997
- Ciclo Combinado
- Diesel Premium
- 1 unidad
- Potencia 379 MW
- Emisión: 30 mg MP/m3



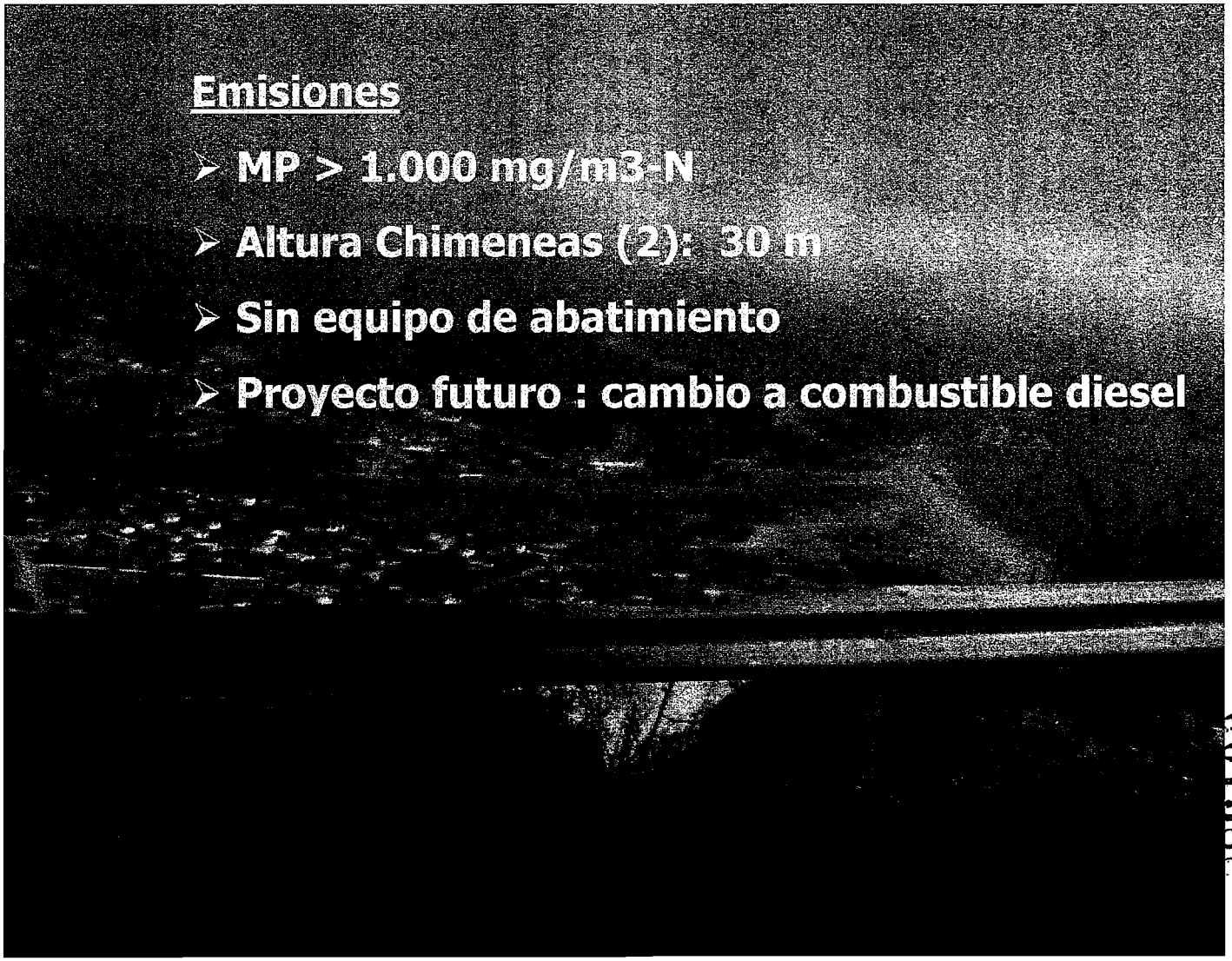
Visita Laguna Verde

Priscilla Ulloa (11.06.2009)

- Puesta en marcha:
  Unidad 1: 1939
  Unidad 2: 1949

- Tecnología
  - Turbina a Vapor (55 MW)
  - Parrilla Móvil

- Unidad a Turbina a Gas (1990):
  18 MW

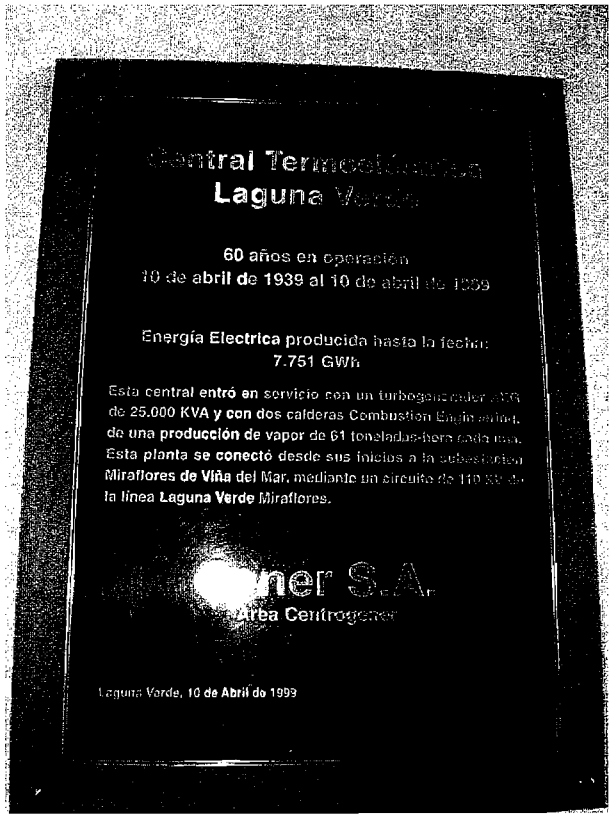


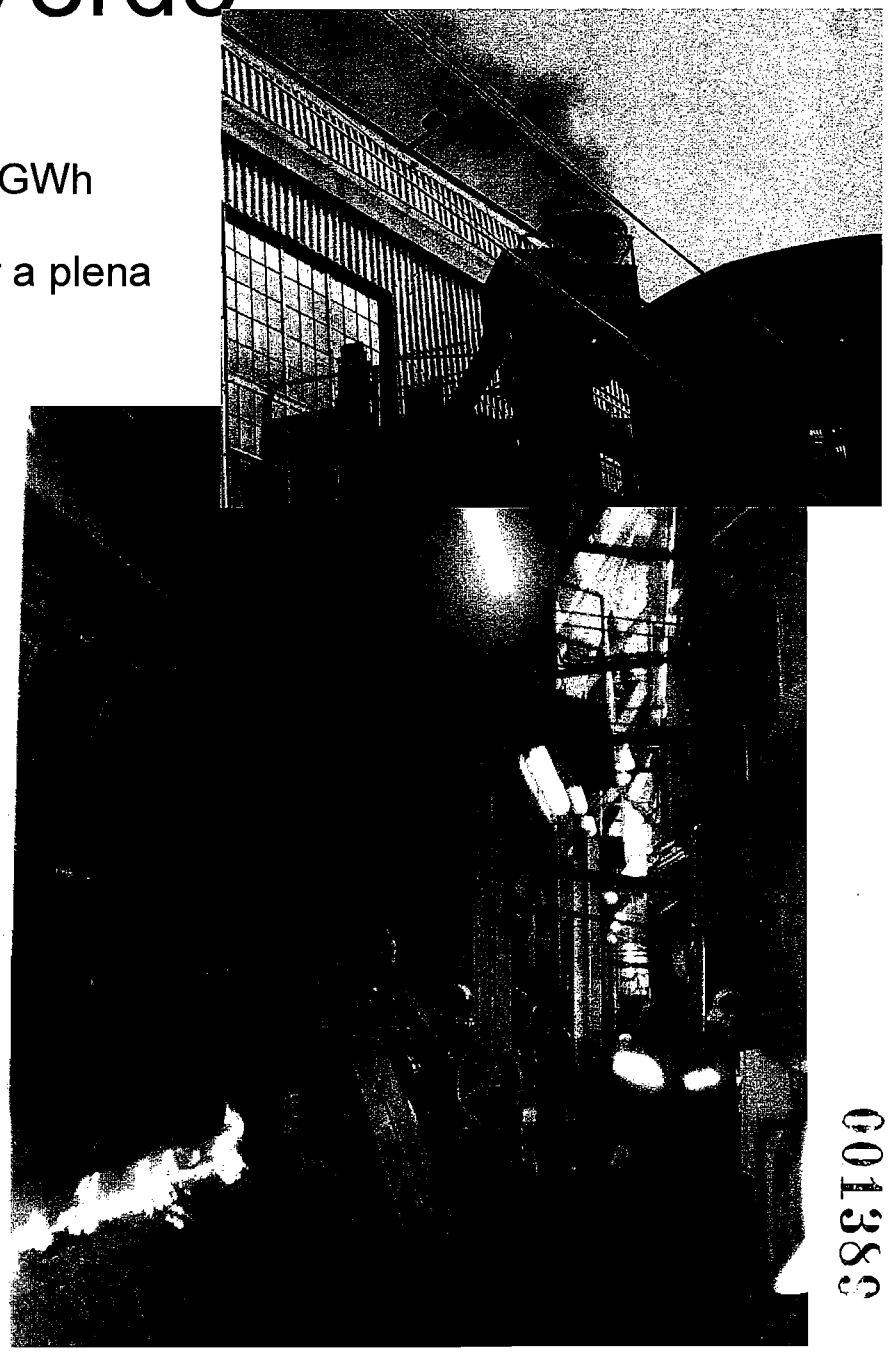
Visita Laguna Verde

Priscilla Ulloa (11.06.2009)

- Energía eléctrica producida hasta 1999: 7.751 GWh
- Tiempo de encendido hasta el despacho: 36 hr a plena carga + 5 hr para sincronizar c/la turbina (*)
- Mínimo Técnico: 5 MW

(*) Fuente: Información entregada por el operador de planta.

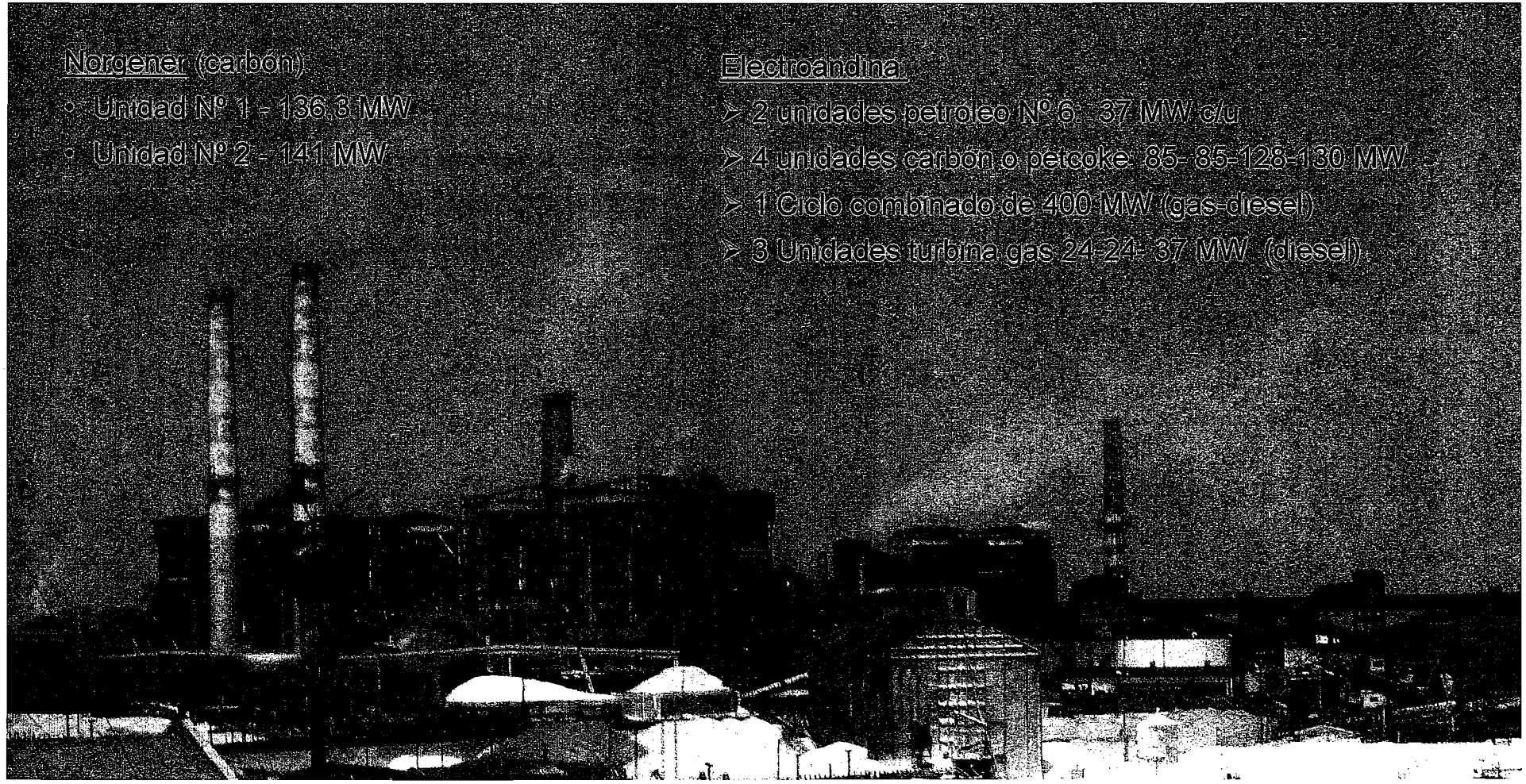




Visita Termoeléctricas Tocopilla

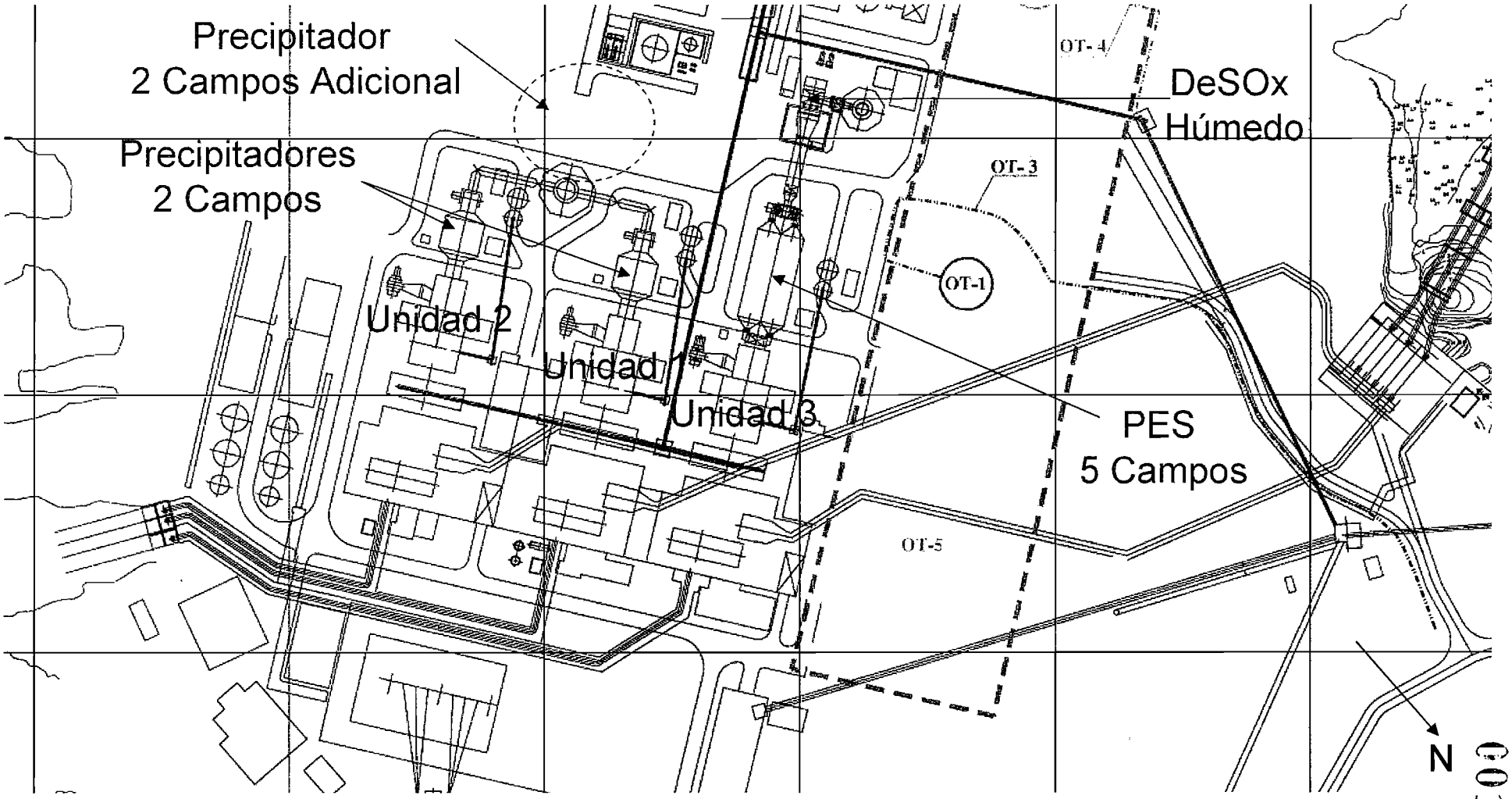
Carmen Gloria Contreras (19.11.2008)

- Ambas empresas cuentan con ESP (unidades a carbón)
- Se sabe que los ESP de Electroandina no son óptimos (Memoria 2008)
- Se constata diferencias y discrepancias entre los resultados de los muestreos isocíneticos de ambas empresas (P. Sanhueza, Dic. 2008).



Visita Guacolda

Camilo Montes (12.08) - Carmen Gloria Contreras (01.2008)

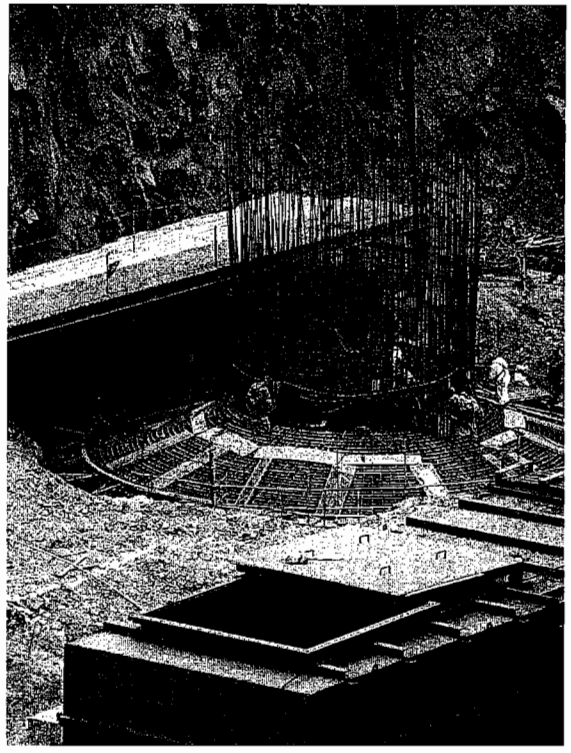


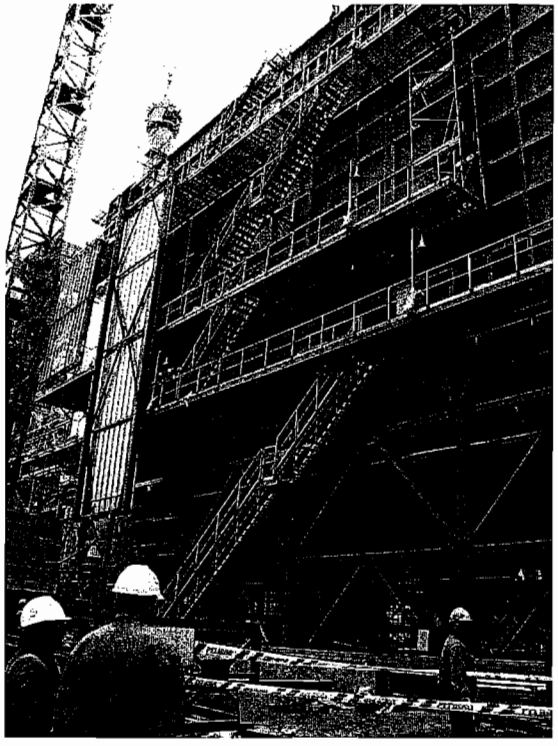
Visita Guacolda

Camilo Montes (12.08) - Carmen Gloria Contreras (01.2008)

Precipitador Electroestático de 5 Campos MP = 39 mg/m3

Control de NOx con Sistema SCR y quemadores de bajo NOx (Low NOx) **NOx = 46 mg/m3**





Descripción Mercados Eléctricos en Chile

Presentación de Kas Ingeniería preparada para CONAMA, en el marco del estudio" Análisis General del Impacto Económico y Social de una Norma de Emisión para Termoeléctricas"

GOBIERNO DE CHILE
COMISIÓN NACIONAL
DEL MEDIO AMBIENTE

KAS Ingeniería, Brown Norte # 694, Ñuñoa, Santiago, Chile
Tel: 56-2-2232346; E-mail: kas@kasing.cl

Santiago, Junio 2009

Contenidos

KAS INGENIERIA

Principales Características Sistemas Eléctricos Chile

KAS INGENIERIA

Total Chile : 13,137 MW

Sistemas Interconectados

3,602 MW
27.4%
SING

9,386 MW
71.4%
SIC

Sistemas Medianos

50 MW
0.4%
AYSEN

99 MW
0.8%
MAGALLANES

Clientes Regulados 10%

Grandes Clientes Industriales 90%

Clientes Regulados 55%

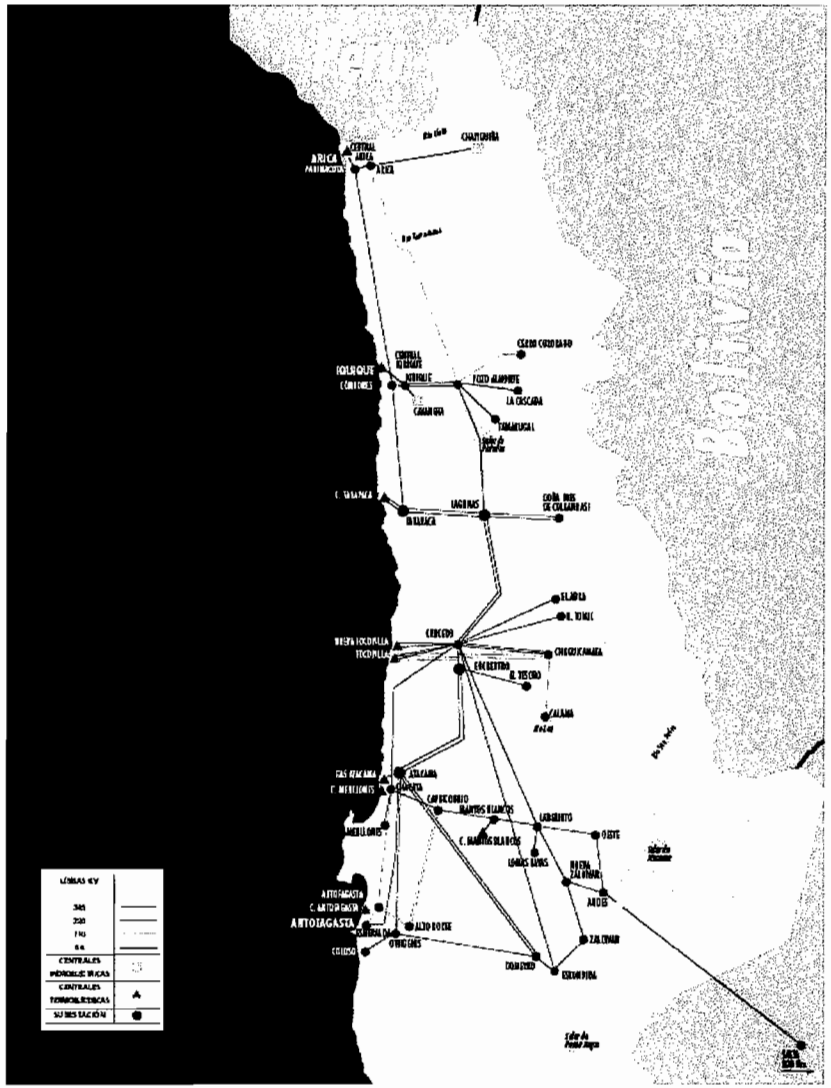
Grandes Clientes Industriales 45%

Clientes Regulados 100%

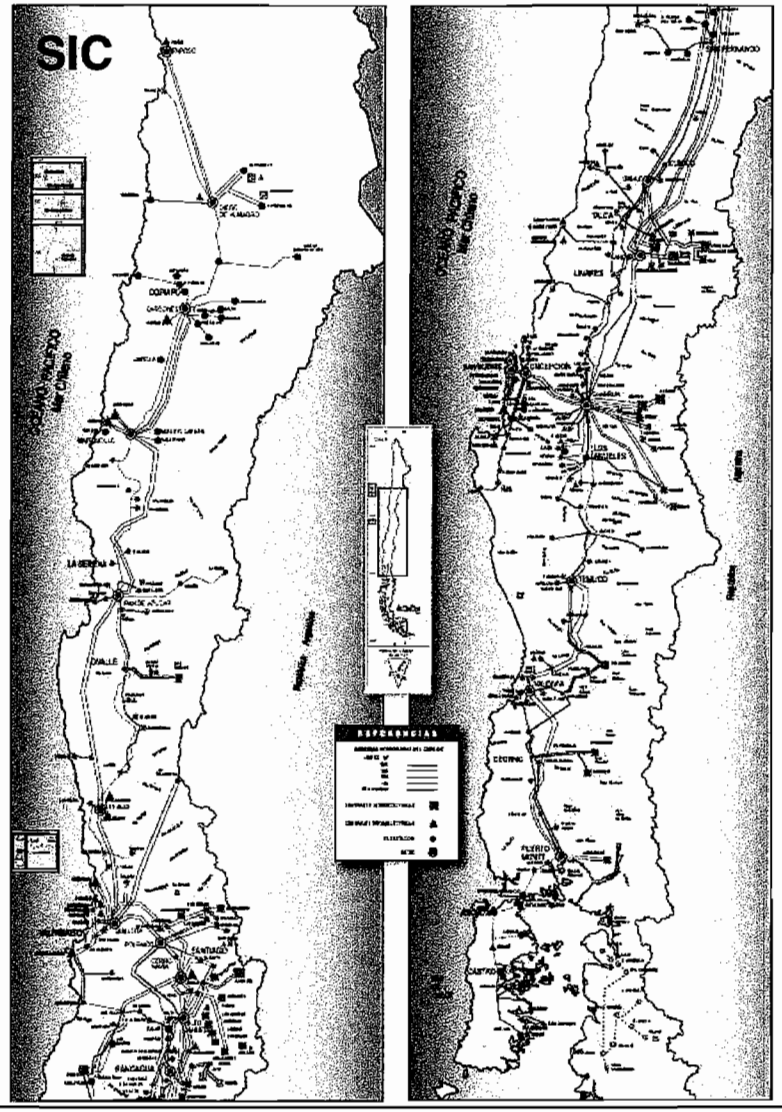
Clientes Regulados 100%

SING y SIC

KAS INGENIERIA



Fuente: HQI Transelec Chile S.A.

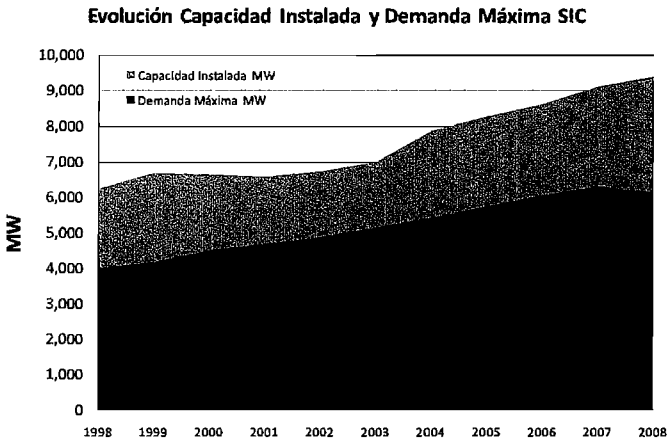


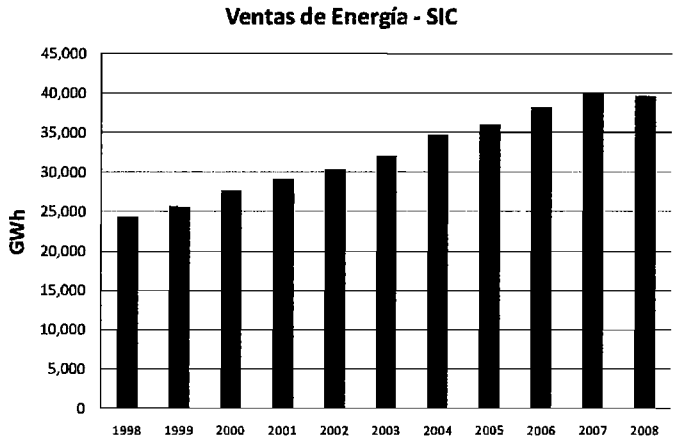
1. Principales Antecedentes

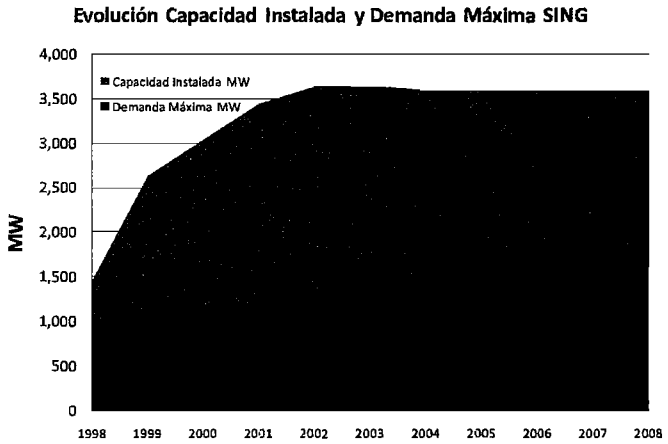
Demanda Eléctrica de Energía y Potencia

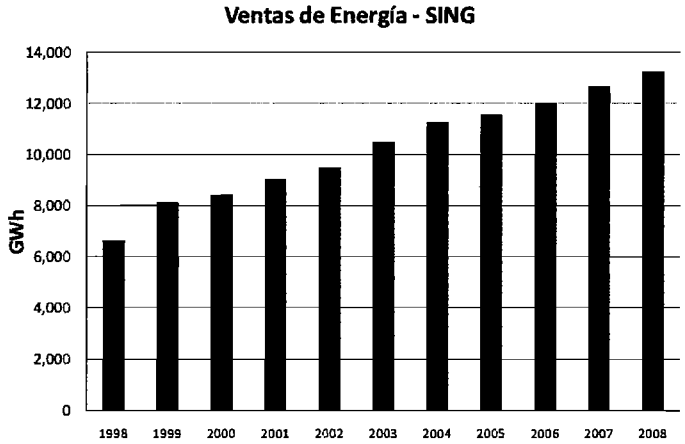
KAS INGENIERIA

Consumo Energía Eléctrica Chile (2008): 53,127 GWh
SIC: 74.5 %
SING: 24.9 %







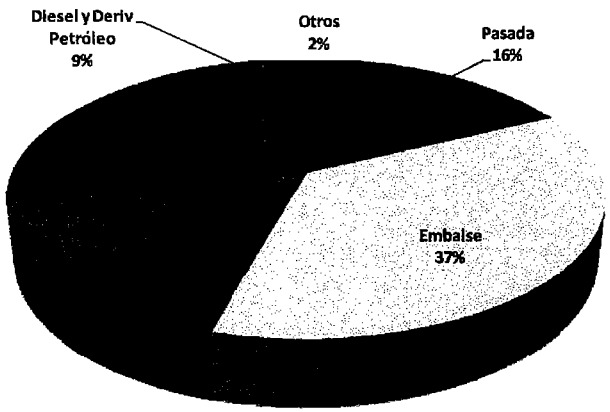


Fuente: CNE, KAS

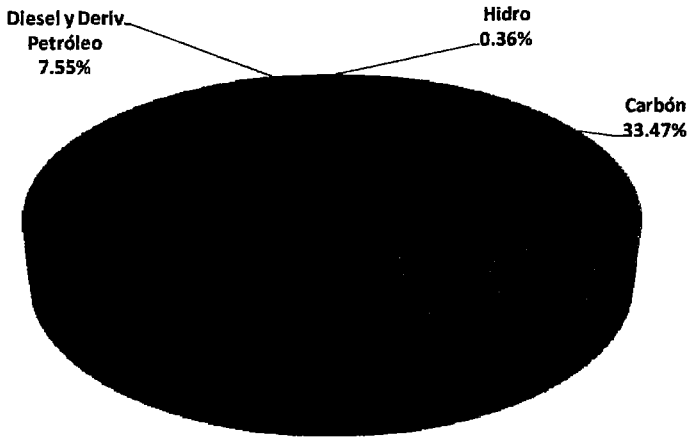
Matriz SIC y SING al 2008

KAS INGENIERIA

Potencia Instalada 2008 - SIC



Potencia Instalada 2008 - SING



Propiedad en el SIC

- Tres empresas poseen el 86 % de la capacidad instalada (reconociendo propiedad de cada una de las filiales)

Empresa	[MW]	Participación
AES Gener	1,564	16.67%
Colbún	2,195	23.39%
Endesa	4,307	45.89%
Arauco Generación	169	1.80%
Ibener S.A.	124	1.32%
Petropower S.A	75	0.80%
Pilmaiquén S.A	39	0.42%
Pullinque S.A.	49	0.52%
Otros	864	9.21%
Total	9,386	100%

Propiedad en el SING

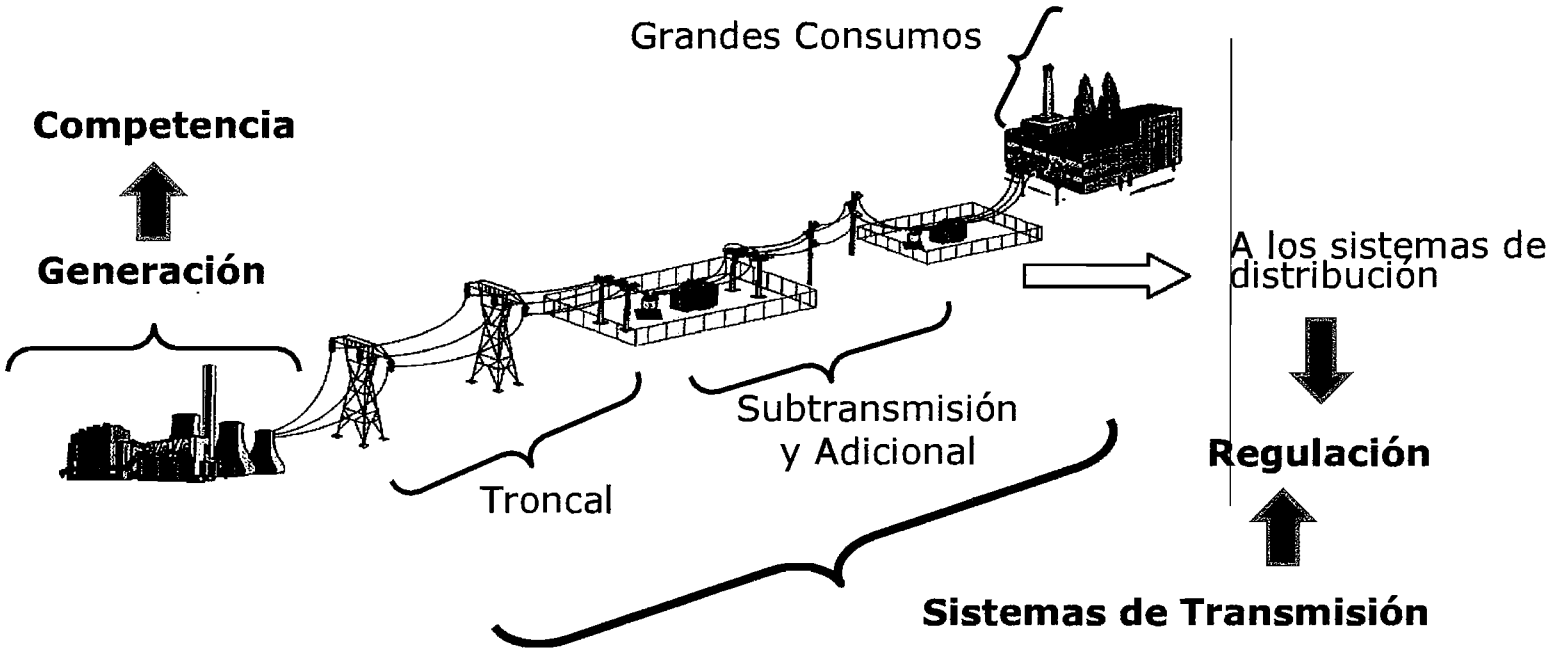
- Tres empresas poseen el 94 % de la capacidad instalada (reconociendo propiedad de cada una de las filiales)

Empresa	[MW]	Participación
Suez Energy	1,682	47%
AES Gener	920	26%
GasAtacama	781	22%
Celta	182	5%
Mantos Blancos	29	1%
Otros	9	0%
Total	3,602	100%

Fuente: CNE, KAS

Estructura Básica Mercado Eléctrico

KAS INGENIERIA



Estructura básica típica de mercados eléctricos a nivel mundial

- Generación: competencia entre generadores
- Transmisión: monopolio natural regulado (economías de escala), debe asegurar libre acceso a las redes, existe competencia ex ante (licitación de tramos troncales)
- Distribución: monopolio natural regulado (economías de ámbito) – tarifas según comparación y eficiencia

Evolución del Marco Legal

KAS INGENIERIA

1982 → **DFL N°1: Ley General de Servicios Eléctricos**

2004 → Ley Corta I : Ley N°19.940, Marzo 2004
- Transmisión Troncal y Subtransmisión
- CDEC, Servicios Auxiliares, NTSyCS
- ERNC

2005 → Ley Corta II : Ley N°20.018, Mayo 2005
- Procesos de subastas en distribución para contratos de suministro de largo plazo
- CDEC
- ERNC

DFL N°4, Febrero 2007 Nuevo texto completo para la Ley General de Servicios Eléctricos

2008 → **Ley ERNC: Ley N°20.057, marzo 2008**

Mercado de Generación Eléctrica

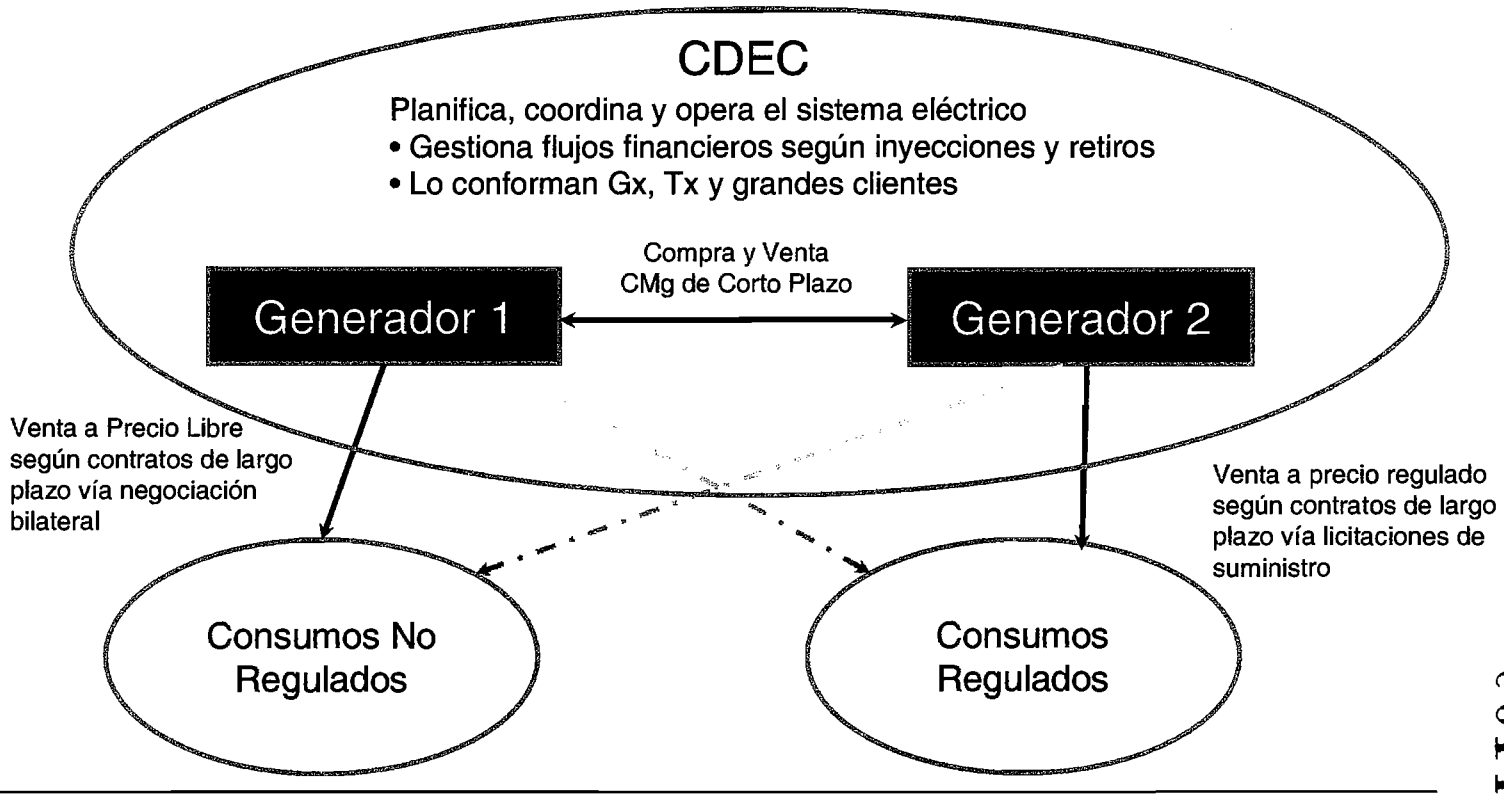
KAS INGENIERIA

Comercialización

- El segmento de generación fue concebido como un mercado competitivo
- Comercialización de Energía y Potencia de punta
- Contratos financieros de mediano o largo plazo
- Mercado abierto de corto plazo a CMg
- Remuneración de la potencia firme en base a precio de la potencia de punta

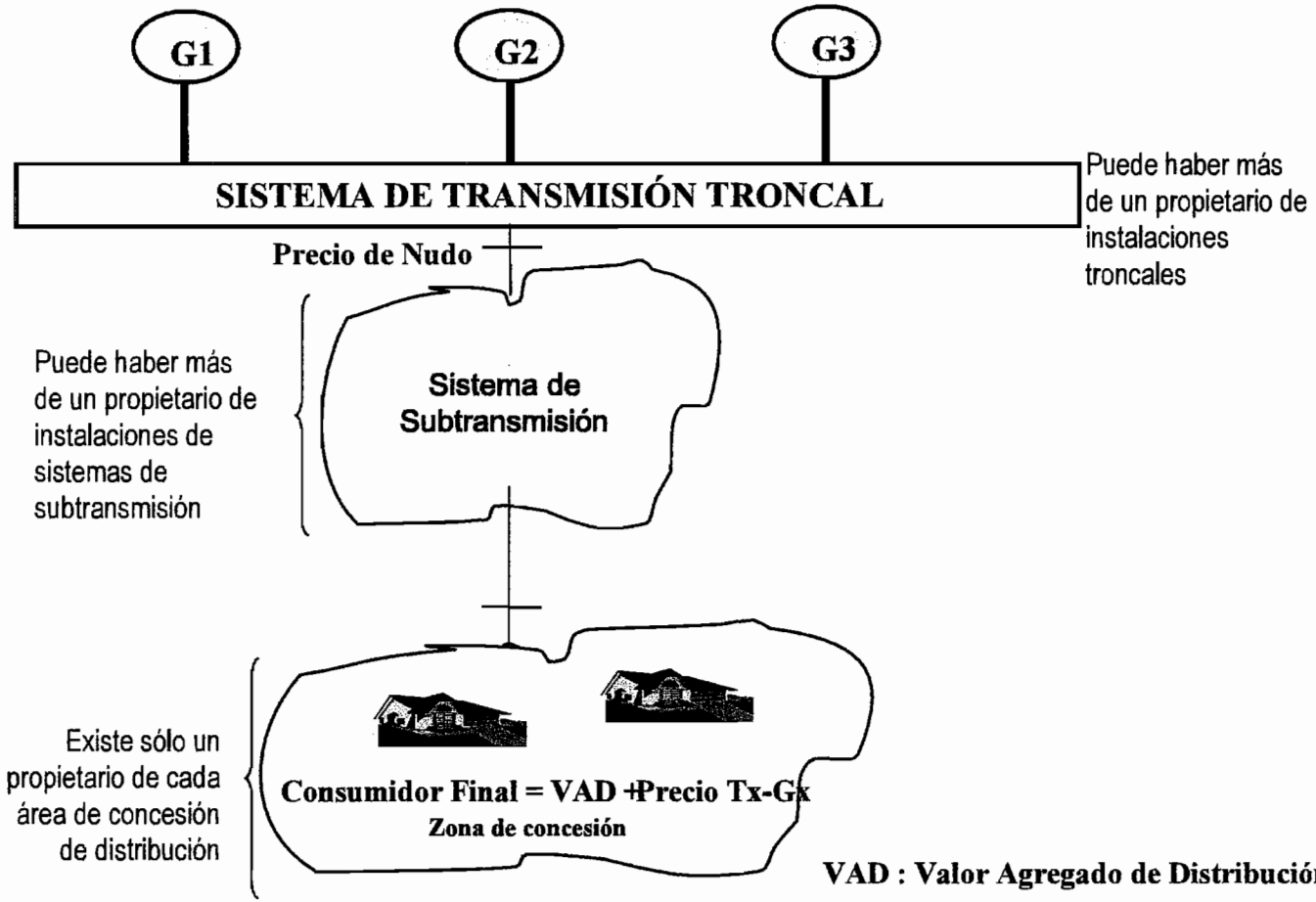
Operación

- CDEC opera centralizadamente a mínimo costo
- El despacho es obligado considerando restricciones técnicas del sistema
- Mantiene estádares de Seguridad y Calidad de Servicio



Estructura de Tarifas a Cliente Regulado

KAS INGENIERIA

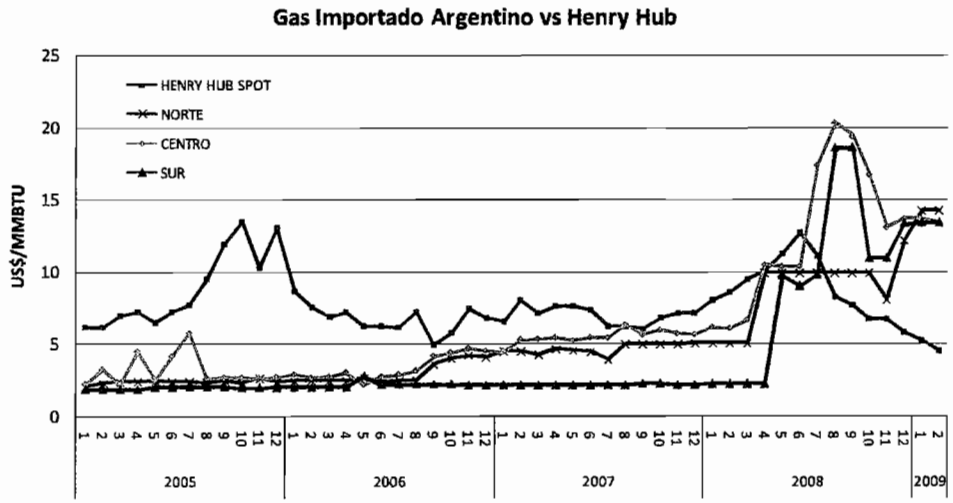


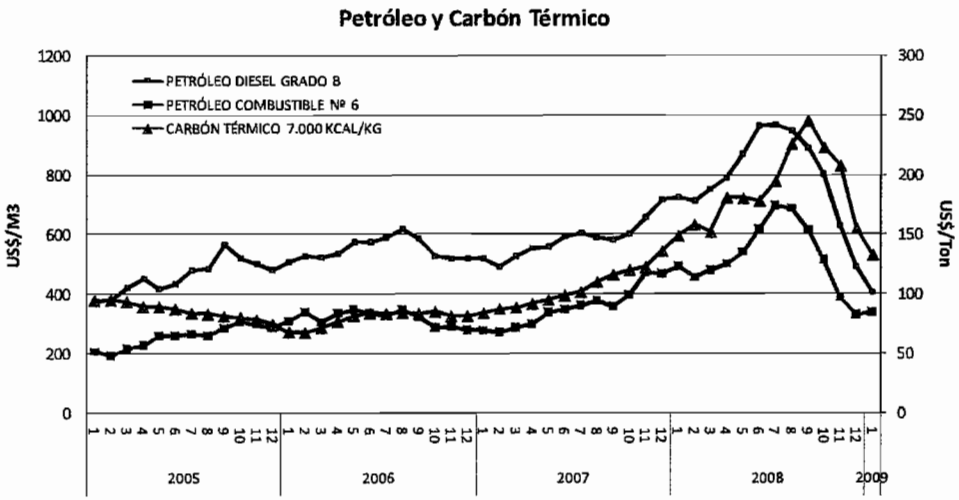
VAD : Valor Agregado de Distribución

Precio Tx-Gx: incluye costos de generación y transmisión

Precios de Combustibles

KAS INGENIERIA





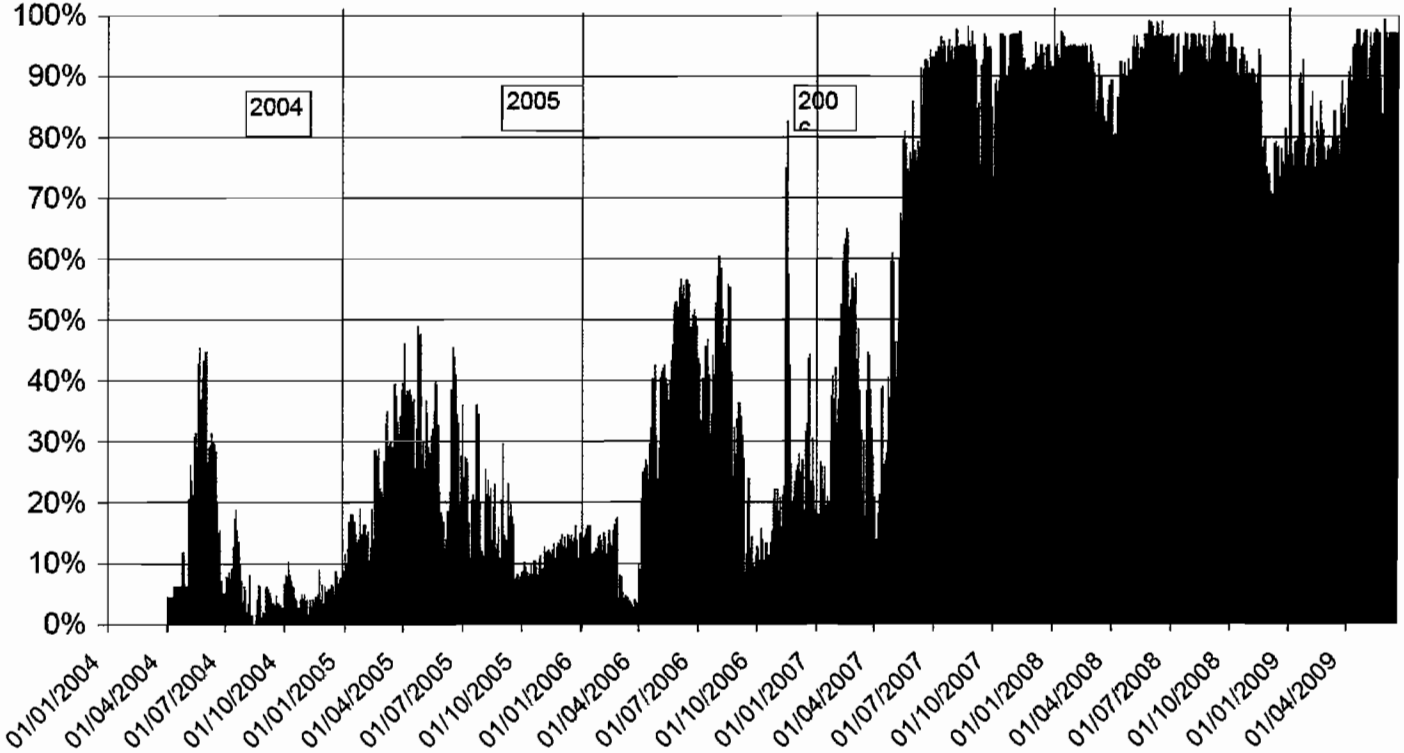
Fuente: CNE, KAS

•Sector Energético tiene amplia dependencia externa de combustibles

Restricciones de Gas Natural

KAS INGENIERIA

Restricciones de Gas desde Argentina
(en % respecto de requerimientos normales)

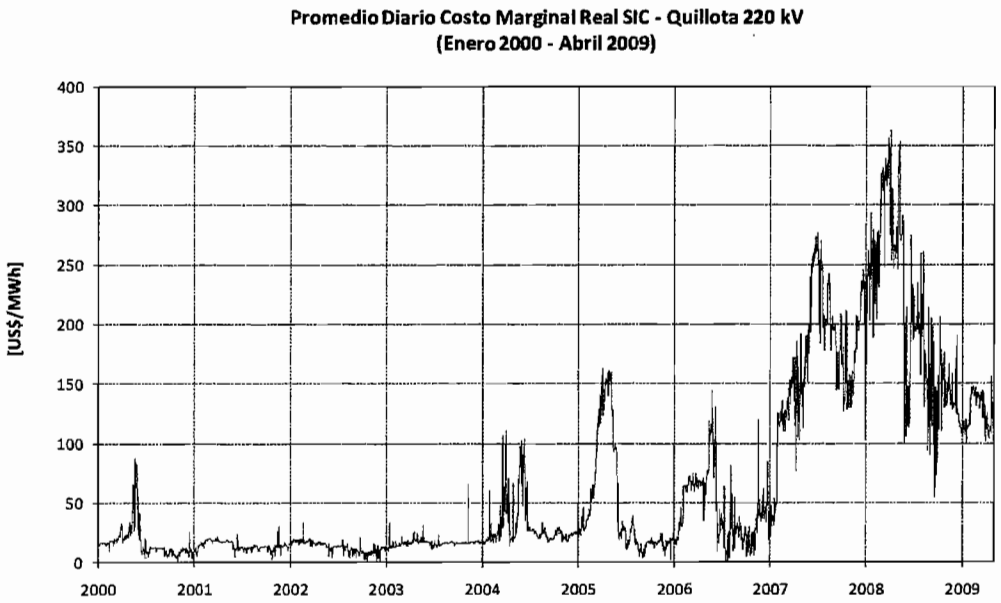


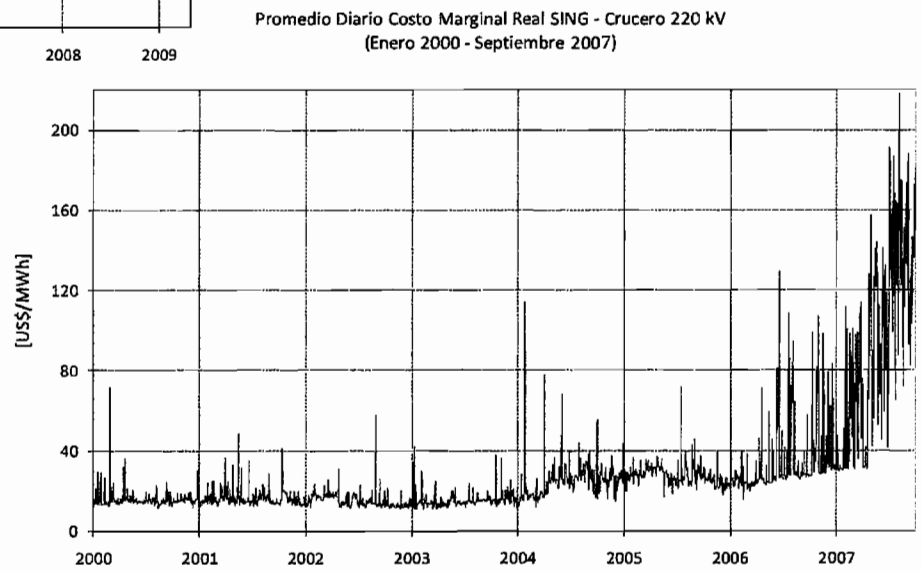
Fuente: CNE

001404

Costos marginales de corto plazo

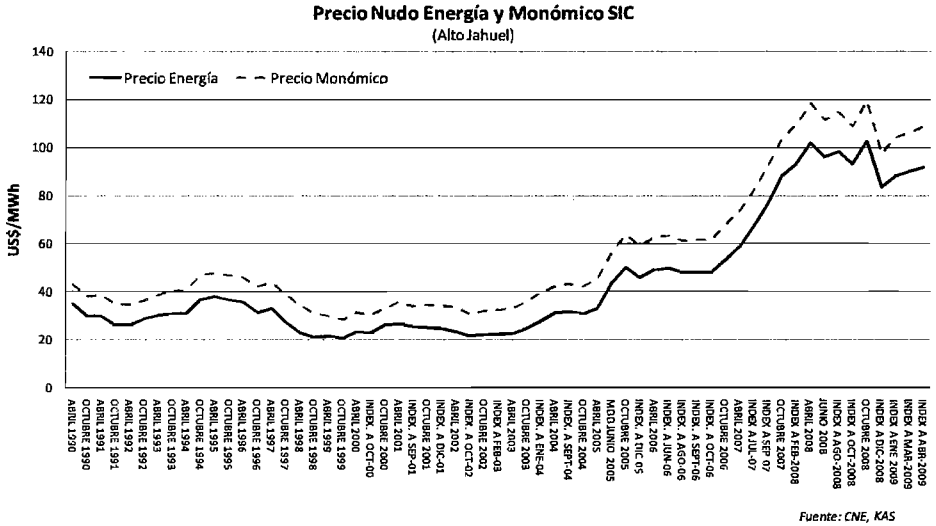
KAS INGENIERIA





Precios de nudo

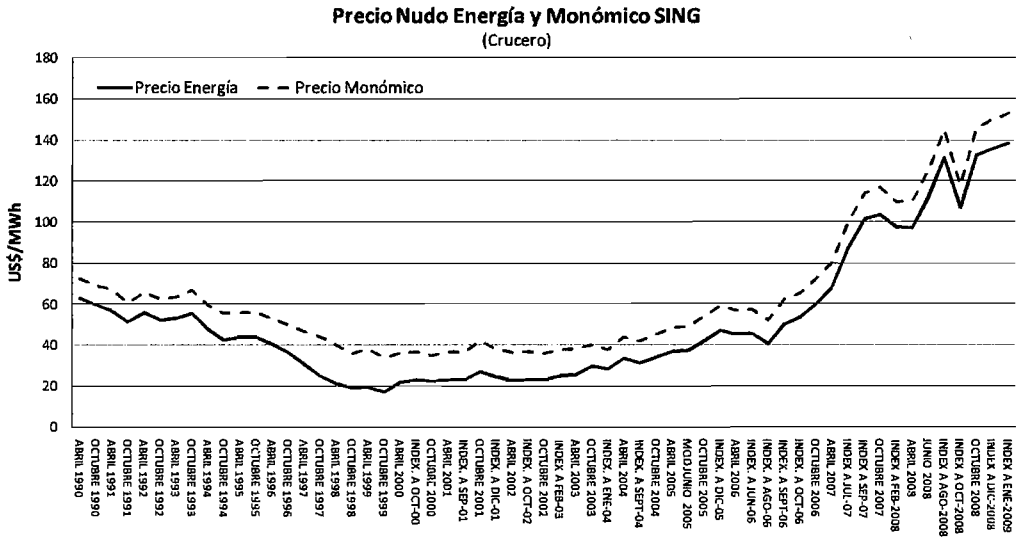
KAS INGENIERIA



Fuente: CNE, KAS

Precios Regulados

- Fijación semestral
- Dependen de banda de precios del segmento de consumos no regulados (precio de mercado)
- Esquema desaparece con licitaciones de suministro (Ley Corta II)

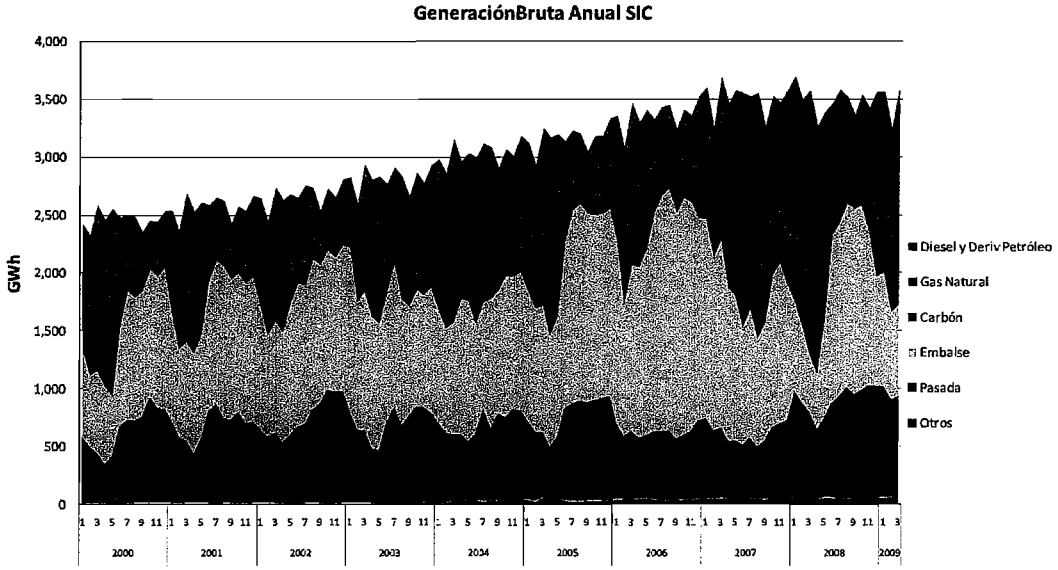


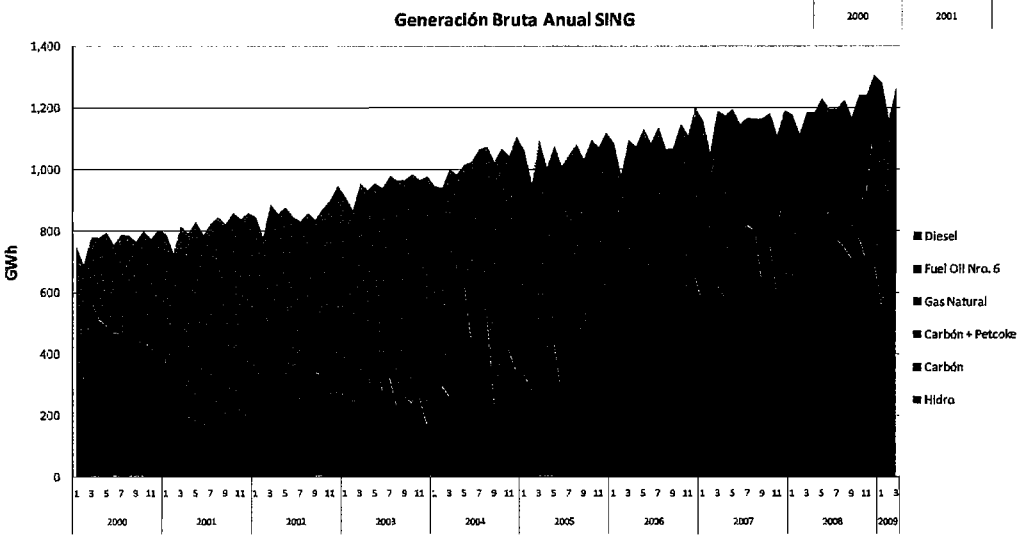
Generación Histórica SIC y SING

KAS INGENIERIA

Generación en el SIC

- 50-60% hidroeléctrico
- Reemplazo del gas natural por diesel



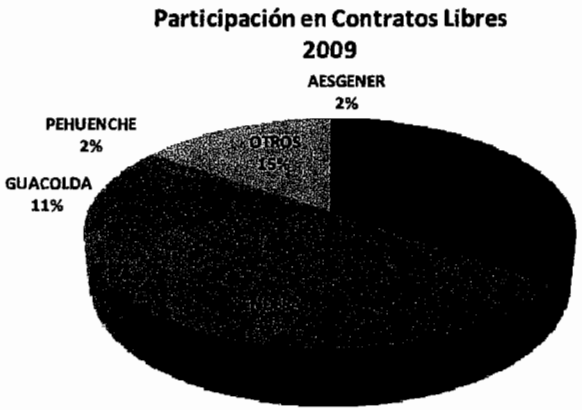


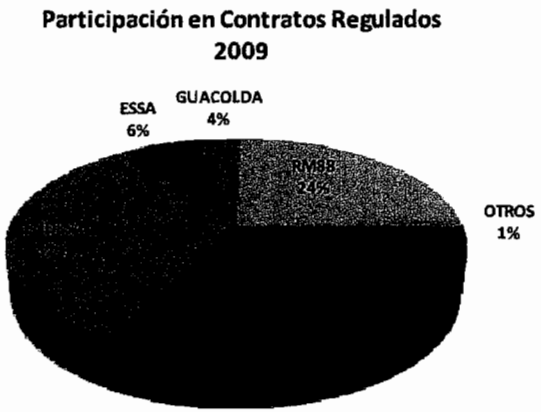
Generación en el SING

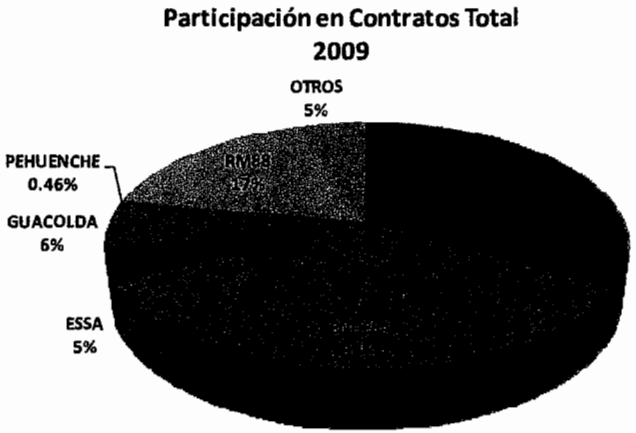
- 100% térmico
- Reemplazo del gas natural por diesel

Participación Generación/Consumos SIC 2009

KAS INGENIERIA

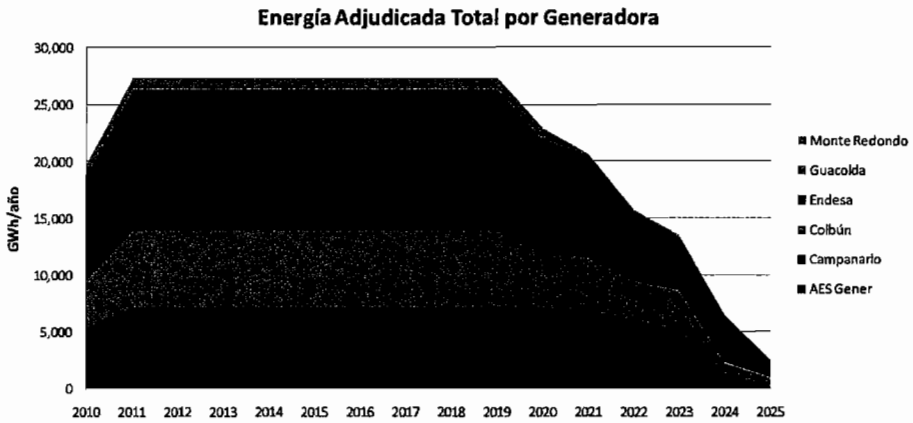


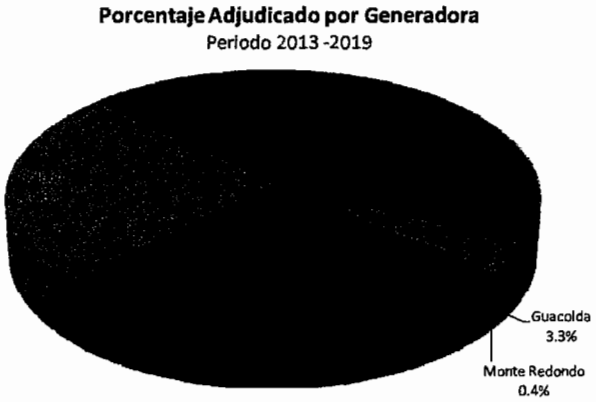




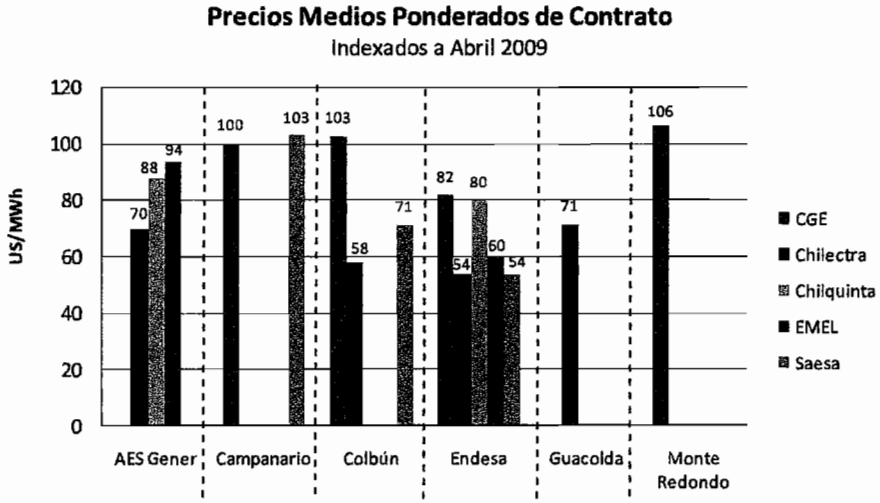
Resultado de Licitaciones de Distribuidoras

KAS INGENIERIA





Fuente: CDEC-SIC, KAS

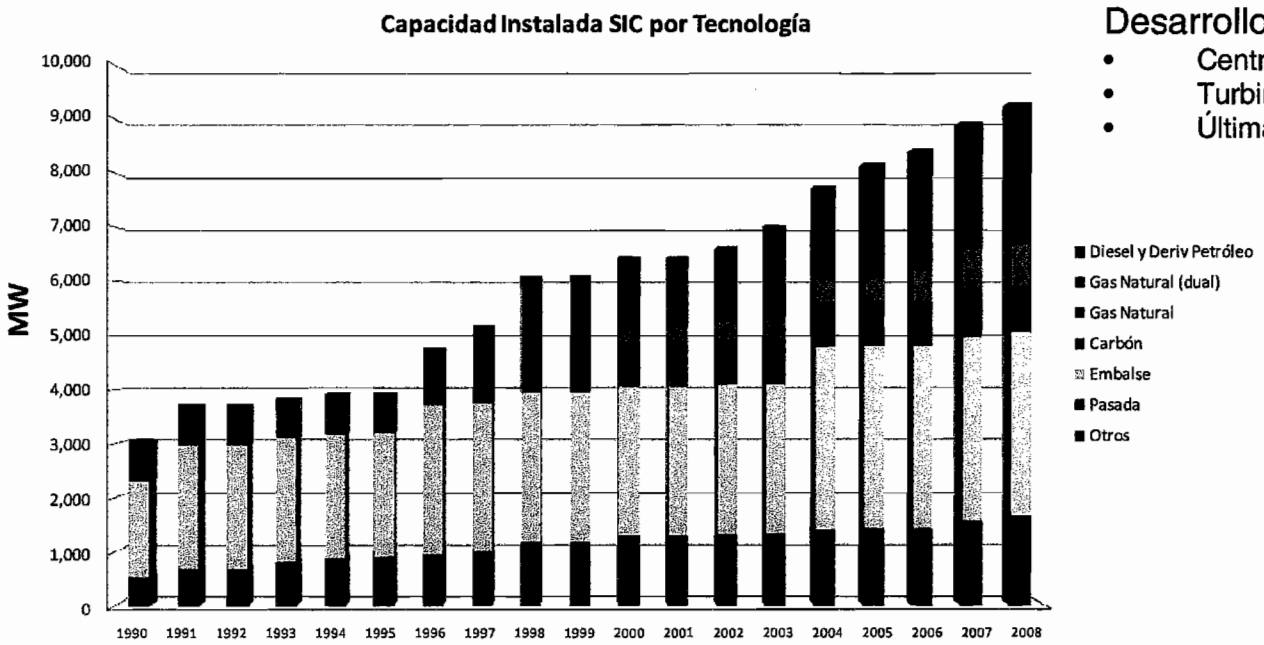


Desarrollo de Inversiones

KAS INGENIERIA

Inversiones en generación

- Normativa legal no prevé existencia de autorizaciones especiales como concesiones o permisos de explotación (excepto derechos de agua y geotermia)
- Requiere sólo aprobación del Sistema de Evaluación de Impacto Ambiental (SEIA)
- Además se exigen cumplimientos de Norma Técnica de SyCS para la conexión
- Las decisiones se basan únicamente en las perspectivas y estrategias de los inversionistas, que operan dentro o fuera del mercado
- La localización y características de los sistemas de transmisión influyen en las decisiones



Desarrollo últimos 10 años

- Centrales gas natural
- Turbinas Diesel
- Última gran hidroeléctrica: Ralco (2004)

Proyectos en SEIA > 100 MW (SIC)

KAS INGENIERIA

Nombre	Titular	Potencia [MW]	Inversión (MMU$)	Estado	Combustible	Región
Proyecto Hidroeléctrico Aysén	HidroAysén (Endesa y Colbún)	2750	3200	En Calificación	Hidráulica	XI
Central Termoeléctrica Castilla	MPX Energia S.A.	2354	4400	Retirada	Carbón	III
Central Termoeléctrica Energía Minera	Energía Minera S.A.	1050	1700	Aprobado	Carbón	V
CENTRAL TERMOELÉCTRICA LOS ROBLES	AES GENER S.A	750	1300	Aprobado	Carbón	VII
Central Termoeléctrica Punta Alcalde	ENDESA	740	1400	En Calificación	Carbón	III
CENTRAL TÉRMICA RC GENERACIÓN	Río Corriente S.A.	700	1082	En Calificación	Carbón	V
Central Combinada ERA	ENAP REFINERIAS S.A	579	390	Aprobado	Gas-Cogeneración	V
Central Térmica Barrancones	Suez Energy	540	1100	En Calificación	Carbón	IV
Parque Eólico Talinay	Eólica Talinay S. A.	500	1000	Aprobado	Eólico	IV
Central Hidroelectrica Maqueo	Trayenko S.A	320	1000	En Calificación	Hidráulica	XIV
Proyecto Central Hidroeléctrica Angostura PCH-Angostura	Colbún S.A.	316	500	En Calificación	Embalse	VIII
Central Termoeléctrica Cruz Grande	CAP S.A.	300	460	En Calificación	Carbón	IV
PROYECTO HIDROELÉCTRICO ALTO MAIPO Exp. N°105	AES GENER S.A	272	700	Aprobado	Hidráulica	RM
Central Termoeléctrica Campiche	AES GENER S.A	270	500	En Construcción	Carbón	V
Central Termoeléctrica Quintero	ENDESA	240	110	En Construcción	GNL	V
Unidad 5 Central Térmica Guacolda S.A	Guacolda S.A.	152	235	En Calificación	Carbón	III
"Central Hidroeléctrica Los Cóndores"	ENDESA	150	180	En Calificación	Hidráulica	VII
Central Hidroeléctrica San Pedro	Colbún S.A.	144	202	En Construcción	Hidráulica	XIV
Central Térmica Cardones (e-seia)	S.W. CONSULTING S.A.	141	62	En Calificación	Diesel	III
Proyecto hidroeléctrico ACHIBUENO	Hidroeléctrica Centinela Ltda.	135	285	En Calificación	Hidráulica	VII
Central Termoeléctrica Santa Lidia en Charrúa . (e-seia)	AES GENER S.A	130	175	En Calificación	Carbón	VIII
Parque Eólico Lebu Sur (e-seia)	Inversiones Bosquemar Ltda	108	224	En Calificación	Eólico	VIII
Central Hidroeléctrica Chacayes	Pacific Hydro Chile S.A.	106	230	En Construcción	Hidráulica	VI
Incremento de Generación y Control de Emisiones Guacolda S.A	Guacolda S.A.	104	230	En Construcción	Carbón	III
Parque Eólico Punta Palmeras (e-seia)	Acciona Energía Chile S.A.	104	230	En Calificación	Eólico	IV
Central Espino (e-seia)	Termoeléctrica Los Espinos S.A.	100	45	En Construcción	Diesel	IV
Generación de Respaldo Peumo (e-seia)	Río Cautín S.A.	100	45	En Calificación	Diesel	VII

Más de 9000 MW en el SEIA

- Aprobados: 2651 MW
- En construcción: 1094 MW

Plan de Obras CNE Abril 2009 SIC - Térmicas

KAS INGENIERIA

Térmicas a Carbón: 1441 MW en construcción

Central	Puesta en Servicio	Barra Inyección	Potencia Neta [MW]	Propiedad	Estado
Guacolda 03	sep-2009	Guacolda 220	135	GUACOLDA	En Construcción
Nueva Ventanas	ene-2010	Nogales 220	240	AES GENER	En Construcción
Guacolda 04	jun-2010	Guacolda 220	139	GUACOLDA	En Construcción
Santa María (Coronel 1)	oct-2010	Charrúa 220	343	COLBÚN	En Construcción
Bocamina 02	oct-2010	Hualpén 220	342	ENDESA	En Construcción
Campiche	jun-2011	Nogales 220	242	AES GENER	En Construcción
Carbón V Región 01	mar-2013	Nogales 220	200	Plan de Obra	En Estudio
Carbón Maitencillo 01	dic-2015	Maitencillo 220	139	Plan de Obra	En Estudio
Carbón Pan de Azúcar 01	oct-2017	Pan de Azúcar 220	200	Plan de Obra	En Estudio

Llegada del GNL

Central	Puesta en Servicio	Barra Inyección	Potencia Neta [MW]	Propiedad
San Isidro 02 GNL	jul-2009	San Luis 220	350	ENDESA
San Isidro 02 FA GNL	jul-2009	San Luis 220	19	ENDESA
San Isidro GNL	abr-2010	San Luis 220	350	SAN ISIDRO SA
San Isidro FA GNL	abr-2010	San Luis 220	20	SAN ISIDRO SA
Quintero 01 CA GNL	abr-2010	San Luis 220	240	ENDESA
Taltal 01 GNL	jul-2012	Paposo 220	121.5	ENDESA
Taltal 02 GNL	jul-2012	Paposo 220	123.4	ENDESA
Quintero 01 CC GNL	nov-2013	San Luis 220	350	Plan de Obra
Quintero 01 CC FA GNL	nov-2013	San Luis 220	35	Plan de Obra
Taltal CC GNL	ene-2014	Diego de Almagro 220	360	ENDESA
Nueva Renca GNL	abr-2014	Renca 110	320.1	ESSA
Nueva Renca Int GNL	abr-2014	Renca 110	49.8	ESSA
Candelaria CA 01 GNL	abr-2014	Candelaria 220	125.3	COLBÚN
Nehuenco 01 GNL	abr-2019	San Luis 220	340.051	COLBÚN
Nehuenco 01 FA GNL	abr-2019	San Luis 220	21.393	COLBÚN
Nehuenco 02 GNL	abr-2019	San Luis 220	384.2	COLBÚN
Candelaria CA 02 GNL	abr-2019	Candelaria 220	128.56	COLBÚN

Plan de Obras CNE Abril 2009 SIC – Hidros y Otros

KAS INGENIERIA

Central	Puesta en Servicio	Barra Inyección	Potencia Neta [MW]	Estado
La Higuera	jul-2009	Tinguiririca 154	155	En Construcción
Lican	nov-2009	Osorno 066	17	En Construcción
Confluencia	jul-2010	Tinguiririca 154	155	En Construcción
Rucatayo	dic-2010	Barro Blanco 220	60	En Estudio
Hidroeléctrica X Región 02	dic-2010	Osorno 066	9.4	En Estudio
Hidroeléctrica VII Región 01	abr-2011	Colbun 220	5.4	En Estudio
Hidroeléctrica VI Región 01	abr-2011	Tinguiririca 154	30.9	En Estudio
Hidroeléctrica VI Región 02	abr-2011	Tinguiririca 154	29.6	En Estudio
Chacayes	abr-2011	Sauzal 110	106	En Estudio
Hidroeléctrica VIII Región 01	sep-2011	Ancoa 220	136	En Estudio
Hidroeléctrica X Región 01	oct-2011	Osorno 066	15	En Estudio
Hidroeléctrica XIV Región 01	sep-2012	Valdivia 220	144	En Estudio
Hidroeléctrica VII Región 03	abr-2013	Ancoa 220	25.4	En Estudio
Modulo 05	abr-2016	Lo Aguirre 500	360	En Estudio
Hidroeléctrica XIV Región 02	ene-2017	Valdivia 220	139	En Estudio
Modulo 03	feb-2018	Lo Aguirre 500	460	En Estudio
Modulo 02	mar-2019	Lo Aguirre 500	500	En Estudio
Modulo 01	jun-2020	Lo Aguirre 500	660	En Estudio
Modulo 04	oct-2021	Lo Aguirre 500	770	En Estudio

Otros proyectos indicados

- Eólico: 662 MW
- Geotérmico: 160 MW

Proyectos en SEIA > 100 MW (SING)

KAS INGENIERIA

Nombre	Titular	Potencia (MW)	Inversión (MMU$)	Estado	Combustible	Región
Infraestructura Energética Mejillones	EDELNOR S.A.	750	1,500	En Calificación	Carbón	II
Central Termoeléctrica Cochrane	NORGENER S.A.	560	1,100	En Calificación	Carbón	II
Central Kelar	Newcoal Generación S.A.	500	800	Aprobado	Carbón	II
Central Térmica Andino	Suez Energy Andino S.A.	400	450	Aprobado	Carbón	II
Central Termoeléctrica Pacífico	Río Seco S.A.	350	750	En Calificación	Carbón	I
Granja Eólica Calama	Codelco Chile, División Codelco Norte	250	700	En Calificación	Eólico	II
Planta de Cogeneración de Energía Eléctrica	Central Patache S.A.	110	150	En Calificación	Carbón	I
Central Barriles	Electroandina S.A.	103	100	Aprobado	Fuel Oil Nº6	II
Proyecto Eólico Quillagua	Ingeniería Seawind Sudamérica Ltda.	100	230	Aprobado	Eólico	II
Proyecto Parque Eólico Valle de los Vientos	Parque Eólico Valle De Los Vientos S.A.	99	200	En Calificación	Eólico	II
Central Termoeléctrica Salar	Codelco Chile, División Codelco Norte	85	65	Aprobado	Diesel	II
Planta de Generación Eléctrica de Respaldo	MINERA ESCONDIDA LIMITADA	60	222	Aprobado	Diesel	II

Proyectos de centrales térmicas a carbón: 2670 MW

Plan de Obras CNE Abril 2009 SING - Térmicas

KAS INGENIERIA

Térmicas a Carbón

Central	Puesta en Servicio	Barra Inyección	Potencia Neta [MW]	Propiedad	Estado
CT ANDINA	abr-2010	Chacaya 220	150	ELECTROANDINA	En Construcción
HORNITOS	oct-2010	Chacaya 220	150	ELECTROANDINA	En Construcción
ANGAMOS I	mar-2011	Laberinto 220	230	AES GENER	En Construcción
ANGAMOS II	oct-2011	Laberinto 220	230	AES GENER	En Construcción
MEJILLONES I	nov-2015	Chacaya 220	200	En Estudio	En Estudio
TARAPACA I	ene-2017	Tarapaca 220	200	En Estudio	En Estudio
TARAPACA II	dic-2018	Tarapaca 220	200	En Estudio	En Estudio
MEJILLONES II	nov-2019	Chacaya 220	200	En Estudio	En Estudio
TARAPACA III	dic-2020	Tarapaca 220	200	En Estudio	En Estudio

Llegada del GNL

Central	Puesta en Servicio	Barra Inyección	Potencia Neta [MW]	Propiedad
U16 GNL	ene-2010	Tocopilla 220	300	ELECTROANDINA
CC1 GNL EG	ene-2010	Central Atacama 220	160	GAS ATACAMA
CTM3 GNL EG	ene-2010	Chacaya 220	160	EDELNOR
CTM3 GNL	jul-2012	Chacaya 220	243.227	EDELNOR
CC1 GNL	jul-2012	Central Atacama 220	300	GAS ATACAMA
CC2 GNL	jul-2012	Central Atacama 220	300	GAS ATACAMA
TG3 GNL	jul-2012	Tocopilla 220	37.2	ELECTROANDINA

Centrales térmicas a carbón: de 1760 MW del plan de obras, 760 MW en construcción

Evaluación Económica de Centrales

KAS INGENIERIA

Central térmica a carbón (350 MW)

Parámetros de Inversión		
Inversión Unitaria	2200	US$/kW
O&M sobre inversión	2%	%anual
Muelle	15	MMUS$
Inversión Línea Adicional	20	MMUS$

Parámetros de Operación		
Rendimiento	0.376	Ton/MWh
Costo Combustible	100.00	US$/Ton
Costo Variable Combustible	37.60	US$/MWh
Costo Variable No Combustible	3.0	US$/MWh
Costo Variable	40.6	US$/MWh
Factor Planta	0.90	pu
Factor Potencia Firme	0.70	pu
Precio Potencia	8.83	US$/kw/mes

Si suponemos aumento de costo de abatimiento en 5%, 10%, 15% del costo unitario de inversión

Aumento Costo Mitigación	Costo Unitario US$/kW
5%	2,310
10%	2,420
15%	2,530

Parámetros de Evaluación

- Vida útil de 24 años
- Tasa descuento 10 %

Resultados de Evaluación Económica

Precio Medio Venta Energía 80 US$/MWh

Sensibilidad Inversión	VAN [MMUS$]	TIR
0%	247	13.9%
5%	202	13.1%
10%	157	12.3%
15%	111	11.6%

Para mantener VAN en 247 MW, con 15% de aumento en la inversión, el precio medio de venta energía debe ser aproximadamente de 85 US$/MWh

Ahora, si duplicamos el costo variable no combustible, los resultados son los siguientes:

Sensibilidad	VAN [MMUS$]	TIR
0%	173	12.8%
5%	128	12.0%
10%	82	11.2%
15%	37	10.5%

Discusión

KAS INGENIERIA

Tamaño de centrales térmicas

- Decisiones privadas: las decisiones de inversión en el mercado de generación las toman agentes privados, bajo su propia perspectiva del negocio, estrategia de desarrollo y financiera (riesgo)
- Localización: la capacidad de evacuación de los sistemas de transmisión puede resultar un factor relevante a la hora de decidir tamaño de las centrales

Plantas antiguas v/s nuevas

- Las estrategias comerciales y financieras de los generadores son parte de decisiones privadas, no existe regulación al respecto
- La CNE crea un Plan de Obras en el cual minimiza los costos de inversión y operación de largo plazo del sistema, el cual tiene carácter INDICATIVO y sirve para fijar los precios de nudo para cada sistema interconectado

Parte de los objetivos del estudio serán

- Analizar los efectos en las tarifas debido a la nueva norma de emisiones
- Estimar los efectos en la rentabilidad de centrales

001418

COMISIÓN NACIONAL DEL MEDIO AMBIENTE
Dirección Ejecutiva
RGR/JJR

APRUEBA Y FUNDAMENTA CONTRATO QUE INDICA

SANTIAGO, 04 AGO. 2009

RESOLUCIÓN EXENTA Nº 4514

VISTOS:

Lo dispuesto en la Ley de Presupuesto del Sector Público; la Resolución Nº1600/2008, de la Contraloría General de la República; la Ley de Bases Generales de la Administración del Estado; la Ley N°19.886, de Bases sobre contratos administrativos de suministro y prestación de servicios y su Reglamento; los Memorándums Nº227, de 7 de mayo y Nº14.223, de 20 de julio de 2009, ambos del Departamento de Control de la Contaminación; las facultades que me confiere la Ley 19.300, sobre Bases Generales del Medio Ambiente y;

CONSIDERANDO:

1.- Que, la Comisión Nacional del Medio Ambiente requiere contratar en forma urgente, los servicios profesionales de una consultora que realice un análisis general del impacto económico y social que tendrá la futura regulación de emisiones para termoeléctricas, considerando la evaluación de tres escenarios regulatorios, y que entre otros:

- Identifique los impactos y posibles efectos de la futura norma de emisión sobre el sector a regular, para el logro de este objetivo se pide analizar la estructura y operación del mercado de generación de energía, describir a la actividad emisora a regular (considerando el parque existente y proyectado), tecnologías de generación, tecnologías de abatimiento, obsolescencia tecnológica, vida útil, entre otros aspectos; y estimar las emisiones en la línea base (sin norma) y proyectar las emisiones (con norma) para los distintos escenarios regulatorios. También se pide analizar el comportamiento de las distintas unidades de generación (de base y de respaldo con su respectivo aporte de emisiones), analizar la tarifa o precio de la energía según clientes, entre otros temas que se evalúen de interés y que surjan durante las discusiones entre el consultor y la contraparte técnica del estudio;
- Permita contar con los fundamentos de los contenidos de la futura regulación de norma de emisión, de acuerdo a los artículos 34 y 35 del D.S. Nº 93/95 del MINSEGPRES;
- Evalúe el impacto en la seguridad del sistema eléctrico (SING y SIC), para cada escenario de regulación y tarifa final según tipo de cliente (costo marginal y costo medio). Se espera en particular contar con un análisis de incertidumbre y analizar efectos distributivos que podría ocasionar la implementación de la norma,

por ejemplo posible subsidio dado el aumento de precio a nivel de generación o transporte según tipo de cliente, para esto se pide analizar las alzas de tarifa experimentadas durante los últimos 36 meses (sin norma), en particular del SIC;

- Permita contar con una identificación y evaluación para cada escenario de regulación de los costos privados que se tienen que incurrir, para dar cumplimiento a la norma y los costos asociados al control y fiscalización (tanto por el Estado como para el sector privado);
- Evalúe para cada escenario de regulación los beneficios sociales y;
- Analice la relación beneficio-costo más óptima de los distintos escenarios evaluados.

2.- Que, el servicio requerido no se encuentra disponible en el Sistema de Información Mercado Público, en la modalidad de Convenios Marcos;

3.- Que, de acuerdo a lo informado por el Departamento de Control de la Contaminación, la urgencia con que se requiere esta contratación se fundamenta en las siguientes razones:

- El año 2008, CONAMA hizo un segundo llamado a licitación pública para la realización del estudio "Análisis técnico-económico de la aplicación de una norma de emisión para termoeléctricas", toda vez que en el primer llamado, realizado a fines del año 2007, no se presentaron ofertas; adjudicándose esta segunda licitación el único oferente que se presentó, la empresa Ecofysvalgesta. El estudio se inició el 10 de julio del 2008, con una duración de cinco meses y finalización programada para fines de diciembre del mismo año. No obstante, el contrato se aplazó hasta enero del 2009 y finalmente, en abril de este año, fue necesario hacer efectiva la boleta de garantía de fiel cumplimiento del contrato debido al incumplimiento de la empresa y el mal desarrollo del estudio.
- Como consecuencia de lo anterior, no fue posible dar cumplimiento al plazo que inicialmente estaba fijado para la formulación del anteproyecto (20 de febrero de 2009) posponiéndose para el 26 de junio de 2009, fecha que también ha sido prorrogada para enero del año 2010, porque aún no se cuenta con los resultados que permitan evaluar la relación beneficio-costo de los escenarios de regulación para las termoeléctricas.
- Tanto la Ministra del Medio Ambiente, como el Director Ejecutivo de CONAMA, han instruido contar con el anteproyecto en el mínimo plazo posible, toda vez que el país lo requiere a la brevedad, asegurando que se cuente con los fundamentos que respalden el diseño regulatorio y que se cuente con los resultados de la evaluación del impacto económico y social que tendrá la futura norma de emisión.
- Por otra parte, el estudio debe ser abordado por especialistas, con conocimientos y experiencia comprobada en el mercado eléctrico, en particular en la generación térmica (fuente emisora a regular); en la aplicación de modelos económicos del mercado eléctrico, que puedan proyectar y evaluar el efecto que tendrá la futura norma de emisión en el sistema eléctrico y en el precio de la tarifa sobre los distintos clientes (regulados y libres). Complementariamente, se requiere, contar con expertos que manejen la evaluación de beneficios y costos evitados, que tendrá como efecto la regulación, que manejen modelos de dispersión (aplicables a zonas de terreno complejo, pues el parque existente se localiza principalmente en zonas costeras y las futuras centrales también), se necesita incluir la emisión de gases precursores (óxido de nitrógeno y óxidos de azufre) en la formación de particulado secundario y ver el efecto de la norma de emisión en la reducción de tales emisiones y en la calidad del aire, que se proyecte la diferencia o el efecto entre un escenario sin norma y con norma.
- Finalmente, debido a la complejidad de los requerimientos anteriores se ha considerado, después de un análisis exhaustivo, realizado en conjunto con la

Comisión Nacional de Energía, optar por las empresas Kas Ambiental S.A. y Asesorías en Ingeniería Ambiental Pedro Alex Sanhueza Herrera E.I.R.L.

4.- Que, conforme lo disponen los artículos 8, letra c), de la ley N°19.886, de Compras Públicas y 10 N° 3, de su Reglamento, se hace procedente la contratación directa en casos de urgencia, como ocurre en la especie;

RESUELVO :

1. Apruébase el Contrato denominado **"Análisis de impacto económico y social de la Norma de Emisión para Termoeléctricas",** suscrito con fecha 22 de julio de 2009, entre la **Comisión Nacional del Medio Ambiente**, representada por su Director Ejecutivo, don **Álvaro Sapag Rajevic** y las empresas **KAS AMBIENTAL S.A.,** representada por doña **MARCELA EUGENIA JERARDINO ETCHEVERRY,** y **ASESORÍAS EN INGENIERÍA AMBIENTAL PEDRO ALEX SANHUEZA HERRERA, E.I.R.L.,** representada por don **PEDRO ALEX SANHUEZA HERRERA.**

2.- El monto de dicho contrato es la suma de **$70.000.000 (setenta millones de pesos),** impuesto incluido, suma que se pagará en una primera cuota de $28.000.000 (veintiocho millones de pesos), a los 10 días hábiles siguientes al inicio del contrato; una segunda cuota de $21.000.000 (veintiún millones de pesos), una vez aprobado sin observaciones el Informe de Avance y una tercera cuota también de de $21.000.000 (veintiún millones de pesos), una vez aprobado el Informe Final. Todos estos pagos requerirán además la entrega de las respectivas facturas.

3.- El texto de los Términos de Referencia se acompaña formando parte integrante de esta Resolución.

4. Impútese el gasto que demande el pago del presente contrato al Programa 3, Subtítulo 22, Ítem 11, Asignación 1, del Presupuesto vigente de la Comisión Nacional del Medio Ambiente.

Anótese, Tómese Razón, Comuníquese

COMISION NACIONAL DEL MEDIO AMBIENTE
DIRECTOR EJECUTIVO

ÁLVARO SAPAG RAJEVIC
Director Ejecutivo
Comisión Nacional del Medio Ambiente

Distribución:
- Dirección Ejecutiva.
- Departamento de Administración y Finanzas.
- Unidad de Compras y Contrataciones.
- Departamento de Planificación, Presupuesto

y Control de Gestión
- Departamento de Control de la Contaminación.
- División Jurídica.
- Interesados (2).
- Oficina de Partes.

Lo que transcribo a Ud.
para su conocimiento
saluda atentamente a Ud.
NURY VALBUENA OVEJERO
Oficial de Partes
Comisión Nacional del
Medio Ambiente (CONAMA)

Contrato

"Análisis de impacto económico y social de la Norma de Emisión para Termoeléctricas"

En Santiago, a 22 de julio de 2009, entre la **COMISIÓN NACIONAL DEL MEDIO AMBIENTE**, en adelante CONAMA, RUT Nº 72.443.600-5, representada por su Director Ejecutivo, don **ÁLVARO SAPAG RAJEVIC**, cédula nacional de identidad Nº8.535.667-4, ambos domiciliados en Teatinos Nº258, comuna y ciudad de Santiago, por una parte, y por la otra, las empresas **KAS AMBIENTAL S.A.,** RUT Nº76.977.500-5, representada por doña **MARCELA EUGENIA JERARDINO ETCHEVERRY,** cédula de identidad Nº7.665.428-K, ambos domiciliados en calle Brown Norte Nº694, comuna de Ñuñoa y **ASESORÍAS EN INGENIERÍA AMBIENTAL PEDRO ALEX SANHUEZA HERRERA, E.I.R.L.,** representada por don **PEDRO ALEX SANHUEZA HERRERA,** cédula de identidad Nº9.095.116-5, ambos domiciliados en calle Mardoñal Nº8525, comuna de Las Condes; en adelante, indistintamente, "las empresas", se acuerda lo siguiente:

PRIMERO: La Comisión Nacional del Medio Ambiente requiere contratar los servicios profesionales de una consultora que realice un análisis general del impacto económico y social que tendrá la futura regulación de emisiones para termoeléctricas, considerando la evaluación de tres escenarios regulatorios, y que entre otros:

- Identifique los impactos y posibles efectos de la futura norma de emisión sobre el sector a regular, para el logro de este objetivo se pide analizar la estructura y operación del mercado de generación de energía, describir a la actividad emisora a regular (considerando el parque existente y proyectado), tecnologías de generación, tecnologías de abatimiento, obsolescencia tecnológica, vida útil, entre otros aspectos; y estimar las emisiones en la línea base (sin norma) y proyectar las emisiones (con norma) para los distintos escenarios regulatorios. También se pide analizar el comportamiento de las distintas unidades de generación (de base y de respaldo con su respectivo aporte de emisiones), analizar la tarifa o precio de la energía según clientes, entre otros temas que se evalúen de interés y que surjan durante las discusiones entre el consultor y la contraparte técnica del estudio;
- Permita contar con los fundamentos de los contenidos de la futura regulación de norma de emisión, de acuerdo a los artículos 34 y 35 del D.S. Nº 93/95 del MINSEGPRES;
- Evalúe el impacto en la seguridad del sistema eléctrico (SING y SIC), para cada escenario de regulación y tarifa final según tipo de cliente (costo marginal y costo medio). Se espera en particular contar con un

análisis de incertidumbre y analizar efectos distributivos que podría ocasionar la implementación de la norma, por ejemplo posible subsidio dado el aumento de precio a nivel de generación o transporte según tipo de cliente, para esto se pide analizar las alzas de tarifa experimentadas durante los últimos 36 meses (sin norma), en particular del SIC;

- Permita contar con una identificación y evaluación para cada escenario de regulación de los costos privados que se tienen que incurrir, para dar cumplimiento a la norma y los costos asociados al control y fiscalización (tanto por el Estado como para el sector privado);
- Evalúe para cada escenario de regulación los beneficios sociales y;
- Analice la relación beneficio-costo más óptima de los distintos escenarios evaluados.

SEGUNDO: Por el presente instrumento, CONAMA contrata a las empresas KAS AMBIENTAL S.A. y ASESORÍAS EN INGENIERÍA AMBIENTAL PEDRO ALEX SANHUEZA HERRERA, E.I.R.L., quienes aceptan, y se obligan a realizar el trabajo descrito precedentemente, con estricta sujeción a las condiciones acordadas en el presente contrato y en los Términos de Referencia, especialmente a los objetivos, consideraciones para los escenarios a regular, análisis requeridos, actividades complementarias solicitadas, carta Gantt y metodología, contenidas en ellas, documentos que forman parte integrante de este contrato.

TERCERO: El presente contrato tendrá una duración de ciento cincuenta días a contar de la resolución que lo apruebe, plazo que se podrá ampliar de común acuerdo por las partes.

CUARTO: El equipo de contraparte técnica estará compuesto por profesionales del Área Control de la Contaminación Atmosférica de la CONAMA Dirección Ejecutiva; representantes del Comité Operativo del Área Medio Ambiente y Energías Renovables de la CNE, del Ministerio de Salud, Servicio Agrícola y Ganadero del Ministerio de Agricultura; pudiendo asimismo participar un profesional del Departamento Jurídico y un profesional del Departamento de Estudios, ambos de la CONAMA Dirección Ejecutiva. Entre sus facultades estará el control, la inspección y evaluación del avance y calidad de los servicios y trabajos a efectuar y la aprobación de los informes a que se refiere la cláusula siguiente.

QUINTO: La empresa deberá entregar un Informe de Avance, que incluya un avance estimado en un 50%, relativo al análisis y a los resultados esperados de este estudio según se detalla en los Términos de Referencia, a los 80 días contados desde que quede totalmente tramitada la Resolución que apruebe el contrato y un Informe Final, 20 días hábiles antes de la fecha de término del contrato, el cual debe contener en forma completa los resultados que dan respuesta a los objetivos de este estudio

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establecidos en el numeral II y de acuerdo al análisis para cada uno de ellos indicados en el numeral IV.

Los informes deberán ser entregados en la Oficina de Partes de la CONAMA, en 4 copias papel, B/N, con su correspondiente respaldo magnético en extensión *.pdf y *.doc. Además, se deben acompañar las planillas Excel *.xls o .extensión *.txt, *.doc o la que corresponda, con toda la información que se genere para la evaluación social y económica. El informe Final se presentará en 6 copias.

Una vez finalizado el estudio, las empresas deberán presentar los resultados al Comité Operativo, autoridades o grupos de interés. Todas las reuniones serán coordinadas por la contraparte técnica de CONAMA, previendo la disponibilidad de las empresas.

SEXTO: CONAMA pagará por los servicios encomendados la suma total y única de $70.000.000 (setenta millones de pesos) impuesto incluido, suma que se pagará en una primera cuota de $28.000.000 (veintiocho millones de pesos), a los 10 días hábiles siguientes al inicio del contrato; una segunda cuota de $21.000.000 (veintiún millones de pesos), a una vez aprobado sin observaciones el Informe de Avance y una tercera cuota también de $21.000.000 (veintiún millones de pesos), una vez aprobado el Informe Final. Todos estos pagos requerirán además la entrega de las respectivas facturas.

Se deja constancia que CONAMA no podrá efectuar pago alguno a la empresa mientras no se encuentre totalmente tramitado el acto administrativo que apruebe este contrato. Sin perjuicio de lo anterior, en aplicación del artículo 19 bis, inciso primero, del Decreto Ley N°1.263, Ley Orgánica de la Administración Financiera del Estado, CONAMA sólo responderá de las inversiones hasta la concurrencia de los fondos que se consulten para estos efectos en cada año, en el respectivo presupuesto.

SÉPTIMO: Para garantizar el fiel cumplimiento de este contrato, la empresa KAS AMBIENTAL S.A., o en su defecto la empresa ASESORÍAS EN INGENIERÍA AMBIENTAL PEDRO ALEX SANHUEZA HERRERA, E.I.R.L., deberá al momento de firmar el presente contrato, hacer entrega de un Vale Vista Bancario o Boleta de Garantía, a la orden de la Comisión Nacional del Medio Ambiente, que señale expresamente que está tomada como **"GARANTÍA DE FIEL CUMPLIMIENTO DEL CONTRATO "ANÁLISIS DE IMPACTO ECONÓMICO Y SOCIAL DE LA NORMA DE EMISIÓN PARA TERMOELÉCTRICAS"**, extendida nominativamente a nombre de la Comisión Nacional del Medio Ambiente, RUT N° 72.443.600-5, por un valor equivalente, en pesos chilenos, al 10% del monto del contrato y con una vigencia equivalente al plazo del contrato más sesenta (60) días.

Dicha garantía deberá ser pagadera a la vista, tomada por uno o varios integrantes de la empresa y tener el carácter de irrevocable.

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Cabe señalar que esta garantía deberá asegurar el pago de las obligaciones laborales y sociales con los trabajadores de los contratantes.

Si eventualmente fuese necesario un aumento del plazo del contrato, la Garantía deberá ajustarse a dicho aumento, facultándose a la CONAMA para el cobro de la garantía original de no procederse a la prórroga según lo indicado.

OCTAVO: Las empresas deberán guardar confidencialidad de todos los antecedentes que de CONAMA conozcan con motivo del contrato y no podrán hacer uso de éstos con fines ajenos a los establecidos en los Términos de Referencia y al propio contrato, y bajo ninguna circunstancia, podrán, por cualquier titulo o medio, relevar, difundir, publicar, vender, ceder, copiar, reproducir, interferir, interceptar, alterar, modificar, dañar, inutilizar, destruir, en todo o en parte esta información ya sea durante la vigencia del contrato como después de su finalización.

Esta prohibición afecta a las empresas y a su personal directo e indirecto, en cualquier calidad, que se encuentren ligados a esta contratación, en cualquiera de sus etapas, y su responsabilidad será solidaria, incluso después de la expiración del contrato.

Las empresas sólo podrán copiar o reproducir la información que sea necesaria para dar cumplimiento al Contrato.

En caso de incumplimiento de esta obligación, CONAMA, estará facultada para cobrar la garantía de fiel cumplimiento del contrato, sin perjuicio de iniciar las acciones legales procedentes.

NOVENO: Toda información y materiales que utilicen las empresas, tales como textos, tablas, planos, modelos, programas, aplicaciones computacionales, fotografías, medios audiovisuales u otros proporcionados por CONAMA, se entenderán regidas bajo las disposiciones de propiedad intelectual o industrial, según y cuando corresponda. Por otro lado, los informes, antecedentes, datos y cualquier tipo de información generada durante la ejecución del trabajo no podrán utilizarse por las empresas, ni por sus profesionales, sin previa autorización expresa y por escrito de la CONAMA. Lo anterior, sin perjuicio de las normas vigentes asociadas al acceso a la información pública de la documentación que obre en poder de la Administración del Estado.

DÉCIMO: Las empresas no podrán ceder o transferir el contrato en cuanto a las obligaciones por él contraídas a persona natural o jurídica alguna. Asimismo, el equipo de trabajo comprometido por el consultor deberá mantenerse hasta el final del estudio, salvo casos fundados y debidamente autorizados por CONAMA, para lo cual las empresas deberán informar oportunamente los cambios que se pretenden en dicho equipo y cómo se subsanarían las temáticas abordadas por el o los especialistas. Para estos efectos se adjunta al presente contrato un anexo dando cuenta de los profesionales que integrarán el equipo de trabajo.

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DÉCIMO PRIMERO: Las remuneraciones, sueldos o emolumentos de cualquier naturaleza que se paguen a los trabajadores que presten el servicio, serán de cargo exclusivo de las empresas, al igual que las cotizaciones provisionales que correspondan, de forma que CONAMA no tendrá ninguna relación contractual con dicho personal; sin perjuicio de lo establecido en la Ley N°20.123.

No será causal eximente del cumplimiento del contrato por parte las empresas, el hecho de que el personal contratado por éste se declare en huelga. En todo caso, las empresas deberán arbitrar oportunamente las medidas para que las labores se continúen efectuando, sin afectar los intereses de CONAMA.

Las empresas deberán cumplir con todas las normas laborales, tributarias y otras contenidas en la legislación y reglamentación vigente.

La prestación del servicio y la demás obligaciones que asumen las empresas en virtud del presente contrato, se deberán ejecutar y cumplir con suma diligencia.

DÉCIMO SEGUNDO: Si las empresas no cumplen lo convenido en los plazos indicados, sin causa justificada, a consideración de CONAMA, ésta quedará facultada para cobrar una multa por cada día de atraso, equivalente al 3/1000 (tres por mil) del monto del contrato. CONAMA hará efectiva esta multa, descontando su valor del pago respectivo, sin perjuicio de su derecho de poner término anticipado al contrato. La aplicación de las multas se hará administrativamente, sin forma de juicio.

Las empresas podrán apelar por escrito de las multas que se le cursen ante el Director Ejecutivo. Dicha apelación se interpondrá a más tardar, al tercer día hábil siguiente a la respectiva notificación de la sanción.

DÉCIMO TERCERO: CONAMA podrá poner término ipso facto, anticipadamente, y en forma unilateral y administrativa al Contrato por las causas que más adelante se señalan.

Causales que ameritan el término anticipado, ipso facto, administrativo y unilateral del contrato:

a) Si cualquiera de los socios de las empresas o su representante legal fuere procesado, formalizado o condenado por algún delito que merezca pena aflictiva.
b) Por quiebra, cesión de bienes o notoria insolvencia. Se presumirá insolvencia de las empresas cuando tengan documentos protestados o se encuentren en mora en el pago de obligaciones laborales, previsionales o tributarias.
c) Incumplimiento por parte de las empresas de alguna de las obligaciones que emana del contrato y de los Términos de Referencia, relacionados con:
    - Incumplimiento del programa o de las actividades programadas.
    - Atraso en el inicio de los trabajos o paralizacióm sin causa justificada.

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- No destinar recursos materiales o humanos suficientes para el normal desarrollo del trabajo, en términos que haga difícil o imposible la ejecución de lo pactado, dentro del plazo estipulado.
- Si la calidad del trabajo no satisface las exigencias mínimas para los objetivos tenidos en consideración al solicitar su realización.
- Atrasos injustificados.
- Incumplimiento de las instrucciones que imparta CONAMA.
- Si las multas sobrepasan el 20% del monto total del contrato.

d) Por resciliación o mutuo acuerdo.
e) Por exigirlo el interés público o la seguridad nacional.

De la Resolución Administrativa con Cargo:
Las causales señaladas en las letras a) b) y c) implicarán el término del contrato, que implica la facultad que tiene CONAMA de poner término anticipado a un contrato, sin necesidad de recurrir a la justicia ordinaria. Para tales efectos, habida consideración de la aceptación de las empresas por el sólo hecho de suscribir el contrato correspondiente, serán de cargo de éstas todos los gastos directos o indirectos que su incumplimiento le signifique a CONAMA.

Puesto término anticipado al contrato se harán efectivas las garantías que lo caucionan y se mantendrán las retenciones del contrato si las hubiere, las que servirán para responder del mayor precio que pueda llevar a buen término el servicio materia del contrato, como asimismo, de las multas que corresponda pagar por el atraso que se produzca, o cualquier perjuicio que resultare para CONAMA o para los trabajadores de las empresas. Asimismo, CONAMA se reserva el derecho de ejercer las acciones legales que eventualmente correspondieren.

De la Terminación Administrativa Sin Cargo:
Las causales d) y e) implicarán la terminación anticipada del contrato sin cargo para las empresas.

De efectuarse la resciliación de contrato ésta deberá constar por escrito.

En el caso en que CONAMA ponga término anticipado o suspenda transitoriamente la ejecución de los servicios cuando razones de fuerza mayor, caso fortuito o interés público así lo ameriten, por causas ajenas a la responsabilidad de las empresas, debe dar aviso de inmediato a éstas.

En dicho caso se pagará el monto que corresponda por el servicio prestado y recibido conforme por la Contraparte Técnica.

El término anticipado del contrato definitivo, se realizará mediante resolución fundada, que se publicará en el Sistema de Información Chilecompra, a más tardar dentro de las 24 horas de dictada.

DÉCIMO TERCERO: Para todos los efectos legales derivados del presente contrato, las partes fijan su domicilio en la ciudad y comuna de Santiago y se someten a la jurisdicción de sus Tribunales Ordinarios de Justicia.

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DÉCIMO CUARTO: El presente contrato se suscribe en seis ejemplares del mismo tenor y fecha, quedando dos en poder de cada parte.

DÉCIMO QUINTO: La personería de don Álvaro Sapag Rajevic, Director Ejecutivo de CONAMA, consta en D.S. N°75, de 15 de junio de 2007, del Ministerio Secretaría General de la Presidencia de la República. La personería de doña Marcela Eugenia Jerardino Etcheverry, para representar a la empresa KAS AMBIENTAL S.A., consta en Acta de la Primera Sesión de Directorio de dicha empresa, de fecha 25 de septiembre de 2007, reducida a escritura pública con fecha 8 de octubre de 2007, ante don Raúl Undurraga Laso, Notario Público titular de la Vigésimo Novena Notaría de Santiago. La personería de don Pedro Alex Sanhueza Herrera, consta en escritura pública de Constitución de la empresa individual de responsabilidad limitada "Asesorías en Ingeniería Ambiental Pedro Alex Sanhueza Herrera E.I.R.L.", de fecha 1 de marzo de 2005, autorizada ante don Osvaldo Pereira González, Notario Público de Santiago.

COMISION NACIONAL DEL MEDIO AMBIENTE * DIRECTOR EJECUTIVO

ALVARO SAPAG RAJEVIC
Director Ejecutivo
Comisión Nacional del Medio Ambiente

MARCELA EUGENIA JERARDINO ETCHEVERRY
Representante Legal
KAS AMBIENTAL S.A.

PEDRO ALEX SANHUEZA HERRERA
Representante Legal
Asesorías en Ingeniería Ambiental Pedro Alex Sanhueza Herrera E.I.R.L

COMISION NACIONAL DEL MEDIO AMBIENTE * JEFE DIVISION JURIDICA

CURRÍCULUM DE LOS CONSULTORES

Carlos Barría Quezada: Jefe de Proyecto del Estudio
Candidato a Doctor en Ciencias de la Ingeniería, Pontificia Universidad Católica de Chile, Magíster en Ciencias de la Ingeniería, Pontificia Universidad Católica de Chile, Ingeniero Civil Industrial mención Electricidad, Pontificia Universidad Católica de Chile.
Experiencia Profesional
Jefe de estudios de mercados y regulación de KAS Ingeniería, ha sido jefe y coordinador en el desarrollo de estudios de análisis económico de mercados eléctricos, planificación y operación de sistemas eléctricos, regulación y normativa del sector energético para entidades públicas y privadas, nacionales y extranjeras. Además, es miembro del equipo de investigación del área de energía del Departamento de Ingeniería Eléctrica de la Pontificia Universidad Católica de Chile.

Samuel Jerardino Etcheverry
Magister en Administración de Empresas (M.B.A.). Universidad Adolfo Ibañez Santiago. Diplomado en Administración de Empresas (DPA). Universidad Adolfo Ibañez, Santiago. Ingeniero Civil Electricista. Universidad Técnica Federico Santa María, Valparaíso. Ingeniero Ejecución Electricista. Universidad Técnica Federico Santa María, Valparaíso.
Experiencia Profesional
Con más de 21 años de experiencia profesional en el sector eléctrico chileno en la Operación Económica de Sistemas de Potencia; Sistemas de Control de Tiempo Real (SCADA); Desarrollo de Modelos de Optimización de la Operación de Sistemas Eléctricos; Participación en temas de orden legal y normativo, relacionados con divergencias y recursos legales en el SIC. Se ha desempeñado en cargos de diversas jefaturas en Colbún S.A. Director de Operaciones en representación de Colbún S.A. en el Centro Económico de Despacho de Carga de SIC (CDEC-SIC), representante de dicha empresa en el Directorio del (CDEC-SIC). Actualmente es Director de Kas Ingeniería, en donde ha realizado diversas asesorías a empresas generadoras del sector eléctrico y a la CNE y ha encabezado el desarrollo del modelo de operación económica Ose2000.

Pedro Sanhueza Herrera
Ph.D. en Ingenieria Ambiental, University of Tennessee, Civil and Environmental Engineering. Major: Air Quality Management. Magister en Ingeniería Industrial y de Sistemas. Pontificia Universidad Católica de Chile. Ingeniero Civil en Geografía. Universidad de Santiago de Chile. Licenciado en Ciencias de la Ingeniería. Universidad de Santiago de Chile. Auditor Ambiental. GTZ, Frankfurt – Alemania.
Experiencia Profesional
Profesional con 20 años de experiencia. Actualmente es Gerente de la empresa Consultora Asesorías en Ingeniería Ambiental Pedro Sanhueza E.I.R.L., empresa especializada en Gestión de la calidad del Aire, modelación a escala local, urbana, y regional, modelación meteorológica, estimación de emisiones, planes de descontaminación, gestión de calidad del aire, modelación del efecto sobre la salud debido a la contaminación del aire, estadística aplicada y capacitación.

Enzo Enrique Sauma
Ph.D. en Industrial Engineering and Operations Research, University of California at Berkeley. M.S. en Industrial Engineering and Operations Research, University of California at Berkeley. Magíster en Ciencias de la Ingeniería, Pontificia Universidad Católica de Chile. Ingeniero Industrial, Pontificia Universidad Católica de Chile.
Experiencia Profesional
Asesoría a KAS Ingeniería S.A., como investigador asociado, en proyecto "Análisis de Factibilidad Técnico-Económica de Alternativas de Interconexión Eléctrica entre Chile, Bolivia, Colombia, Ecuador y Perú" del Programa de las Naciones Unidas para el Desarrollo (PNUD). Asesoría a la Subsecretaría de Economía, Fomento y Reconstrucción del Ministerio de Economía, como investigador responsable, en proyecto "Estudio del Marco Regulatorio de la Distribución de Energía Eléctrica en Chile: Investigación, Análisis y Propuestas Para Fomentar la Incorporación de Criterios de Eficiencia Energética por Parte de las Empresas Distribuidoras". "Análisis de opciones futuras de mitigación de gases de efecto invernadero para Chile en el sector Energía", proyecto encargado por la Comisión Nacional de Medioambiente y la Comisión Nacional de Energía de Chile , 2009 – Co-investigador. "Estudio sobre

Estimaciones de Costo y Potencial de Abatimiento de Emisiones de Gases de Efecto Invernadero para Diferentes Escenarios Futuros", proyecto encargado por el Ministerio de Hacienda de Chile, 2009 – Co-investigador."Co-control Benefits Analysis Project for Chile", proyecto financiado por el National Renewable Energy Laboratory of Unites States (NREL U.S.), contrato N. AMD-9-29778-01, 1999-2000 – Co-investigador.

Marcelo Mena
Doctor of Philosophy, Ingeniería Ambiental. Master of Science, Ingeniería Ambiental. Licenciado en Ciencias de la Ingeniería. Titulado Ingeniero Civil Bioquímico. Docente Universidad Andrés Bello.
Experiencia Profesional
Trabaja para el grupo de Gregory Carmichael en modelación de contaminación atmosférica, llevando a cabo varias campañas de medición y pronóstico de calidad de aire. Tesis: "Mejorías al pronóstico de calidad de aire mediante análisis sistemático de sesgo en un contexto tridimensional". Se otorga el grado de maestría en ciencias, mención ingeniería civil y ambiental. Tesis: "Estudios exploratorios en la formación de nitrosaminas cancerígenas en la desinfección de agua potable y residual". Se gradúa Cum Laude. Tesis: Factibilidad-Técnica Económica de la Instalación de una Fábrica Productora de Polihidroxibutirato por Fermentación.

Marcela Fernández
Abogada, Universidad Católica de Chile, Licenciada en Ciencias Jurídicas y Sociales, Facultad de Derecho, Universidad Católica de Chile. Master en Derecho, Law School, Stanford University, California, USA. Abogada asociada en derecho ambiental y sanitario, en Estudio Jurídico Gillmore, Salas y Asociados. Abogada senior en derecho ambiental y sanitario, asociada del Estudio Jurídico Cariola Díez Pérez-Cotapos & Cía Ltda.
Experiencia Profesional
Abogada consultora independiente en derecho ambiental, sanitario y silvo-agropecuario. Participación en estudios y declaraciones de impacto ambiental de líneas de transmisión eléctrica. Estudio "Apoyo en formulación de plan descontaminación Valle Central Región O'Higgins", miembro del equipo de Asesorías en Ingeniería Ambiental Pedro Alex Sanhueza Herrera E.I.R.L., encargado por el Gobierno Regional y CONAMA, ambos de la Región del Libertador Bernardo O'Higgins. Asesoría Central Termoeléctrica para ingreso al SEIA. Asesoría permanente a Minería y Medio Ambiente Limitada (MYMA). Estudio antecedente para la elaboración de la norma ambiental de ruido de aeropuertos, Jefa de proyecto del equipo de Rialto Consultores Ltda., encargado por la Comisión Nacional del Medio Ambiente, CONAMA.

Paulino González
Ingeniero Civil Quimicó, Gerente Técnico Corporativo Empresas IANSA, Gerente Técnico, Gerente de las Plantas Rapaco, Ñuble y Linares, Superintendente producción y Mantenimiento todos cargos desempeñados en IANSA.
Experiencia Profesional
Proyectos varios de ampliación y racionalización de plantas azucareras, en temas de incremento capacidad de elaboración, optimización costos fijos y variable, generación y consumo energía eléctrica, instalación centrales envasado, almacenamiento de azúcar, manejo residuos industriales (RILES, emisiones), programas de calidad. Muchos de estos proyectos asociados a numerosos viajes al extranjero para conocimiento de tecnologías y compra de maquinarias.

Evelyn Salazar Melgarejo
Ingeniero Civil en Geografía de la Universidad de Santiago de Chile, Licenciada en Ciencias de la Ingeniería.
Experiencia Profesional
Ha participado en declaraciones y estudios de impacto ambiental, así como también en el estudio denominado "Apoyo en la formulación del plan de descontaminación del Valle Central Región O'Higgins". Se ha especializado en la elaboración de Inventarios de Emisiones de proyectos mineros e industriales. Desde Septiembre de 2008, se desempeña como Jefe de Proyecto en la empresa Consultora Asesorías en Ingeniería Ambiental Pedro Sanhueza E.I.R.L.

Mónica Torreblanca Valdebenito
Ingeniero de Ejecución en Ambiente de la Universidad de Santiago de Chile.
Experiencia Profesional
Desde el año 2003, se desempeña como Gerente Técnico en la empresa Consultora Asesorías en Ingeniería Ambiental Pedro Sanhueza E.I.R.L. Ha participado en diversos proyectos relacionados con la evaluación de calidad del aire, especializándose en modelación a través de programas como ISCST-3, AERMOD y CALMET-CALPUFF.

María José Rodríguez Arancibia
Ingeniero Civil en Geografía de la Universidad de Santiago de Chile, Licenciada en Ciencias de la Ingeniería.
Experiencia Profesional
Ha participado en declaraciones y estudios de impacto ambiental. Se ha especializado en análisis de Calidad del Aire y Meteorología. Desde Junio de 2009, se desempeña como Ingeniero de Proyecto en la empresa Consultora Asesorías en Ingeniería Ambiental Pedro Sanhueza E.I.R.L.

Marcela Jerardino Etcheverry
Doctora en Ciencias Biológicas de la Universidad de Salamanca, España, Licenciada en Ciencias Biológicas y Profesora de Biología por la Universidad de Católica de Valparaíso.

Experiencia Profesional
Ha desarrollado investigaciones en el área ecológica y se ha desempeñado como profesora del Magíster en Biología Ambiental en la Universidad de Salamanca, España. Se ha especializada en la dirección y asesoría de proyectos del sector eléctrico, en la línea de trabajo centrada en Ecología y el Medio Ambiente. Ha dirigido, coordinado y participado de forma activa en numerosas evaluaciones ambientales como líneas de transmisión de alto voltaje, subestaciones y parques eólicos. Es Socia de KAS Ingeniería.

María Pía Bravo Rivera
Ingeniero Civil Industrial Universidad de Concepción, Experta en Evaluación de Impacto Ambiental y Energía Eólica, Formaselect Escuela de Negocios de Madrid, con sólida formación comercial, más de 14 años en cargos de jefaturas y gerenciales en el sector manufacturas y telecomunicaciones.
Experiencia Profesional
Participación en licitaciones internacionales, aperturas de mercados tanto en Europa como en Sudamérica. Experiencia en due diligence para empresas de energía. Socia de la Consultora BRESH Ingeniería y Derecho Ambiental, desarrollando estudios para empresas procesadoras de alimentos y diversas frutícolas de la región. Desde Octubre de 2008, se desempeña como Gerente Ambiental en KAS Ingeniería S.A.

Francisco Javier Aguirre González
Ingeniero Civil en Geografía (E) de la Universidad de Santiago de Chile, Licenciado en Ciencias de la Ingeniería.
Experiencia Profesional
Especialista en SIG. Ha participado en diseños de proyectos de Ingeniería, así como también en análisis de Calidad del Aire y Meteorología. Desde Enero de 2009, se desempeña como Ayudante de Proyecto en la empresa Consultora Asesorías en Ingeniería Ambiental Pedro Sanhueza E.I.R.L.

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001432

REPÚBLICA DE CHILE
COMISIÓN NACIONAL DEL MEDIO AMBIENTE
RF/HMA

AMPLIA PLAZO PARA PREPARACIÓN DE ANTEPROYECTO DE NORMA DE EMISIÓN PARA CENTRALES TERMOELÉCTRICAS.

SANTIAGO, 26 de junio 2009

RESOLUCIÓN EXENTA Nº 3704

VISTOS:

Lo dispuesto en la Ley Nº 19.300, sobre Bases Generales del Medio Ambiente; el Decreto Supremo Nº 93 de 1995, del Ministerio Secretaría General de la Presidencia, que establece el Reglamento para la Dictación de Normas de Calidad Ambiental y de Emisión; la Resolución Exenta Nº 1690 de la Dirección Ejecutiva de la Comisión Nacional del Medio Ambiente, de fecha 10 de julio de 2006, publicada en el Diario Oficial el 7 de agosto del mismo año, que dio inicio a la elaboración de la norma.

CONSIDERANDO:

Que, el plazo para la elaboración de la Norma de Emisión para Centrales Termoeléctricas fue ampliado por las Resoluciones Exentas Nº 6/07, Nº 2223/07, Nº 3912/08 y Nº 1005/09, todas de la Dirección Ejecutiva de CONAMA. El plazo fijado en la última resolución mencionada vence el 26 de junio del presente.

Que, el Departamento de Control de la Contaminación de CONAMA, mediante Memorándum N° 319-A, de 23 de junio de 2009, ha planteado la necesidad de ampliar los plazos para la preparación del anteproyecto de la norma referida, fundado en la necesidad de contar con los resultados del estudio de análisis técnico- económico de los escenarios regulatorios para la aplicación de una norma de emisión para Termoeléctricas.

Que, dicho estudio será realizado, mediante contratación directa, por la asociación de la consultora KAS ingeniería y el académico Pedro Sanhueza, estimándose la entrega del informe final en el mes de diciembre del presente año.

Por todo lo anterior, es que ser requiere contar con un plazo adicional para la entrega del anteproyecto de la norma, el que sería hasta el día 30 de enero de 2010.

RESUELVO:

AMPLÍESE el plazo para la preparación del anteproyecto de la Norma de Emisión para Centrales Termoeléctricas, hasta el día 30 de enero de 2010.
Anótese, comuníquese, y archívese.

RODRIGO GUZMÁN ROSEN
DIRECTOR EJECUTIVO (S)
COMISIÓN NACIONAL DEL MEDIO AMBIENTE

IHC/CGC
Distribución:
- Departamento Jurídico, CONAMA.
- Departamento de Control de la Contaminación, CONAMA.
- Expediente Público de la Norma.
- Comité Operativo de la Norma.

Lo que transcribo a Ud. para su conocimiento saluda atentamente a Ud.
NURY VALBUENA OVEJERO
Oficial de Partes
Comisión Nacional del Medio Ambiente (CONAMA)

[redacted]

Acta reunión Comité Operativo Norma de Emisión para Termoeléctricas
Miércoles 1º de julio 2009 Inicio: 11:00 hrs. - Término: 12:40 hrs.

Temas:

1. Se informa sobre reunión entre profesionales de CONAMA y el Sr. Kjell-Frode Nodland, especialista en desulfurizadores con agua de mar de ALSTOM. Toda la información entregada durante la entrevista se integrará al Expediente.

2. Exposición: Evaluación de beneficios por la aplicación de la norma de emisión para termoeléctricas. Expositor: PhD Ing. Ambiental Pedro Sanhueza. Se adjunta exposición.

3. Se informa que se realizará una encuesta al sector de termoeléctricas, con el fin de actualizar la información del sector. La última información actualizada es del año 2005 que recogió el estudio de GAMMA. Se da énfasis a que el propio sector regulado en reunión de comité ampliado hizo ver la necesidad de actualizar dicha base de datos.

4. Próxima reunión: miércoles 15 de julio de 11:00 a 13:00 hrs. Tema: discusión sobre diseño de escenarios y a la versión de anteproyecto.

Acuerdos:

Una vez diseñada la encuesta se enviará a la CNE para su revisión y VBº.

Contacto en CONAMA D.E.:
Carmen Gloria Contreras Fierro
cgcontreras@conama.cl
fono: 240 5772

..//

BIERNO DE CHILE
CONAMA

"COMITÉ OPERATIVO DE NORMA DE EMISION PARA TERMOELECTRICAS"

HA : 01/07/2009
RA INICIO : _____
RA TÉRMINO: _____
AR : Sala de Reuniones 4° piso – Teatinos 258

	NOMBRE	INSTITUCION	DIRECCION	FONO	E-MAIL
.	PRISCILLA ULLOA	CONAMA		2405787.	pulloa@conama.cl
.	MARCELO MENA	KAS		6618230	mmena@unab.cl
.	Ingrid Jiménez	CONAMA		2405698	ihenriquez@conama.cl
.	SANDRA BRICEÑO	CONAMA		2411878	~~sandra~~ sbriceno@conama.cl
.	Rodolfo Granifo	KAS ING		2232346	RODOLFO.GRANIFO@KASING.cl
.	Carlos Barrio	KAS ING		2232346	carlos.barrio@kasing.cl
.	Marcela Gerardino	KAS Ingeniería		2232346	marcela.gerardino@kasing.cl

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	NOMBRE	INSTITUCION	DIRECCION	FONO	E-MAIL
8.	MARIA PIA BRAVO	KAS			PIA.BRAVO@KAS.ING.CL
9.	Angela Soriano H	MINVU		3513641	asoriano@minvu.cl
0.	Caudine Gómez A	CNE		3656876	cgomez@cne.cl
1.	WALTER FOLCH	MINSAL		5740787	wfolch@minsal.cl
2.	Carmen Contreras	CONAMA			
3.	Pedro Sanhueza	Consultor			
4.	Cristian Urrutia	CONAMA VIII			
5.					
6.					
7.					
8.					
9.					
20.					

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GOBIERNO DE CHILE
COMISIÓN NACIONAL DEL MEDIO AMBIENTE

GEOAIRE

ESTIMACION DE BENEFICIOS ASOCIADOS A REDUCCIÓN DE EMISIONES ATMOSFÉRICAS

"Análisis General del Impacto Económico y Social de una Norma de Emisión para Termoeléctricas"

Dr. Pedro Sanhueza H

Julio - 2009

1

http://www.geoaire.cl – 56-2-2093838

Pregunta a responder

GEOAIRE

- Los <u>beneficios ambientales y de salud</u> debidos al control de la contaminación del aire, <u>justifican los costos incurridos</u> por la Industria y los consumidores ?

2

CONTENIDO

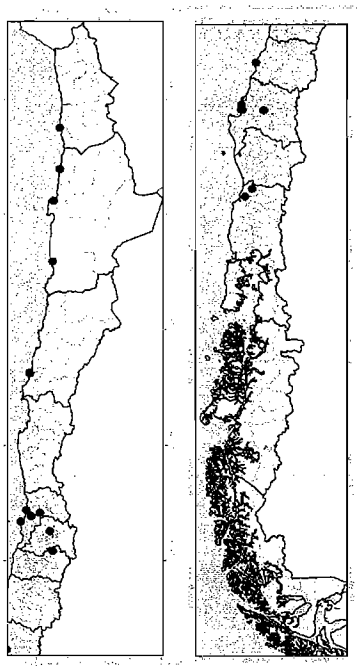
- Fuente emisora a Regular
  - Localización
  - Emisiones
  - Efectos ambientales
- Enfoque metodológico
  - Análisis de Impacto Regulatorio (AIR)
- Análisis de casos
  - Extranjeros
  - Caso Tocopilla

3

Fuente a normar

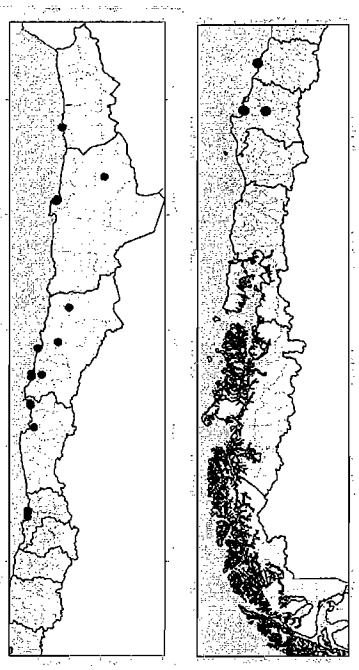
- Localización

4



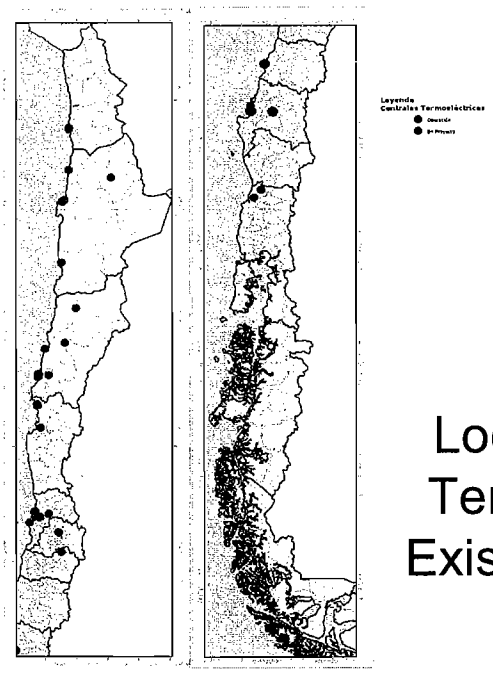
Localización de Termoeléctricas Existentes

5



Localización de Termoeléctricas En Evaluación SEIA

6



Localización de Termoeléctricas Existentes + SEIA

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GEOAIRE

Fuente a normar

- Emisiones
  - Gases
    - SOx, NOx, CO, CO_2
  - Materia Particulada
    - MPS, MP10, MP2.5, Hg, Ni, V, Cd, Cr, Co,
  - COVs
    - Benceno, Tolueno, xyleno. Aldehídos, etylbenceno, etc.
- Reacciones en la atmósfera
  - Contaminantes secundarios
    - SO_4, NO_3, O_3

MP10
MP2.5
SO_2
NO_2
Hg
V
Ni

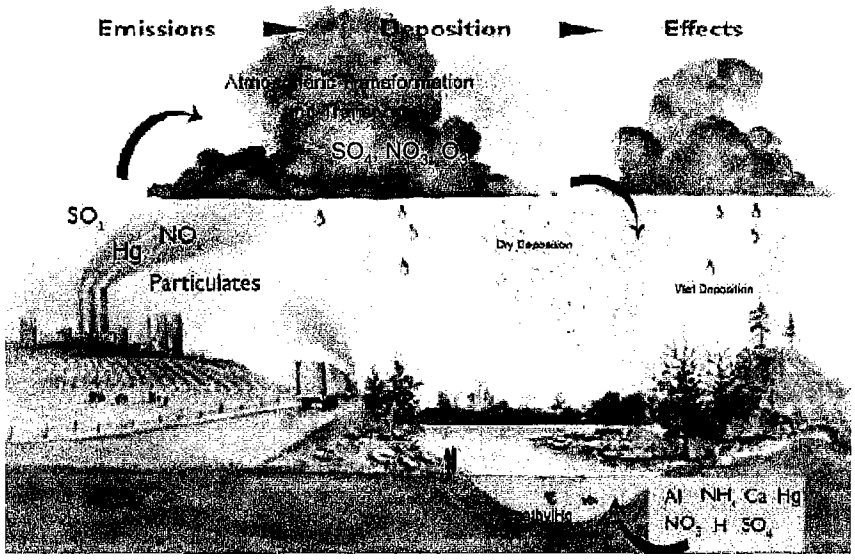
8

Fuente a normar

- Efectos ambientales esperados

9

Camino de las emisiones



Efectos de los Contaminantes

- Salud Humana
  - Sistema Respiratorio
  - Sistema Cardiovascular
  - Sistema Neurológico
  - Sistema Inmunológico

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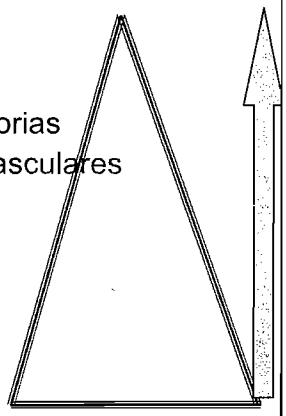
Efectos en salud asociados a la Contaminación Atmosférica (con evidencia científica)

- Mortalidad (adultos mayores)
- Mortalidad infantil
- Admisiones Hospitalarias causas respiratorias
- Admisiones Hospitalarias causas cardiovasculares
- Visitas a salas de urgencia
- IRAs
- Síntomas respiratorios
- Días ausentismo laboral y escolar
- Días de actividad restringida
- Irritación a los ojos



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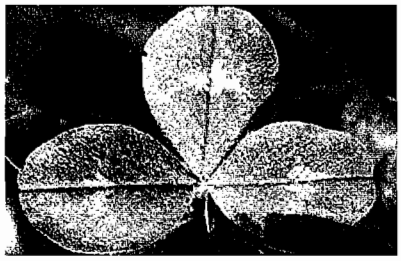
Efectos de los Contaminantes

- Ecosistema
  - Vegetación
  - Cuerpos de agua (eutrofización, acidificación)



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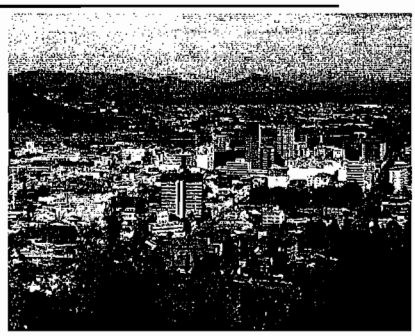
Efectos de los Contaminantes

- Visibilidad
  - Absorción
  - Dispersión



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Efectos de los Contaminantes

- Bienes Materiales
  - Deterioro (caliza, mármol)
  - Corrosión

How acid rain affects stonework.
The picture on the left was taken in 1908.
The picture on the right was taken in 1968

Efectos sobre la salud

- Corto Plazo
  - Agudos MP10, MP2,5, SO_2, NO_2
- Largo Plazo
  - Cancerígenos Ni
  - No Cancerígeno Hg

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Función Concentración-Respuesta

$$\text{Log(Efecto\_salud)} = \alpha_o + \alpha_1 f(T) + \alpha_2 f(S) + \alpha_3 f(M) + \gamma f(P) + \beta MP_{10} + \varepsilon$$

Medidas de Efecto:

$$\text{Riesgo Relativo} = e^{\{\beta * \Delta MP_{10}\}}$$

Características de la Función C-R

Es una función Lineal

Sin Umbral

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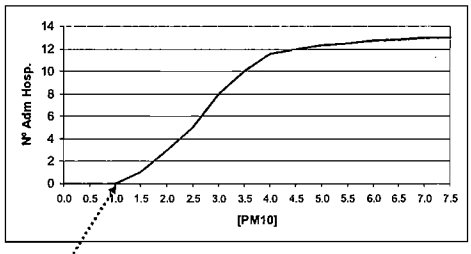
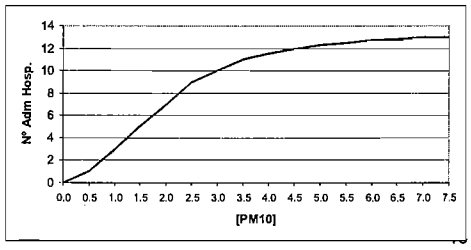
Umbral



Umbral de daño

Sin Umbral



Beneficio Ambiental

- No significa Cumplimiento de Norma de Calidad del aire
- ➔ Reducción de Riesgo
  - Salud – eventos evitados
  - Recursos naturales renovables
- Beneficio Valorado – Valor económico (Salud)
- Beneficio No Valorado – Cualitativo

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Metodología para Evaluar Beneficios de una Regulación

- Comparar dos Escenarios
  - Base
  - Con Regulación
- En términos de
  - Emisiones
  - Concentraciones
  - Efecto (Salud/Ecosistema)
  - Monetario

Análisis de Impacto Regulatorio

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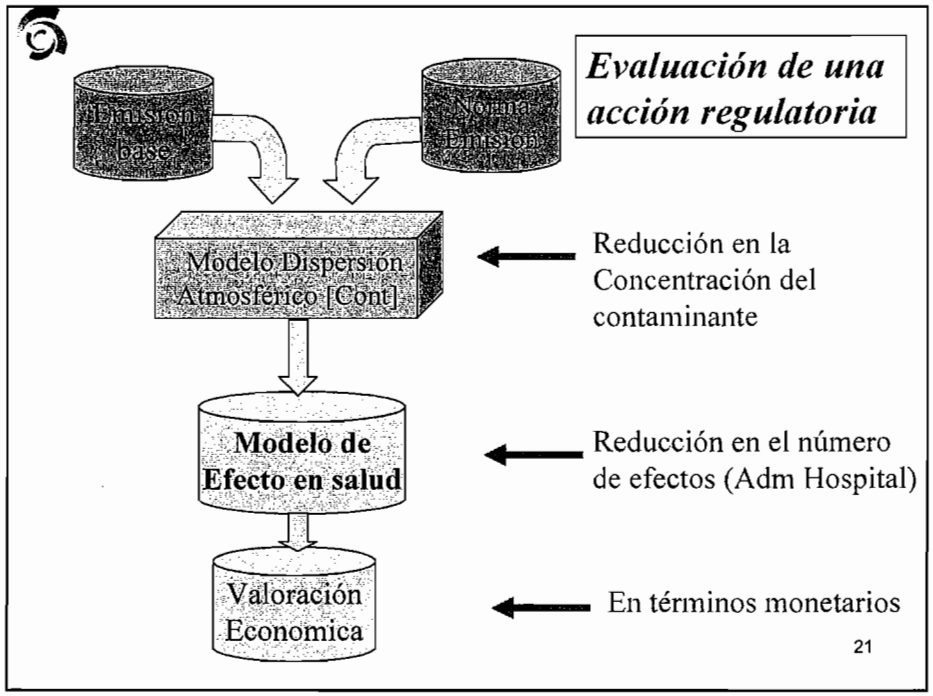

Número de Efectos Evitados

$$\Delta E_{\delta} = \sum_{i=1}^{Nc} Eo_{\delta} * \left(e^{\{\beta_{\delta} \Delta C\}} - 1\right) * Pop_i$$

ΔE_{δ} : Número de Efectos tipo d evitados, debido a la Norma

Nc : Número de celdas del área de estudio

β_{δ} : Coeficiente de Concentracion-Respuesta para la enfermedad δ

Eo : Tasa de admisión hospitalaria por enfermedad δ

ΔC : Delta Concentración (Base – Norma) obtenido con Modelo de Dispersión Atm

Pop_i : Población en celda i obtenido con Modelo de Dispersión Atm

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Ecuación Beneficios de Medida Regulatoria

$$\text{Beneficio}_{\delta} = \sum \text{Dha}_{\delta} * \left(e^{\{\beta_{\delta}(O_{ik} - O_{th})\}} - 1 \right) * \text{Pop}_{k} * \text{WTP}_{\delta}$$

Beneficio : Costo evitado ($) por enfermedad δ en ciudad c

WTPδ : Valor monetario asociado a la enfermedad δ

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ANALISIS DE CASOS

GEOAIRE

PERGAMON

Atmospheric Environment 36 (2002) 1063–1075

ATMOSPHERIC ENVIRONMENT

www.elsevier.com/locate/atmosenv

Using CALPUFF to evaluate the impacts of power plant emissions in Illinois: model sensitivity and implications

Jonathan I. Levy[a,*], John D. Spengler[a], Dennis Hlinka[b], David Sullivan[b], Dennis Moon[c]

[a] *Department of Environmental Health, Harvard School of Public Health, Landmark Center, P.O. Box 15677, Boston, MA 02115, USA*
[b] *Sullivan Environmental Consulting, 1900 Elkin St. Suite 240, Alexandria, VA 22308, USA*
[c] *SSESCO, 3490 Lexington Ave. N. Suite 110, Shoreview, MN 55126, USA*

Received 4 March 2001; accepted 10 September 2001

24

Evaluación del Impacto de regular Plantas eléctricas en Illinois

- Bajo la CAA, las Plantas antiguas están exentas de cumplir normas de emisión
- En Illinois existen 9 (7600 MW)
- Evaluar el beneficio en salud, si se aplica BACT
  - Población $33x10^6$
  - Area de modelación = 750x780 Km
  - Celdas de 15 km
  - PM2.5, SO_4, NO_3

25

Evaluación del Impacto de regular Plantas eléctricas en Illinois

- Análisis de sensibilidad
  - Configuración del Modelo de Dispersión
  - Tamaño del área a modelar

	PM2.5 $\mu g/m^3$	SO_4 $\mu g/m^3$	NO_3 $\mu g/m^3$	Media Annual PM2.5
Delta Actual /BACT	0,04	0,13	0,1	22

26

ANALISIS DE CASOS

- US EPA
- RIA: Regulatory Impact Assessment
  - Normas de Emisión
    - De Contaminantes peligrosos (HAPs) generados por combustibles fósiles en turbinas de combustión (Formaldehído, Acetaldehído, Benceno, Tolueno)
    - De Mercurio en Planta eléctricas a carbón
  - Normas de Calidad del aire
    - Ozono

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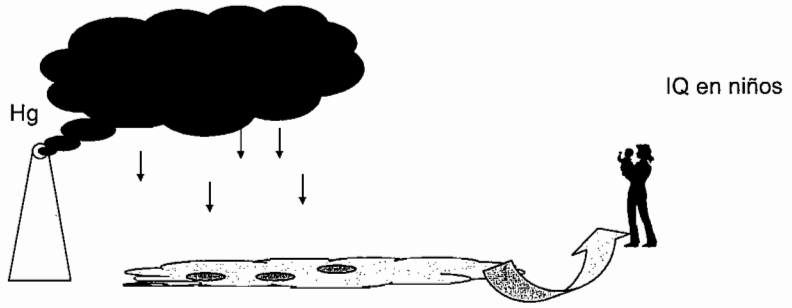
ANALISIS DE CASOS

- RIA: Norma Emisión Mercurio en Termoeléctricas
  - Hg contaminante no cancerígeno, que produce daño neurológico
  - RfD = 0,0001 mg/kg-d en 70 años
  - Bioacumula en peces
- Indiacador de beneficios
  - Coeficiente intelectual (IQ) en niños
  - Mujeres embarazadas
  - Sólo la mitad Este de USA

28

Método para estimar beneficios Hg



29

Evaluación Beneficio Norma Hg

- Sin Norma: ↓ 0,06 – 0,07 el IQ
- Con Norma: ↓ 0,007 – 0,009 el IQ

- US$ 8800 por mejorar 1 punto de IQ por persona

- Beneficios = US$2,6x$10^6$/año

30

Caso Tocopilla

Termoeléctrica	Concentración MP mg/m³N	Concentración MP mg/m³N
Electroandina S.A	U12-13: **190**	U14-15: **102**
Norgener S.A.	U1 : **180**	U2: **132**

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Caso Tocopilla

Evaluar el Beneficio en Salud, de una Norma de Emisión para MP en Tocopilla

Alternativas de Regulación:

- 100 mg/m³N
- 50 mg/m³N
- 18 mg/m³N

32

Caso Tocopilla

Información requerida:

Nº de habitantes (2006)	**22807**

Estadistica de Morbilidad

Cardiovascular (I)	248
Respiratorias (J)	549

Estadistica de Mortalidad

Muertes (I+J)	145

Ausentismo Laboral

Días de trabajo perdido	2483

33

Fuente: AGIES

Caso Tocopilla

Norma Emisión MP10 (mg/m³N)	Emision de MP10 (ton/año)	Concentración de MP10 (µg/m³)	Δ [MP10] (µg/m³)
Base	3388	56	--
100	2598	53	3
50	1299	48	8
18	468	45	11

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Caso Tocopilla

Norma Emisión MP10 (mg/m³N)	Casos Evitados				Beneficio anual $x10^6$
	Nº Muertes Cardiorespiratorias	Nº Admisiones Causas Respiratorias	Nº Admisiones Causas Cardiovasculares	Días de trabajo perdidos	
100	0	4	3	44	9,4
50	1	11	9	118	410,9
18	2	15	12	164	804,2

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Fuentes de Información

- Salud - DEIS 2006
- Población – INE Proy 2006
- Betas C-R: Cifuentes 2005 / Sanhueza-Conama 2006-2007
- Valoración de efectos en salud: Cifuentes 2005
- Meteorología: - Bases TE
- Calidad del Aire: Bases TE

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Herramientas computacionales

- Transporte/Dispersión/Química atmosférica
  - Calmet/Calpuff
  - Transporte grandes distancias / Interfase T-A / Rx Químicas
- Asignación espacial
  - ArcGIS
  - Spatial Analyst
- Valoración de beneficios en Salud
  - BenMap

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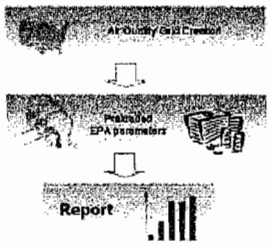
BenMAP

Environmental Benefits Mapping and Analysis Program

Herramienta para estimar los efectos en salud humana, y los beneficios económicos asociados a cambios en las concentraciones de contaminantes en el aire

One-Step Analysis

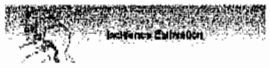
After you import the air quality data for your area, use this tool to apply default settings and create a report.



Custom Analysis

Step 1 – Import air quality data

Step 2 – Set custom parameters



Step 3 – Use results from Step 2 to set custom parameters

Step 4 – Run report

Evaluación de Beneficios

- **Valorados**
  - MP10 C-R - $
  - MP2.5 C-R - $
  - NO_2 C-R - $
  - SO_2 C-R - $ / Delta Depositación N.Sec.
  - MPS Delta Delta Depositación N.Sec.
  - Hg Delta Riesgo RfC (vía inhalación)
  - Ni Delta Riesgo de Cáncer
  - Vn
- **No Valorados**
  - Visibilidad Cualitativamente
  - Daño materiales Cualitativamente

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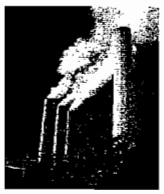

GOBIERNO DE CHILE
COMISIÓN NACIONAL DEL MEDIO AMBIENTE

GEOAIRE

ESTIMACION DE BENEFICIOS ASOCIADOS A REDUCCIÓN DE EMISIONES ATMOSFÉRICAS

"Análisis General del Impacto Económico y Social de una Norma de Emisión para Termoeléctricas"

Julio - 2009

40

http://www.geoaire.cl – 56-2-2093838

GOBIERNO DE CHILE
COMISION NACIONAL
DEL MEDIO AMBIENTE

60145C

Carta D.E. N°: 092494

Mat.: Encuesta para estudio: Análisis del impacto económico y social de la norma de emisión para termoeléctricas.

Santiago,
22 JUL. 2009

Señor
Según Distribución
Presente

De mi consideración,

Junto con saludarle, le informo que la Comisión Nacional del Medio Ambiente (CONAMA) en conjunto con la Comisión Nacional de Energía (CNE), han encomendado a la asociación de consultoras KAS Ingeniería y Asesorías en Ingeniería Ambiental Pedro Sanhueza, la realización del estudio "Análisis del Impacto Económico y Social de la Norma de Emisión para Termoeléctricas", cuyo objetivo es evaluar el impacto económico y social de la mencionada norma.

Por lo anterior, se ha enviado a cada empresa generadora un cuestionario donde se ha solicitado se proporcione información para el estudio. Por este motivo, se agradecerá a ustedes en sus roles de Presidencia de los Centros de Despacho Económico de Carga del Sistema Interconectado Central (SIC) y del Norte Grande (SING), tengan a bien colaborar difundiendo con las empresas que conforman los distintos Directorios este requerimiento que responde a un interés común entre el regulador y el sector a regular.

El plazo del estudio es bastante acotado por lo que es indispensable contar con la respuesta al cuestionario antes del 30 de julio del presente año. Se adjunta en CD carta tipo enviada y encuesta. Ante cualquier consulta agradeceré contactar a la profesional de CONAMA Carmen Gloria Contreras Fierro, fono: 2405772, cgcontreras@conama.cl.

Agradeciendo de antemano su colaboración,

Saluda atentamente a usted,

COMISION NACIONAL DEL MEDIO AMBIENTE
DIRECTOR EJECUTIVO

Álvaro Sapag Rajevic
Director Ejecutivo
Comisión Nacional de Medio Ambiente

HWA/GLS/CGCF/aat
Distribución:
- Sr. Jaime Bravo, Jefe Área Medio Ambiente y Energías Renovables, CNE.
- Sr. Eduardo Ricke Muñoz, Director Ejecutivo CDEC-SIC Ltda.
- Sr. Pedro de la Sota, Presidencia Directorio CDEC-SING.
- Expediente Público de la Norma de Emisión para Termoeléctricas.
- Archivo Dirección Ejecutiva

13.536

001457

GOBIERNO DE CHILE
COMISION NACIONAL
DEL MEDIO AMBIENTE

Carta D.E. N°: 092363/

Mat.: Encuesta para estudio, Análisis del Impacto Económico y Social de la Norma de Emisión para Termoeléctricas.

Santiago, 07 JUL. 2009

Señor
Luis Felipe Cerón
AES Gener
Presente

De mi consideración,

Junto con saludarle, le informo que la Comisión Nacional del Medio Ambiente (CONAMA) en conjunto con la Comisión Nacional de Energía (CNE), han encomendado a la asociación de consultoras KAS Ingeniería y Asesorías en Ingeniería Ambiental Pedro Sanhueza, la realización del estudio "Análisis del Impacto Económico y Social de la Norma de Emisión para Termoeléctricas", cuyo objetivo es evaluar el impacto económico y social de la mencionada norma.

Con este fin, agradeceré a usted nos proporcione la información requerida en el cuestionario adjunto y solicitamos tenga a bien designar un profesional de su empresa para coordinar la entrega de la información y resolver posibles consultas. El plazo del estudio es bastante acotado por lo que es indispensable contar con la respuesta al cuestionario antes del 30 de julio del presente año.

Se solicita entregar el cuestionario respondido en forma completa en formato digital (CD o DVD) y enviar al Sr. Hans Willumsen, Jefe del Dpto. Control de la Contaminación, CONAMA, Teatinos 258, 8° piso. Además, de enviar el cuestionario al correo electrónico de la profesional Srta. Carmen Gloria Contreras, cgcontreras@conama.cl. Indicando en el asunto: cuestionario termoeléctrica - *Nombre de la Central*. Para cualquier consulta sobre el cuestionario, ruego contactar al Sr. Rodolfo Granifo, teléfono 2232346 o al mail rodolfo.granifo@kasing.cl.

Agradeciendo de antemano su colaboración,

Saluda atentamente a Ud.

COMISION NACIONAL DEL MEDIO AMBIENTE
DIRECTOR EJECUTIVO

Álvaro Sapag Rajevic
Director Ejecutivo
Comisión Nacional de Medio Ambiente

HWA/CGCF/aat

Distribución:
- Sr. Jaime Bravo, Jefe Área Medio Ambiente y Energías Renovables, CNE.
- Expediente

GOBIERNO DE CHILE
COMISION NACIONAL DEL MEDIO AMBIENTE

KAS INGENIERIA

GEOAIRE

CUESTIONARIO
PARA CENTRALES TERMOLECTRICAS
Julio, 2009

Introducción:

Este cuestionario forma parte del estudio: "Análisis General del Impacto Económico y Social de una Norma de Emisión para Termoeléctricas", desarrollado para la Comisión Nacional del Medio Ambiente (CONAMA) y la Comisión Nacional de Energía (CNE) por la asociación de consultoras KAS Ingeniería y Asesorías en ingeniería Ambiental P. Sanhueza.
El objetivo principal de la encuesta es contar con los antecedentes necesarios que permitan describir la situación actual de las distintas unidades de generación que existen a la fecha en el país.

La encuesta contempla 10 secciones, que comprenden información sobre:

1. Identificación de la Empresa
2. Antecedentes de la Central Térmica
3. Características Técnicas Generales
4. Características del Combustible
5. Características de las Chimeneas
6. Descripción de la Combustión
7. Descripción de Equipos de Abatimiento
8. Descripción de Emisiones
9. Descripción de monitoreo continuo de emisiones (si es que tiene)
10. Información Calidad del Aire y Meteorología

Instrucciones Generales:

Se solicita entregar el cuestionario respondido en forma completa en formato digital (CD o DVD) y enviar al Sr. Hans Willumsen, Jefe del Dpto. Control de la Contaminación, CONAMA D.E. Teatinos 258, 8º piso. Además, se solicita enviar el cuestionario respondido en forma completa al correo electrónico de la Srta. Carmen Gloria Contreras, cgcontreras@conama.cl, responsable técnico del diseño de la regulación. Indicando en el asunto: Cuestionario termoeléctrica - Nombre de la Central.

Contactos en caso de consultas:

En caso de consultas por favor contacta al Sr. Rodolfo Granifo, fono: 02- 223 23 46, correo electrónico: rodolfo.granifo@kasing.cl

C01456

CENTRAL: INDICAR NOMBRE COMPLETO CENTRAL

1. Identificación de la Empresa

1.1 Nombre Empresa:

Propietario:

Representante legal:

R.U.T.:

Dirección:

Teléfonos:

1.2 Persona que responde cuestionario:

Cargo:

Dirección:

Teléfono de contacto:

Correo electrónico:

2. Antecedentes de la Central Térmica

2.1 Ubicación

Dirección:

Comuna: Región:

Año puesta en marcha: Vida útil [años]:

2.2 Ubicación Georreferenciada UTM

Coord. Norte:	Coord. Este:	Datum:	Huso (18 o 19):

2.3 Superficie Central Térmica

Sup. Terrenos [m²]:

Sup. en Planta Construida [m²]:

Adjuntar un Layout de la Planta Formato autocad georreferenciado.

2.4 Unidades de Generación

Número total de unidades de generación individual:

Número total de unidades de generación dual:

3. Características Técnicas Generales

3.1 Características unidades de generación individuales

Características	Unidades de Generación Individuales							
	Unidad 1	Unidad 2	Unidad 3	Unidad 4	Unidad 5	Unidad 6	Unidad 7	Unidad 8
Nombre Unidad CDEC								
Tipo turbina								
Combustible utilizado								
Potencia bruta [MW]								
Consumo propios [%]								
Potencia neta [MW]								
Mínimo Técnico [MW]								
Tiempo de Partida [minutos]								
Rampa a Minimo Técnico [MW/Minutos]								
Rampa a Plena Carga [MW/Minutos]								
Tasa Indisponibilidad Forzada [h/año]								
Tasa Indisponibilidad Programada [h/año]								
Factor de Planta anual [%]								
Tiempo anual de operación [h]								
Generación media anual [MWh/año]								
Año de puesta en servicio								
Tipo combustible								
Consumo específico[1]								
[t/MWh]								
[m³/MWh]								
[m³N/MWh]								
Rendimiento energético plena carga [kcal/kWh]								
Identificación chimenea a la cual descarga[2]								
Rendimiento energético carga promedio [kcal/kWh]								
Resolución de Calificación Ambiental (sólo si aplica)								

1: Ingrese el consumo específico de combustible y a continuación, marque con una "x" la unidad correspondiente según tipo de combustible.

2: Indicar nombre de chimenea a la cual descarga. El nombre de la Chimenea se obtiene al completar la Sección 5 de este cuestionario.

3.2 Características unidades de generación dual (completar sólo si posee unidades duales)

Características	Unidades de Generación Dual							
	Unidad 1		Unidad 2		Unidad 3		Unidad 4	
	Combustible 1	Combustible 2	Combustible 1	Combustible 2	Combustible 1	Combustible 2	Combustible 1	Combustible 2
Nombre Unidad CDEC								
Tipo turbina								
Combustible utilizado								
Potencia bruta [MW]								
Consumo propios [%]								
Potencia neta [MW]								
Mínimo Técnico [MW]								
Tiempo de Partida [minutos]								
Rampa a Minimo Técnico [MW/Minutos]								
Rampa a Plena Carga [MW/Minutos]								
Tasa Indisponibilidad Forzada [h/año]								
Tasa Indisponibilidad Programada [h/año]								
Factor de Planta anual [%]								
Tiempo anual de operación [h]								
Generación media anual [MWh/año]								
Año de puesta en servicio								
Consumo específico[1]								
[t/MWh]								
[m³/MWh]								
[m³N/MWh]								
Rendimiento energético plena carga [kcal/kWh]								
Identificación chimenea a la cual descarga[2]								
Rendimiento energético carga promedio [kcal/kWh]								
Resolución de Calificación Ambiental (sólo si aplica)								

1: Ingrese el consumo específico de combustible y a continuación, marque con una "x" la unidad correspondiente.

2: Indicar nombre de chimenea a la cual descarga. El nombre de la Chimenea se obtiene al completar la Sección 5 de este cuestionario.

4. Características del Combustible

4.1 Características combustible unidades de generación individuales

Características	Unidades de Generación Individual							
	Unidad 1	Unidad 2	Unidad 3	Unidad 4	Unidad 5	Unidad 6	Unidad 7	Unidad 8
Nombre Unidad CDEC								
Combustible utilizado								
Tipo de combustible[1]								
Mezcla de combustible[2] [%]								
Consumo anual[3]								
[t/año]								
[m³/año]								
[m³N/año]								
Cenizas [%]								
Humedad [%]								
Azufre [%]								

1: Indentifique claramente el tipo de combustible utilizado. (Ej: Carbón Bituminoso).

2: Si utiliza mezcla de combustibles, indique porcentaje de combustibles utilizados en mezcla. (Ej: Carbón - 95% Bituminoso; 5% Subbituminoso).

3: Ingrese el consumo específico de combustible y a continuación, marque con una "x" la unidad correspondiente.

4.2 Características combustible unidades de generación dual (completar sólo si posee unidades duales)

Características	Unidades de Generación Dual							
	Unidad 1		Unidad 2		Unidad 3		Unidad 4	
	Combustible 1	Combustible 2	Combustible 1	Combustible 2	Combustible 1	Combustible 2	Combustible 1	Combustible 2
Nombre Unidad CDEC								
Combustible utilizado								
Tipo de combustible[1]								
Consumo anual[2]								
[t/año]								
[m³/año]								
[m³N/año]								
Cenizas [%]								
Humedad [%]								
Azufre [%]								

1: Indentifique claramente el tipo de combustible utilizado. (Ej: Carbón Bituminoso).

2: Ingrese el consumo específico de combustible y a continuación, marque con una "x" la unidad correspondiente.

m^3N: Presión 1 atm; 0°C.

5. Características de las Chimeneas

5.1 Características	Chimeneas							
	Ch. N° 1	Ch. N° 2	Ch. N° 3	Ch. N° 4	Ch. N° 5	Ch. N° 6	Ch. N° 7	Ch. N° 8
Identificación de Chimenea (Asigne un número único con respecto al plano de layout)								
Altura [m]								
Diámetro a la salida de los gases [m]								
Temperatura de los gases a la salida [°C]								
Velocidad de salida de los gases [m/s]								
Flujo volumétrico [m³N/h]								
Nombres de unidades CDEC que descargan a esta chimenea								

5.2 Georeferenciación de Chimeneas

Chimenea	Identificación N° de Chimenea	Ubicación Georreferenciada UTM				Cota [m.s.n.m]
		Coord. Este	Coord. Norte	Datum	Huso	
Ch. N° 1						
Ch. N° 2						
Ch. N° 3						
Ch. N° 4						
Ch. N° 5						
Ch. N° 6						
Ch. N° 7						
Ch. N° 8						
Ch. N° 9						

6. Descripción de la Combustión

6.1 Características combustión de unidades de generación individuales

		Unidades de Generación						
		Unidad 1	Unidad 2	Unidad 3	Unidad 4	Unidad 5	Unidad 6	Unidad 7
Tipo de Quemador (Low Nox, Tangencial, Frontal, otro)								
Volumen estimado Escorias [t/año]								
Quemables en escorias [kg combustible/kg escoria]								
Gases a la salida de la caldera	Temp. [°C]							
	CO_2 [%]							
	CO [%]							
	SO_2 [%]							
Exceso de aire [%]								
Temperatura vapor a la salida de la caldera [°C]								
Presión de vapor a la salida de la caldera [psi]								
Temperatura vapor a la salida de la turbina [°C]								
Presión de vapor a la salida de la turbina [psi]								
Toneladas vapor/kWh								

6.2 Características combustión de unidades de generación dual

Características		Unidades de Generación Dual						
		Unidad 1	Unidad 2	Unidad 3	Unidad 4	Unidad 5	Unidad 6	Unidad 7
Gases a la salida de la caldera	Temp. [°C]							
	CO_2 [%]							
	CO [%]							
	SO_2 [%]							
Exceso de aire [%]								
Temperatura vapor a la salida de la caldera [°C]								
Presión de vapor a la salida de la caldera [psi]								
Temperatura vapor a la salida de la turbina [°C]								
Presión de vapor a la salida de la turbina [psi]								
Toneladas vapor/kWh								

7. Descripción de Equipos de Abatimiento

7.1 Equipos para abatir Material particulado

Tipo de Equipo (filtro de mangas, PE, otro)	Identificación de Unidad/es (nombre unidad según CDEC)	Eficiencia abatimiento [%]	Flujo de diseño [m³/h]	Año puesta en marcha	R. C. A. (sólo si aplica)

7.2 Equipos para abatir Gases (NOx; SOx)

Equipo (SOX: desulfurizador seco, humedo, c/agua de mar, otro. NOx: SCR, NSCR)	Identificación de Unidad/es (nombre unidad según CDEC)	Flujo de diseño [m³/h]	Año puesta en marcha	R. C. A. (sólo si aplica)

8. Descripción de Emisiones

Nombre Unidad CDEC	Tipo de unidad de Generación (Individual o Dual)	Tipo de combustibles	Identificación de la Chimenea a la cual descarga	MP [mg/m³N]	NOx [mg/m³N]	SOx [mg/m³N]	CO [mg/m³N]

m^3N: 1 atm, 25°C. Señalar si usa otra normalización.

9. Descripción de monitoreo continuo de emisiones (si es que tiene)

	SI	NO
9.1 Incluye algún sistema de medición de emisiones continua		
9.2 Cuenta con algún sistema de control de calidad del monitoreo y de los datos		

Si la respuesta es **SI**, continue la encuesta. Si es **No** pase a la siguiente hoja sobre Información Calidad del Aire.

9.3 Equipo de monitoreo (nombre y marca)	Contaminante medido	Tipo de sistema (extracción, in-situ u otro)	Frecuencia de muestreo	Límites de detección	
				Inferior (indique unidad)	Superior (indique unidad)

Fin de esta parte .-

CENTRAL: INDICAR NOMBRE COMPLETO CENTRAL

10. Información sobre Monitoreo de Calidad del Aire y Meteorología

Estaciones de monitoreo y/o de meteorología propiedad de la empresa

10.1 Identificación de profesional responsable y Nº de estaciones (meterología y/o calidad del aire)

Nombre persona que responde esta parte:	
Teléfono de contacto:	
E-mail	
Nº de estaciones de monitoreo:	
Nº de estaciones meteorológicas:	

Representatividad:

EMRP: Estación de monitoreo con representatividad poblacional para partículas

EMRPG: Estación de monitoreo con representatividad poblacional para partículas

10.2 Monitoreo de variables (meteorologicas y/o de calidad del aire)

				Variables monitoreadas (marcar con una X)								Representatividad (marcar con una X)		Temporalidad
Nombre Estación	Coord. Norte	Coord. Este	Cota [msnm]	MP10	SO2	NOX	O3	Velocidad del viento [m/s]	Dirección del viento [Grados]	Temperatura [ºC]	Otras (indicar cuál)	EMRP	EMRPG	permanente (P) o campaña (C)

Indicar datum y huso:

10.3 Se solicita adjuntar base de datos de variables meteorológicas hora a hora, de los últimos 3 años (2006 - 2007 - 2008)

Incluyendo:

Velocidad del viento [m/s]
Direccion del viento [Grados]
Temperatura [ºC]
Radiacion Solar [Watt/m²]
Humedad relativa [%]
Sigma Theta [Grados]

Importante: se pide entregar en formato electrónico / planilla excel en CD y enviar por correo electrónico.

10.4 Se solicita adjuntar base de datos de concentración de contaminantes hora a hora de los últimos 3 años (2006 - 2007 - 2008)

Incluyendo: Concentraciones diarias de MP10 [ug/m³]
Concentraciones horarias de SO2 [ug/m³]
Concentraciones horarias de NO2 [ug/m³]
Concentraciones horarias de O3 [ug/m³]
Concentraciones horarias de CO [ug/m³]

Importante: se pide entregar en formato electrónico / planilla excel en CD y enviar por correo electrónico.

CGE GENERACIÓN S.A.
Gertrudis Echeñique 485
Teléfono : (56-2) 680 7556
Fax : (56-2) 263 3601
Las Condes, Santiago, Chile

Santiago, 20 de julio de 2009
GERENCIA GENERAL Nº 025

OFICINA DE PARTES
22 JUL. 2009
RECIBIDO
CONAMA
14639

Señor
Alvaro Sapag R.
Director Ejecutivo
Comisión Nacional del Media Ambiente
Teatinos 258 – Piso 2
Santiago

De mi consideración:

Mediante la presente, solicito a Ud. la incorporación de CGE Generación S.A. al Comité Ampliado que participa en la elaboración de la Norma de Emisión Termoeléctrica, dado lo atingente del tema en cuestión para nuestra compañía.

CGE Generación S.A. es la filial de generación de energía eléctrica del Grupo CGE, creada para participar en dicho mercado.

CGE Generación adquirió recientemente la empresa de generación Ibener S.A., con lo que cuenta con una capacidad instalada de generación de 124 MW con plantas hidráulicas.

Por otra parte, CGE Generación está desarrollando el proyecto Ñuble, consistente en una central hidroeléctrica de pasada de 136 MW, que cuenta con RCA aprobada. Adicionalmente, CGE Generación podrá desarrollar proyectos de generación tanto hidráulica como térmica, por lo que es de gran interés conocer bajo qué condiciones de emisiones se desarrollarán estas últimas.

Según lo solicitado por la Sra. Carmen Gloria Contreras, Depto. Control de la Contaminación, iniciamos el procedimiento de incorporación al Comité, mediante el envío de una solicitud por correo electrónico.

La representante de CGE Generación en el Comité Ampliado será la señora Rosita Gómez Inzunza, cuya información de contacto es: teléfono 680 7556 y dirección electrónica rgomezi@cgegeneracion.cl.

Sin otro particular, saluda atentamente a usted,

CGE GENERACIÓN S.A.

Javier Guevara Moreno
Gerente General

001468

elektragen

Santiago, 29 de julio de 2009
GG N° 075/09

OF. DE PARTES
29 JUL 2009
RECIBIDO
CONAMA

15204

Señor
Hans Willumsen
Jefe del Depto. Control de la Contaminación
CONAMA
Teatinos 258, 8° piso
Santiago

Ref.: Carta D.E. CONAMA N° 092371 del 7 de julio de 2009

Mat.: Encuesta para estudio. Análisis del Impacto Económico y Social de la Norma de Emisión para Termoeléctricas.

De mi consideración:

En relación a lo dispuesto en carta de la referencia, adjunto remito a usted CD con cuestionario debidamente completado respecto de nuestras centrales térmicas y de la de nuestra relacionada Consorcio Energético Nacional S.A. (CEN) a quién también representamos. Se hace presente que *dicha información ya fue enviada por correo electrónico a la Srta. Carmen Gloria Contreras, según* lo solicitado.

Para su información, el profesional designado para coordinar la entrega de la información y resolver las eventuales consultas que pudiesen surgir, es nuestro Gerente de Proyectos Sr. Carlos Lagos.

Sin otro particular, saluda atentamente a usted,

Elektra Generación S.A.

Alejandro Larenas Mantellero
Gerente General

Av. Luis Thayer Ojeda 260, Of. 3 • Providencia • Santiago • Fono Fax: 2336819

Arauco Generación S.A.
Av. El Golf Nª 150, Piso 7
Las Condes - Santiago, Chile
FONO N° (56-2) 462 37 00
FAX N° (56-2) 462 38 57

C01469

Santiago, 30 de julio de 2009
GAG-C016/2009

31 JUL. 2009
RECIBIDO
CONAMA
15405

Comisión Nacional del Medio Ambiente
Teatinos 258, 8° Piso
Santiago

At. : Sr. Hans Willumsen
Jefe del Dpto. Control de la Contaminación

Ref. : Encuesta para estudio. Análisis del Impacto Económico y Social de la Norma de Emisión para Termoeléctricas.

Estimados señores:

En relación a la encuesta de la referencia y la información en ella solicitada, adjunto estamos enviando a Uds. las respuestas correspondientes a las centrales generadoras de nuestra matriz, Celulosa Arauco y Constitución S.A., de nuestra sociedad relacionada, Paneles Arauco S.A., y las pertenecientes a nuestra empresa, Arauco Generación S.A..

Hacemos presente a Uds. que las centrales generadoras de nuestra matriz y nuestra sociedad relacionada, ya antes indicadas, representan los excedentes de sus centrales cogeneradoras, aportados al Sistema Interconectado Central (SIC). Estas centrales cogeneradoras fueron diseñadas y su operación está destinada, en primer lugar, a satisfacer los requerimientos de energía térmica y eléctrica de los complejos industriales donde se encuentran instaladas. No obstante, en razón de un diseño y operación eficientes, estas instalaciones cuentan con capacidad excedentaria para ser aportada al SIC. En virtud de esta característica, lo que tiene como consecuencia de que se trata de establecimientos esencialmente diferentes a las plantas cuya emisión se proyecta regular, la estructura original planteada en la encuesta no se adapta en plenitud a su condición de plantas cogeneradoras, por lo que ha sido modificada para tratar de ilustrar esta realidad. Adicionalmente, comunicamos a Uds. la situación de las centrales mencionadas con el fin de que los datos de las encuestas correspondientes puedan ser correctamente interpretados por el consultor.

En paralelo, de acuerdo a lo solicitado, se está enviando el cuestionario vía correo electrónico a la profesional Srta. Carmen Gloria Contreras.

Sin otro particular, saluda atentamente a Uds.,

ARAUCO GENERACIÓN S.A.

Carlos Rauld J.

GASATACAMA

C01470 H.W. 15.411

OF. DE PARTES
31 JUL 2009
RECIBIDO
CONAMA

Santiago, 30 de julio de 2009
GAGG049.09

Señor
Alvaro Sapag Rajevic
Director Ejecutivo
Comisión Nacional del Medio Ambiente
PRESENTE

Ref.: Carta DE N° 092384, Encuesta para estudio, análisis del impacto económico y social de la norma de emisión para termoeléctricas

De nuestra consideración:

De acuerdo a lo solicitado en la carta de la referencia, adjunto información del cuestionario para el estudio y análisis del impacto económico y social de la norma de emisión para termoeléctricas que CONAMA y la CNE están gestionando.

GasAtacama estima de la mayor importancia para el país el contar a la brevedad posible con una norma de emisiones para centrales termoeléctricas, de forma de minimizar los impactos que este tipo de centrales generan en el medio ambiente, así como promover el uso eficiente de las tecnologías disponibles para generación.

En esta misma línea, como es de conocimiento de CONAMA y de la CNE, GasAtacama aportó una propuesta concreta en Agosto del 2006 a la Ministra de Minería y Energía a través del documento titulado "Análisis de Normas de Emisión para Centrales Termoeléctricas a Nivel Internacional y Propuesta para Chile", elaborado por el Sr. Ricardo Katz y su equipo de Gestión Ambiental Consultores.

Por otra parte GasAtacama sigue trabajando en perfeccionar esta propuesta que permita al país tener una norma de calidad mundial y de acuerdo a los estándares que el país pretende adoptar como las normas de países de la OECD.

Sin otro particular, se despide atentamente

Rudolf Araneda Kauert
Gerente General

CC: Sr. Hans Willumsen, Jefe del Depto Control de la Contaminación CONAMA

GASATACAMA CHILE S.A.

OPERACIONES EN CHILE

Central Atacama
Costanera Oriente N° 2500 Barrio Industrial, Mejillones
Tel +56 (55) 357200 Fax +56 (55) 623170

Operaciones Gasoducto
Los Topacios N° 320, La Chimba, Antofagasta
Tel +56 (55) 219237 Fax +56 (55) 214949

Casa Matriz
Isidora Goyenechea 3365 p.8, Las Condes, Santiago
Codigo Postal: 755-0120
Tel +56 (2) 366-3800 Fax +56 (2) 366-3802
www.gasatacama.cl e-mail: info@gasatacama.cl

OPERACIONES EN ARGENTINA

Gasoducto Atacama Argentina S.A.
Ruta Provincial N°1, Km 5½ El Arenal
San Salvador de Jujuy, Argentina
Tel +54 (388) 425-7500 Fax +54 (388) 425-4062

OF. DE PARTES
31 JUL 2009
RECIBIDO
CONAMA
15431

001471

tinguiririca energía
generación sustentable

HIDROELECTRICA LA HIGUERA

Santiago, 30 de Julio de 2009

Carta No.: **COL/LH/CON/EN/0113**
Página 1/1

Señor
Hans Willumsen
Jefe del Departamento Control de la Contaminación
Comisión Nacional del Medio Ambiente

REF.: Carta Conama D.E. N°092377. Encuesta para Estudio, Análisis del Impacto Económico y Social de la Norma de Emisión para Termoeléctricas.
MAT.: Entrega Encuesta de la Referencia

De nuestra consideración:

En atención al llamado efectuado por el Director Ejecutivo de la Comisión Nacional de Medio Ambiente, Sr. Alvaro Sapag Rejevic, en orden a responder Encuesta para Estudio, Análisis del Impacto Económico y Social de la Norma de Emisión para Termoeléctricas, Hidroeléctrica La Higuera hace entrega de dicha Encuesta en la forma requerida en la carta de la referencia, adjuntando CD con el cuestionario respondido y antecedentes adicionales.

Sin otro particular, se despide atentamente

Francisco Martínez
Gerente de Medio Ambiente y Relaciones Comunitarias
Hidroeléctrica La Higuera S.A.

Adj: CD Cuestionario para Centrales Termoeléctricas – Central de Respaldo Eléctrico Colmito

C.c.:
- Sr. Alvaro Sapag Rajevic, Dirección Ejecutiva CONAMA
- Archivo.

001472

CAMPANARIO
GENERACION S.A.

Santiago, 30 de Julio de 2009
F.OT N° 16/2009

15.517

OF. DE PARTES
03 AGO 2009
RECIBIDO
CONAMA

Señor
Hans Willumsen
Jefe del Dpto. Control de la Contaminación
CONAMA
Presente

Ref: Cuestionario termoeléctrica Centrales Campanario y Tierra Amarilla

De nuestra consideración:

Nos referimos a la carta de la COREMA Carta D.E. N° 092494, de fecha 22 de julio de 2009, en la cual se solicita a las empresas generadoras completar un cuestionario, el cual será utilizado para el estudio "Análisis del Impacto Económico y Social de la Norma de Emisión para Termoeléctricas".

Al respecto, adjunto enviamos un CD con la siguiente información, referida a las centrales Campanario y Tierra Amarilla:

- Respuesta a Cuestionario Termoeléctricas para la central Campanario, perteneciente a la empresa Campanario Generación S.A.
- Layout de la central Campanario en formato Autocad.
- Respuesta a Cuestionario Termoeléctricas para la central Tierra Amarilla, perteneciente a la empresa Central Tierra Amarilla S.A.
- Layout de la central Tierra Amarilla en formato Autocad.

Además, adjuntamos en otro CD los datos históricos de las estaciones de monitoreo para la central Campanario.

Sin otro particular, saluda atentamente a Ud.

Miguel Roca O.
Campanario Generación S.A.

GUACOLDA

601473

Huasco, Julio 31, 2009
GPU3-EEG-0175/2009

OFICINA DE PARTES
03 AGO. 2009
RECIBIDO
CONAMA

1 fJ 38

Señor
Hans Willumsen
Jefe Dpto. Control de la Contaminación CONAMA
Teatinos 258, 8° piso
Santiago
Presente

Ref: **Encuesta para estudio Análisis Impacto Socio y Social de la Norma de Emisión para Termoeléctricas**

De nuestra consideración:

De acuerdo a lo solicitado en su carta D. E. s/n, sírvase encontrar adjunto encuesta en formato digital de las Unidades de la Central Termoeléctrica Guacolda. Se incluye archivo con datos meteorológicos, monitoreos ambientales y plano Layout de la central. Esta misma información fue enviada por correo electrónico a la Srta. Carmen Gloria Contreras el 30 de Julio 2009.

Sin otro particular, saluda atentamente a usted,

EMPRESA ELECTRICA GUACOLDA S.A.

Hernan Fujii Gambero
Gerente de Ingeniería

001474

EDELNOR ELECTROANDINA CTANDINA

GERENCIA DESARROLLO

Santiago, 10 de Agosto de 2009

GD/2009/269

Señor
Hans Willumsen A.
Jefe del Dpto. Control de la Contaminación
CONAMA
Teatinos 258, 8º piso.
Santiago

Ref: Cuestionario Termoeléctrica – *Central Termoeléctrica Tocopilla (Electroandina S.A) y Central Térmica Mejillones (Edelnor S.A.)*

De nuestra consideración:

En relación con el tema de la referencia, y en cumplimiento de lo solicitado por el señor Director Ejecutivo de la Comisión Nacional del Medio Ambiente, don Álvaro Sapag, mediante carta D.E sin número, *Mat.: Encuesta para estudio, Análisis del Impacto Económico y Social de la Norma de Emisión para Termoeléctricas,* hacemos llegar a usted dos CDs, cada uno conteniendo las respuestas a los cuestionarios de la referencia, correspondientes a las instalaciones de Central Termoeléctrica Tocopilla de Electroandina S.A. y Central Térmica Mejillones de Edelnor S.A.

Copia de esta carta y de los CDs se hará llegar directamente a la Srta. Carmen Gloria Contreras.

Hacemos presente a Ud. que la información entregada en los referidos medios magnéticos, constituye información de propiedad de Electroandina S.A. y de Edelnor S.A. la que, debido a su carácter estratégico y de conformidad a las políticas de manejo de información de dichas Compañías, ha de ser tratada como información de carácter confidencial, para el uso exclusivo del estudio sobre el impacto social y económico de la norma de emisiones de las empresas termoeléctricas y con prohibición de ser divulgada a terceros.

Sin otro particular, saluda atentamente,

Alejandro Lorenzini L.
Gerente de Desarrollo

Pablo Espinosa
Jefe Medio Ambiente

16286

OFICINA DE PARTES
12 AGO 2009
RECIBIDO
CONAMA

Incl.: Lo indicado

c.c. Director Ejecutivo Conama

Energía Verde
una empresa AES Gener

001475

Concepción, 12 de Agosto de 2009.

ENERGÍA VERDE S.A.	
N° 010/09	12/08/2009
CONCEPCIÓN	

Hu. 16375

OF. DE PARTES
13 AGO 2009
RECIBIDO
CONAMA

Señor
Hans Willumsen
Jefe Depto. Control de la Contaminación - CONAMA
Teatinos 258 – 8° piso
SANTIAGO

Ref.: Envía respaldo en CD de encuesta termoelectricas.

De nuestra consideración:

Adjunto a la presente, le estamos enviando un CD de respaldo con las respuestas a la encuesta referente a la norma de emisión de centrales termoeléctricas de la empresa Energía Verde S. A.

Esta información fue enviada previamente por correo electrónico a la Sra. Carmen Gloria Contreras el 30 de julio del presente.

Sin otro particular le saluda atentamente a usted,

ENERGÍA VERDE S.A.

LORENZO MARZOLO L.
Jefe de Producción y Medio Ambiente

c.c. : Archivo

C0147C

Norgener
una empresa AES Gener

M. Sánchez Fontecilla 310, piso 3
Las Condes, Santiago, Chile
Tel: 56 2 - 686 89 00
Fax: 56 2 - 686 89 90
www.aesgener.cl

Santiago, 12 de agosto de 2009
Norg. 120/2009

OF. DE PARTES
13 AGO 2009
RECIBIDO
CONAMA

Señor
Hans Willumsen
Jefe del Departamento Control de la Contaminación
CONAMA
Teatinos 258, piso 8
Presente

Ref.: Carta D.E. N° 092378

De nuestra consideración:

Por medio de la presente, y en virtud de lo solicitado en carta de la referencia de fecha 7 de julio de 2009, envío a usted respuesta a encuesta para estudio "Análisis del Impacto Económico y Social de la Norma de Emisión para Termoeléctricas".

De acuerdo a lo solicitado esta misma información ha sido enviado mediante correo electrónico a la Srta. Carmen Gloria Contreras.

Desde ya quedamos atentos a dar respuesta a cualquier duda que surja respecto de la información enviada.

Saluda muy atentamente a usted,

NORGENER S.A.

Juan Carlos Olmedo Hidalgo
Gerente General

cc.: Sr. Álvaro Sapag Rajevic
Director Ejecutivo CONAMA

001477

Gener
una empresa AES

M. Sánchez Fontecilla 310, piso 3
Las Condes, Santiago, Chile
Tel: 56 2 - 686 89 00
Fax: 56 2 - 686 89 90
www.aesgener.cl

Santiago, 12 de agosto de 2009
Ger. Op. 08/2009

HW.
AS 16353

OF. DE PARTES
13 AGO 2009
RECIBIDO
CONAMA

Señor
Hans Willumsen
Jefe del Departamento Control de la Contaminación
CONAMA
Teatinos 258, piso 8
Presente

Ref.: Carta D.E. N° 092378

De nuestra consideración:

Por medio de la presente, y en virtud de lo solicitado en carta de la referencia de fecha 7 de julio de 2009, envío a usted respuesta a encuesta para estudio "Análisis del Impacto Económico y Social de la Norma de Emisión para Termoeléctricas", correspondiente al Complejo Ventanas.

De acuerdo a lo solicitado esta misma información ha sido enviado mediante correo electrónico a la Srta. Carmen Gloria Contreras.

Desde ya quedamos atentos a dar respuesta a cualquier duda que surja respecto de la información enviada.

Saluda muy atentamente a usted,

AES Gener S. A.

Juan Carlos Olmedo Hidalgo
Gerente de Operaciones

cc.: Sr. Álvaro Sapag Rajevic
Director Ejecutivo CONAMA

001478

Colbún

Av. Apoquindo 4775, piso 11
Las Condes, Santiago - Chile
Tel.: (56-2) 460 40 00
Fax: (56-2) 460 40 05

Santiago, 12 de agosto de 2009
AMB N° 058/2009

OF. DE PARTES
13 AGO 2009
RECIBIDO
CONAMA

Señor
Hans Willumsen
Jefe Departamento Control de la Contaminación
CONAMA Dirección Ejecutiva.
Teatinos 254
Santiago

Att: Srta. Carmen Gloria Contreras

Ref.: Envía Cuestionario Centrales Termoeléctricas

De nuestra consideración:

En el marco de la participación de Colbún S.A. en el Comité Ampliado para la formulación de la Norma de Emisión de Termoeléctricas, se adjuntan los Cuestionarios de Centrales Termoélectricas con la información solicitada.

De acuerdo a lo solicitado, los cuestionarios también fueron enviados al mail de la Srta. Carmen Gloria Contreras

Se adjunta un CD con la información en formato digital.

Sin otro particular, le saluda atentamente,

Daniel Gordon A.
Subgerente de Medio Ambiente
COLBÚN S.A.

001479

endesa chile

HX 15 928

G.G. N° 080/

Santiago, 30 de julio de 2009

SEÑOR
ALVARO SAPAG RAJEVIC
DIRECTOR EJECUTIVO
COMISIÓN NACIONAL DEL MEDIO AMBIENTE
TEATINOS 258, 5TO PISO
SANTIAGO

REF.: Respuesta a carta D.E. N°092372. Encuesta para estudio, Análisis del Impacto Económico y Social de la Norma de Emisiones.

De mi consideración:

En respuesta a su carta D.E. N° 092372 del 7 de julio de 2009, donde nos solicita información técnica de nuestras instalaciones termoeléctricas en Chile a través del llenado de un cuestionarios por instalación, en el marco del proceso de elaboración de un de una Norma de emisión para centrales termoeléctrica, es que adjuntamos la documentación requerida de acuerdo a las indicaciones mencionadas.

Se informa además, que a través de la presente documentación se incluyen las empresas filiales de Endesa Chile, como lo son San Isidro S.A. y Celta S.A.

Frente a cualquier consulta en los datos presentados, agradeceré canalizar sus dudas a la Gerencia de Medio Ambiente y Desarrollo Sostenible de Endesa Chile con el Sr. Hugo Pérez Guzmán, teléfono 6309681 o al mail hpg@endesa.cl.

Agradeciendo su atención, le saluda atentamente,

Rafael Mateo Alcalá
Representante Legal

Adj.: - 1 CD con los archivos computacionales

001480

Eléctrica Santiago
una empresa AES Gener

Jorge Hirmas 2964
Renca, Santiago, Chile
Tel: 56 2 - 680 47 60
Fax: 56 2 - 680 47 43
www.aesgener.cl

DE PARTES 2009 17 RECIBIDO CONAMA

16675

Santiago, agosto 12 de 2009
ESSA GG - 09/149

Señor
Hans Willumsen
Jefe de Depto. Control de la Contaminación
CONAMA
Teatinos 258
Presente

De su consideración:

Por la presente adjunto envío a usted un CD con la documentación de respuesta al Cuestionario de Centrales Termoeléctricas para las centrales Renca y Nueva Renca.

Sin otro particular, le saluda atentamente

Sociedad Eléctrica Santiago S.A.

Rodrigo Osorio B.
Gerente General

ROB/rmp
Adj: CD

001481

Carmen Gloria Contreras Fierro

De: Carmen Gloria Contreras Fierro

Enviado el: miércoles, 22 de julio de 2009 18:50

Para: 'Pedro Bardessi C.'; 'Lorenzini, Alejandro'; 'Hector Rojas B.'; 'sdelcamp@guacolda.cl'; 'sdelcampo@guacolda.cl'; 'Marcia Montero'; 'Viviana Flores'; 'Andres Cabello'; 'Italo Cuneo'; 'Vicente Saglietto S.'; 'Marcela Alday'; 'Perez Guzman, Hugo, ENDESA CHILE'; 'mamestica@endesa.cl'; 'pablo.astudillo@power.alstom.com'; 'Pedro Navarrete (CMPC Celulosa G.Tecnica)'; 'Sixto Fraile S.'; 'Juan Carlos Olmedo H.'; 'Paulina Pino'; 'Jaime Zuazagoitia V.'; 'carolina.soler@arauco.cl'; 'Verónica Constanza Díaz Dosque'; 'CED Sustentabilidad Ambiental y Social'; 'dgordon@colbun.cl'; Andreani Carlos; 'Carolina Soler'; 'HCuadro@colbun.cl'; Espinosa, Pablo; 'cituc@med.puc.cl'; 'acabello@aes.com'; 'soledad.henriquez@aes.com'; 'arauco.generacion@arauco.cl'; 'info@snc.cl'; 'aahh@endesa.cl'; 'susana.gutierrez@edelnor.cl'; 'teresa.benavente@electroandina.cl'; 'r.araneda@gasatacama.cl'; 'gperez@guacolda.cl'; 'Merino, Carolina C (Ctta)'; 'carolina.canete@fnt.cl'; 'info@terram.cl'; 'Sara Larrain'; 'info@sanisidro.cl'; 'eparra@guacolda.cl'; jmoyano@guacolda.cl; 'bernhard.stohr@empresascopec.cl'; 'pamela.harris@empresascopec.cl'; 'alarenas@electragen.cl'; 'r.araneda@gasatacama.cl'; 'jmorel@colbun.cl'; 'jose_bahamonde@fwt.cl'; 'waldo.ibacache@aes.com'; 'esaphores@campanariogeneracion.cl'; '"Couso, Iván"'; 'Pía Bravo'; 'kandinsky.dintrans@saesa.cl'; 'Rodolfo Granifo Vásquez'; 'Rodolfo Granifo Vásquez'; 'Rodolfo Granifo Vásquez'; 'Pía Bravo'; 'Pedro Sanhueza'; 'Rosita Gomez Inzunza'; 'hfujii@guacolda.cl'; 'ecalderon@colbun.cl'; 'luis.hernandez@arauco.cl'; 'pnavarrete@celulosa.cmpc.cl'; 'richard_torres@fwt.cl'; 'brian_mace@fwt.cl'; 'nfs@endesa.cl'; 'rosorio@aes.com'; 'Merino, Carolina C (Ctta)'; 'Marcia Montero'; 'pablo.norambuena@saesa.cl'; 'rguerrero@aes.com'; 'Carolina Soler'; 'pamela.harris@empresascopec.cl'; 'jsalinas@colbun.cl'; 'cmrojasg@tecnet.cl'

CC: Gonzalo Leon Silva; Priscila Andrea Ulloa Menare; Ingrid Henriquez Cortes

Asunto: Compromisos Reunión C. Ampliado/Norma Termoelectricas

Datos adjuntos: bco_mundial_1998.pdf; FINAL_Thermal+Power.pdf; Pollution prevention_guideline_worlbank.pdf; portadas_paper CALPUFF CALMET.pdf

Estimados Señores - Señoras,

1. Se adjunta link del Bco. Mundial http://www.ifc.org/ifcext/sustainability.nsf/Content/EnvironmentalGuidelines (aquí están las guías disponibles en varios idiomas para distintas actividades económicas, buscar thermal power) y también las guías del año 1998 y 2008

2. Se adjunta portadas de paper con aplicaciones de modelos CALPUFF-CALMET. Si están interesados en conocer más sobre estos, se sugiere escribir a los autores y solicitar paper o revisar el link http://www.epa.gov/scram001/dispersion_prefrec.htm (Support Center for Regulatory Atmospheric Modeling de US-EPA).

Atentamente,

Carmen Gloria Contreras Fierro
Responsable Regulación Norma de Emisión para Termoeléctricas
CONAMA D.E.

Thermal Power: Rehabilitation of Existing Plants

Key Issues

The range of circumstances in which the rehabilitation of an existing thermal power plant may be considered is extremely large. It is neither possible nor desirable to attempt to prescribe specific environmental guidelines for all of the different cases that may arise in the World Bank's operational work. Hence, this document focuses on the process that should be followed in order to arrive at an agreed set of site-specific standards that should be met by the plant after its rehabilitation.

At the heart of this process is the preparation of a combined environmental audit of the existing plant and assessment of alternative rehabilitation options relevant to the future impact of the plant on nearby populations and ecosystems. The coverage of the environmental assessment component of the study will depend on the rehabilitation activities involved and may be similar to that required for a new thermal power plant when major portions of the plant are being replaced or retrofitted. The amount of data required, the range of options considered, and the coverage of the environmental analysis will typically be less than appropriate for a new plant. At the same time, the initial environmental audit should not be restricted to those parts of the existing plant that may be affected by the rehabilitation. It should review all the major aspects of the plant's equipment and operating procedures in order to identify environmental problems and recommend cost-effective measures that would improve the plant's environmental performance.

The time and resources devoted to preparing the environmental audit and assessment should be appropriate to the nature and scale of the proposed rehabilitation. It would, for example, not be appropriate to carry out an extensive environmental assessment in cases involving minor modifications or the installation or upgrading of environmental controls such as a wastewater treatment plant or dust filters or precipitators. For larger projects, such as the installation of flue gas desulfurization (FGD) equipment, the environmental assessment might focus particularly on the range of options for reducing sulfur emissions and for disposing of the gypsum or solid waste generated by the equipment.

It is, however, recommended that an environmental audit be undertaken in almost all cases. Experience suggests that such investigations will often pay for themselves by identifying zero- or low-cost options for energy conservation and waste minimization. In addition, such an audit may indicate ways in which the project could be redesigned in order to address the most serious environmental problems associated with the plant.

Major rehabilitations that imply a substantial extension (10 years or more) of the expected operating life of the plant should be subject to an environmental assessment similar in depth and coverage to one that would be prepared for a new plant. In such cases, the plant will normally be expected to meet the basic guidelines that apply to new thermal power plants for emissions of particulates, nitrogen oxides (NO_x), wastewater discharges, and solid wastes. Where the rehabilitated plant would be unable to meet the basic guidelines for sulfur dioxide (SO_2) without additional and potentially expensive controls, the environmental assessment should review the full range of options for reducing SO_2 emissions, both from the plant itself and from other sources within the same airshed or elsewhere in the country. On the basis of this analysis, the government, the enterprise, and the World Bank Group will agree on specific measures, either at the plant or

elsewhere, to mitigate the impact of these emissions and will also agree on the associated emissions requirements.

Any rehabilitation that involves a shift in fuel type—i.e., from coal or oil to gas, as distinguished from a change from one grade or quality of coal or oil to another—will be subject to the same basic emissions guidelines as would apply to a new plant burning the same fuel.

Environmental Audit

An audit of the environmental performance of the existing plant should do at least the following:

- Review the actual operating and environmental performance of the plant in relation to its original design parameters.
- Examine the reasons for poor performance to identify measures that should be taken to address specific problems or to provide a basis for more appropriate assumptions about operating conditions in the future—for example, with respect to average fuel characteristics.
- Assess the scope for making improvements in maintenance and housekeeping inside and around the plant (e.g., check for excess oxygen levels, actual emissions levels, fuel spills, coal pile runoff, fugitive dust from coal piles, recordkeeping, monitoring, and other indicators of operation and maintenance of thermal power plants).
- Evaluate the readiness and capacity of the plant's emergency management systems to cope with incidents varying from small spills to major accidents (check storage of flammables, safe boiler and air pollution control system operation, and so on).
- Examine the plant's record with respect to worker safety and occupational health.

The report on the environmental audit should provide recommendations on the measures required to rectify any serious problems that were identified in the course of the study. These recommendations should be accompanied by approximate estimates of the capital and operating costs that would be involved and by an indication of the actions that should be taken either to implement the recommendations or to evaluate alternative options.

The management of the plant or the borrower should submit the report on the environmental audit to the World Bank Group, along with a statement of the steps taken to address the problems that were identified and to ensure that such problems do not recur in the future. Implementation of the actions outlined in the statement will be treated as one of the elements of the site-specific requirements for the project.

Environmental Assessment

An environmental assessment of the proposed rehabilitation should be carried out early in the process of preparing the project in order to allow an opportunity to evaluate alternative rehabilitation options before key design decisions are finalized. The assessment should examine the impacts of the existing plant's operations on nearby populations and ecosystems, the changes in these impacts that would result under alternative specifications for the rehabilitation, and the estimated capital and operating costs associated with each option.

Depending on the scale and nature of the rehabilitation, the environmental assessment may be relatively narrow in scope, focusing on only a small number of specific concerns that would be affected by the project, or it may be as extensive as would be appropriate for the construction of a new unit at the same site. Normally, it should cover the following points:

- Ambient environmental quality in the airshed or water basin affected by the plant, together with approximate estimates of the contribution of the plant to total emissions loads of the main pollutants of concern
- The impact of the plant, under existing operating conditions and under alternative scenarios for rehabilitation, on ambient air and water quality affecting neighboring populations and sensitive ecosystems
- The likely costs of achieving alternative emissions standards or other environmental targets for the plant as a whole or for specific aspects of its operations
- Recommendations concerning a range of cost-effective measures for improving the environmental performance of the plant within the

framework of the rehabilitation project and any associated emissions standards or other requirements implied by the adoption of specific measures.

These issues should be covered at a level of detail appropriate to the nature and scale of the proposed project.

If the plant is located in an airshed or water basin that is polluted as a result of emissions from a range of sources, including the plant itself, comparisons should be made of the relative costs of improving ambient air or water quality by reducing emissions from the plant or by reducing emissions from other sources. As a result of such an analysis, the government, the enterprise, and the World Bank Group would agree to set site-specific emissions standards for the plant after it has been rehabilitated that take account of actions to reduce other emissions elsewhere in the airshed or water basin.

Emissions Guidelines

The following measures must be incorporated when rehabilitating thermal power plants:

- Normally, the energy conversion efficiency of the plant should be increased by at least 25% of its current level.
- Baseline emissions levels for particulate matter, nitrogen oxides, and sulfur oxides should be computed.
- An analysis of the feasibility (including benefits) of switching to a cleaner fuel should be conducted. Gas is preferred where its supply can be assured at or below world average prices. Coal with high heat content and low sulfur content is preferred over coal with high heat content and high sulfur content, which in turn is preferred over coal with low heat content and high sulfur content.
- Washed coal should be used, if feasible.
- Low-NO_x burners should be used, where feasible.
- Either the emissions levels recommended for new plants, or at least a 25% reduction in baseline level, should be achieved for the pollutant being addressed by the rehabilitation project.
- The maximum emissions level for PM is 100 milligrams per normal cubic meter (mg/Nm^3), but the target should be 50 mg/Nm^3. In rare cases, an emissions level of up to 150 mg/Nm^3 may be acceptable.
- SO_2 emissions levels should meet regional load targets. Cleaner fuels should be used, to avoid short-term exposure to sulfur dioxide.

Monitoring and Reporting

Monitoring and reporting requirements for a thermal power plant that has been rehabilitated should be the same as those for a new thermal power plant of similar size and fuel type.

Thermal Power: Guidelines for New Plants

Industry Description and Practices

This document sets forth procedures for establishing maximum emissions levels for all fossil-fuel-based thermal power plants with a capacity of 50 or more megawatts of electricity (MWe) that use coal, fuel oil, or natural gas.[1]

Conventional steam-producing thermal power plants generate electricity through a series of energy conversion stages: fuel is burned in boilers to convert water to high-pressure steam, which is then used to drive a turbine to generate electricity.

Combined-cycle units burn fuel in a combustion chamber, and the exhaust gases are used to drive a turbine. Waste heat boilers recover energy from the turbine exhaust gases for the production of steam, which is then used to drive another turbine. Generally, the total efficiency of a combined-cycle system in terms of the amount of electricity generated per unit of fuel is greater than for conventional thermal power systems, but the combined-cycle system may require fuels such as natural gas.

Advanced coal utilization technologies (e.g., fluidized-bed combustion and integrated gasification combined cycle) are becoming available, and other systems such as cogeneration offer improvements in thermal efficiency, environmental performance, or both, relative to conventional power plants. The economic and environmental costs and benefits of such advanced technologies need to be examined case by case, taking into account alternative fuel choices, demonstrated commercial viability, and plant location. The criteria spelled out in this document apply regardless of the particular technology chosen.

Engine-driven power plants are usually considered for power generation capacities of up to 150 MWe. They have the added advantages of shorter building period, higher overall efficiency (low fuel consumption per unit of output), optimal matching of different load demands, and moderate investment costs, compared with conventional thermal power plants. Further information on engine-driven plants is given in Annex A.

Waste Characteristics

The wastes generated by thermal power plants are typical of those from combustion processes. The exhaust gases from burning coal and oil contain primarily particulates (including heavy metals, if they are present in significant concentrations in the fuel), sulfur and nitrogen oxides (SO_x and NO_x), and volatile organic compounds (VOCs). For example, a 500 MWe plant using coal with 2.5% sulfur (S), 16% ash, and 30,000 kilojoules per kilogram (kJ/kg) heat content will emit each day 200 metric tons of sulfur dioxide (SO_2), 70 tons of nitrogen dioxide (NO_2), and 500 tons of fly ash if no controls are present. In addition, the plant will generate about 500 tons of solid waste and about 17 gigawatt-hours (GWh) of thermal discharge.

This document focuses primarily on emissions of particulates less than 10 microns (μm) in size (PM_{10}, including sulfates), of sulfur dioxide, and of nitrogen oxides. Nitrogen oxides are of concern because of their direct effects and because they are precursors for the formation of ground-level ozone. Information concerning the health and other damage caused by these and other pollutants, as well as on alternative methods of emissions control, is provided in the relevant pollutant and pollutant control documents.

The concentrations of these pollutants in the exhaust gases are a function of firing configuration, operating practices, and fuel composition. Gas-fired plants generally produce negligible

quantities of particulates and sulfur oxides, and levels of nitrogen oxides are about 60% of those from plants using coal. Gas-fired plants also release lower quantities of carbon dioxide, a greenhouse gas.

Ash residues and the dust removed from exhaust gases may contain significant levels of heavy metals and some organic compounds, in addition to inert materials. Fly ash removed from exhaust gases makes up 60–85% of the coal ash residue in pulverized-coal boilers. Bottom ash includes slag and particles that are coarser and heavier than fly ash. The volume of solid wastes may be substantially higher if environmental measures such as flue gas desulfurization (FGD) are adopted and the residues are not reused in other industries.

Steam turbines and other equipment may require large quantities of water for cooling, including steam condensation. Water is also required for auxiliary station equipment, ash handling, and FGD systems. The characteristics of the wastewaters generated depend on the ways in which the water has been used. Contamination arises from demineralizers, lubricating and auxiliary fuel oils, and chlorine, biocides, and other chemicals used to manage the quality of water in cooling systems. Once-through cooling systems increase the temperature of the receiving water.

Policy Framework

The development of a set of environmental requirements for a new thermal power plant involves decisions of two distinct kinds. First, there are the specific requirements of the power plant itself. These are the responsibility of the project developer in collaboration with relevant local or other environmental authorities. This document focuses on the issues that should be addressed in arriving at project-specific emissions standards and other requirements.

Second, there are requirements that relate to the operation of the power system as a whole. These strategic issues must be the concern of national or regional authorities with the responsibility for setting the overall policy framework for the development of the power sector. Examples of such requirements include measures to promote energy conservation via better demand-side management, to encourage the use of renewable sources of energy rather than fossil fuels, and to meet overall targets for the reduction of emissions of sulfur dioxide, nitrogen oxides, or greenhouse gases.

In the context of its regular country dialogue on energy and environmental issues, the World Bank is willing to assist its clients to develop the policy framework for implementing such environmental requirements for the power sector as a whole. One step in this process might be the preparation of a sectoral environmental assessment. This document assumes that the project is consistent with broad sectoral policies and requirements that have been promulgated by the relevant authorities in order to meet international obligations and other environmental goals affecting the power sector.

In some cases, strategies for meeting system-wide goals may be developed through a power-sector planning exercise that takes account of environmental and social factors. This would, for instance, be appropriate for a small country with a single integrated utility. In other cases, governments may decide to rely on a set of incentives and environmental standards designed to influence the decisions made by many independent operators.

Determining Site-Specific Requirements

This document spells out the process—starting from a set of maximum emissions levels acceptable to the World Bank Group—that should be followed in determining the site-specific emissions guidelines. The guidelines could encompass both controls on the plant and other measures, perhaps outside the plant, that may be necessary to mitigate the impact of the plant on the airshed or watershed in which it is located. The process outlines how the World Bank Group's policy on Environmental Assessment (OP 4.01) for thermal power plants can be implemented. The guidelines are designed to protect human health; reduce mass loading to the environment to acceptable levels; achieve emissions levels based on commercially proven and widely used technologies; follow current regulatory and technology trends; be cost-effective; and promote the use of cleaner fuels and good-management practices that increase energy efficiency and productivity.

It is important to stress that the results of the environmental assessment (EA) are critical to defining many of the design parameters and other assumptions, such as location, fuel choice, and the like, required to develop the detailed specification of a project. The assessment results must be integrated with economic analyses of the key design options. Thus, it is essential that the work of preparing an environmental assessment be initiated during the early stages of project conception and design so that the initial results of the study can be used in subsequent stages of project development. It is not acceptable to prepare an environmental assessment that considers a small number of options in order to justify a predetermined set of design choices.

Evaluation of Project Alternatives

The EA should include an analysis of reasonable alternatives that meet the ultimate objective of the project. The assessment may lead to alternatives that are sounder, from an environmental, sociocultural, and economic point of view, than the originally proposed project. Alternatives need to be considered for various aspects of the system, including:

- Fuels used
- Power generation technologies
- Heat rejection systems
- Water supply or intakes
- Solid waste disposal systems
- Plant and sanitary waste discharge
- Engineering and pollution control equipment (see Annex B for some examples)
- Management systems.

The alternatives should be evaluated as a part of the conceptual design process. Those alternatives that provide cost-effective environmental management are preferred.

Clean Development Mechanism (CDM)

The Kyoto Protocol provisions allow for the use of the clean development mechanism (CDM), under which, beginning in 2000, greenhouse gas emissions from projects in non–Annex I countries that are certified by designated operating entities can be acquired by Annex I countries and credited against their emissions binding commitments. The availability of CDM financing may alter, in some cases, the choice of the least-cost project alternative. Once the CDM is enacted, it will be advisable to incorporate the following steps into the process of evaluating project alternatives:

- Identification and assessment of alternatives that are eligible for CDM-type financing (e.g., alternatives that are not economical without carbon offsets and whose incremental costs above the least-cost baseline alternative, taking account of local environmental externalities, are smaller than the costs of resulting carbon offsets).
- Negotiation with Annex I parties of possible offset arrangements, if CDM-eligible alternatives exist. The World Bank Group will be prepared to assist in the process of identifying the CDM-eligible alternatives and negotiating offset arrangements for projects that are partly financed or guaranteed by the World Bank Group.

Environmental Assessment

An EA should be carried out early in the project cycle in order to establish emissions requirements and other measures on a site-specific basis for a new thermal power plant or unit of 50 MWe or larger. The initial tasks in carrying out the EA should include:

- Collection of baseline data on ambient concentrations of PM_{10} and sulfur oxides (for oil and coal-fired plants), nitrogen oxides, (and ground-level ozone, if levels of ambient exposure to ozone are thought to be a problem) within a defined airshed encompassing the proposed project.[2]
- Collection of similar baseline data for critical water quality indicators that might be affected by the plant.
- Use of appropriate air quality and dispersion models to estimate the impact of the project on the ambient concentrations of these pollutants, on the assumption that the maximum emissions levels described below apply. (See the chapters on airshed models in Part II of this *Handbook*.)

When there is a reasonable likelihood that in the medium or long term the power plant will be ex-

panded or other pollution sources will increase significantly, the analysis should take account of the impact of the proposed plant design both immediately and after any probable expansion in capacity or in other sources of pollution. The EA should also include impacts from construction work and other activities that normally occur, such as migration of workers when large facilities are built. Plant design should allow for future installation of additional pollution control equipment, should this prove desirable or necessary.

The EA should also address other project-specific environmental concerns, such as emissions of cadmium, mercury, and other heavy metals resulting from burning certain types of coal or heavy fuel oil. If emissions of this kind are a concern, the government (or the project sponsor) and the World Bank Group will agree on specific measures for mitigating the impact of such emissions and on the associated emissions guidelines.

The quality of the EA (including systematic cost estimates) is likely to have a major influence on the ease and speed of project preparation. A good EA prepared early in the project cycle should make a significant contribution to keeping the overall costs of the project down.

Emissions Guidelines

Emissions levels for the design and operation of each project must be established through the EA process on the basis of country legislation and the *Pollution Prevention and Abatement Handbook*, as applied to local conditions. The emissions levels selected must be justified in the EA and acceptable to the World Bank Group.

The following maximum emissions levels are normally acceptable to the World Bank Group in making decisions regarding the provision of World Bank Group assistance for new fossil-fuel-fired thermal power plants or units of 50 MWe or larger (using conventional fuels). The emissions levels have been set so they can be achieved by adopting a variety of cost-effective options or technologies, including the use of clean fuels or washed coal. For example, dust controls capable of over 99% removal efficiency, such as electrostatic precipitators (ESPs) or baghouses, should always be installed for coal-fired power plants. Similarly, the use of low-NO_x burners with other combustion modifications such as low excess air (LEA) firing should be standard practice. The range of options for the control of sulfur oxides is greater because of large differences in the sulfur content of different fuels and in control costs. In general, for low-sulfur (less than 1% S), high-calorific-value fuels, specific controls may not be required, while coal cleaning, when feasible, or sorbent injection (in that order) may be adequate for medium-sulfur fuels (1–3% S). FGD may be considered for high-sulfur fuels (more than 3% S). Fluidized-bed combustion, when technically and economically feasible, has relatively low SO_x emissions. The choice of technology depends on a benefit-cost analysis of the environmental performance of different fuels and the cost of controls.

Any deviations from the following emissions levels must be described in the World Bank Group project documentation.

Air Emissions

The maximum emissions levels given here can be consistently achieved by well-designed, well-operated, and well-maintained pollution control systems. In contrast, poor operating or maintenance procedures affect actual pollutant removal efficiency and may reduce it to well below the design specification. The maximum emissions levels are expressed as concentrations to facilitate monitoring. Dilution of air emissions to achieve these guidelines is unacceptable. Compliance with ambient air quality guidelines should be assessed on the basis of good engineering practice (GEP) recommendations. See Annex C for ambient air quality guidelines to be applied if local standards have not been set.[3] Plants should not use stack heights less than the GEP recommended values unless the air quality impact analysis has taken into account building downwash effects. All of the maximum emissions levels should be achieved for at least 95% of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours.[4] The remaining 5% of annual operating hours is assumed to be for start-up, shutdown, emergency fuel use, and unexpected incidents. For peaking units where the start-up mode is expected to be longer than 5% of the annual operating hours,

exceedance should be justified by the EA with regard to air quality impacts.

Power plants in degraded airsheds. The following definitions apply in airsheds where there already exists a significant level of pollution.

An airshed will be classified as having *moderate air quality* with respect to particulates, sulfur dioxide, or nitrogen dioxide if either 1 or 2 applies:

1. (a) The annual mean value of PM_{10} exceeds 50 micrograms per cubic meter (μg/m³) for the airshed (80 μg/m³ for total suspended particulates, TSP); (b) the annual mean value of sulfur dioxide exceeds 50 μg/m³; or (c) the annual mean value of nitrogen dioxide exceeds 100 μg/m³ for the airshed.

2. The 98th percentile of 24-hour mean values of PM_{10}, sulfur dioxide, or nitrogen dioxide for the airshed over a period of a year exceeds 150 μg/m³ (230 μg/m³ for TSP).

An airshed will be classified as having *poor air quality* with respect to particulates, sulfur dioxide, or nitrogen dioxide if either 1 or 2 applies:

1. (a) The annual mean of PM_{10} exceeds 100 μg/m³ for the airshed (160 μg/m³ for TSP); (b) the annual mean of sulfur dioxide exceeds 100 μg/m³ for the airshed; or (c) the annual mean of nitrogen dioxide exceeds 200 μg/m³ for the airshed.

2. The 95th percentile of 24-hour mean values of PM_{10}, sulfur dioxide, or nitrogen dioxide for the airshed over a period of a year exceeds 150 μg/m³ (230 μg/m³ for TSP).

Plants smaller than 500 MWe in airsheds with moderate air quality are subject to the maximum emissions levels indicated below, provided that the EA shows that the plan will not lead *either* to the airshed dropping into the "poor air quality" category *or* to an increase of more than 5 μg/m³ in the annual mean level of particulates (PM_{10} or TSP), sulfur dioxide, or nitrogen dioxide for the entire airshed. If either of these conditions is not satisfied, lower site-specific emissions levels should be established that would ensure that the conditions can be satisfied. The limit of a 5 μg/m³ increase in the annual mean will apply to the cumulative total impact of all power plants built in the airshed within any 10-year period beginning on or after the date at which the guidelines come into effect.

Plants larger than or equal to 500 MWe in airsheds with moderate air quality and all plants in airsheds with poor air quality are subject to site-specific requirements that include offset provisions to ensure that (a) there is no net increase in the total emissions of particulates or sulfur dioxide within the airshed and (b) the resultant ambient levels of nitrogen dioxide do not exceed the levels specified for moderately degraded airsheds.[5] The measures agreed under the offset provisions must be implemented before the power plant comes fully on stream. Suitable offset measures could include reductions in emissions of particulates, sulfur dioxide, or nitrogen dioxide as a result of (a) the installation of new or more effective controls at other units within the same power plant or at other power plants in the same airshed, (b) the installation of new or more effective controls at other large sources, such as district heating plants or industrial plants, in the same airshed, or (c) investments in gas distribution or district heating systems designed to substitute for the use of coal for residential heating and other small boilers.[6] The monitoring and enforcement of the offset provisions would be the responsibility of the local or national agency responsible for granting and supervising environmental permits. Such offset provisions would normally be described in detail in a specific covenant in the project loan agreement.

Project sponsors who do not wish to engage in the negotiations necessary to put together an offset agreement would have the option of relying on an appropriate combination of clean fuels, controls, or both.

Particulate matter. For all plants or units, PM emissions (all sizes) should not exceed 50 mg/Nm³.[7] The EA should pay specific attention to particulates smaller than 10 μm in aerodynamic diameter (PM_{10}) in the airshed, since these are inhaled into the lungs and are associated with the most serious effects on human health. Where possible, ambient levels of fine particulates (less than 2.5 mm in diameter) should be measured. Recent epidemiologic evidence suggests that much of the health damage caused by exposure to particulates is associated with these fine particles, which penetrate most deeply into the lungs. Emissions of PM_{10} and fine particulates include ash, soot, and carbon compounds (often

the results of incomplete combustion), acid condensates, sulfates, and nitrates, as well as lead, cadmium, and other metals. Fine particulates, including sulfates, nitrates, and carbon compounds, are also formed by chemical processes in the atmosphere, but they tend to disperse over the whole airshed.

Sulfur dioxide. Total sulfur dioxide emissions from the power plant or unit should be less than 0.20 metric tons per day (tpd) per MWe of capacity for the first 500 MWe, plus 0.10 tpd for each additional MWe of capacity over 500 MWe.[8] In addition, the concentration of sulfur dioxide in flue gases should not exceed 2,000 mg/Nm^3 (see note 4 for assumptions), with a maximum emissions level of 500 tpd. Construction of two or more separate plants in the same airshed to circumvent this cap is not acceptable.

Nitrogen oxides. The specific emissions limits for nitrogen oxides are 750 mg/Nm^3, or 260 nanograms per joule (ng/J), or 365 parts per million parts (ppm) for a coal-fired power plant, and up to 1,500 mg/Nm^3 for plants using coal with volatile matter less than 10%; 460 mg/Nm^3 (or 130 ng/J, or 225 ppm) for an oil-fired power plant; and 320 mg/Nm^3 (or 86 ng/J, or 155 ppm) for a gas-fired power plant.

For combustion turbine units, the maximum NO_x emissions levels are 125 mg/Nm^3 (dry at 15% oxygen) for gas; 165 mg/Nm^3 (dry at 15% oxygen) for diesel (No. 2 oil); and 300 mg/Nm^3 (dry at 15% oxygen) for fuel oil (No. 6 and others).[9] Where there are technical difficulties, such as scarcity of water available for water injection, an emissions variance allowing a maximum emissions level of up to 400 mg/Nm^3 dry (at 15% oxygen) is considered acceptable, provided there are no significant environmental concerns associated with ambient levels of ozone or nitrogen dioxide.

For engine-driven power plants, the EA should pay particular attention to levels of nitrogen oxides before and after the completion of the project. Provided that the resultant maximum ambient levels of nitrogen dioxide are less than 150 µg/m^3 (24-hour average), the specific emissions guidelines are as follows: (a) for funding applications received after July 1, 2000, the NO_x emissions levels should be less than 2,000 mg/Nm^3 (or 13 grams per kilowatt-hour, g/kWh dry at 15% oxygen); and (b) for funding applications received before July 1, 2000, the NO_x emissions levels should be less than 2,300 mg/Nm^3 (or 17 g/kWh dry at 15% oxygen). In all other cases, the maximum emissions level of nitrogen oxides is 400 mg/Nm^3 (dry at 15% oxygen).

Offsets and the role of the World Bank Group. Large power complexes should normally not be developed in airsheds with moderate or poor air quality, or, if they must be developed, then only with appropriate offset measures. The costs of identifying and negotiating offsets for large power complexes are not large in relation to the total cost of preparing such projects. In the context of its regular country dialogue on energy and environmental issues, the World Bank is prepared to assist the process of formulating and implementing offset agreements for projects that are partly financed or guaranteed by the World Bank Group. If the offsets for a particular power project that will be financed by a World Bank Group loan involve specific investments to reduce emissions of particulates, sulfur oxides, or nitrogen oxides, these may be included within the scope of the project and may thus be eligible for financing under the loan.[10]

Long-range transport of acid pollutants. Where ground-level ozone or acidification is or may in future be a significant problem, governments are encouraged to undertake regional or national studies of the impact of sulfur dioxide, nitrogen oxides, and other pollutants that damage sensitive ecosystems, with, in appropriate cases, support from the World Bank (see Policy Framework, above). The aim of such studies is to identify least-cost options for reducing total emissions of these pollutants from a region or a country so as to achieve load targets, as appropriate.[11]

A possible (but not the only) approach to identifying sensitive ecosystems is to estimate critical loads for acid depositions and critical levels for ozone in different geographic areas. The analysis must, however, take into account the large degree of uncertainty involved in making such estimates.

In appropriate cases, governments should develop cost-effective strategies, as well as legal instruments, to protect sensitive ecosystems or to reduce transboundary flows of pollutants.

Where such regional studies have been carried out, the environmental assessment should take account of their results in assessing the overall impact of a proposed power plant.

The site-specific emissions requirements should be consistent with any strategy and applicable legal framework that have been adopted by the host country government to protect sensitive ecosystems or to reduce transboundary flows of pollutants.

Liquid Effluents

The effluent levels presented in Table 1 (for the applicable parameters) should be achieved daily without dilution.

Coal pile runoff and leachate may contain significant concentrations of toxics such as heavy metals. Where leaching of toxics to groundwater or their transport in surface runoff is a concern, suitable preventive and control measures such as protective liners and collection and treatment of runoff should be put in place.

Solid Wastes

Solid wastes, including ash and FGD sludges, that do not leach toxic substances or other contaminants of concern to the environment may be disposed in landfills or other disposal sites provided that they do not impact nearby water bodies. Where toxics or other contaminants are expected to leach out, they should be treated by, for example, stabilization before disposal.

Table 1. Effluents from Thermal Power Plants
(milligrams per liter, except for pH and temperature)

Parameter	*Maximum value*
pH	6–9
TSS	50
Oil and grease	10
Total residual chlorine[a]	0.2
Chromium (total)	0.5
Copper	0.5
Iron	1.0
Zinc	1.0
Temperature increase	≤ 3°C[b]

a. "Chlorine shocking" may be preferable in certain circumstances. This involves using high chlorine levels for a few seconds rather than a continuous low-level release. The maximum value is 2 mg/l for up to 2 hours, not to be repeated more frequently than once in 24 hours, with a 24-hour average of 0.2 mg/l. (The same limits would apply to bromine and fluorine.)
b. The effluent should result in a temperature increase of no more than 3° C at the edge of the zone where initial mixing and dilution take place. Where the zone is not defined, use 100 meters from the point of discharge when there are no sensitive aquatic ecosystems within this distance.

Ambient Noise

Noise abatement measures should achieve either the levels given below or a maximum increase in background levels of 3 decibels (measured on the A scale) [dB(A)]. Measurements are to be taken at noise receptors located outside the project property boundary.

	Maximum allowable log equivalent (hourly measurements), in dB(A)	
Receptor	*Day (07:00–22:00)*	*Night (22:00–07:00)*
Residential, institutional, educational	55	45
Industrial, commercial	70	70

Monitoring and Reporting

For measurement methods, see the chapter on Monitoring in this *Handbook*.

Maintaining the combustion temperature and the excess oxygen level within the optimal band in which particulate matter and NO_x emissions are minimized simultaneously ensures the greatest energy efficiency and the most economic plant operation. Monitoring should therefore aim at achieving this optimal performance as consistently as possible. Systems for continuous monitoring of particulate matter, sulfur oxides, and nitrogen oxides in the stack exhaust can be installed and are desirable whenever their maintenance and calibration can be ensured. Alternatively, surrogate performance monitoring should be performed on the basis of initial calibration. The following surrogate parameters are relevant for assessing environmental performance. (They require no changes in plant design but do call for appropriate training of operating personnel.)

- *Particulate matter.* Ash and heavy metal content of fuel; maximum flue gas flow rate; minimum power supply to the ESP or minimum pressure drop across the baghouse; minimum combustion temperature; and minimum excess oxygen level.
- *Sulfur dioxide.* Sulfur content of fuel.
- *Nitrogen oxides.* Maximum combustion temperature and maximum excess oxygen level.

Direct measurement of the concentrations of emissions in samples of flue gases should be performed regularly (for example, on an annual basis) to validate surrogate monitoring results or for the calibration of the continuous monitor (if used). The samples should be monitored for PM and nitrogen oxides and may be monitored for sulfur oxides and heavy metals, although monitoring the sulfur and heavy metal content of fuel is considered adequate. At least three data sets for direct emissions measurements should be used, based on an hourly rolling average.

Automatic air quality monitoring systems measuring ambient levels of PM_{10}, sulfur oxides, and nitrogen oxides outside the plant boundary should be installed where maximum ambient concentration is expected or where there are sensitive receptors such as protected areas and population centers. (PM_{10} and SO_x measurements are, however, not required for gas-fired plants.) The number of air quality monitors should be greater if the area in which the power plant is located is prone to temperature inversions or other meteorological conditions that lead to high levels of air pollutants affecting nearby populations or sensitive ecosystems. The purpose of such ambient air quality monitoring is to help assess the possible need for changes in operating practices (including burning cleaner fuels to avoid high short-term exposures), especially during periods of adverse meteorological conditions. The pollutant guidelines specify short-term ambient air quality guideline values which, if exceeded, call for emergency measures such as burning cleaner fuels.

Any measures should be taken in close collaboration with local authorities. The specific design of the ambient monitoring system should be based on the findings of the EA. The frequency of ambient measurements depends on prevailing conditions; ambient measurements, when taken, should normally be averaged daily.

The pH and temperature of the wastewater discharges should be monitored continuously. Levels of suspended solids, oil and grease, and residual chlorine should be measured daily, and heavy metals and other pollutants in wastewater discharges should be measured monthly if treatment is provided.

Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Records of monitoring results should be kept in an acceptable format. The results should be reported in summary form, with notification of exceptions, if any, to the responsible government authorities and relevant parties, as required. In the absence of specific national or local government guidelines, actual monitoring or surrogate performance data should be reported at least annually. The government may require additional explanation and may take corrective action if plants are found to exceed maximum emissions levels for more than 5% of the operating time, or on the occasion of a plant audit. The objective is to ensure continuing compliance with the emissions limits agreed at the outset, based on sound operation and maintenance. Exceedances of the maximum emissions levels would normally be reviewed in light of the enterprise's good-faith efforts in this regard.

As part of the Framework Convention on Climate Change, countries will be asked to record their emissions of greenhouse gases (GHG). As an input to this, and to facilitate possible future activities implemented jointly with Annex I countries, the emissions of individual projects should be estimated on the basis of the chemical composition of the fuel or measured directly. Table 2 in the chapter on Greenhouse Gas Abatement and Climate Change in Part II of this *Handbook* provides relevant emissions factors.

In order to develop institutional capacity, training should be provided with adequate budgets to ensure satisfactory environmental performance. The training may include education on environmental assessment, environmental mitigation plans, and environmental monitoring. In some cases, it may be appropriate to include the staff from the environmental implementation agencies,

such as the state pollution control board, in the training program

Key Issues

The key production and emissions control practices that will lead to compliance with the above guidelines are summarized below. It is assumed that the proposed project represents a least-cost solution, taking into account environmental and social factors.

- Choose the cleanest fuel economically available (natural gas is preferable to oil, which is preferable to coal).
- Give preference to high-heat-content, low-ash, low-sulfur coal (or high-heat-content, high-sulfur coal, in that order) and consider beneficiation for high-ash, high-sulfur coal.
- Select the best power generation technology for the fuel chosen to balance the environmental and economic benefits. The choice of technology and pollution control systems will be based on the site-specific environmental assessment.

  Keep in mind that particulates smaller than 10 microns in size are most important from a health perspective. Acceptable levels of particulate matter removal are achievable at relatively low cost.

  Consider cost-effective technologies such as pre-ESP sorbent injection, along with coal washing, before in-stack removal of sulfur dioxide.

  Use low-NO_x burners and other combustion modifications to reduce emissions of nitrogen oxides.
- Before adopting expensive control technologies, consider using offsetting reductions in emissions of critical pollutants at other sources within the airshed to achieve acceptable ambient levels.
- Use SO_x removal systems that generate less wastewater, if feasible; however, the environmental and cost characteristics of both inputs and wastes should be assessed case by case.
- Manage ash disposal and reclamation so as to minimize environmental impacts—especially the migration of toxic metals, if present, to nearby surface and groundwater bodies, in addition to the transport of suspended solids in surface runoff. Consider reusing ash for building materials.
- Consider recirculating cooling systems where thermal discharge to water bodies may be of concern.
- Note that a comprehensive monitoring and reporting system is required.

Annex A. Engine-Driven Power Plants

Engine-driven power plants use fuels such as diesel oil, fuel oil, gas, orimulsion, and crude oil. The two types of engines normally used are the medium-speed four-stroke trunk piston engine and the low-speed two-stroke crosshead engine. Both types of engine operate on the air-standard diesel thermodynamic cycle. Air is drawn or forced into a cylinder and is compressed by a piston. Fuel is injected into the cylinder and is ignited by the heat of the compression of the air. The burning mixture of fuel and air expands, pushing the piston. Finally the products of combustion are removed from the cylinder, completing the cycle. The energy released from the combustion of fuel is used to drive an engine, which rotates the shaft of an alternator to generate electricity. The combustion process typically includes preheating the fuel to the required viscosity, typically 16–20 centiStokes (cSt), for good fuel atomization at the nozzle. The fuel pressure is boosted to about 1,300 bar to achieve a droplet distribution small enough for fast combustion and low smoke values. The nozzle design is critical to the ignition and combustion process. Fuel spray penetrating to the liner can damage the liner and cause smoke formation. Spray in the vicinity of the valves may increase the valve temperature and contribute to hot corrosion and burned valves. If the fuel timing is too early, the cylinder pressure will increase, resulting in higher nitrogen oxide formation. If injection is timed too late, fuel consumption and turbocharger speed will increase. NO_x emissions can be reduced by later injection timing, but then particulate matter and the amount of unburned species will increase.

Ignition quality. For distillate fuels, methods for establishing ignition quality include cetane number and cetane index for diesel. The CCAI number,

based on fuel density and viscosity, gives a rough indication of the ignition behavior of heavy fuel oil.

Fuel quality. Fuel ash constituents may lead to abrasive wear, deposit formation, and high-temperature corrosion, in addition to emissions of particulate matter. The properties of fuel that may affect engine operation include viscosity, specific gravity, stability (poor stability results in the precipitation of sludge, which may block the filters), cetane number, asphaltene content, carbon residue, sulfur content, vanadium and sodium content (an indicator of corrosion, especially on exhaust valves), presence of solids such as rust, sand, and aluminum silicate, which may result in blockage of fuel pumps and liner wear, and water content.

Waste characteristics. The wastes generated are typical of those from combustion processes. The exhaust gases contain particulates (including heavy metals if present in the fuel), sulfur and nitrogen oxides, and, in some cases, VOCs. Nitrogen oxides are the main concern after particulate matter in the air emissions. NO_x emissions levels are (almost exponentially) dependent on the temperature of combustion, in addition to other factors. Most of the NO_x emissions are formed from the air used for combustion and typically range from 1,100 to 2,000 ppm at 15% oxygen. Carbon dioxide emissions are approximately 600 g/kWh of electricity, and total hydrocarbons (calculated as methane equivalent) are 0.5 g/kWh of electricity.

The exhaust gases from an engine are affected by (a) the load profile of the prime mover; (b) ambient conditions such as air humidity and temperature; (c) fuel oil quality, such as sulfur content, nitrogen content, viscosity, ignition ability, density, and ash content; and (d) site conditions and the auxiliary equipment associated with the prime mover, such as cooling properties and exhaust gas back pressure. The engine parameters that affect nitrogen oxide emissions are (a) fuel injection in terms of timing, duration, and atomization; (b) combustion air conditions, which are affected by valve timing, the charge air system, and charge air cooling before cylinders; and (c) the combustion process, which is affected by air and fuel mixing, combustion chamber design, and the compression ratio. The particulate matter emissions are dependent on the general conditions of the engine, especially the fuel injection system and its maintenance, in addition to the ash content of the fuel, which is in the range 0.05–0.2%. SO_x emissions are directly dependent on the sulfur content of the fuel. Fuel oil may contain around 0.3% sulfur and, in some cases, up to 5%.

Annex B. Illustrative Pollution Prevention and Control Technologies

A wide variety of control technology options is available. As usual, these options should be considered after an adequate assessment of broader policy options, including pricing and institutional measures. Additional information is provided in the relevant documents on pollution control technologies.

Cleaner Fuels

The simplest and, in many circumstances, most cost-effective form of pollution prevention is to use cleaner fuels. For new power plants, combined-cycle plants burning natural gas currently have a decisive advantage in terms of their capital costs, thermal efficiency, and environmental performance. Natural gas is also the preferred fuel for minimizing GHG emissions because it produces lower carbon dioxide emissions per unit of energy and enhances energy efficiency.

If availability or price rule out natural gas as an option, the use of low-sulfur fuel oil or high-heat-content, low-sulfur, low-ash coal should be considered. Typically, such fuels command a premium price over their dirtier equivalents, but the reductions in operating or environmental costs that they permit are likely to outweigh this premium. In preparing projects, an evaluation of alternative fuel options should be conducted at the outset to establish the most cost-effective combination of fuel, technology, and environmental controls for meeting performance and environmental objectives.

If coal is used, optimal environmental performance and economic efficiency will be achieved through an integrated approach across the whole coal-energy chain, including the policy and investment aspects of mining, preparation, transport, power generation and heat conversion, and clean coal technologies. Coal washing, in particular, has

a beneficial impact in terms of reducing the ash content and ash variability of coal used in thermal power plants, which leads to consistent boiler performance, reduced emissions, and less maintenance.

Abatement of Particulate Matter

The options for removing particulates from exhaust gases are cyclones, baghouses (fabric filters), and ESPs. Cyclones may be adequate as precleaning devices; they have an overall removal efficiency of less than 90% for all particulate matter and considerably lower for PM_{10}. Baghouses can achieve removal efficiencies of 99.9% or better for particulate matter of all sizes, and they have the potential to enhance the removal of sulfur oxides when sorbent injection, dry-scrubbing, or spray dryer absorption systems are used. ESPs are available in a broad range of sizes for power plants and can achieve removal efficiencies of 99.9% or better for particulate matter of all sizes.

The choice between a baghouse and an ESP will depend on fuel and ash characteristics, as well as on operating and environmental factors. ESPs can be less sensitive to plant upsets than fabric filters because their operating effectiveness is not as sensitive to maximum temperatures and they have a low pressure drop. However, ESP performance can be affected by fuel characteristics. Modern baghouses can be designed to achieve very high removal efficiencies for PM_{10} at a capital cost that is comparable to that for ESPs, but it is necessary to ensure appropriate training of operating and maintenance staff.

Abatement of Sulfur Oxides

The range of options and removal efficiencies for SO_x controls is wide. Pre-ESP sorbent injection can remove 30–70% of sulfur oxides, at a cost of US$50–$100 per kW. Post-ESP sorbent injection can achieve 70–90% SO_x removal, at a cost of US$80–$170 per kW. Wet and semidry FGD units consisting of dedicated SO_x absorbers can remove 70–95%, at a cost of US$80–$170 per kW (1997 prices). The operating costs of most FGDs are substantial because of the power consumed (of the order of 1–2% of the electricity generated), the chemicals used, and disposal of residues. Estimates by the International Energy Agency (IEA) suggest that the extra levelized annual cost for adding to a coal-fired power plant an FGD designed to remove 90% of sulfur oxides amounts to 10–14% depending on capacity utilization.

An integrated pollution management approach should be adopted that does not involve switching from one form of pollution to another. For example, FGD scrubber wastes, when improperly managed, can lead to contamination of the water supply, and such SO_x removal systems could result in greater emissions of particulate matter from materials handling and windblown dust. This suggests the need for careful benefit-cost analysis of the types and extent of SO_x abatement.

Abatement of Nitrogen Oxides

The main options for controlling NO_x emissions are combustion modifications: low-NO_x burners with or without overfire air or reburning, water/steam injection, and selective catalytic or noncatalytic reduction (SCR/SNCR). Combustion modifications can remove 30–70% of nitrogen oxides, at a capital cost of less than US$20 per kW and a small increase in operating costs. SNCR systems can remove 30–70% of nitrogen oxides, at a capital cost of US$20–$40 per kW and a moderate increase in operating cost. However, plugging of the preheater because of the formation of ammonium bisulfate may pose some problems. SCR units can remove 70–90% of nitrogen oxides but involve a much larger capital cost of US$40–$80 per kW and a significant increase in operating costs, especially for coal-fired plants. Moreover, SCR may require low-sulfur fuels (less than 1.5% sulfur content) because the catalyst elements are sensitive to the sulfur dioxide content in the flue gas.

Fly Ash Handling

Fly ash handling systems may be generally categorized as dry or wet, even though the dry handling system involves wetting the ash to 10–20% moisture to improve handling characteristics and to mitigate the dust generated during disposal. In wet systems, the ash is mixed with water to produce a liquid slurry containing 5–10% solids by weight. This is discharged to settling ponds, often with bottom ash and FGD sludges, as well. The ponds

may be used as the final disposal site, or the settled solids may be dredged and removed for final disposal in a landfill. Wherever feasible, decanted water from ash disposal ponds should be recycled to formulate ash slurry. Where heavy metals are pre-sent in ash residues or FGD sludges, care must be taken to monitor and treat leachates and overflows from settling ponds, in addition to disposing of them in lined places to avoid contamination of water bodies. In some cases, ash residues are being used for building materials and in road construction. Gradual reclamation of ash ponds should be practiced.

Water Use

It is possible to reduce the fresh water intake for cooling systems by installing evaporative recirculating cooling systems. Such systems require a greater capital investment, but they may use only 5% of the water volume required for once-through cooling systems. Where once-through cooling systems are used, the volume of water required and the impact of its discharge can be reduced by careful siting of intakes and outfalls, by minimizing the use of biocides and anticorrosion chemicals (effective nonchromium-based alternatives are available to inhibit scale and products of corrosion in cooling water systems), and by controlling discharge temperatures and thermal plumes. Wastewaters from other processes, including boiler blowdown, demineralizer backwash, and resin regenerator wastewater, can also be recycled, but again, this requires careful management and treatment for reuse. Water use can also be reduced in certain circumstances through the use of air-cooled condensers.

Annex C. Ambient Air Quality

The guidelines presented in Table C.1 are to be used only for carrying out an environment assessment in the absence of local ambient standards. They were constructed as consensus values taking particular account of WHO, USEPA, and EU standards and guidelines. *They do not in any way substitute for a country's own ambient air quality standards.*

Table C.1. Ambient Air Quality in Thermal Power Plants

(micrograms per cubic meter)

Pollutant	*24-hour average*	*Annual average*
PM_{10}	150	50
TSP[a]	230	80
Nitrogen dioxide	150	100
Sulfur dioxide	150	80

a. Measurement of PM_{10} is preferable to measurement of TSP.

Notes

1. For plants smaller than 50 MWe, including those burning nonfossil fuels, PM emissions levels may be as much as 100 mg/Nm³. If justified by the EA, PM emissions levels up to 150 mg/Nm³ may be acceptable in special circumstances. The maximum emissions levels for nitrogen oxides remain the same, while for sulfur dioxide, the maximum emissions level is 2,000 mg/Nm³.

2. *Airshed* refers to the local area around the plant whose ambient air quality is directly affected by emissions from the plant. The size of the relevant local airshed will depend on plant characteristics, such as stack height, as well as on local meteorological conditions and topography. In some cases, airsheds are defined in legislation or by the relevant environmental authorities. If not, the EA should clearly define the airshed on the basis of consultations with those responsible for local environmental management.

In collecting baseline data, qualitative assessments may suffice for plants proposed in greenfield sites. For nondegraded airsheds, quantitative assessment using models and representative monitoring data may suffice.

3. See, e.g., United States, 40 CFR, Part 51, 100 (ii). Normally, GEP stack height = $H + 1.5L$, where H is the height of nearby structures and L is the lesser dimension of either height or projected width of nearby structures.

4. The assumptions are as follows: for coal, flue gas dry 6% excess oxygen—assumes 350 Nm³/GJ. For oil, flue gas dry 3% excess oxygen—assumes 280 Nm³/GJ. For gas, flue gas dry 3% excess oxygen—assumes 270 Nm³/GJ (see annex D). The oxygen level in engine exhausts and combustion turbines is assumed to be 15%, dry. See the document on Monitoring for measurement methods.

5. Gas-fired plants (in which the backup fuel contains less than 0.3% sulfur) and other plants that achieve emissions levels of less than 400 mg/Nm³ for sulfur oxides and nitrogen oxides are exempt from the offset requirements, since their emissions are relatively lower.

Annex D. Conversion Chart

Table D.1. SO_2 and NO_x Emissions Conversion Chart for Steam-Based Thermal Power Plants

To convert	*To (multiply by):*								
		ppm	*ppm*	*g/GJ*			*lb/10⁶ Btu*		
From	*Mg/Nm³*	*NO_x*	*SO_2*	*Coal [a]*	*Oil [b]*	*Gas [c]*	*Coal [a]*	*Oil [b]*	*Gas [c]*
Mg/Nm³	1	0.487	0.350	0.350	0.280	0.270	8.14 x 10-4	6.51 x 10-4	6.28 x 10-4
ppm NO_x	2.05	1		0.718	0.575	0.554	1.67 x 10-3	1.34 x 10-3	1.29 x 10-3
ppm SO_2	2.86		1	1.00	0.801	0.771	2.33 x 10-3	1.86 x 10-3	1.79 x 10-3
G/GJ									
Coal[a]	2.86	1.39	1.00	1			2.33 x 10-3		
Oil[b]	3.57	1.74	1.25		1			2.33 x 10-3	
Gas[c]	3.70	1.80	1.30			1			2.33 x 10-3
lb/10⁶ Btu									
Coal[a]	1,230	598	430	430			1		
Oil[b]	1,540	748	538		430			1	
Gas[c]	1,590	775	557			430			1

Note: g/GJ, grams per gigajoule; lb/10⁶ Btu, pounds per 100,000 British thermal units; Mg/Nm³, megagrams per normal cubic meter; ppm, parts per million.
a. Flue gas dry 6% excess O_2; assumes 350 Nm³/GJ.
b. Flue gas dry 3% excess O_2; assumes 280 Nm³/GJ.
c. Flue gas dry 3% excess O_2; assumes 270 Nm³/GJ.
Source: International Combustion Ltd.; data for coal, oil, and gas based on IEA 1986.

6. Wherever possible, the offset provisions should be implemented within the framework of an overall air quality management strategy designed to ensure that air quality in the airshed is brought into compliance with ambient standards.

7. A normal cubic meter (Nm³) is measured at 1 atmosphere and 0° C. The additional cost of controls designed to meet the 50 mg/Nm³ requirement, rather than one of 150 mg/Nm³ (e.g., less than 0.5% of total investment costs for a 600 MW plant) is expected to be less than the benefits of reducing ambient exposure to particulates. The high overall removal rate is necessary to capture PM_{10} and fine particulates that seriously affect human health. Typically about 40% of PM by mass is smaller than 10 µm, but the collection efficiency of ESPs drops considerably for smaller particles. A properly designed and well-operated plant can normally achieve the lower emissions levels as easily as it can achieve higher emissions levels.

An exception to the maximum PM emissions level may be granted to engine-driven power plants for which funding applications are received before January 1, 2001. PM emissions levels of up to 75 mg/Nm³ would be allowed, provided that the EA presents documentation to show that (a) lower-ash grades of fuel oil are not commercially available; (b) emissions control technologies are not commercially available; and (c) the resultant ambient levels for PM_{10} (annual average of less than 50 µg/m³ and 24-hour mean of less than 150 µg/m³) will be maintained for the entire duration of the project.

8. The maximum SO_x emissions levels were back-calculated using the U.S. Environmental Protection Agency Industrial Source Complex (ISC) Model, with the objective of complying with the 1987 WHO Air Quality Guidelines for acceptable one-hour (peak) ambient concentration levels (350 µg/m³). The modeling results show that, in general, an emissions level of 2,000 mg/m³ (equivalent to 0.2 tpd per MWe) results in a one-hour level of 300 µg/m³, which, when added to a typical existing background level of 50 µg/m³ for greenfield sites, produces a one-hour level of 350 µg/m³ (see the discussion of degraded airsheds in the text). Compliance with the WHO one-hour level is normally the most significant, as short-term health impacts are considered to be the most important; compliance with this level also, in general, implies compliance with the WHO 24-hour and annual average guidelines. For large plants, the emissions guidelines for sulfur dioxide were further reduced to 0.1 tpd per MWe for capacities above 500 MWe to maintain acceptable mass loadings to the environment and thus address ecological concerns (acid rain). This results in a sulfur dioxide emissions level of 0.15 tpd/MWe (or 1.275 lb/mm Btu) for a 1,000 MWe plant.

9. Where the nitrogen content of the liquid fuel is greater than 0.015% and the selected equipment manufacturer cannot guarantee the emissions levels pro-

vided in the text, an NO_x emissions allowance (i.e., added to the maximum emissions level) can be computed based on the following data as exceptions:

Nitrogen content (percentage by weight)	*Correction factor (NO_x percentage by volume)*
0.015–0.1	0.04 N
0.1–0.25	0.004 + 0.0067 (N – 0.1)
> 0.25	0.005

Note: Correction factor, 0.004% = 40 ppm = 80 mg/ Nm^3.

There may be cases in which cost-effective NO_x controls may not be technically feasible. Exceptions to the NO_x emissions requirements (including those given in this note) are acceptable provided it can be shown that (a) for the entire duration of the project, the alternative emissions level will not result in ambient conditions that have a significant impact on human health and the environment, and (b) cost-effective techniques such as low-NO_x burners, LEA, water or steam injection, and reburning are not feasible.

10. It should be noted that the offset requirement, which focuses on the level of total emissions, should result in an improvement in ambient air quality within the airshed, compared with the baseline scenario (as documented with ambient air monitoring data), if the offset measures are implemented for non-power-plant sources. Such sources typically emit from stacks of a lower average height than those for the new power plant.

11. Part II of this *Handbook* provides guidance on possible approaches for dealing with acid emissions. There is substantial scope for exploiting the synergies between the local and long-range benefits of emissions reductions.

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Environmental, Health, and Safety Guidelines for Thermal Power Plants

Introduction

The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP)[1]. When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards. These industry sector EHS guidelines are designed to be used together with the **General EHS Guidelines** document, which provides guidance to users on common EHS issues potentially applicable to all industry sectors. For complex projects, use of multiple industry-sector guidelines may be necessary. A complete list of industry-sector guidelines can be found at: www.ifc.org/ifcext/sustainability.nsf/Content/EnvironmentalGuidelines

The EHS Guidelines contain the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, based on environmental assessments and/or environmental audits as appropriate, with an appropriate timetable for achieving them. The applicability of the EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables, such as host country context, assimilative capacity of the environment, and other project factors, are taken into account. The applicability of specific technical recommendations should be based on the professional opinion of qualified and experienced persons. When host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent levels or measures than those provided in these EHS Guidelines are appropriate, in view of specific project circumstances, a full and detailed justification for any proposed alternatives is needed as part of the site-specific environmental assessment. This justification should demonstrate that the choice for any alternate performance levels is protective of human health and the environment.

Applicability

This document includes information relevant to combustion processes fueled by gaseous, liquid and solid fossil fuels and biomass and designed to deliver electrical or mechanical power, steam, heat, or any combination of these, regardless of the fuel type (except for solid waste which is covered under a separate Guideline for Waste Management Facilities), with a total rated heat input capacity above 50 Megawatt thermal input (MWth) on Higher Heating Value (HHV) basis.[2] It applies to boilers, reciprocating engines, and combustion turbines in new and existing facilities. Annex A contains a detailed description of industry activities for this sector, and Annex B contains guidance for Environmental Assessment (EA) of thermal power projects. Emissions guidelines applicable to facilities with a total heat input capacity of less than 50 MWth are presented in Section 1.1 of the **General EHS Guidelines.** Depending on the characteristics of the project and its associated activities (i.e., fuel sourcing and evacuation of generated electricity), readers should also consult

[1] Defined as the exercise of professional skill, diligence, prudence and foresight that would be reasonably expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally. The circumstances that skilled and experienced professionals may find when evaluating the range of pollution prevention and control techniques available to a project may include, but are not limited to, varying levels of environmental degradation and environmental assimilative capacity as well as varying levels of financial and technical feasibility.

[2] Total capacity applicable to a facility with multiple units.

the EHS Guidelines for Mining and the EHS Guidelines for Electric Power Transmission and Distribution.

Decisions to invest in this sector by one or more members of the World Bank Group are made within the context of the World Bank Group strategy on climate change.

This document is organized according to the following sections:

Section 1.0 – Industry Specific Impacts and Management
Section 2.0 – Performance Indicators and Monitoring
Section 3.0 – References and Additional Sources
Annex A – General Description of Industry Activities
Annex B – Environmental Assessment Guidance for Thermal Power Projects.

1.0 Industry-Specific Impacts and Management

The following section provides a summary of the most significant EHS issues associated with thermal power plants, which occur during the operational phase, along with recommendations for their management.

As described in the introduction to the **General EHS Guidelines**, the general approach to the management of EHS issues in industrial development activities, including power plants, should consider potential impacts as early as possible in the project cycle, including the incorporation of EHS considerations into the site selection and plant design processes in order to maximize the range of options available to prevent and control potential negative impacts.

Recommendations for the management of EHS issues common to most large industrial and infrastructure facilities during the construction and decommissioning phases are provided in the **General EHS Guidelines**.

1.1 Environment

Environmental issues in thermal power plant projects primarily include the following:

- Air emissions
- Energy efficiency and Greenhouse Gas emissions
- Water consumption and aquatic habitat alteration
- Effluents
- Solid wastes
- Hazardous materials and oil
- Noise

Air Emissions

The primary emissions to air from the combustion of fossil fuels or biomass are sulfur dioxide (SO_2), nitrogen oxides (NO_X), particulate matter (PM), carbon monoxide (CO), and greenhouse gases, such as carbon dioxide (CO_2). Depending on the fuel type and quality, mainly waste fuels or solid fuels, other substances such as heavy metals (i.e., mercury, arsenic, cadmium, vanadium, nickel, etc), halide compounds (including hydrogen fluoride), unburned hydrocarbons and other volatile organic compounds (VOCs) may be emitted in smaller quantities, but may have a significant influence on the environment due to their toxicity and/or persistence. Sulfur dioxide and nitrogen oxide are also implicated in long-range and trans-boundary acid deposition.

The amount and nature of air emissions depends on factors such as the fuel (e.g., coal, fuel oil, natural gas, or biomass), the type and design of the combustion unit (e.g., reciprocating engines, combustion turbines, or boilers), operating practices, emission control measures (e.g., primary combustion control, secondary flue gas treatment), and the overall system efficiency. For example, gas-fired plants generally produce negligible quantities of particulate matter and sulfur oxides, and levels of nitrogen oxides are about 60% of those from plants using coal (without

emission reduction measures). Natural gas-fired plants also release lower quantities of carbon dioxide, a greenhouse gas.

Some measures, such as choice of fuel and use of measures to increase energy conversion efficiency, will reduce emissions of multiple air pollutants, including CO_2, per unit of energy generation. Optimizing energy utilization efficiency of the generation process depends on a variety of factors, including the nature and quality of fuel, the type of combustion system, the operating temperature of the combustion turbines, the operating pressure and temperature of steam turbines, the local climate conditions, the type of cooling system used, etc. Recommended measures to prevent, minimize, and control air emissions include:

- Use of the cleanest fuel economically available (natural gas is preferable to oil, which is preferable to coal) if that is consistent with the overall energy and environmental policy of the country or the region where the plant is proposed. For most large power plants, fuel choice is often part of the national energy policy, and fuels, combustion technology and pollution control technology, which are all interrelated, should be evaluated very carefully upstream of the project to optimize the project's environmental performance;
- When burning coal, giving preference to high-heat-content, low-ash, and low-sulfur coal;
- Considering beneficiation to reduce ash content, especially for high ash coal;[3]
- Selection of the best power generation technology for the fuel chosen to balance the environmental and economic benefits. The choice of technology and pollution control systems will be based on the site-specific environmental assessment (some examples include the use of higher energy-efficient systems, such as combined cycle gas turbine system for natural gas and oil-fired units, and supercritical, ultra-supercritical or integrated coal gasification combined cycle (IGCC) technology for coal-fired units);
- Designing stack heights according to Good International Industry Practice (GIIP) to avoid excessive ground level concentrations and minimize impacts, including acid deposition;[4]
- Considering use of combined heat and power (CHP, or co-generation) facilities. By making use of otherwise wasted heat, CHP facilities can achieve thermal efficiencies of 70 – 90 percent, compared with 32 – 45 percent for conventional thermal power plants.
- As stated in the General EHS Guidelines, emissions from a single project should not contribute more than 25% of the applicable ambient air quality standards to allow additional, future sustainable development in the same airshed.[5]

Pollutant-specific control recommendations are provided below.

Sulfur Dioxide

The range of options for the control of sulfur oxides varies substantially because of large differences in the sulfur content of different fuels and in control costs as described in Table 1. The choice of technology depends on a benefit-cost analysis of the environmental performance of different fuels, the cost of controls, and the existence of a market for sulfur control by-products[6]. Recommended measures to prevent, minimize, and control SO_2 emissions include:

[3] If sulfur is inorganically bound to the ash, this will also reduce sulfur content.

[4] For specific guidance on calculating stack height see Annex 1.1.3 of the General EHS Guidelines. Raising stack height should not be used to allow more emissions. However, if the proposed emission rates result in significant incremental ambient air quality impacts to the attainment of the relevant ambient air quality standards, options to raise stack height and/or to further reduce emissions should be considered in the EA. Typical examples of GIIP stack heights are up to around 200m for large coal-fired power plants, up to around 80m for HFO-fueled diesel engine power plants, and up to 100m for gas-fired combined cycle gas turbine power plants. Final selection of the stack height will depend on the terrain of the surrounding areas, nearby buildings, meteorological conditions, predicted incremental impacts and the location of existing and future receptors.

[5] For example, the US EPA Prevention of Significant Deterioration Increments Limits applicable to non-degraded airsheds provide the following: SO_2 (91 µg/m³ for 2nd highest 24-hour, 20 µg/m³ for annual average), NO_2 (20 µg/m³ for annual average), and PM_{10} (30 µg/m³ for 2nd highest 24-hour, and 17 µg/m³ for annual average).

- Use of fuels with a lower content of sulfur where economically feasible;
- Use of lime (CaO) or limestone ($CaCO_3$) in coal-fired fluidized bed combustion boilers to have integrated desulfurization which can achieve a removal efficiency of up to 80-90 % through use of Fluidized Bed Combustion[7, 8];
- Depending on the plant size, fuel quality, and potential for significant emissions of SO_2, use of flue gas desulfurization (FGD) for large boilers using coal or oil and for large reciprocating engines . The optimal type of FGD system (e.g., wet FGD using limestone with 85 to 98% removal efficiency, dry FGD using lime with 70 to 94% removal efficiency, seawater FGD with up to 90% removal efficiency) depends on the capacity of the plant, fuel properties, site conditions, and the cost and availability of reagent as well as by-product disposal and utilization.[9]

Table 1 - Performance / Characteristics of FGDs

Type of FGD	Characteristics	Plant Capital Cost Increase
Wet FGD	• Flue gas is saturated with water • Limestone ($CaCO_3$) as reagent • Removal efficiency up to 98% • Use 1-1.5% of electricity generated • Most widely used • Distance to limestone source and the limestone reactivity to be considered • High water consumption • Need to treat wastewater • Gypsum as a saleable by-product or waste	11-14%
Semi-dry FGD	• Also called "Dry Scrubbing" – under controlled humidification. • Lime (CaO) as reagent • Removal efficiency up to 94% • Can remove SO_3 as well at higher removal rate than Wet FGD • Use 0.5-1.0% of electricity generated, less than Wet FGD • Lime is more expensive than limestone • No wastewater • Waste – mixture of fly ash, unreacted additive and $CaSO_3$	9-12%
Seawater FGD	• Removal efficiency up to 90% • Not practical for high S coal (>1%S) • Impacts on marine environment need to be carefully examined (e.g., reduction of pH, inputs of remaining heavy metals, fly ash, temperature, sulfate, dissolved oxygen, and chemical oxygen demand) • Use 0.8-1.6% of electricity generated • Simple process, no wastewater or solid waste,	7-10%

Sources: EC (2006) and World Bank Group.

Nitrogen Oxides

Formation of nitrogen oxides can be controlled by modifying operational and design parameters of the combustion process (primary measures). Additional treatment of NO_X from the flue gas (secondary measures; see Table 2) may be required in some cases depending on the ambient air quality objectives. Recommended measures to prevent, minimize, and control NO_X emissions include:

- Use of low NO_X burners with other combustion modifications, such as low excess air (LEA) firing, for boiler plants. Installation of additional NO_X controls for boilers may be necessary to meet emissions limits; a selective catalytic reduction (SCR) system can be used for pulverized coal-fired, oil-fired, and gas-fired boilers or a selective non-catalytic reduction (SNCR) system for a fluidized-bed boiler;
- Use of dry low-NO_X combustors for combustion turbines burning natural gas;
- Use of water injection or SCR for combustion turbines and

[6] Regenerative Flue Gas Desulfurization (FGD) options (either wet or semi-dray) may be considered under these conditions.

[7] EC (2006).

[8] The SO2 removal efficiency of FBC technologies depends on the sulfur and lime content of fuel, sorbent quantity, ratio, and quality.

[9] The use of wet scrubbers, in addition to dust control equipment (e.g. ESP or Fabric Filter), has the advantage of also reducing emissions of HCl, HF, heavy metals, and further dust remaining after ESP or Fabric Filter. Because of higher costs, the wet scrubbing process is generally not used at plants with a capacity of less than 100 MWth (EC 2006).

reciprocating engines burning liquid fuels;[10]

- Optimization of operational parameters for existing reciprocating engines burning natural gas to reduce NOx emissions;
- Use of lean-burn concept or SCR for new gas engines.

Table 2 - Performance / Characteristics of Secondary NOx Reduction Systems

Type	Characteristics	Plant Capital Cost Increase
	• NOx emission reduction rate of 80 – 95% • Use 0.5% of electricity generated • Use ammonia or urea as reagent. • Ammonia slip increases with increasing NH_3/NOx ratio may cause a problem (e.g., too high ammonia in the fly ash). Larger catalyst volume / improving the mixing of NH_3 and NOx in the flue gas may be needed to avoid this problem. • Catalysts may contain heavy metals. Proper handling and disposal / recycle of spent catalysts is needed. • Life of catalysts has been 6-10 years (coal-fired), 8-12 years (oil-fired) and more than 10 years (gas-fired).	4-9% (coal-fired boiler) 1-2% (gas-fired combined cycle gas turbine) 20-30% (reciprocating engines)
	• NOx emission reduction rate of 30 – 50% • Use 0.1-0.3% of electricity generated • Use ammonia or urea as reagent. • Cannot be used on gas turbines or gas engines. • Operates without using catalysts.	1-2%

Source: EC (2006), World Bank Group

Particulate Matter

Particulate matter[11] is emitted from the combustion process, especially from the use of heavy fuel oil, coal, and solid biomass. The proven technologies for particulate removal in power plants are fabric filters and electrostatic precipitators (ESPs), shown in Table 3. The choice between a fabric filter and an ESP depends on the fuel properties, type of FGD system if used for SO_2 control, and ambient air quality objectives. Particulate matter can also be released during transfer and storage of coal and additives, such as lime. Recommendations to prevent, minimize, and control particulate matter emissions include:

- Installation of dust controls capable of over 99% removal efficiency, such as ESPs or Fabric Filters (baghouses), for coal-fired power plants. The advanced control for particulates is a wet ESP, which further increases the removal efficiency and also collects condensables (e.g., sulfuric acid mist) that are not effectively captured by an ESP or a fabric filter;[12]
- Use of loading and unloading equipment that minimizes the height of fuel drop to the stockpile to reduce the generation of fugitive dust and installing of cyclone dust collectors;
- Use of water spray systems to reduce the formation of fugitive dust from solid fuel storage in arid environments;
- Use of enclosed conveyors with well designed, extraction and filtration equipment on conveyor transfer points to prevent the emission of dust;
- For solid fuels of which fine fugitive dust could contain vanadium, nickel and Polycyclic Aromatic Hydrocarbons (PAHs) (e.g., in coal and petroleum coke), use of full enclosure during transportation and covering stockpiles where necessary;
- Design and operate transport systems to minimize the generation and transport of dust on site;
- Storage of lime or limestone in silos with well designed, extraction and filtration equipment;
- Use of wind fences in open storage of coal or use of enclosed storage structures to minimize fugitive dust

[10] Water injection may not be practical for industrial combustion turbines in all cases. Even if water is available, the facilities for water treatment and the operating and maintenance costs of water injection may be costly and may complicate the operation of a small combustion turbine.

[11] Including all particle sizes (e.g. TSP, PM_{10}, and $PM_{2.5}$)

[12] Flue gas conditioning (FGC) is a recommended approach to address the issue of low gas conductivity and lower ESP collection performance which occurs when ESPs are used to collect dust from very low sulfur fuels. One particular FGC design involves introduction of sulfur trioxide (SO_3) gas into the flue gas upstream of the ESP, to increase the conductivity of the flue gas dramatically improve the ESP collection efficiency. There is typically no risk of increased SOx emissions as the SO_3 is highly reactive and adheres to the dust.

emissions where necessary, applying special ventilation systems in enclosed storage to avoid dust explosions (e.g., use of cyclone separators at coal transfer points).

See Annex 1.1.2 of the **General EHS Guidelines** for an additional illustrative presentation of point source emissions prevention and control technologies.

Table 3 – Performance / Characteristics of Dust Removal Systems

Type	Performance / Characteristics
[illegible]	• Removal efficiency of >96.5% (<1 µm), >99.95% (>10 µm) • 0.1-1.8% of electricity generated is used • It might not work on particulates with very high electrical resistivity. In these cases, flue gas conditioning (FGC) may improve ESP performance. • Can handle very large gas volume with low pressure drops
[illegible]	• Removal efficiency of >99.6% (<1 µm), >99.95% (>10 µm). Removes smaller particles than ESPs. • 0.2-3% of electricity generated is used • Filter life decreases as coal S content increases • Operating costs go up considerably as the fabric filter becomes dense to remove more particles • If ash is particularly reactive, it can weaken the fabric and eventually it disintegrates.
[illegible]	• Removal efficiency of >98.5% (<1 µm), >99.9% (>10 µm) • Up to 3% of electricity generated is used. • As a secondary effect, can remove and absorb gaseous heavy metals • Wastewater needs to be treated

Source: EC Recommend World Bank Group

Other Pollutants

Depending on the fuel type and quality, other air pollutants may be present in environmentally significant quantities requiring proper consideration in the evaluation of potential impacts to ambient air quality and in the design and implementation of management actions and environmental controls. Examples of additional pollutants include mercury in coal, vanadium in heavy fuel oil, and other heavy metals present in waste fuels such as petroleum coke (petcoke) and used lubricating oils[13]. Recommendations to prevent, minimize, and control emissions of other air pollutants such as mercury in particular from thermal power plants include the use of conventional secondary controls such as fabric filters or ESPs operated in combination with FGD techniques, such as limestone FGD, Dry Lime FGD, or sorbent injection.[14] Additional removal of metals such as mercury can be achieved in a high dust SCR system along with powered activated carbon, bromine-enhanced Powdered Activated Carbon (PAC) or other sorbents. Since mercury emissions from thermal power plants pose potentially significant local and transboundary impacts to ecosystems and public health and safety through bioaccumulation, particular consideration should be given to their minimization in the environmental assessment and accordingly in plant design.[15]

Emissions Offsets

Facilities in degraded airsheds should minimize incremental impacts by achieving emissions values outlined in Table 6. Where these emissions values result nonetheless in excessive ambient impacts relative to local regulatory standards (or in their absence, other international recognized standards or guidelines, including World Health Organization guidelines), the project should explore and implement site-specific offsets that result in no net increase in the total emissions of those pollutants (e.g., particulate matter, sulfur dioxide, or nitrogen dioxide) that are responsible for the degradation of the airshed. Offset provisions should be implemented before the power plant comes fully on stream. Suitable offset measures could include reductions in emissions of particulate matter, sulfur dioxide, or nitrogen dioxide, as necessary through (a) the installation of new or more effective controls at other units within the same power plant or at other power plants in

[13] In these cases, the EA should address potential impacts to ambient air quality for such heavy metals as mercury, nickel, vanadium, cadmium, lead, etc.

[14] For Fabric Filters or Electrostatic Precipitators operated in combination with FGD techniques, an average removal rate of 75% or 90 % in the additional presence of SCR can be obtained (EC, 2006).

[15] Although no major industrial country has formally adopted regulatory limits for mercury emissions from thermal power plants, such limitations where under consideration in the United States and European Union as of 2008. Future updates of these EHS Guidelines will reflect changes in the international state of

the same airshed, (b) the installation of new or more effective controls at other large sources, such as district heating plants or industrial plants, in the same airshed, or (c) investments in gas distribution or district heating systems designed to substitute for the use of coal for residential heating and other small boilers. Wherever possible, the offset provisions should be implemented within the framework of an overall air quality management strategy designed to ensure that air quality in the airshed is brought into compliance with ambient standards. The monitoring and enforcement of ambient air quality in the airshed to ensure that offset provisions are complied with would be the responsibility of the local or national agency responsible for granting and supervising environmental permits. Project sponsors who cannot engage in the negotiations necessary to put together an offset agreement (for example, due to the lack of the local or national air quality management framework) should consider the option of relying on an appropriate combination of using cleaner fuels, more effective pollution controls, or reconsidering the selection of the proposed project site. The overall objective is that the new thermal power plants should not contribute to deterioration of the already degraded airshed.

Energy Efficiency and GHG Emissions

Carbon dioxide, one of the major greenhouse gases (GHGs) under the UN Framework Convention on Climate Change, is emitted from the combustion of fossil fuels. Recommendations to avoid, minimize, and offset emissions of carbon dioxide from new and existing thermal power plants include, among others:

- Use of less carbon intensive fossil fuels (i.e., less carbon containing fuel per unit of calorific value – gas is less than oil and oil is less than coal) or co-firing with carbon neutral fuels (i.e., biomass);
- Use of combined heat and power plants (CHP) where feasible;
- Use of higher energy conversion efficiency technology of the same fuel type / power plant size than that of the country/region average. New facilities should be aimed to be in top quartile of the country/region average of the same fuel type and power plant size. Rehabilitation of existing facilities must achieve significant improvements in efficiency. Typical CO_2 emissions performance of different fuels / technologies are presented below in Table 4;
- Consider efficiency-relevant trade-offs between capital and operating costs involved in the use of different technologies. For example, supercritical plants may have a higher capital cost than subcritical plants for the same capacity, but lower operating costs. On the other hand, characteristics of existing and future size of the grid may impose limitations in plant size and hence technological choice. These tradeoffs need to be fully examined in the EA;
- Use of high performance monitoring and process control techniques, good design and maintenance of the combustion system so that initially designed efficiency performance can be maintained;
- Where feasible, arrangement of emissions offsets (including the Kyoto Protocol's flexible mechanisms and the voluntary carbon market), including reforestation, afforestation, or capture and storage of CO_2 or other currently experimental options[16];
- Where feasible, include transmission and distribution loss reduction and demand side measures. For example, an investment in peak load management could reduce cycling requirements of the generation facility thereby improving its operating efficiency. The feasibility of these types of off-set options may vary depending on whether the facility is part of a vertically integrated utility or an independent power producer;
- Consider fuel cycle emissions and off-site factors (e.g., fuel

practice regarding mercury emissions prevention and control.

[16] The application of carbon capture and storage (CCS) from thermal power projects is still in experimental stages worldwide although consideration has started to be given to CCS-ready design. Several options are currently under evaluation including CO_2 storage in coal seams or deep aquifers and oil reservoir injection for enhanced oil recovery.

supply, proximity to load centers, potential for off-site use of waste heat, or use of nearby waste gases (blast furnace gases or coal bed methane) as fuel. etc).

Table 4 - Typical CO_2 Emissions Performance of New Thermal Power Plants

Fuel	Efficiency	CO_2 (gCO_2 / kWh – Gross)
	[illegible]	
	Ultra-Supercritical (*1):	
	37.6 – 42.7	676-795
	Supercritical:	
	35.9-38.3 (*1)	756-836
	39.1 (w/o CCS) (*2)	763
	24.9 (with CCS) (*2)	95
	Subcritical:	
	33.1-35.9 (*1)	807-907
	36.8 (w/o CCS) (*2)	808
	24.9 (with CCS) (*2)	102
	IGCC:	
	39.2-41.8 (*1)	654-719
	38.2–41.1 (w/o CCS) (*2)	640 – 662
	31.7–32.5 (with CCS) (*2)	68 – 86
	Advanced CCGT (*2):	
	50.8 (w/o CCS)	355
	43.7 (with CCS)	39
	[illegible]	
	42 (Ultra-Supercritical)	811
	40 (Supercritical)	851
	30 – 38 (Subcritical)	896-1,050
	46 (IGCC)	760
	38 (IGCC+CCS)	134
	(*4) 43-47 (Coal-PC)	(*6) 725-792 (Net)
	>41(Coal-FBC)	<831 (Net)
	42-45 (Lignite-PC)	808-866 (Net)
	>40 (Lignite-FBC)	<909 (Net)
	(*4) 36–40 (Simple Cycle GT)	(*6) 505-561 (Net)
	38-45 (Gas Engine)	531-449 (Net)
	40-42 (Boiler)	481-505 (Net)
	54-58 (CCGT)	348-374 (Net)
	(*4) 40 – 45 (HFO/LFO Reciprocating Engine)	(*6) 449-505 (Net)
	[illegible]	
	(*5) 47 (Ultra-supercritical)	(*6) 725
	44 (Supercritical)	774
	41-42 (Subcritical)	811-831
	47-48 (IGCC)	710-725
	(*5) 43 (Reciprocating Engine)	(*6) 648
	41 (Boiler)	680
	(*5) 34 (Simple Cycle GT)	(*6) 594
	51 (CCGT)	396

Source: (*1) US EPA 2006, (*2) US DOE/NETL 2007, (*3) World Bank, April 2006, (*4) European Commission 2006, (*5) World Bank Group, Sep 2006, (*6) World Bank Group estimates

Water Consumption and Aquatic Habitat Alteration

Steam turbines used with boilers and heat recovery steam generators(HRSG) used in combined cycle gas turbine units require a cooling system to condense steam used to generate electricity. Typical cooling systems used in thermal power plants include: (i) once-through cooling system where sufficient cooling water and receiving surface water are available; (ii) closed circuit wet cooling system; and (iii) closed circuit dry cooling system (e.g., air cooled condensers).

Combustion facilities using once-through cooling systems require large quantities of water which are discharged back to receiving surface water with elevated temperature. Water is also required for boiler makeup, auxiliary station equipment, ash handling, and FGD systems.[17] The withdrawal of such large quantities of water has the potential to compete with other important water uses such as agricultural irrigation or drinking water sources. Withdrawal and discharge with elevated temperature and chemical contaminants such as biocides or other additives, if used, may affect aquatic organisms, including phytoplankton, zooplankton, fish, crustaceans, shellfish, and many other forms of aquatic life. Aquatic organisms drawn into cooling water intake structures are either impinged on components of the cooling water intake structure or entrained in the cooling water system itself. In the case of either impingement or entrainment, aquatic organisms may be killed or subjected to significant harm. In some cases (e.g., sea turtles), organisms are entrapped in the intake canals. There may be special concerns about the potential impacts of cooling water intake structures located in or near habitat areas that support threatened, endangered, or other protected species or where local fishery is active.

Conventional intake structures include traveling screens with relative high through-screen velocities and no fish handling or

[17] The availability of water and impact of water use may affect the choice of FGD

return system.[18] Measures to prevent, minimize, and control environmental impacts associated with water withdrawal should be established based on the results of a project EA, considering the availability and use of water resources locally and the ecological characteristics of the project affected area. Recommended management measures to prevent or control impacts to water resources and aquatic habitats include[19]:

- Conserving water resources, particularly in areas with limited water resources, by:
  - Use of a closed-cycle, recirculating cooling water system (e.g., natural or forced draft cooling tower), or closed circuit dry cooling system (e.g., air cooled condensers) if necessary to prevent unacceptable adverse impacts. Cooling ponds or cooling towers are the primary technologies for a recirculating cooling water system. Once-through cooling water systems may be acceptable if compatible with the hydrology and ecology of the water source and the receiving water and may be the preferred or feasible alternative for certain pollution control technologies such as seawater scrubbers
  - Use of dry scrubbers in situations where these controls are also required or recycling of wastewater in coal-fired plants for use as FGD makeup
  - Use of air-cooled systems
- Reduction of maximum through-screen design intake velocity to 0.5 ft/s;
- Reduction of intake flow to the following levels:
  - For freshwater rivers or streams to a flow sufficient to maintain resource use (i.e., irrigation and fisheries) as well as biodiversity during annual mean low flow conditions[20]
  - For lakes or reservoirs, intake flow must not disrupt the thermal stratification or turnover pattern of the source water
  - For estuaries or tidal rivers, reduction of intake flow to 1% of the tidal excursion volume
- If there are threatened, endangered, or other protected species or if there are fisheries within the hydraulic zone of influence of the intake, reduction of impingement and entrainment of fish and shellfish by the installation of technologies such as barrier nets (seasonal or year-round), fish handling and return systems, fine mesh screens, wedgewire screens, and aquatic filter barrier systems. Examples of operational measures to reduce impingement and entrainment include seasonal shutdowns, if necessary, or reductions in flow or continuous use of screens. Designing the location of the intake structure in a different direction or further out into the water body may also reduce impingement and entrainment.

Effluents

Effluents from thermal power plants include thermal discharges, wastewater effluents, and sanitary wastewater.

Thermal Discharges

As noted above, thermal power plants with steam-powered generators and once-through cooling systems use significant volume of water to cool and condense the steam for return to the boiler. The heated water is normally discharged back to the source water (i.e., river, lake, estuary, or the ocean) or the nearest surface water body. In general, thermal discharge should be designed to ensure that discharge water temperature does not result in exceeding relevant ambient water quality temperature standards outside a scientifically established mixing zone. The mixing zone is typically defined as the zone where initial dilution of a discharge takes place within which relevant water quality

system used (i.e., wet vs. semi-dry).

[18] The velocity generally considered suitable for the management of debris is 1 fps [0.30 m/s] with wide mesh screens; a standard mesh for power plants of 3/8 in (9.5 mm).

[19] For additional information refer to Schimmoller (2004) and USEPA (2001).

[20] Stream flow requirements may be based on mean annual flow or mean low flow. Regulatory requirements may be 5% or higher for mean annual flows and 10% to 25% for mean low flows. Their applicability should be verified on a site-specific

temperature standards are allowed to exceed and takes into account cumulative impact of seasonal variations, ambient water quality, receiving water use, potential receptors and assimilative capacity among other considerations. Establishment of such a mixing zone is project specific and may be established by local regulatory agencies and confirmed or updated through the project's environmental assessment process. Where no regulatory standard exists, the acceptable ambient water temperature change will be established through the environmental assessment process. Thermal discharges should be designed to prevent negative impacts to the receiving water taking into account the following criteria:

- The elevated temperature areas because of thermal discharge from the project should not impair the integrity of the water body as a whole or endanger sensitive areas (such as recreational areas, breeding grounds, or areas with sensitive biota);
- There should be no lethality or significant impact to breeding and feeding habits of organisms passing through the elevated temperature areas;
- There should be no significant risk to human health or the environment due to the elevated temperature or residual levels of water treatment chemicals.

If a once-through cooling system is used for large projects (i.e., a plant with > 1,200MWth steam generating capacity), impacts of thermal discharges should be evaluated in the EA with a mathematical or physical hydrodynamic plume model, which can be a relatively effective method for evaluating a thermal discharge to find the maximum discharge temperatures and flow rates that would meet the environmental objectives of the receiving water.[21]

Recommendations to prevent, minimize, and control thermal discharges include:

- Use of multi-port diffusers;
- Adjustment of the discharge temperature, flow, outfall location, and outfall design to minimize impacts to acceptable level (i.e., extend length of discharge channel before reaching the surface water body for pre-cooling or change location of discharge point to minimize the elevated temperature areas);
- Use of a closed-cycle, recirculating cooling water system as described above (e.g., natural or forced draft cooling tower), or closed circuit dry cooling system (e.g., air cooled condensers) if necessary to prevent unacceptable adverse impacts. Cooling ponds or cooling towers are the primary technologies for a recirculating cooling water system.

Liquid Waste

The wastewater streams in a thermal power plant include cooling tower blowdown; ash handling wastewater; wet FGD system discharges; material storage runoff; metal cleaning wastewater; and low-volume wastewater, such as air heater and precipitator wash water, boiler blowdown, boiler chemical cleaning waste, floor and yard drains and sumps, laboratory wastes, and backflush from ion exchange boiler water purification units. All of these wastewaters are usually present in plants burning coal or biomass; some of these streams (e.g., ash handling wastewater) may be present in reduced quantities or may not be present at all in oil-fired or gas-fired power plants. The characteristics of the wastewaters generated depend on the ways in which the water has been used. Contamination arises from demineralizers; lubricating and auxiliary fuel oils; trace contaminants in the fuel (introduced through the ash-handling wastewater and wet FGD system discharges); and chlorine, biocides, and other chemicals used to manage the quality of water in cooling systems. Cooling tower blowdown tends to be very high in total dissolved solids but is generally classified as non-contact cooling water and, as such,

basis taking into consideration resource use and biodiversity requirements.

[21] An example model is CORMIX (Cornell Mixing Zone Expert System) hydrodynamic mixing zone computer simulation, which has been developed by the U.S. Environmental Protection Agency. This model emphasizes predicting the site- and discharge-specific geometry and dilution characteristics to assess the environmental effects of a proposed discharge.

is typically subject to limits for pH, residual chlorine, and toxic chemicals that may be present in cooling tower additives (including corrosion inhibiting chemicals containing chromium and zinc whose use should be eliminated).

Recommended water treatment and wastewater conservation methods are discussed in Sections 1.3 and 1.4, respectively, of the **General EHS Guidelines**. In addition, recommended measures to prevent, minimize, and control wastewater effluents from thermal power plants include:

- Recycling of wastewater in coal-fired plants for use as FGD makeup. This practice conserves water and reduces the number of wastewater streams requiring treatment and discharge[22];
- In coal-fired power plants without FGD systems, treatment of process wastewater in conventional physical-chemical treatment systems for pH adjustment and removal of total suspended solids (TSS), and oil / grease, at a minimum. Depending on local regulations, these treatment systems can also be used to remove most heavy metals to part-per-billion (ppb) levels by chemical precipitation as either metal hydroxide or metal organosulfide compounds;
- Collection of fly ash in dry form and bottom ash in drag chain conveyor systems in new coal-fired power plants;
- Consider use of soot blowers or other dry methods to remove fireside wastes from heat transfer surfaces so as to minimize the frequency and amount of water used in fireside washes;
- Use of infiltration and runoff control measures such as compacted soils, protective liners, and sedimentation controls for runoff from coal piles;
- Spraying of coal piles with anionic detergents to inhibit bacterial growth and minimize acidity of leachate;[23]
- Use of SO_X removal systems that generate less wastewater, if feasible; however, the environmental and cost characteristics of both inputs and wastes should be assessed on a case-by-case basis;
- Treatment of low-volume wastewater streams that are typically collected in the boiler and turbine room sumps in conventional oil-water separators before discharge;
- Treatment of acidic low-volume wastewater streams, such as those associated with the regeneration of makeup demineralizer and deep-bed condensate polishing systems, by chemical neutralization in-situ before discharge;
- Pretreatment of cooling tower makeup water, installation of automated bleed/feed controllers, and use of inert construction materials to reduce chemical treatment requirements for cooling towers;
- Elimination of metals such as chromium and zinc from chemical additives used to control scaling and corrosion in cooling towers;
- Use the minimum required quantities of chlorinated biocides in place of brominated biocides or alternatively apply intermittent shock dosing of chlorine as opposed to continuous low level feed.

Sanitary Wastewater

Sewage and other wastewater generated from washrooms, etc. are similar to domestic wastewater. Impacts and management of sanitary wastewater is addressed in Section 1.3 of the **General EHS Guidelines.**

Solid Wastes

Coal-fired and biomass-fired thermal power plants generate the greatest amount of solid wastes due to the relatively high percentage of ash in the fuel.[24] The large-volume coal

[22] Suitable wastewater streams for reuse include gypsum wash water, which is a different wastewater stream than the FGD wastewater. In plants that produce marketable gypsum, the gypsum is rinsed to remove chloride and other undesirable trace elements.

[23] If coal pile runoff will be used as makeup to the FGD system, anionic detergents may increase or create foaming within the scrubber system. Therefore, use of anionic surfactants on coal piles should be evaluated on a case-by-case basis.

[24] For example, a 500 MWe plant using coal with 2.5% sulfur (S), 16% ash, and 30,000 kilojoules per kilogram (kJ/kg) heat content will generate about 500 tons of

combustion wastes (CCW) are fly ash, bottom ash, boiler slag, and FGD sludge. Biomass contains less sulfur; therefore FGD may not be necessary. Fluidized-bed combustion (FBC) boilers generate fly ash and bottom ash, which is called bed ash. Fly ash removed from exhaust gases makes up 60–85% of the coal ash residue in pulverized-coal boilers and 20% in stoker boilers. Bottom ash includes slag and particles that are coarser and heavier than fly ash. Due to the presence of sorbent material, FBC wastes have a higher content of calcium and sulfate and a lower content of silica and alumina than conventional coal combustion wastes. Low-volume solid wastes from coal-fired thermal power plants and other plants include coal mill rejects/pyrites, cooling tower sludge, wastewater treatment sludge, and water treatment sludge.

Oil combustion wastes include fly ash and bottom ash and are normally only generated in significant quantities when residual fuel oil is burned in oil-fired steam electric boilers. Other technologies (e.g., combustion turbines and diesel engines) and fuels (e.g., distillate oil) generate little or no solid wastes. Overall, oil combustion wastes are generated in much smaller quantities than the large-volume CCW discussed above. Gas-fired thermal power plants generate essentially no solid waste because of the negligible ash content, regardless of the combustion technology.

Metals are constituents of concern in both CCW and low-volume solid wastes. For example, ash residues and the dust removed from exhaust gases may contain significant levels of heavy metals and some organic compounds, in addition to inert materials.

Ash residues are not typically classified as a hazardous waste due to their inert nature.[25] However, where ash residues are expected to contain potentially significant levels of heavy metals, radioactivity, or other potentially hazardous materials, they should be tested at the start of plant operations to verify their classification as hazardous or non-hazardous according to local regulations or internationally recognized standards. Additional information about the classification and management of hazardous and non-hazardous wastes is presented in Section 1.6 of the **General EHS Guidelines.**

The high-volume CCWs wastes are typically managed in landfills or surface impoundments or, increasingly, may be applied to a variety of beneficial uses. Low-volume wastes are also managed in landfills or surface impoundments, but are more frequently managed in surface impoundments. Many coal-fired plants co-manage large-volume and low-volume wastes.

Recommended measures to prevent, minimize, and control the volume of solid wastes from thermal power plants include:

- Dry handling of the coal combustion wastes, in particular fly ash. Dry handling methods do not involve surface impoundments and, therefore, do not present the ecological risks identified for impoundments (e.g., metal uptake by wildlife);
- Recycling of CCWs in uses such as cement and other concrete products, construction fills (including structural fill, flowable fill, and road base), agricultural uses such as calcium fertilizers (provided trace metals or other potentially hazardous materials levels are within accepted thresholds), waste management applications, mining applications, construction materials (e.g., synthetic gypsum for plasterboard), and incorporation into other products provided the residues (such as trace metals and radioactivity) are not considered hazardous. Ensuring consistent quality of fuels and additives helps to ensure the CCWs can be recycled. If beneficial reuse is not feasible, disposal of CCW in permitted landfills with environmental controls such as run-on/run-off controls, liners, leachate collection systems, ground-water monitoring, closure controls, daily (or other operational) cover, and fugitive dust controls is recommended;

solid waste per day.

[25] Some countries may categorize fly ash as hazardous due to the presence of arsenic or radioactivity, precluding its use as a construction material.

- Dry collection of bottom ash and fly ash from power plants combusting heavy fuel oil if containing high levels of economically valuable metals such as vanadium and recycle for vanadium recovery (where economically viable) or disposal in a permitted landfill with environmental controls;
- Management of ash disposal and reclamation so as to minimize environmental impacts – especially the migration of toxic metals, if present, to nearby surface and groundwater bodies, in addition to the transport of suspended solids in surface runoff due to seasonal precipitation and flooding. In particular, construction, operation, and maintenance of surface impoundments should be conducted in accordance with internationally recognized standards.[26, 27]
- Reuse of sludge from treatment of waste waters from FGD plants. This sludge may be re-used in the FGD plant due to the calcium components. It can also be used as an additive in coal-fired plant combustion to improve the ash melting behavior

Hazardous Materials and Oil

Hazardous materials stored and used at combustion facilities include solid, liquid, and gaseous waste-based fuels; air, water, and wastewater treatment chemicals; and equipment and facility maintenance chemicals (e.g., paint certain types of lubricants, and cleaners). Spill prevention and response guidance is addressed in Sections 1.5 and 3.7 of the **General EHS Guidelines**.

In addition, recommended measures to prevent, minimize, and control hazards associated with hazardous materials storage and handling at thermal power plants include the use of double-walled, underground pressurized tanks for storage of pure liquefied ammonia (e.g., for use as reagent for SCR) in quantities over 100 m^3; tanks of lesser capacity should be manufactured using annealing processes (EC 2006).

Noise

Principal sources of noise in thermal power plants include the turbine generators and auxiliaries; boilers and auxiliaries, such as coal pulverizers; reciprocating engines; fans and ductwork; pumps; compressors; condensers; precipitators, including rappers and plate vibrators; piping and valves; motors; transformers; circuit breakers; and cooling towers. Thermal power plants used for base load operation may operate continually while smaller plants may operate less frequently but still pose a significant source of noise if located in urban areas.

Noise impacts, control measures, and recommended ambient noise levels are presented in Section 1.7 of the **General EHS Guidelines**. Additional recommended measures to prevent, minimize, and control noise from thermal power plants include:

- Siting new facilities with consideration of distances from the noise sources to the receptors (e.g., residential receptors, schools, hospitals, religious places) to the extent possible. If the local land use is not controlled through zoning or is not effectively enforced, examine whether residential receptors could come outside the acquired plant boundary. In some cases, it could be more cost effective to acquire additional land as buffer zone than relying on technical noise control measures, where possible;
- Use of noise control techniques such as: using acoustic machine enclosures; selecting structures according to their noise isolation effect to envelop the building; using mufflers or silencers in intake and exhaust channels; using sound-absorptive materials in walls and ceilings; using vibration isolators and flexible connections (e.g., helical steel springs and rubber elements); applying a carefully detailed design to prevent possible noise leakage through openings or to minimize pressure variations in piping;

[26] See, for example, U.S. Department of Labor, Mine Safety and Health Administration regulations at 30 CFR §§ 77.214 - 77.216.

[27] Additional detailed guidance applicable to the prevention and control of impacts to soil and water resources from non-hazardous and hazardous solid waste disposal is presented in the World Bank Group EHS Guidelines for Waste Management Facilities.

- Modification of the plant configuration or use of noise barriers such as berms and vegetation to limit ambient noise at plant property lines, especially where sensitive noise receptors may be present.

Noise propagation models may be effective tools to help evaluate noise management options such as alternative plant locations, general arrangement of the plant and auxiliary equipment, building enclosure design, and, together with the results of a baseline noise assessment, expected compliance with the applicable community noise requirements.

1.2 Occupational Health and Safety

Occupational health and safety risks and mitigation measures during construction, operation, and decommissioning of thermal power plants are similar to those at other large industrial facilities, and are addressed in Section 2.0 of the **General EHS Guidelines**. In addition, the following health and safety impacts are of particular concern during operation of thermal power plants:

- Non-ionizing radiation
- Heat
- Noise
- Confined spaces
- Electrical hazards
- Fire and explosion hazards
- Chemical hazards
- Dust

Non-ionizing radiation

Combustion facility workers may have a higher exposure to electric and magnetic fields (EMF) than the general public due to working in proximity to electric power generators, equipment, and connecting high-voltage transmission lines. Occupational EMF exposure should be prevented or minimized through the preparation and implementation of an EMF safety program including the following components:

- Identification of potential exposure levels in the workplace, including surveys of exposure levels in new projects and the use of personal monitors during working activities;
- Training of workers in the identification of occupational EMF levels and hazards;
- Establishment and identification of safety zones to differentiate between work areas with expected elevated EMF levels compared to those acceptable for public exposure, limiting access to properly trained workers;
- Implementation of action plans to address potential or confirmed exposure levels that exceed reference occupational exposure levels developed by international organizations such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the Institute of Electrical and Electronics Engineers (IEEE).[28] Personal exposure monitoring equipment should be set to warn of exposure levels that are below occupational exposure reference levels (e.g., 50 percent). Action plans to address occupational exposure may include limiting exposure time through work rotation, increasing the distance between the source and the worker, when feasible, or the use of shielding materials.

Heat

Occupational exposure to heat occurs during operation and maintenance of combustion units, pipes, and related hot equipment. Recommended prevention and control measures to address heat exposure at thermal power plants include:

- Regular inspection and maintenance of pressure vessels and piping;
- Provision of adequate ventilation in work areas to reduce heat and humidity;

[28] The ICNIRP exposure guidelines for Occupational Exposure are listed in Section 2.2 of this Guideline.

- Reducing the time required for work in elevated temperature environments and ensuring access to drinking water;
- Shielding surfaces where workers come in close contact with hot equipment, including generating equipment, pipes etc;
- Use of warning signs near high temperature surfaces and personal protective equipment (PPE) as appropriate, including insulated gloves and shoes.

Noise

Noise sources in combustion facilities include the turbine generators and auxiliaries; boilers and auxiliaries, such as pulverizers; diesel engines; fans and ductwork; pumps; compressors; condensers; precipitators, including rappers and plate vibrators; piping and valves; motors; transformers; circuit breakers; and cooling towers. Recommendations for reducing noise and vibration are discussed in Section 1.1, above. In addition, recommendations to prevent, minimize, and control occupational noise exposures in thermal power plants include:

- Provision of sound-insulated control rooms with noise levels below 60 dBA[29];
- Design of generators to meet applicable occupational noise levels;
- Identify and mark high noise areas and require that personal noise protecting gear is used all the time when working in such high noise areas (typically areas with noise levels >85 dBA).

Confined Spaces

Specific areas for confined space entry may include coal ash containers, turbines, condensers, and cooling water towers (during maintenance activities). Recommend confined space entry procedures are discussed in Section 2.8 of the **General EHS Guidelines**.

Electrical Hazards

Energized equipment and power lines can pose electrical hazards for workers at thermal power plants. Recommended measures to prevent, minimize, and control electrical hazards at thermal power plants include:

- Consider installation of hazard warning lights inside electrical equipment enclosures to warn of inadvertent energization;
- Use of voltage sensors prior to and during workers' entrance into enclosures containing electrical components;
- Deactivation and proper grounding of live power equipment and distribution lines according to applicable legislation and guidelines whenever possible before work is performed on or proximal to them;
- Provision of specialized electrical safety training to those workers working with or around exposed components of electric circuits. This training should include, but not be limited to, training in basic electrical theory, proper safe work procedures, hazard awareness and identification, proper use of PPE, proper lockout/tagout procedures, first aid including CPR, and proper rescue procedures. Provisions should be made for periodic retraining as necessary.

Fire and Explosion Hazards

Thermal power plants store, transfer, and use large quantities of fuels; therefore, careful handling is necessary to mitigate fire and explosion risks. In particular, fire and explosion hazards increase as the particle size of coal is reduced. Particle sizes of coal that can fuel a propagating explosion occur within thermal dryers, cyclones, baghouses, pulverized-fuel systems, grinding mills, and other process or conveyance equipment. Fire and explosion prevention management guidance is provided in Section 2.1 and

[29] Depending on the type and size of the thermal power plants, distance between control room and the noise emitting sources differs. CSA Z107.58 provides design guidelines for control rooms as 60 dBA. Large thermal power plants using steam boilers or combustion turbines tend to be quieter than 60 dBA. Reciprocating engine manufacturers recommend 65 to 70 dBA instead of 60 dBA (Euromot Position as of 9 May 2008). This guideline recommends 60 dBA as GIIP, with an understanding that up to 65 dBA can be accepted for reciprocating engine power plants if 60 dBA is economically difficult to achieve.

2.4 of the **General EHS Guidelines**. Recommended measures to prevent, minimize, and control physical hazards at thermal power plants include:

- Use of automated combustion and safety controls;
- Proper maintenance of boiler safety controls;
- Implementation of startup and shutdown procedures to minimize the risk of suspending hot coal particles (e.g., in the pulverizer, mill, and cyclone) during startup;
- Regular cleaning of the facility to prevent accumulation of coal dust (e.g., on floors, ledges, beams, and equipment);
- Removal of hot spots from the coal stockpile (caused by spontaneous combustion) and spread until cooled, never loading hot coal into the pulverized fuel system;
- Use of automated systems such as temperature gauges or carbon monoxide sensors to survey solid fuel storage areas to detect fires caused by self-ignition and to identify risk points.

Chemical Hazards

Thermal power plants utilize hazardous materials, including ammonia for NO_x control systems, and chlorine gas for treatment of cooling tower and boiler water. Guidance on chemical hazards management is provided in Section 2.4 of the **General EHS Guidelines.** Additional, recommended measures to prevent, minimize, and control physical hazards at thermal power plants include:

- Consider generation of ammonia on site from urea or use of aqueous ammonia in place of pure liquefied ammonia;
- Consider use of sodium hypochlorite in place of gaseous chlorine.

Dust

Dust is generated in handing solid fuels, additives, and solid wastes (e.g., ash). Dust may contain silica (associated with silicosis), arsenic (skin and lung cancer), coal dust (black lung), and other potentially harmful substances. Dust management guidance is provided in the Section 2.1 and 2.4 of the **General EHS Guidelines.** Recommended measures to prevent, minimize, and control occupational exposure to dust in thermal power plants include:

- Use of dust controls (e.g., exhaust ventilation) to keep dust below applicable guidelines (see Section 2) or wherever free silica levels in airborne dust exceed 1 percent;
- Regular inspection and maintenance of asbestos containing materials (e.g., insulation in older plants may contain asbestos) to prevent airborne asbestos particles.

1.3 Community Health and Safety

Many community health and safety impacts during the construction, operation, and decommissioning of thermal power plant projects are common to those of most infrastructure and industrial facilities and are discussed in Section 3.0 the **General EHS Guidelines**. In addition to these and other aspects covered in Section 1.1, the following community health and safety impacts may be of particular concern for thermal power plant projects:

- Water Consumption;
- Traffic Safety.

Water Consumption

Boiler units require large amounts of cooling water for steam condensation and efficient thermal operation. The cooling water flow rate through the condenser is by far the largest process water flow, normally equating to about 98 percent of the total process water flow for the entire unit. In a once-through cooling water system, water is usually taken into the plant from surface waters, but sometimes ground waters or municipal supplies are used. The potential effects of water use should be assessed, as discussed in Section 3.1 of the **General EHS Guidelines**, to

ensure that the project does not compromise the availability of water for personal hygiene, agriculture, recreation, and other community needs.

Traffic Safety

Operation of a thermal power plant will increase traffic volume, in particular for facilities with fuels transported via land and sea, including heavy trucks carrying fuel, additives, etc. The increased traffic can be especially significant in sparsely populate areas where some thermal power plants are located. Prevention and control of traffic-related injuries are discussed in Section 3.4 of the **General EHS Guidelines**. Water transport safety is covered in the **EHS Guidelines for Shipping**.

2.0 Performance Indicators and Monitoring

2.1 Environment

Emissions and Effluent Guidelines

Effluent guidelines are described in Table 5. Emissions guidelines are described in Table 6. Effluent guidelines are applicable for direct discharges of treated effluents to surface waters for general use. Site-specific discharge levels may be established based on the availability and conditions in the use of publicly operated sewage collection and treatment systems or, if discharged directly to surface waters, on the receiving water use classification as described in the **General EHS Guideline.** Guideline values for process emissions and effluents in this sector are indicative of good international industry practice as reflected in standards of countries with recognized regulatory frameworks. These levels should be achieved, without dilution, at least 95 percent of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours. Deviation from these levels due to specific local project conditions should be justified in the environmental assessment.

Table 5 - Effluent Guidelines
(To be applicable at relevant wastewater stream: e.g., from FGD system, wet ash transport, washing boiler / air preheater and precipitator, boiler acid washing, regeneration of demineralizers and condensate polishers, oil-separated water, site drainage, coal pile runoff, and cooling water)

Parameter	mg/L, except pH and temp
	6 – 9
	50
	10
	0.2
	0.5
	0.5
	1.0
	1.0
	0.5
	0.1
	0.005
	0.5
	• Site specific requirement to be established by the EA. • Elevated temperature areas due to discharge of once-through cooling water (e.g., 1 Celsius above, 2 Celsius above, 3 Celsius above ambient water temperature) should be minimized by adjusting intake and outfall design through the project specific EA depending on the sensitive aquatic ecosystems around the discharge point.

Note: Applicability of heavy metals should be determined in the EA. Guideline limits in the Table are from various references of effluent performance by thermal power plants.

Emissions levels for the design and operation of each project should be established through the EA process on the basis of country legislation and the recommendations provided in this guidance document, as applied to local conditions. The emissions levels selected should be justified in the EA.[30] The maximum emissions levels given here can be consistently achieved by well-designed, well-operated, and well-maintained pollution control systems. In contrast, poor operating or maintenance procedures affect actual pollutant removal efficiency and may reduce it to well

[30] For example, in cases where potential for acid deposition has been identified as a significant issue in the EA, plant design and operation should ensure that emissions mass loadings are effectively reduced to prevent or minimize such impacts.

below the design specification. Dilution of air emissions to achieve these guidelines is unacceptable. Compliance with ambient air quality guidelines should be assessed on the basis of good international industry practice (GIIP) recommendations.

As described in the General EHS Guidelines, emissions should not result in pollutant concentrations that reach or exceed relevant ambient quality guidelines and standards[31] by applying national legislated standards, or in their absence, the current WHO Air Quality Guidelines[32], or other internationally recognized sources[33]. Also, emissions from a single project should not contribute more than 25% of the applicable ambient air quality standards to allow additional, future sustainable development in the same airshed. [34]

As described in the General EHS Guidelines, facilities or projects located within poor quality airsheds[35], and within or next to areas established as ecologically sensitive (e.g., national parks), should ensure that any increase in pollution levels is as small as feasible, and amounts to a fraction of the applicable short-term and annual average air quality guidelines or standards as established in the project-specific environmental assessment.

Environmental Monitoring

Environmental monitoring programs for this sector are presented in Table 7. Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Examples of emissions, stack testing, ambient air quality, and noise monitoring recommendations applicable to power plants are provided in Table 7. Additional guidance on applicable sampling and analytical methods for emissions and effluents is provided in the **General EHS Guidelines**.

[31] Ambient air quality standards are ambient air quality levels established and published through national legislative and regulatory processes, and ambient quality guidelines refer to ambient quality levels primarily developed through clinical, toxicological, and epidemiological evidence (such as those published by the World Health Organization).

[32] Available at World Health Organization (WHO). http://www.who.int/en

[33] For example the United States National Ambient Air Quality Standards (NAAQS) (http://www.epa.gov/air/criteria.html) and the relevant European Council Directives (Council Directive 1999/30/EC of 22 April 1999 / Council Directive 2002/3/EC of February 12 2002).

[34] US EPA Prevention of Significant Deterioration Increments Limits applicable to non-degraded airsheds.

[35] An airshed should be considered as having poor air quality if nationally legislated air quality standards or WHO Air Quality Guidelines are exceeded significantly.

Table 6 (A) - Emissions Guidelines (in mg/Nm³ or as indicated) for Reciprocating Engine

Note:

- Guidelines are applicable for new facilities.
- EA may justify more stringent or less stringent limits due to ambient environment, technical and economic considerations provided there is compliance with applicable ambient air quality standards and incremental impacts are minimized.
- For projects to rehabilitate existing facilities, case-by-case emission requirements should be established by the EA considering (i) the existing emission levels and impacts on the environment and community health, and (ii) cost and technical feasibility of bringing the existing emission levels to meet these new facilities limits.
- EA should demonstrate that emissions do not contribute a significant portion to the attainment of relevant ambient air quality guidelines or standards, and more stringent limits may be required.

Combustion Technology / Fuel	Particulate Matter (PM)		Sulfur Dioxide (SO_2)		Nitrogen Oxides (NOx)		Dry Gas, Excess O_2 Content (%)
Reciprocating Engine	NDA	DA	NDA	DA	NDA	DA	
Natural Gas	N/A	N/A	N/A	N/A	200 (Spark Ignition) 400 (Dual Fuel) (a)	200(SI) 400 (Dual Fuel / CI)	15%
Liquid Fuels (Plant >50 MWth to <300 MWth)	50	30	1,170 or use of 2% or less S fuel	0.5% S	1,460 (Compression Ignition, bore size diameter [mm] < 400) 1,850 (Compression Ignition, bore size diameter [mm] ≥ 400) 2,000 (Dual Fuel)	400	15%
Liquid Fuels (Plant >/=300 MWth)	50	30	585 or use of 1% or less S fuel	0.2% S	740 (contingent upon water availability for injection)	400	15%
Biofuels / Gaseous Fuels other than Natural Gas	50	30	N/A	N/A	30% higher limits than those provided above for Natural Gas and Liquid Fuels.	200 (SI, Natural Gas), 400 (other)	15%

General notes:

- MWth = Megawatt thermal input on HHV basis; N/A = not applicable; NDA = Non-degraded airshed; DA = Degraded airshed (poor air quality); Airshed should be considered as being degraded if nationally legislated air quality standards are exceeded or, in their absence, if WHO Air Quality Guidelines are exceeded significantly; S = sulfur content (expressed as a percent by mass); Nm³ is at one atmospheric pressure, 0 degree Celsius; MWth category is to apply to the entire facility consisting of multiple units that are reasonably considered to be emitted from a common stack. Guideline limits apply to facilities operating more than 500 hours per year. Emission levels should be evaluated on a one hour average basis and be achieved 95% of annual operating hours.
- (a) Compression Ignition (CI) engines may require different emissions values which should be evaluated on a case-by-case basis through the EA process.

Comparison of the Guideline limits with standards of selected countries / region (as of August 2008):

- Natural Gas-fired Reciprocating Engine – NOx
  - Guideline limits: 200 (SI), 400 (DF)
  - UK: 100 (CI) , US: Reduce by 90% or more, or alternatively 1.6 g/kWh
- Liquid Fuels-fired Reciprocating Engine – NOx (Plant >50 MWth to <300 MWth)
  - Guideline limits: 1,460 (CI, bore size diameter < 400 mm), 1,850 (CI, bore size diameter ≥ 400 mm), 2,000 (DF)
  - UK: 300 (> 25 MWth), India: 1,460 (Urban area & ≤ 75 MWe (≈ 190 MWth), Rural area & ≤ 150 MWe (≈ 380 MWth))
- Liquid Fuels-fired Reciprocating Engine – NOx (Plant ≥300 MWth)
  - Guideline limits: 740 (contingent upon water availability for injection)
  - UK: 300 (> 25 MWth), India: 740 (Urban area & > 75MWe (≈ 190 MWth), Rural area & > 150 MWe (≈ 380 MWth))
- Liquid Fuels-fired Reciprocating Engine – SO2
  - Guideline limits: 1,170 or use of ≤ 2% S (Plant >50 MWth to <300 MWth), 585 or use of ≤ 1% S (Plant ≥300 MWth)
  - EU: Use of low S fuel oil or the secondary FGD (IPCC LCP BREF), HFO S content ≤ 1% (Liquid Fuel Quality Directive), US: Use of diesel fuel with max S of 500 ppm (0.05%); EU: Marine HFO S content ≤ 1.5% (Liquid Fuel Quality Directive) used in SOx Emission Control Areas; India: Urban (< 2% S), Rural (< 4%S), Only diesel fuels (HSD, LDO) should be used in Urban

Source: UK (S2 1.03 Combustion Processes: Compression Ignition Engines, 50 MWth and over), India (SOx/NOx Emission Standards for Diesel Engines ≥ 0.8 MW), EU (IPCC LCP BREF July 2006), EU (Liquid Fuel Quality Directive 1999/32/EC amended by 2005/33/EC), US (NSPS for Stationary Compression Ignition Internal Combustion Engine – Final Rule – July 11, 2006)

Table 6 (B) - Emissions Guidelines (in mg/Nm³ or as indicated) for Combustion Turbine

Note:

- Guidelines are applicable for new facilities.
- EA may justify more stringent or less stringent limits due to ambient environment, technical and economic considerations provided there is compliance with applicable ambient air quality standards and incremental impacts are minimized.
- For projects to rehabilitate existing facilities, case-by-case emission requirements should be established by the EA considering (i) the existing emission levels and impacts on the environment and community health, and (ii) cost and technical feasibility of bringing the existing emission levels to meet these new facilities limits.
- EA should demonstrate that emissions do not contribute a significant portion to the attainment of relevant ambient air quality guidelines or standards, and more stringent limits may be required.

Combustion Technology / Fuel	Particulate Matter (PM)		Sulfur Dioxide (SO_2)		Nitrogen Oxides (NOx)	Dry Gas, Excess O_2 Content (%)
Combustion Turbine			NDA/DA		NDA/DA	
Natural Gas (all turbine types of Unit > 50MWth)	N/A	N/A	N/A	N/A	51 (25 ppm)	15%
Fuels other than Natural Gas (Unit > > 50MWth)	50	30	Use of 1% or less S fuel	Use of 0.5% or less S fuel	152 (74 ppm)[a]	15%

General notes:

- MWth = Megawatt thermal input on HHV basis; N/A = not applicable; NDA = Non-degraded airshed; DA = Degraded airshed (poor air quality); Airshed should be considered as being degraded if nationally legislated air quality standards are exceeded or, in their absence, if WHO Air Quality Guidelines are exceeded significantly; S = sulfur content (expressed as a percent by mass); Nm³ is at one atmospheric pressure, 0 degree Celsius; MWth category is to apply to single units; Guideline limits apply to facilities operating more than 500 hours per year. Emission levels should be evaluated on a one hour average basis and be achieved 95% of annual operating hours.
- If supplemental firing is used in a combined cycle gas turbine mode, the relevant guideline limits for combustion turbines should be achieved including emissions from those supplemental firing units (e.g., duct burners).
- (a) Technological differences (for example the use of Aeroderivatives) may require different emissions values which should be evaluated on a cases-by-case basis through the EA process but which should not exceed 200 mg/Nm3.

Comparison of the Guideline limits with standards of selected countries / region (as of August 2008):

- Natural Gas-fired Combustion Turbine – NOx
  - Guideline limits: 51 (25 ppm)
  - EU: 50 (24 ppm), 75 (37 ppm) (if combined cycle efficiency > 55%), 50*η / 35 (where η = simple cycle efficiency)
  - US: 25 ppm (> 50 MMBtu/h (≈ 14.6 MWth) and ≤ 850 MMBtu/h (≈ 249MWth)), 15 ppm (> 850 MMBtu/h (≈ 249 MWth))
  - (Note: further reduced NOx ppm in the range of 2 to 9 ppm is typically required through air permit)
- Liquid Fuel-fired Combustion Turbine – NOx
  - Guideline limits: 152 (74 ppm) – Heavy Duty Frame Turbines & LFO/HFO, 300 (146 ppm) – Aeroderivatives & HFO, 200 (97 ppm) – Aeroderivatives & LFO
  - EU: 120 (58 ppm), US: 74 ppm (> 50 MMBtu/h (≈ 14.6 MWth) and ≤ 850 MMBtu/h (≈ 249MWth)), 42 ppm (> 850 MMBtu/h (≈ 249 MWth))
- Liquid Fuel-fired Combustion Turbine – SOx
  - Guideline limits: Use of 1% or less S fuel
  - EU: S content of light fuel oil used in gas turbines below 0.1% / US: S content of about 0.05% (continental area) and 0.4% (non-continental area)

Source: EU (LCP Directive 2001/80/EC October 23 2001), EU (Liquid Fuel Quality Directive 1999/32/EC, 2005/33/EC), US (NSPS for Stationary Combustion Turbines, Final Rule – July 6, 2006)

Table 6 (C) - Emissions Guidelines (in mg/Nm³ or as indicated) for Boiler

Note:

- Guidelines are applicable for new facilities.
- EA may justify more stringent or less stringent limits due to ambient environment, technical and economic considerations provided there is compliance with applicable ambient air quality standards and incremental impacts are minimized.
- For projects to rehabilitate existing facilities, case-by-case emission requirements should be established by the EA considering (i) the existing emission levels and impacts on the environment and community health, and (ii) cost and technical feasibility of bringing the existing emission levels to meet these new facilities limits.
- EA should demonstrate that emissions do not contribute a significant portion to the attainment of relevant ambient air quality guidelines or standards, and more stringent limits may be required.

Combustion Technology / Fuel	Particulate Matter (PM)		Sulfur Dioxide (SO_2)		Nitrogen Oxides (NOx)		Dry Gas, Excess O_2 Content (%)
Boiler	NDA	DA	NDA	DA	NDA	DA	
Natural Gas	N/A	N/A	N/A	N/A	240	240	3%
Other Gaseous Fuels	50	30	400	400	240	240	3%
Liquid Fuels (Plant >50 MWth to <600 MWth)	50	30	900 – 1,500[a]	400	400	200	3%
Liquid Fuels (Plant >/=600 MWth)	50	30	200 – 850[b]	200	400	200	3%
Solid Fuels (Plant >50 MWth to <600 MWth)	50	30	900 – 1,500[a]	400	510[c] Or up to 1,100 if volatile matter of fuel < 10%	200	6%
Solid Fuels (Plant >/=600 MWth)	50	30	200 – 850[b]	200			6%

General notes:

- MWth = Megawatt thermal input on HHV basis; N/A = not applicable; NDA = Non-degraded airshed; DA = Degraded airshed (poor air quality); Airshed should be considered as being degraded if nationally legislated air quality standards are exceeded or, in their absence, if WHO Air Quality Guidelines are exceeded significantly; CFB = circulating fluidized bed coal-fired; PC = pulverized coal-fired; Nm³ is at one atmospheric pressure, 0 degree Celsius; MWth category is to apply to the entire facility consisting of multiple units that are reasonably considered to be emitted from a common stack. Guideline limits apply to facilities operating more than 500 hours per year. Emission levels should be evaluated on a one hour average basis and be achieved 95% of annual operating hours.
- a. Targeting the lower guidelines values and recognizing issues related to quality of available fuel, cost effectiveness of controls on smaller units, and the potential for higher energy conversion efficiencies (FGD may consume between 0.5% and 1.6% of electricity generated by the plant). b. Targeting the lower guidelines values and recognizing variability in approaches to the management of SO_2 emissions (fuel quality vs. use of secondary controls) and the potential for higher energy conversion efficiencies (FGD may consume between 0.5% and 1.6% of electricity generated by the plant). Larger plants are expected to have additional emission control measures. Selection of the emission level in the range is to be determined by EA considering the project's sustainability, development impact, and cost-benefit of the pollution control performance. c. Stoker boilers may require different emissions values which should be evaluated on a case-by-case basis through the EA process.

Comparison of the Guideline limits with standards of selected countries / region (as of August 2008):

- Natural Gas-fired Boiler – NOx
  - Guideline limits: 240
  - EU: 150 (50 to 300 MWth), 200 (> 300 MWth)
- Solid Fuels-fired Boiler - PM
  - Guideline limits: 50
  - EU: 50 (50 to 100 MWth), 30 (> 100 MWth), China: 50, India: 100 - 150
- Solid Fuels-fired Boiler – SO_2
  - Guideline limits: 900 – 1,500 (Plant > 50 MWth to < 600 MWth), 200 – 850 (Plant ≥ 600 MWth)
  - EU: 850 (50 – 100 MWth), 200 (> 100 MWth)
  - US: 180 ng/J gross energy output OR 95% reduction (≈ 200 mg/Nm3 at 6%O_2 assuming 38% HHV efficiency)
  - China: 400 (general), 800 (if using coal < 12,550 kJ/kg), 1,200 (if mine-mouth plant located in non-double control area of western region and burning low S coal (<0.5%))

Source: EU (LCP Directive 2001/80/EC October 23 2001), US (NSPS for Electric Utility Steam Generating Units (Subpart Da), Final Rule – June 13, 2007), China (GB 13223-2003)

Table 7 – Typical Air Emission Monitoring Parameters / Frequency for Thermal Power Plants
(Note: Detailed monitoring programs should be determined based on EA)

Combustion Technology / Fuel	Emission Monitoring: Particulate Matter (PM)	Emission Monitoring: Sulfur Dioxide (SO_2)	Emission Monitoring: Nitrogen Oxides (NOx)	Stack Emission Testing: PM	Stack Emission Testing: SO_2	Stack Emission Testing: NOx	Stack Emission Testing: Heavy Metals	Ambient Air Quality	Noise
Reciprocating Engine									
[illegible]	N/A	N/A	Continuous or indicative	N/A	N/A	Annual	N/A	If incremental impacts predicted by EA >/= 25 % of relevant short-term ambient air quality standards or if the plant >/= 1,200 MWth: - Monitor parameters (e.g., $PM_{10}/PM_{2.5}/SO_2/NOx$ to be consistent with the relevant ambient air quality standards) by continuous ambient air quality monitoring system (typically a minimum of 2 systems to cover predicted maximum ground level concentration point / sensitive receptor / background point). If incremental impacts predicted by EA < 25% of relevant short term ambient air quality standards and if the facility < 1,200 MWth but >/= 100 MWth - Monitor parameters either by passive samplers (monthly average) or by seasonal manual sampling (e.g., 1 weeks/season) for parameters consistent with the relevant air quality standards. Effectiveness of the ambient air quality monitoring program should be reviewed regularly. It could be simplified or reduced if alternative program is developed (e.g., local government's monitoring network). Continuation of the program is recommended during the life of the project if there are sensitive receptors or if monitored levels are not far below the relevant ambient air quality standards.	If EA predicts noise levels at residential receptors or other sensitive receptors are close to the relevant ambient noise standards / guidelines, or if there are such receptors close to the plant boundary (e.g., within 100m) then, conduct ambient noise monitoring every year to three years depending on the project circumstances. Elimination of noise monitoring can be considered acceptable if a comprehensive survey showed that there are no receptors affected by the project or affected noise levels are far below the relevant ambient noise standards / guidelines.
[illegible]	N/A	N/A	Continuous	N/A	N/A	Annual	N/A		
[illegible]	Continuous or indicative	Continuous if FGD is used or monitor by S content.	Continuous or indicative	Annual					
[illegible]	Continuous or indicative		Continuous						
[illegible]	Continuous or indicative	N/A	Continuous or indicative	Annual	N/A	Annual	N/A		
Combustion Turbine									
[illegible]	N/A	N/A	Continuous or indicative	N/A	N/A	Annual	N/A		
[illegible]	Continuous or indicative	Continuous if FGD is used or monitor by S content.	Continuous or indicative	Annual					
Boiler									
[illegible]	N/A	N/A	Continuous or indicative	N/A	N/A	Annual	N/A		
				Annual	Annual	Annual	N/A		
[illegible]	Indicative	Indicative	Continuous or indicative	Annual					
[illegible]	Continuous or indicative	Continuous if FGD is used or monitor by S content.	Continuous or indicative						
[illegible]		Continuous							
[illegible]		Continuous if FGD is used or monitor by S Content.	Continuous or indicative						
[illegible]		Continuous							

Note: Continuous or indicative means "Continuously monitor emissions or continuously monitor indicative parameters". Stack emission testing is to have direct measurement of emission levels to counter check the emission monitoring system.

2.2 Occupational Health and Safety

Occupational Health and Safety Guidelines

Occupational health and safety performance should be evaluated against internationally published exposure guidelines, of which examples include the Threshold Limit Value (TLV®) occupational exposure guidelines and Biological Exposure Indices (BEIs®) published by American Conference of Governmental Industrial Hygienists (ACGIH),[36] the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),[37] Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States (OSHA),[38] Indicative Occupational Exposure Limit Values published by European Union member states,[39] or other similar sources.

Additional indicators specifically applicable to electric power sector activities include the ICNIRP exposure limits for occupational exposure to electric and magnetic fields listed in Table 8. Additional applicable indicators such as noise, electrical hazards, air quality, etc. are presented in Section 2.0 of the **General EHS Guidelines**.

Table 8 - ICNIRP exposure limits for occupational exposure to electric and magnetic fields.

Frequency	Electric Field (V/m)	Magnetic Field (μT)
50 Hz	10,000	500
60 Hz	8300	415

Source: ICNIRP (1998), "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)"

Accident and Fatality Rates

Projects should try to reduce the number of accidents among project workers (whether directly employed or subcontracted) to a rate of zero, especially accidents that could result in lost work time, different levels of disability, or even fatalities. The accident and fatality rates of the specific facility may be benchmarked against the performance of facilities in this sector in developed countries through consultation with published sources (e.g., US Bureau of Labor Statistics and UK Health and Safety Executive)[40].

Occupational Health and Safety Monitoring

The working environment should be monitored for occupational hazards relevant to the specific project. Monitoring should be designed and implemented by accredited professionals[41] as part of an occupational health and safety monitoring program. Facilities should also maintain a record of occupational accidents and diseases and dangerous occurrences and accidents. Additional guidance on occupational health and safety monitoring programs is provided in the **General EHS Guidelines**.

[36] http://www.acgih.org/TLV/[36] Available at: http://www.acgih.org/TLV/ and http://www.acgih.org/store/

[37] Available at: http://www.cdc.gov/niosh/npg/

[38] Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

[39] Available at: http://europe.osha.eu.int/good_practice/risks/ds/oel/

[40] Available at: http://www.bls.gov/iif/ and http://www.hse.gov.uk/statistics/index.htm

[41] Accredited professionals may include Certified Industrial Hygienists, Registered Occupational Hygienists, or Certified Safety Professionals or their equivalent.

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Annex A: General Description of Industry Activities

Thermal power plants burn fossil fuels or biomass to generate electrical energy and heat. Mechanical power is produced by a heat engine, which transforms thermal energy from combustion of a fossil fuel into rotational energy. A generator converts that mechanical energy into electrical energy by creating relative motion between a magnetic field and a conductor. Figure A-1 is a generalized flow diagram of a boiler-based thermal power plant and its associated operations.

Not all thermal energy can be transformed to mechanical power, according to the second law of thermodynamics. Therefore, thermal power plants also produce low-temperature heat. If no use is found for the heat, it is lost to the environment. If reject heat is employed as useful heat (e.g., for industrial processes or district heating), the power plant is referred to as a cogeneration power plant or CHP (combined heat-and-power) plant.

Types of Thermal power plants

Thermal power plants can be divided based on the type of combustion or gasification: boilers, internal reciprocating engines, and combustion turbines. In addition, combined-cycle and cogeneration systems increase efficiency by utilizing heat lost by conventional combustion systems. The type of system is chosen based on the loads, the availability of fuels, and the energy requirements of the electric power generation facility. Other ancillary processes, such as coal processing and pollution control, must also be performed to support the generation of electricity. The following subsections describe each system and then discuss ancillary processes at the facility (USEPA 1997).

Boilers (Steam Turbines)

Conventional steam-producing thermal power plants generate electricity through a series of energy conversion stages: fuel is burned in boilers to convert water to high-pressure steam, which is then used to drive a steam turbine to generate electricity. Heat for the system is usually provided by the combustion of coal, natural gas, oil, or biomass as well as other types of waste or recovered fuel. High-temperature, high-pressure steam is generated in the boiler and then enters the steam turbine. At the other end of the steam turbine is the condenser, which is maintained at a low temperature and pressure. Steam rushing from the high-pressure boiler to the low-pressure condenser drives the turbine blades, which powers the electric generator.

Low-pressure steam exiting the turbine enters the condenser shell and is condensed on the condenser tubes, which are maintained at a low temperature by the flow of cooling water. As the steam is cooled to condensate, the condensate is transported by the boiler feedwater system back to the boiler, where it is used again. A constant flow of low-temperature cooling water in the condenser tubes is required to keep the condenser shell (steam side) at proper pressure and to ensure efficient electricity generation. Through the condensing process, the cooling water is warmed. If the cooling system is an open or a once-through system, this warm water is released back to the source water body.[42] In a closed system, the warm water is cooled by recirculation through cooling towers, lakes, or ponds, where the heat is released into the air through evaporation and/or sensible heat transfer. If a recirculating cooling system is used, only a relatively small amount of make-up water is required to offset the evaporative losses and cooling tower blowdown that must be discharged periodically to control the build-up of solids. A recirculating system uses about one-twentieth the water of a once-through system.

Steam turbines typically have a thermal efficiency of about 35 percent, meaning that 35 percent of the heat of combustion is transformed into electricity. The remaining 65 percent of the heat either goes up the stack (typically 10 percent) or is

[42] If groundwater is used for cooling, the cooling water is usually discharged to a

discharged with the condenser cooling water (typically 55 percent).

Coal and lignite are the most common fuels in thermal power plants although heavy fuel oil is also used. Coal-fired steam generation systems are designed to use pulverized coal or crushed coal. Several types of coal-fired steam generators are in use, and are generally classified based on the characteristics of the coal fed to the burners and the mode of burning the coal. In fluidized-bed combustors, fuel materials are forced by gas into a state of buoyancy. The gas cushion between the solids allows the particles to move freely, thus flowing like a liquid. By using this technology, SO_2 and NO_X emissions are reduced because an SO_2 sorbent, such as limestone, can be used efficiently. Also, because the operating temperature is low, the amount of NO_X gases formed is lower than those produced using conventional technology.

Natural gas and liquid fuels are usually transported to thermal power plants via pipelines. Coal and biomass fuels can be transported by rail, barge, or truck. In some cases, coal is mixed with water to form slurry that can be pumped to the thermal power plant in a pipeline. Once coal arrives at the plant, it is unloaded to storage or directly to the stoker or hopper. In transporting coal during warmer months and in dry climates, dust suppression may be necessary.

Coal may be cleaned and prepared before being either crushed or pulverized. Impurities in coal such as ash, metals, silica, and sulfur can cause boiler fouling and slagging. Coal cleaning can be used to reduce sulfur in the coal to meet sulfur dioxide (SO_2) emissions regulations and also reduce ash content and the amount of heavy metals. Cleaning the coal is costly, but the cost can be at least partially offset by an increase in fuel efficiency, reduced emission control requirements, and lower waste management costs. Coal cleaning is typically performed at the mine by using gravity concentration, flotation, or dewatering methods.

Coal is transported from the coal bunker or silo to be crushed, ground, and dried further before it is fired in the burner or combustion system. Many mechanisms can be used to grind the coal and prepare it for firing. Pulverizers, cyclones, and stokers are all used to grind and dry the coal. Increasing the coal's particle surface area and decreasing its moisture content greatly boosting its heating capacity. Once prepared, the coal is transported within the plant to the combustion system. Devices at the bottom of the boilers catch ash and/or slag.

Reciprocating Engines

Internal combustion engines convert the chemical energy of fuels (typically diesel fuel or heavy fuel oil) into mechanical energy in a design similar to a truck engine, and the mechanical energy is used to turn a generator. Two types of engines normally used: the medium-speed, four-stroke trunk piston engine and the low-speed, two-stroke crosshead engine. Both types of engine operate on the air-standard diesel thermodynamic cycle. Air is drawn or forced into a cylinder and is compressed by a piston. Fuel is injected into the cylinder and is ignited by the heat of the compression of the air. The burning mixture of fuel and air expands, pushing the piston. The products of combustion are then removed from the cylinder, completing the cycle.

The exhaust gases from an engine are affected by the load profile of the prime mover; ambient conditions such as air humidity and temperature; fuel oil quality, such as sulfur content, nitrogen content, viscosity, ignition ability, density, and ash content; and site conditions and the auxiliary equipment associated with the prime mover, such as cooling properties and exhaust gas back pressure. The engine parameters that affect NO_X emissions are fuel injection in terms of timing, duration, and atomization; combustion air conditions, which are affected by

surface water body.

valve timing, the charge air system, and charge air cooling before cylinders; and the combustion process, which is affected by air and fuel mixing, combustion chamber design, and the compression ratio.[43] The particulate matter emissions are dependent on the general conditions of the engine, especially the fuel injection system and its maintenance, in addition to the ash content of the fuel, which is in the range 0.05–0.2%. SOx emissions are directly dependent on the sulfur content of the fuel. Fuel oil may contain as little as 0.3% sulfur and, in some cases, up to 5% sulfur.

Diesel engines are fuel flexible and can use fuels such as diesel oil, heavy fuel oil, natural gas, crude oil, bio-fuels (such as palm oil, etc.) and emulsified fuels (such as Orimulsion, etc.).

Typical electrical efficiencies in single mode are typically ranging from 40 % for the medium speed engines up to about 50 % for large engines and even higher efficiencies in combined cycle mode. Total efficiency in CHP (Combined Heat and Power) is typically in liquid operation up to 60 – 80 % and in gas mode even higher dependent on the application. The heat to power ratio is typically 0.5 to 1.3 in CHP applications, dependent on the application.

Lean Burn Gas Engines

Typical electrical efficiencies for bigger stationary medium speed engines in single mode are typically 40 – 47 % and up to close to 50 % in combined cycle mode. Total efficiency in CHP facilities is typically up to 90 % dependent on the application. The heat to power ratios are typically 0.5 to 1.3 in CHP-applications, dependent on the application.

Spark Ignition (SG)

Often a spark ignited gas-otto engine works according to the lean burn concept meaning that a lean mixture of combustion air and fuel is used in the cylinder (e.g., much more air than needed for the combustion). In order to stabilize the ignition and combustion of the lean mixture, in bigger engine types a prechamber with a richer air/fuel mixture is used. The ignition is initiated with a spark plug or some other device located in the prechamber, resulting in a high-energy ignition source for the main fuel charge in the cylinder. The most important parameter governing the rate of NOx formation in internal combustion engines is the combustion temperature; the higher the temperature the higher the NOx content of the exhaust gases. One method is to lower the fuel/air ratio, the same specific heat quantity released by the combustion of the fuel is then used to heat up a larger mass of exhaust gases, resulting in a lower maximum combustion temperature. This method low fuel/air ratio is called lean burn and it reduces NOx effectively. The spark-ignited lean-burn engine has therefore low NOx emissions. This is a pure gas engine; it operates only on gaseous fuels.

Dual fuel engines (DF)

Some DF engine types are fuel versatile, these can be run on low pressure natural gas or liquid fuels such as diesel oil (as back-up fuel, etc.), heavy fuel oil, etc. This engine type can operate at full load in both fuel modes. Dual Fuel (DF) engines can also be designed to work in gas mode only with a pilot liquid fuel used for ignition of the gas.

Combustion Turbines

Gas turbine systems operate in a manner similar to steam turbine systems except that combustion gases are used to turn the turbine blades instead of steam. In addition to the electric generator, the turbine also drives a rotating compressor to pressurize the air, which is then mixed with either gas or liquid

[43] If the fuel timing is too early, the cylinder pressure will increase, resulting in higher nitrogen oxide formation. If injection is timed too late, fuel consumption and turbocharger speed will increase. NO_x emissions can be reduced by later injection timing, but then particulate matter and the amount of unburned species will increase.

fuel in a combustion chamber. The greater the compression, the higher the temperature and the efficiency that can be achieved in a gas turbine. Higher temperatures, however, typically lead to increases in NO_X emissions. Exhaust gases are emitted to the atmosphere from the turbine. Unlike a steam turbine system, gas turbine systems do not have boilers or a steam supply, condensers, or a waste heat disposal system. Therefore, capital costs are much lower for a gas turbine system than for a steam system.

In electrical power applications, gas turbines are often used for peaking duty, where rapid startup and short runs are needed. Most installed simple gas turbines with no controls have only a 20- to 30-percent efficiency.

Combined Cycle

Combined-cycle generation is a configuration using both gas turbines and steam generators. In a combined-cycle gas turbine (CCGT), the hot exhaust gases of a gas turbine are used to provide all, or a portion of, the heat source for the boiler, which produces steam for the steam generator turbine. This combination increases the thermal efficiency to approximately 50 - 60 percent. Combined-cycle systems may have multiple gas turbines driving one steam turbine. Combined-cycle systems with diesel engines and steam generators are also sometimes used.

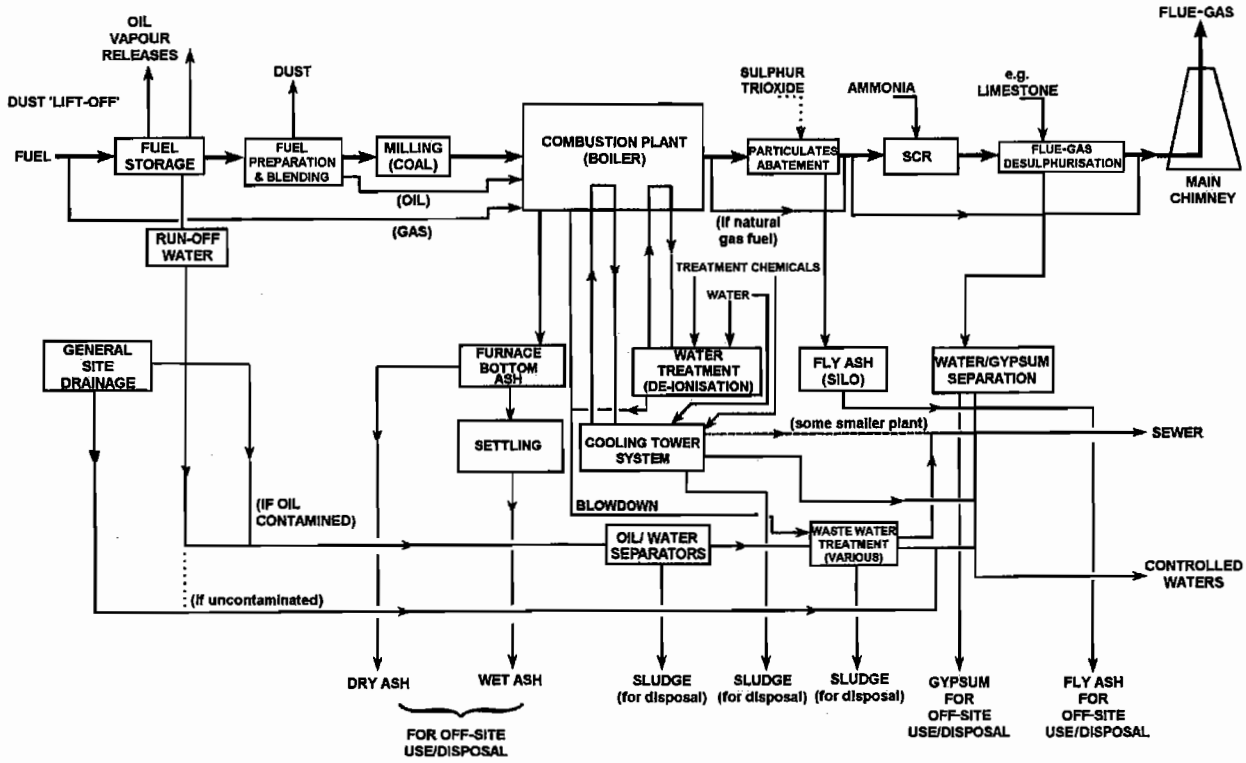
In addition, integrated coal gasification combined-cycle (IGCC) units are emerging technologies. In an IGCC system, coal gas is manufactured and cleaned in a "gasifier" under pressure, thereby reducing emissions and particulates.[44] The coal gas then is combusted in a CCGT generation system.

Cogeneration

Cogeneration is the merging of a system designed to produce electric power and a system used for producing industrial heat and steam and/or municipal heating. This system is a more efficient way of using energy inputs and allows the recovery of otherwise wasted thermal energy for use in an industrial process. Cogeneration technologies are classified as "topping cycle" and "bottoming cycle" systems, depending on whether electrical (topping cycle) or thermal (bottoming cycle) energy is derived first. Most cogeneration systems use a topping cycle.

[44] Gasification is a process in which coal is introduced to a reducing atmosphere with oxygen or air and steam.

Figure A-1
Generalized Flow Diagram of a Thermal power plant[45] and Associated Operations



Source: EC 2006

[45] Applicable to boiler plant with cooling tower only. Diagram does not apply to engines and turbines which have completely different configurations.

Annex B: Environmental Assessment Guidance for Thermal Power Projects

The development of an environmental assessment (EA) for a thermal power project should take into account any government energy and/or environmental policy or strategy including strategic aspects such as energy efficiency improvements in existing power generation, transmission, and distribution systems, demand side management, project siting, fuel choice, technology choice, and environmental performance.

New Facilities and Expansion of Existing Facilities

An (EA) for new facilities and a combined EA and environmental audit for existing facilities should be carried out early in the project cycle in order to establish site-specific emissions requirements and other measures for a new or expanded thermal power plant. Table B-1 provides suggested key elements of the EA, the scope of which will depend on project-specific circumstances.

Table B-1 Suggested Key EHS Elements for EA of New Thermal Power Project	

[illegible]	• Fuel selection including non-fossil fuel options (coal, oil, gas, biomass, other renewable options – wind, solar, geothermal, hydro), fuel supply sources
	• Power generation technology
	  o Thermal generating efficiency (HHV-gross, LHV-gross, HHV-net, LHV-net)
	  o Cost
	  o CO_2 emissions performance (gCO2/kWh)
	• GHG emissions reduction / offset options
	  o Energy conversion efficiency
	  o Offset arrangement
	  o Use of renewable energy sources, etc.
	• Baseline water quality of receiving water bodies
	• Water supply
	  o Surface water, underground water, desalination
	• Cooling system
	  o Once-through, wet closed circuit, dry closed circuit
	• Ash disposal system - wet disposal vs. dry disposal
	• Pollution control
	  o Air emission – primary vs. secondary flue gas treatment (cost, performance)
	  o Effluent (cost, performance)
	• Effluent discharge
	  o Surface water
	  o Evaporation
	  o Recycling – zero discharge
	• Siting
	  o Land acquisition consideration
	  o Access to fuel / electricity grid
	  o Existing and future land use zoning
	  o Existing and predicted environmental baseline (air, water, noise)

[illegible]	• Estimation of GHG emissions (tCO_2/year, gCO_2/kWh)
	• Air quality impact
	  o SO_2, NO_2, PM_{10}, $PM_{2.5}$, Heavy metals as appropriate, Acid deposition if relevant
	  o Incremental impacts to the attainment of relevant air quality standards
	  o Isopleth concentration lines (short-term, annual average, as appropriate) overlaid with land use and topographic map
	  o Cumulative impacts of existing sources / future projects if known
	  o Stack height determination
	  o Health impact consideration
	• Water quality / intake impact
	  o thermal discharge if once-through cooling system is used
	  o other key contaminants as appropriate
	  o water intake impact
	• Noise impact
	  o Noise contour lines overlaid with land use and locations of receptors
	• Determination of pollution prevention and abatement measures

[illegible]	• Air (Stack height, pollution control measures, cost)

[illegible]	• Effluent (wastewater treatment measures, cost) • Noise (noise control measures, cost) • Waste utilization / disposal (e.g., ash, FGD by-product, used oil) o Ash management plan (quantitative balance of ash generation, disposal, utilization, size of ash disposal site, ash transportation arrangement) • Fuel supply arrangement • Emergency preparedness and response plan • Industrial risk assessment if relevant
[illegible]	• Parameters • Sampling Frequency • Evaluation Criteria • Sampling points overlaid with relevant site layout / surrounding maps • Cost

Tasks related to carrying out the quality impact analysis for the EA should include:

- Collection of baseline data ranging from relatively simple qualitative information (for smaller projects) to more comprehensive quantitative data (for larger projects) on ambient concentrations of parameters and averaging time consistent with relevant host country air quality standards (e.g., parameters such as PM_{10}, $PM_{2.5}$, SO_2 (for oil and coal-fired plants), NO_X, and ground-level ozone; and averaging time such as 1-hour maximum, 24-hour maximum, annual average), within a defined airshed encompassing the proposed project;[46]
- Evaluation of the baseline airshed quality (e.g., degraded or non-degraded);
- Evaluation of baseline water quality, where relevant;
- Use of appropriate mathematical or physical air quality dispersion models to estimate the impact of the project on the ambient concentrations of these pollutants;
- If acid deposition is considered a potentially significant impact, use of appropriate air quality models to evaluate long-range and trans-boundary acid deposition;
- The scope of baseline data collection and air quality impact assessment will depend on the project circumstances (e.g., project size, amount of air emissions and the potential impacts on the airshed). Examples of suggested practices are presented in Table B-2.

Table B-2 - Suggested Air Quality Impact Assessment Approach

[illegible]	• Qualitative information (for small projects e.g., < 100MWth) • Seasonal manual sampling (for mid-sized projects e.g., < 1,200MWth) • Continuous automatic sampling (for large projects e.g., >= 1,200MWth) • Modeling existing sources
[illegible]	• Continuous one-year data for dispersion modeling from nearby existing meteorological station (e.g., airport, meteorological station) or site-specific station, if installed, for mid-sized and large projects
[illegible]	• Determining if the airshed is degraded (i.e., ambient air quality standards are not attained) or non-degraded (i.e., ambient air quality standards are attained)
[illegible]	• Assess incremental and resultant levels by screening models (for small projects) • Assess incremental and resultant levels by refined models (for mid-sized and large projects, or for small projects if determined necessary after using screening models)[47] • Modify emission levels, if needed, to ensure that incremental impacts are small (e.g., 25% of relevant ambient air quality standard levels) and that the airshed will not become degraded.

[46] The term "airshed" refers to the local area around the plant whose ambient air quality is directly affected by emissions from the plant. The size of the relevant local airshed will depend on plant characteristics, such as stack height, as well as on local meteorological conditions and topography. In some cases, airsheds are defined in legislation or by the relevant environmental authorities. If not, the EA should clearly define the airshed on the basis of consultations with those responsible for local environmental management.

[47] For further guidance on refined / screening models, see Appendix W to Part 51 – Guidelines on Air Quality Models by US EPA (Final Rule, November 9, 2005)

When there is a reasonable likelihood that in the medium or long term the power plant will be expanded or other pollution sources will increase significantly, the analysis should take account of the impact of the proposed plant design both immediately and after any formally planned expansion in capacity or in other sources of pollution. Plant design should allow for future installation of additional pollution control equipment, should this prove desirable or necessary based upon predicted air quality impacts and/or anticipated changes in emission standards (i.e., impending membership into the EU). The EA should also address other project-specific environmental concerns, such as fuel and emissions from fuel impurities. In cases where fuel impurities lead to known hazardous emissions, the EA should estimate the emission amount, assess impacts and propose mitigations to reduce emissions.[48] Examples of compounds which may be present in certain types of coal, heavy fuel oil, petroleum coke, etc. include cadmium, mercury, and other heavy metals.

Rehabilitation of Existing Facilities

An environmental assessment of the proposed rehabilitation should be carried out early in the process of preparing the project in order to allow an opportunity to evaluate alternative rehabilitation options before key design decisions are finalized. The assessment should include an environmental audit that examines the impacts of the existing plant's operations on nearby populations and ecosystems, supplemented by an EA that examines the changes in these impacts that would result under alternative specifications for the rehabilitation, and the estimated capital and operating costs associated with each option. Depending on the scale and nature of the rehabilitation, the audit/environmental assessment may be relatively narrow in scope, focusing on only a small number of specific concerns that would be affected by the project, or it may be as extensive as would be appropriate for the construction of a new unit at the same site. Normally, it should cover the following points:

- Ambient environmental quality in the airshed or water basin affected by the plant, together with approximate estimates of the contribution of the plant to total emissions loads of the main pollutants of concern
- The impact of the plant, under existing operating conditions and under alternative scenarios for rehabilitation, on ambient air and water quality affecting neighboring populations and sensitive ecosystems
- The likely costs of achieving alternative emissions standards or other environmental targets for the plant as a whole or for specific aspects of its operations
- Recommendations concerning a range of cost effective measures for improving the environmental performance of the plant within the framework of the rehabilitation project and any associated emissions standards or other requirements implied by the adoption of specific measures.

These issues should be covered at a level of detail appropriate to the nature and scale of the proposed project. If the plant is located in an airshed or water basin that is polluted as a result of emissions from a range of sources, including the plant itself, comparisons should be made of the relative costs of improving ambient air or water quality by reducing emissions from the plant or by reducing emissions from other sources.

[48] Several U.S. states have adopted regulations that give coal-fired power plants the option to meet either a mercury emissions standard based on electricity output or a control-based standard. For instance, Illinois requires all coal-fired power plants of 25 MW electrical capacity or greater to meet either an emissions standard of 0.0080 lbs mercury per gigawatt hour (GWh) gross electrical output or an emissions control requirement of 90 percent relative to mercury input.

Guías sobre medio ambiente, salud y seguridad para las plantas de energía térmica

Introducción

Las guías sobre medio ambiente, salud y seguridad (MASS) son documentos de referencia técnica que contienen ejemplos generales y específicos de la práctica internacional recomendada para la industria en cuestión[1].Cuando uno o más miembros del Grupo del Banco Mundial participan en un proyecto, estas guías sobre MASS se aplican con arreglo a los requisitos de sus respectivas políticas y normas. Las presentes guías sobre MASS para este sector de la industria deben usarse junto con el documento que contiene las **guías generales sobre MASS**, en el que se ofrece orientación a los usuarios respecto de cuestiones generales sobre la materia que pueden aplicarse potencialmente a todos los sectores industriales. Los proyectos más complejos podrían requerir el uso de múltiples guías para distintos sectores de la industria. Para una lista completa de guías sobre los distintos sectores de la industria, visitar: http://www.ifc.org/ifcext/sustainability.nsf/Content/EnvironmentalGuidelines.

Las guías sobre MASS contienen los niveles y los indicadores de desempeño que generalmente pueden lograrse en instalaciones nuevas, con la tecnología existente y a costos razonables. En lo que respecta a la posibilidad de aplicar estas guías a instalaciones ya existentes, podría ser necesario establecer metas específicas del lugar, tomando como referencia las evaluaciones ambientales y/o las auditorías ambientales (según corresponda), así como un calendario adecuado para alcanzarlas. La aplicación de las guías debe adaptarse a los peligros y riesgos establecidos para cada proyecto sobre la base de los resultados de una evaluación ambiental en la que se tengan en cuenta las variables específicas del emplazamiento, tales como las circunstancias del país receptor, la capacidad de asimilación del medio ambiente y otros factores relativos al proyecto. La decisión de aplicar recomendaciones técnicas específicas debe basarse en la opinión profesional de personas idóneas y con experiencia. En los casos en que el país receptor tenga reglamentaciones diferentes a los niveles e indicadores presentados en las guías, los proyectos deben alcanzar los que sean más rigurosos. Cuando, en vista de las circunstancias específicas de cada proyecto, se considere necesario aplicar medidas o niveles menos exigentes que aquéllos proporcionados por estas guías sobre MASS, será necesario aportar una justificación exhaustiva y detallada de las alternativas propuestas como parte de la evaluación ambiental en un sector concreto. Esta justificación debería demostrar que los niveles de desempeño escogidos garantizan la protección de la salud y el medio ambiente.

Aplicabilidad

Este documento incluye información relativa a los procesos de combustión de combustibles gaseosos, líquidos y fósiles sólidos y biomasa, destinados a la producción de energía eléctrica y mecánica, vapor, calor o cualquier combinación de estos elementos, independientemente del tipo de combustible empleado (salvo los residuos sólidos que se tratan en otra guía sobre plantas de manejo de residuos), con una capacidad total de potencia térmica absorbida por encima de 50 MWth calculada en

[1] Definida como el ejercicio de la aptitud profesional, la diligencia, la prudencia y la previsión que podrían esperarse razonablemente de profesionales idóneos y con experiencia que realizan el mismo tipo de actividades en circunstancias iguales o semejantes en el ámbito mundial. Las circunstancias que los profesionales idóneos y con experiencia pueden encontrar al evaluar el amplio espectro de técnicas de prevención y control de la contaminación a disposición de un proyecto pueden incluir, sin que la mención sea limitativa, diversos grados de degradación ambiental y de capacidad de asimilación del medio ambiente, así como diversos niveles de factibilidad financiera y técnica.

función del poder calorífico superior (PCS)[2]. Se aplica a las calderas, los motores de combustión interna y las turbinas de combustión de instalaciones existentes y nuevas. El Anexo A contiene una descripción detallada de las actividades industriales de este sector y el Anexo B contiene orientaciones para la evaluación ambiental (EA) de los proyectos de generación de energía térmica. La Sección 1.1 de las **guías generales sobre MASS** contiene criterios sobre emisiones aplicables a las instalaciones con una capacidad total de potencia térmica inferior a 50 MWth. Según las características del proyecto y las actividades asociadas (es decir, obtención del combustible y evacuación de la electricidad generada), los lectores deben consultar también las guías sobre MASS para la minería y la transmisión y distribución de electricidad.

Las decisiones de algún miembro del Grupo del Banco Mundial de invertir en este sector se adoptan teniendo en cuenta la estrategia sobre cambio climático del Grupo.

Este documento está dividido en las siguientes secciones:

Sección 1.0: Manejo e impactos específicos de la industria
Sección 2.0: Indicadores y seguimiento del desempeño
Sección 3.0: Referencias y fuentes adicionales
Anexo A: Descripción general de las actividades de la industria
Anexo B: Orientaciones para la evaluación ambiental de proyectos de energía térmica.

1.0 Manejo e impactos específicos de la industria

La siguiente sección contiene una síntesis de las principales cuestiones relativas al medio ambiente, la salud y la seguridad asociadas a las operaciones de las plantas de energía térmica, que corresponden a la etapa de operaciones, así como recomendaciones para su manejo.

Como se señala en la introducción de las **guías generales sobre MASS**, la estrategia general para el manejo de las cuestiones relativas al MASS en las actividades de desarrollo industrial, incluidas las plantas de generación de energía, debe tener en cuenta los posibles impactos lo antes posible dentro del ciclo del proyecto, lo que conlleva la incorporación de consideraciones con respecto al MASS en los procesos de selección de la ubicación y el diseño de la planta, con el fin de maximizar las opciones disponibles para prevenir y controlar los posibles impactos negativos.

Por otra parte, en las **guías generales sobre medio ambiente, salud y seguridad** se ofrecen recomendaciones sobre la gestión de las cuestiones de este tipo que son comunes a la mayoría de los grandes establecimientos industriales y de infraestructura durante las etapas de construcción y desmantelamiento.

1.1 Medio Ambiente

Los principales problemas ambientales relativos a los proyectos de plantas de energía térmica incluyen:

- Emisiones a la atmósfera
- Eficiencia energética y emisiones de gases de efecto invernadero
- Consumo de agua y alteración del hábitat acuático
- Efluentes
- Desechos sólidos
- Materiales peligrosos y petróleo
- Ruido

Emisiones a la atmósfera

Las principales emisiones al aire procedentes de la combustión de combustibles fósiles o biomasa consisten en dióxido de azufre (SO_2), óxidos de nitrógeno (NO_X), material particulado (MP), monóxido de carbono (CO) y gases de efecto invernadero, como el dióxido de carbono (CO_2). Dependiendo del tipo y la calidad del combustible empleado, sobre todo de la biomasa y los

[2] Capacidad total aplicable a una instalación con múltiples unidades.

combustibles sólidos, pueden producirse emisiones más pequeñas, aunque con importantes repercusiones para el medio ambiente debido a su toxicidad y/o persistencia, de otras sustancias como metales pesados (es decir, mercurio, arsénico, cadmio, vanadio, níquel, etcétera), halógenos (como el fluoruro de hidrógeno), hidrocarburos no quemados y otros componentes orgánicos volátiles (COV). El dióxido de azufre y el óxido de nitrógeno generan también una lluvia ácida de largo alcance.

La cantidad y las características de las emisiones a la atmósfera dependen de factores como el combustible (por ejemplo, carbón, fuel oil, gas natural o biomasa), el tipo y el diseño de la unidad de combustión (por ejemplo, motor de combustión interna, turbina de combustión o calderas), las prácticas operacionales, las medidas de control de las emisiones (por ejemplo, control primario de la combustión, tratamiento secundario del gas de combustión) y la eficiencia general del sistema. Por ejemplo, las plantas de gas producen generalmente cantidades insignificantes de material particulado y óxidos de azufre, y los niveles de óxidos de nitrógeno son alrededor del 60% de los de las plantas de carbón (sin medidas de reducción de las emisiones). Las plantas de gas natural también emiten pequeñas cantidades de dióxido de carbono, un gas de efecto invernadero.

Algunas medidas, como la elección de combustibles y el uso de medidas para incrementar la eficiencia de la conversión de la energía, reducirán las emisiones de muchos agentes contaminantes del aire, como el CO_2, por cada unidad de energía generada. La optimización de la eficiencia en el uso de energía dentro del proceso de generación depende de una variedad de factores, entre ellos, las características y la calidad del combustible, el tipo de sistema de combustión, la temperatura de funcionamiento de las turbinas de combustión, la presión y temperatura de funcionamiento de las turbinas de vapor, las condiciones climáticas locales, el tipo de sistema de refrigeración empleado, etc. Las medidas recomendadas para prevenir, minimizar y controlar las emisiones a la atmósfera incluyen:

- Utilizar el combustible más limpio que pueda costearse (el gas natural es preferible al petróleo, que a su vez es preferible a el carbón), siempre que sea compatible con la política energética y ambiental general del país o la región donde se propone instalar la planta. En el caso de la mayoría de las grandes plantas de generación de energía, la elección del combustible suele formar parte de la política energética nacional, y deben evaluarse muy cuidadosamente desde el principio los factores interrelacionados relativos a los combustibles, la tecnología de combustión y la tecnología de control de la contaminación, con el fin de optimizar el desempeño ambiental del proyecto;
- Cuando se utilice carbón, quemar preferentemente carbón con alto contenido calorífico, pocas cenizas y poco azufre;
- Considerar la valorización para reducir la ceniza, especialmente para el carbón con alto contenido de ceniza[3];
- Seleccionar la mejor tecnología de generación de energía para el combustible elegido con un equilibrio entre los beneficios ambientales y económicos. La selección de la tecnología y los sistemas de control de la contaminación dependerá de la evaluación ambiental de la ubicación (algunos ejemplos pueden ser el uso de sistemas con mayor eficiencia energética, como las turbinas de gas de ciclo combinado para las unidades de gas natural y petróleo, y la tecnología supercrítica, ultrasupercrítica o integrada del ciclo combinado de gasificación (CCGI) para las unidades de carbón);
- Determinar la altura de la chimenea en función de la práctica internacional recomendada para la industria en cuestión (PIRIC) a fin de evitar las concentraciones excesivas a nivel del suelo y minimizar impactos como la lluvia ácida[4];

[3] Si hay presencia de azufre inorgánico en las cenizas, esto también reducirá el contenido de azufre.

[4] El Anexo 1.1.3 de las **guías generales sobre MASS** contiene orientaciones específicas para el cálculo de la altura de la chimenea. El aumento de la altura no debe provocar un incremento de las emisiones. Sin embargo, si las tasas de emisiones propuestas provocan un aumento significativo del impacto sobre la calidad del aire ambiente para poder cumplir las normas relevantes sobre calidad

- Considerar el uso de instalaciones de cogeneración de calor y electricidad. Al aprovechar un calor que se desperdiciaría de otro modo, las instalaciones de cogeneración pueden lograr una eficiencia térmica del 70% al 90%, en comparación con el 32% al 45% de las plantas convencionales de energía térmica.
- Como se señala en las **guías generales sobre MASS**, las emisiones de un solo proyecto no deben constituir más del 25% del nivel dispuesto en las normas aplicables sobre calidad del aire ambiente para posibilitar un mayor desarrollo sostenible de dicha cuenca atmosférica en el futuro[5].

A continuación se ofrecen recomendaciones relativas al control de contaminantes específicos.

Dióxido de azufre

Las opciones disponibles para el control de los óxidos de azufre varían considerablemente debido a las grandes diferencias en el contenido de azufre de los diversos combustibles y los costos de los controles, como se describe en el Cuadro 1. La elección de la tecnología depende del análisis de beneficios y costos del desempeño ambiental de diferentes combustibles, el costo de los controles y la existencia de un mercado para los productos derivados del control del azufre[6]. Las medidas recomendadas para prevenir, minimizar y controlar las emisiones de SO_2 incluyen:

- Utilizar combustibles con menos contenido de azufre siempre que sea económicamente viable;
- Uso de cal (CaO) o piedra caliza ($CaCO_3$) en calderas de combustión de carbón de lecho fluido para la desulfurización integrada, que puede lograr una eficiencia de eliminación del 80% al 90% mediante el empleo de la combustión en lecho fluido[7, 8];
- Según el tamaño de la planta, la calidad del combustible y la posibilidad de emisiones considerables de SO_2, utilizar la desulfurización de gases de combustión (DGC) en grandes calderas de carbón o petróleo y grandes motores de combustión interna. El sistema óptimo de DGC (por ejemplo, DGC por vía húmeda mediante piedra caliza con una eficiencia de eliminación del 85% al 98%, DGC en seco mediante cal con una eficiencia de eliminación del 70% al 94%, DGC con agua de mar con una eficiencia de eliminación del 90%) depende de la capacidad de la planta, las propiedades del combustible, las condiciones de la ubicación, y el costo y la disponibilidad del agente reactivo, además del desecho o el reciclaje del producto derivado[9].

del aire, se deben tener en cuenta el aumento de la altura de la chimenea y/o una reducción mayor de las emisiones en la EA. Algunos ejemplos de PIRIC con respecto a las chimeneas fijan la altura máxima en alrededor de 200 m para las grandes instalaciones de combustión de carbón, unos 80 m para las plantas de generación de energía mediante combustión de petróleo combustible pesado con motores diésel, y hasta 100 m para las plantas de generación de energía con turbinas de gas de ciclo combinado. La decisión final sobre la altura de la chimenea dependerá del terreno aledaño, las edificaciones cercanas, las condiciones meteorológicas, el incremento previsto del impacto y la ubicación de los recolectores actuales y futuros.

[5] Por ejemplo, las cuotas máximas de la EPA de los Estados Unidos para la prevención del incremento significativo del deterioro en las cuencas atmosféricas no degradadas son: SO_2 (91 μg/m³ para el segundo registro más alto en un período de 24 horas, 20 μg/m³ para el promedio anual), NO_2 (20 μg/m³ para el promedio anual), y MP_{10} (30 μg/m³ para el segundo registro más alto en un período de 24 horas y 17 μg/m³ para el promedio nacional).

[6] En estas condiciones, se pueden considerar opciones de desulfurización regenerativa (húmeda o semiseca) de gases de combustión (DGC).

[7] CE (2006).

[8] La eficiencia de las tecnologías de combustión en lecho fluidizado para eliminar el SO_2 depende del contenido de azufre y cal del combustible, y la cantidad, proporción y la calidad del absorbente.

[9] El uso de la depuración por vía húmeda, además de los equipos de control de polvo (por ejemplo, precipitador electroestático o filtro de tela), tiene la ventaja de reducir también las emisiones de HCl, HF, metales pesados y el polvo restantes después de emplear el PE o el filtro de tela. Por su alto costo, los procesos de depuración por vía húmeda no se utilizan en instalaciones de capacidad inferior a 100 MWth (CE, 2006).

Cuadro 1 - Desempeño/características de la DGC		
Tipo de DGC	Características	Aumento del costo de capital de la planta
DGC húmeda	• El gas de combustión se satura con agua. • La piedra caliza ($CaCO_3$) actúa como reactivo. • Eficiencia de la eliminación de hasta el 98%. • Consumo del 1% al 1,5% de la electricidad generada. • Más utilizado. • Hay que tener en cuenta la distancia con el origen de la piedra caliza y su reactividad. • Consumo elevado de agua. • Necesidad de tratamiento de las aguas residuales. • Yeso como producto comerciable o desechable.	11% al 14%
DGC semiseca	• También denominada "depuración en seco" con humidificación controlada. • La cal (CaO) actúa como reactivo. • Eficiencia de la eliminación de hasta el 94%. • Mayor nivel de eliminación del SO_3 que la DGC húmeda. • Consumo del 0,5% al 1,0% de la electricidad generada, menos que la DGC húmeda. • La cal es más cara que la piedra caliza. • No hay aguas residuales. • Residuos: mezcla de cenizas volantes, aditivos sin reaccionar y $CaSO_3$.	9% al 12%
DGC con agua de mar	• Eficiencia de la eliminación de hasta el 90%. • No es práctica para el carbón con alto contenido de S (> 1% S). • Hay que examinar cuidadosamente el impacto sobre el medio marino (por ejemplo, reducción del pH, vertido de restos de metales pesados, cenizas volantes, temperatura, azufre, oxígeno disuelto y demanda química de oxígeno). • Consumo del 0,8% al 1,6% de la electricidad generada. • Proceso simple sin aguas residuales ni desechos sólidos.	7% al 10%

Fuentes: CE (2006) y Grupo del Banco Mundial.

Óxidos de nitrógeno

La formación de óxidos de nitrógeno puede controlarse mediante la modificación de los parámetros del funcionamiento y el diseño del proceso de combustión (medidas primarias). En ciertos casos, puede ser necesario un tratamiento adicional del NO_X del gas de combustión (medidas secundarias; véase el Cuadro 2) en función de los objetivos de calidad del aire ambiente. Las medidas recomendadas para prevenir, minimizar y controlar las emisiones de NO_X incluyen:

- Usar quemadores con bajas emisiones de NO_X y otras modificaciones de la combustión, como los de bajo exceso de oxígeno, para las plantas de calderas. Puede ser necesario instalar controles adicionales del NO_X en las calderas para cumplir los límites de emisiones: se puede usar un sistema de reducción catalítica selectiva (RCS) para las calderas de carbón pulverizado, petróleo y gas, o un sistema de reducción catalítica no selectiva (RCNS) para las calderas con lecho fluido;
- Usar quemadores de premezclas anti-NO_X por vía seca para las turbinas de combustión de gas natural;
- Usar inyección de agua o RCS para las turbinas de combustión y los motores de combustión interna de combustibles líquidos[10];
- Optimizar los parámetros de funcionamiento de los motores de combustión interna de gas natural existentes para reducir las emisiones de NOx;
- Utilizar sistemas de mezcla pobre o RCS para los nuevos motores de gas.

[10] La inyección de agua puede no ser práctica en todos los casos para las turbinas de combustión industrial. Aunque se disponga de agua, las instalaciones para el tratamiento del agua y la operación y el mantenimiento de este sistema pueden ser costosos y complicar el funcionamiento de una pequeña turbina de combustión.

Cuadro 2 - Desempeño/características de los sistemas de reducción del NOx secundario

Tipo	Características	Aumento del costo de capital de la planta
RCS	• Tasa de reducción de las emisiones del NOx del 80% al 95%. • Consumo del 0,5% de la electricidad generada. • Uso de amoniaco o urea como reactivos. • Puede haber un problema de aumento de los escapes de amoniaco debido a la mayor proporción de NH_3/NOx (por ejemplo, demasiado amoniaco en las cenizas volantes). Puede ser necesario aumentar el volumen del catalizador o mejorar la mezcla de NH_3 y NOx en el gas de combustión para evitar este problema. • Los catalizadores pueden contener metales pesados. Es necesario el manejo, desecho o reciclaje adecuado de los catalizadores gastados. • Los catalizadores han durado de 6 a 10 años (carbón), de 8 a 12 años (petróleo) y más de 10 años (gas).	4% al 9% (caldera de carbón) 1% al 2% (turbinas de gas de ciclo combinado) 20% al 30% (motores de combustión interna)
RCNS	• Tasa de reducción de las emisiones de NOx del 30% al 50%. • Consumo del 0,1% al 0,3% de la electricidad generada. • Uso de amoniaco o urea como reactivos. • No puede usarse con motores o turbinas de gas. • Funciona sin catalizadores.	1% al 2%

Fuentes: CE (2006) y Grupo del Banco Mundial.

Material particulado

El material particulado[11] procede del proceso de combustión, especialmente del uso de combustibles pesados como el fuel oil, el carbón y la biomasa sólida. Se ha demostrado la eficiencia para la eliminación de partículas en las plantas de generación de energía de tecnologías como los filtros de tela y los precipitadores electrostáticos (PE), que aparecen en el Cuadro 3. La elección entre un filtro de tela y un PE depende de las características del combustible, el tipo de sistema de DGC, si se utiliza para el control del SO_2, y los objetivos de calidad del aire ambiente. También se puede emitir material particulado durante el traslado y el almacenamiento de carbón y aditivos como la cal. Las recomendaciones para prevenir, minimizar y controlar las emisiones de material particulado incluyen:

- Instalar controles del polvo con una eficiencia de eliminación de hasta el 99%, como los PE o los filtros de tela (filtros de mangas), en las plantas de generación de energía mediante carbón. Un sistema de control avanzado de las partículas es un PE por vía húmeda, que aumenta aún más la eficiencia de eliminación y captura además los agentes condensables (por ejemplo, lluvia ácida sulfúrica) que no pueden recolectar eficazmente el PE o el filtro de tela[12];
- Usar equipos de carga y descarga que minimicen la altura de la caída del combustible en el almacén para reducir la generación de polvo fugitivo y la instalación de ciclones;
- Usar sistemas de vaporización de agua para reducir la formación de polvo fugitivo procedente del combustible sólido almacenado en entornos áridos;
- Usar cintas de transporte con un equipo de extracción y filtrado bien diseñado en los puntos de transferencia para prevenir la emisión de polvo;
- En el caso de los combustibles sólidos cuyo polvo fugitivo pueda contener vanadio, níquel e hidrocarburos aromáticos policíclicos (por ejemplo, el carbón y el coque de petróleo), usar un cierre hermético durante el transporte y cubrir el producto almacenado cuando sea necesario;

[11] Incluye todos los tamaños de partículas (por ejemplo, PTS, MP_{10} y $MP_{2.5}$)

[12] Se recomienda un sistema de limpieza de los gases de combustión (LGC) para resolver el problema de la baja conductividad de los gases y la reducción del desempeño de los PE que se produce cuando se utilizan para eliminar las partículas de los combustibles con muy bajo contenido de azufre. Un sistema específico de LGC conlleva la incorporación de trióxido de azufre (SO_3) gaseoso en la entrada de gases de combustión al PE, lo que aumenta la conductividad de los gases y mejora drásticamente la capacidad de limpieza del PE. Normalmente, no existe el riesgo de que aumenten las emisiones de SOx, ya que el SO_3 es altamente reactivo y se adhiere a las partículas.

- Diseñar y operar sistemas de traslado que minimicen la generación y el transporte de polvo a las instalaciones;
- Almacenar la cal y la piedra caliza en silos con equipos de extracción y filtrado bien diseñados;
- Utilizar barreras contra el viento para el carbón almacenado en espacios abiertos o, en caso de que sea necesario, usar estructuras de almacenamiento cerradas para minimizar las emisiones de polvo fugitivo y aplicar sistemas de ventilación para evitar las explosiones de polvo (por ejemplo, empleo de ciclones en los puntos de transferencia de carbón).

El Anexo 1.1.2 de las **guías generales sobre MASS** contiene una explicación adicional sobre las tecnologías de prevención y control en los puntos de origen de las emisiones.

Cuadro 3 – Desempeño/características de los sistemas de eliminación de partículas

Tipo	Desempeño/Características
PE	• Eficiencia de eliminación > 96,5% (< 1 μm), > 99,95% (> 10 μm). • Consumo del 0,1% al 1,8% de la electricidad generada. • Puede que no funcione con partículas con mucha resistencia eléctrica. En estos casos, la limpieza de los gases de combustión (LGC) puede mejorar el desempeño del PE. • Puede manejar volúmenes muy grandes de gas con escasas caídas de presión.
Filtro de tela	• Eficiencia de eliminación > 99,6% (< 1 μm), > 99,95% (>10 μm). Elimina partículas más pequeñas que el PE. • Consumo del 0,2% al 3% de la electricidad generada. • Disminuye el tiempo de vida del filtro conforme aumenta el contenido de S en el carbón. • Los costos de operación aumentan considerablemente con el incremento de la densidad del filtro de tela para eliminar más partículas. • Si las cenizas son especialmente reactivas, pueden debilitar la tela y terminar desintegrándola.
Depuración por vía húmeda	• Eficiencia de eliminación > 98,5% (< 1 μm), > 99,9% (> 10 μm). • Consumo de hasta el 3% de la electricidad generada. • Puede tener el efecto secundario de eliminar y absorber metales pesados en estado gaseoso. • Haya que tratar las aguas residuales.

Fuentes: CE (2006) y Grupo del Banco Mundial.

Otros agentes contaminantes

Dependiendo del tipo y la calidad del combustible, puede haber una presencia de otros agentes contaminantes del aire en cantidades importantes para el medio ambiente, que deben considerarse adecuadamente en la evaluación de los posibles impactos sobre la calidad del aire ambiente y el diseño y la implementación de medidas de gestión y controles ambientales. Algunos ejemplos de otros contaminantes son el mercurio en el carbón, el vanadio en el fuel oil pesado, y la presencia de otros metales pesados en biocombustibles, como el coque de petróleo y los aceites lubricantes usados[13]. Las recomendaciones específicas para las plantas de energía térmica para prevenir, minimizar y controlar las emisiones de otros contaminantes del aire, como el mercurio, incluyen el uso de controles secundarios convencionales como los filtros de tela o los PE, en combinación con técnicas de DGC, como la DGC de la piedra caliza, la DGC de cal seca o la inyección de absorbente[14]. Se puede lograr la eliminación adicional de metales como el mercurio con un sistema de RCS de gran capacidad con carbón activado en polvo (CAP), carbón activado en polvo enriquecido con bromo u otros absorbentes. Dado que las emisiones de mercurio de las plantas de energía térmica conllevan posibles impactos significativos a nivel local y transfronterizo para los ecosistemas, la salud pública y la seguridad como consecuencia de la bioacumulación, se debe

[13] En estos casos, la EA debe abordar los posibles impactos en la calidad del aire ambiente de metales pesados como el mercurio, el níquel, el vanadio, el cadmio, el plomo, etc.

[14] Con el uso de filtros de tela o precipitadores electroestáticos en combinación con técnicas de DGC se puede lograr un nivel promedio de eliminación del 75% o del 90% si se utiliza al mismo tiempo una técnica de RCS (CE, 2006).

considerar especialmente su minimización dentro de la evaluación ambiental y un diseño acorde de la planta[15].

Compensaciones de las emisiones

Las instalaciones en cuencas atmosféricas degradadas deben minimizar el incremento del impacto alcanzando los valores de emisiones descritos en el Cuadro 6. No obstante, cuando estos valores provoquen impactos excesivos con respecto a los reglamentos locales (o en su ausencia, otras normas o guías reconocidas internacionalmente, como las guías de la Organización Mundial de la Salud), el proyecto debe estudiar e implementar medidas de compensación concretas para la instalación que no conlleven un aumento neto de las emisiones totales de esos agentes contaminantes (por ejemplo, material particulado, dióxido de azufre o dióxido de nitrógeno) responsables de la degradación de la cuenca atmosférica. Las disposiciones de compensación deben implementarse antes de que la planta esté en pleno funcionamiento. Algunas medidas de compensación adecuadas podrían ser la reducción de las emisiones de material particulado, dióxido de azufre o dióxido de nitrógeno, si fuera necesario, mediante a) la instalación de nuevos controles más eficaces en otras unidades de la misma planta de generación de energía o en otras plantas de la misma cuenca atmosférica, b) la instalación de nuevos controles más eficaces en otras grandes fuentes de emisiones, como las plantas de calefacción regionales o las plantas industriales, dentro de la misma cuenca atmosférica, o c) la inversión en distribución de gas o sistemas de calefacción regionales en sustitución del uso del carbón en la calefacción residencial y otras pequeñas calderas Siempre que sea posible, las disposiciones de compensación deben aplicarse dentro del marco de una estrategia general de gestión de la calidad del aire destinada a garantizar que la calidad del aire en la cuenca atmosférica cumpla las normas ambientales. El organismo local o nacional responsable de conceder y supervisar los permisos ambientales se hará cargo del seguimiento y la aplicación de medidas sobre calidad del aire ambiente en la cuenca atmosférica para garantizar el cumplimiento de las disposiciones de compensación. Los promotores del proyecto que no puedan participar en las negociaciones necesarias para establecer un acuerdo de compensación (debido, por ejemplo, a la falta de un marco local o nacional de gestión de la calidad del aire) deben considerar la opción de utilizar una combinación apropiada de combustibles más limpios, controles más eficaces de la contaminación o replanteamiento de la selección de la ubicación propuesta. El objetivo general es que las nuevas plantas de energía térmica no contribuyan a aumentar el deterioro de una cuenca atmosférica ya degradada.

Eficiencia energética y emisiones de GEI

El dióxido de carbono, uno de los principales gases de efecto invernadero (GEI), de acuerdo con la Convención Marco de las Naciones Unidas sobre el Cambio Climático, procede de la combustión de combustibles fósiles. Las recomendaciones para evitar, minimizar y compensar las emisiones de dióxido de carbono en las plantas de energía térmica nuevas y existentes incluyen:

- Usar combustibles fósiles con menor contenido de carbono (es decir, menos contenido de carbono por unidad calorífica: el gas tiene menos que el petróleo, y éste menos que el carbón) o la quema conjunta de combustibles de emisión neutra de carbono (es decir, biomasa);
- Usar plantas de cogeneración de energía cuando sea posible;
- Usar la misma tecnología para aumentar la eficiencia de la conversión de energía y el mismo tamaño de planta de generación de energía que los empleados normalmente en el país o la región. El objetivo de las nuevas plantas debe ser

[15] Aunque ninguno de los principales países industrializados ha adoptado formalmente límites reglamentarios para las emisiones de mercurio en las plantas de energía térmica, en 2008 se estaban considerando dichas limitaciones en los Estados Unidos y la Unión Europea. En las futuras actualizaciones de las guías sobre MASS se reflejarán los cambios en la práctica internacional con respecto a la prevención y el control de las emisiones de mercurio.

alcanzar el cuartil superior del promedio nacional/egional para el mismo tipo de combustible y tamaño de planta. La rehabilitación de las plantas existentes tienen que generar mejoras importantes de la eficiencia. En el Cuadro 4 se presentan las emisiones habituales de CO_2 con diferentes combustibles/tecnologías;

- Sopesar los costos de capital y de explotación relacionados con la eficiencia para las diferentes tecnologías. Por ejemplo, las plantas supercríticas pueden acarrear mayores costos de capital que las subcríticas con la misma capacidad, aunque costos de explotación inferiores. Por otro lado, las características de la red existente y futura pueden imponer limitaciones al tamaño de la planta y la elección de tecnología. La EA tiene que sopesar detenidamente estos factores;
- Usar técnicas superiores de seguimiento del desempeño y control del proceso, y realizar un buen diseño y mantenimiento del sistema para poder mantener la eficiencia prevista inicialmente;
- Cuando sea posible, establecer mecanismos de compensación de las emisiones (entre ellos, los mecanismos flexibles y la comercialización voluntaria del carbono dispuestos en el Protocolo de Kyoto), lo que incluye la reforestación, la captura y el almacenamiento de CO_2 u otras opciones que actualmente están en fase de experimentación[16];
- Cuando sea viable, incluir la reducción de pérdidas en la transmisión y la distribución, y medidas sobre la demanda de energía. Por ejemplo, una inversión en la gestión de los picos de carga podría reducir los requisitos de ciclos de funcionamiento de la instalación de generación y mejorar, por lo tanto, su eficiencia. La viabilidad de este tipo de opciones compensatorias puede variar dependiendo de que la instalación forme parte de un servicio integrado verticalmente o se trate de una producción independiente de energía;
- Considerar el ciclo de emisiones del combustible y los factores externos (por ejemplo, abastecimiento de combustible, proximidad a centros de carga, posibilidad de aprovechamiento externo del calor residual o uso de gases residuales de instalaciones cercanas —gases de altos hornos o metano de lechos de carbón— como combustible, etcétera).

Cuadro 4 – Emisiones habituales de CO_2 en nuevas plantas de energía térmica

Combustible	Eficiencia	CO_2 (gCO_2/kWh – Bruto)
Eficiencia (% neto, PCS)		
Carbón (*1, *2)	Ultrasupercrítico (*1):	
	37,6-42,7	676-795
	Supercrítico:	
	35,9-38,3 (*1)	756-836
	39,1 (sin CAC) (*2)	763
	24,9 (con CAC) (*2)	95
	Subcrítico:	
	33,1 a 35,9 (*1)	807-907
	36,8 (sin CAC) (*2)	808
	24,9 (con CAC) (*2)	102
	CCGI:	
	39,2-41,8 (*1)	654-719
	38,2-41,1 (sin CAC) (*2)	640-662
	31,7-32,5 (con CAC) (*2)	68-86
Gas (*2)	TGCC avanzada (*2):	
	50,8 (sin CAC)	355
	43,7 (con CAC)	39
Eficiencia (% neto, PEC)		
Carbón (*3)	42 (ultrasupercrítico)	811
	40 (supercrítico)	851
	30-38 (subcrítico)	896-1.050
	46 (CCGI)	760
	38 (CCGI+CAC)	134
Carbón y lignito (*4, *7)	(*4) 43-47 (carbón-CP)	(*6) 725-792 (neto)
	> 41(carbón-CLF)	< 831 (neto)
	42-45 (lignito-CP)	808-866 (neto)
	> 40 (lignito-CLF)	< 909 (neto)
Gas (*4, *7)	(*4) 36-40 (TG de ciclo simple)	(*6) 505-561 (neto)
	38-45 (motor de gas)	531-449 (neto)
	40-42 (caldera)	481-505 (neto)
	54-58 (TGCC)	348-374 (neto)

[16] La aplicación de la captura y el almacenamiento de carbono (CAC) en los proyectos de energía térmica se encuentra todavía en fase experimental en todo el mundo, aunque se han empezado a considerar diseños que prevén la CAC. Se están evaluando diversas opciones como el almacenamiento de CO_2 en minas de carbón o acuíferos profundos y la inyección en pozos de petróleo para mejorar su recuperación.

Petróleo(*4, *7)	(*4) 40-45 (motor de combustión interna de FOP/FOL)	(*6) 449-505 (neto)
Eficiencia (% Bruto, PEC)		
Carbón (*5, *7)	(*5) 47 (ultrasupercrítico) 44 (supercrítico) 41-42 (subcrítico) 47-48 (CCGI)	(*6) 725 774 811-831 710-725
Petróleo (*5, *7)	(*5) 43 (motor de combustión interna) 41 (caldera)	(*6) 648 680
Gas (*5)	(*5) 34 (TG de ciclo simple) 51 (TGCC)	(*6) 594 396
Fuentes: (*1) EE. UU. EPA 2006, (*2) EE. UU. DOE/NETL 2007, (*3) Banco Mundial, abril de 2006, (*4) Comisión Europea 2006, (*5) Grupo del Banco Mundial, septiembre de 2006, (*6) estimaciones del Grupo del Banco Mundial.		

Consumo de agua y alteración del hábitat acuático

Las turbinas de vapor empleadas con calderas y los generadores de vapor con recuperación de calor (GVRC) de las turbinas de gas de ciclo combinado requieren un sistema de refrigeración para condensar el vapor utilizado para generar electricidad. Los sistemas de refrigeración habituales empleados en las plantas de energía térmica incluyen: i) sistema abierto sin recirculación cuando se disponga de suficiente agua refrigerante y aguas superficiales de recepción; ii) sistema húmedo de circuito cerrado, y iii) sistema de refrigeración con aire seco (por ejemplo, condensadores enfriados con aire).

Las instalaciones de combustión con sistemas de refrigeración abiertos sin recirculación exigen grandes cantidades de agua que se vierte de nuevo a las aguas superficiales receptoras a una temperatura elevada. El agua también es necesaria para el funcionamiento de la caldera, el equipo de la estación auxiliar, el manejo de las cenizas y los sistemas de DGC[17]. La extracción de estas grandes cantidades de agua puede suponer una competencia con otros usos importantes como la irrigación agrícola o las fuentes de agua potable. La extracción y el vertido a altas temperaturas y con contaminantes químicos, como biocidas u otros aditivos, pueden afectar a los organismos acuáticos como el fitoplancton, el zooplancton, los peces, los crustáceos, los moluscos y muchas otras formas de vida acuática. Los organismos acuáticos capturados en las estructuras de abastecimiento de agua de refrigeración se insertan o quedan atrapados en el propio sistema de refrigeración. En estos casos, se puede provocar la muerte o graves daños a los organismos acuáticos. En algunos casos (por ejemplo, las tortugas marinas), los organismos quedan atrapados en los canales de abastecimiento. Los posibles impactos de las estructuras de abastecimiento de agua refrigerante situadas en el interior o cerca de ecosistemas con especies amenazadas, en peligro de extinción o protegidas, o donde existe una actividad pesquera, pueden ser motivo de especial preocupación.

Las estructuras de abastecimiento convencionales incluyen pantallas móviles con velocidades relativamente elevadas y sin un sistema de manejo o devolución de peces[18]. Se deben establecer medidas para prevenir, minimizar y controlar el impacto ambiental asociado con la extracción de agua partiendo de los resultados de una EA del proyecto, teniendo en cuenta la disponibilidad y el uso local de los recursos acuíferos, y las características ecológicas de la zona afectada por el proyecto. Las medidas de gestión recomendadas para prevenir y controlar los impactos en los recursos acuíferos y los hábitats acuáticos incluyen[19]:

- Conservar los recursos acuíferos, especialmente en las áreas con recursos limitados:
  - Usar un sistema de refrigeración de ciclo cerrado con recirculación (por ejemplo, torres de refrigeración por tiro natural o mecánico), o un sistema de refrigeración en seco con circuito cerrado (por ejemplo, condensadores enfriados por aire) si fuera necesario

[17] La disponibilidad de agua y el impacto sobre el agua pueden influir en la elección del sistema de DGC empleado (es decir, húmedo o semiseco).

[18] La velocidad que se considera generalmente adecuada para la gestión de sedimentos es 1 pps [0,30 m/s] con pantallas de malla ancha con un diámetro estándar de 3/8 pulgadas (9,5 mm).

[19] Para obtener más información, puede consultar Schimmoller (2004) y EE. UU. EPA (2001).

para prevenir impactos negativos inaceptables. Los estanques o las torres de refrigeración son las principales tecnologías para un sistema de refrigeración con recirculación de agua. Los sistemas abiertos sin recirculación pueden ser aceptables si son compatibles con la hidrología y la ecología de la fuente de agua y las aguas receptoras, y pueden ser una alternativa preferible y viable para ciertas tecnologías de control de la contaminación como los depuradores con agua de mar;

- Usar depuradores por vía seca en las situaciones en que también sean necesarios estos controles o reciclar las aguas residuales en las plantas de generación con carbón para su uso en la DGC;
- Usar sistemas de refrigeración por aire.

- Reducción de la velocidad máxima de recogida de la pantalla a 0,5 pps [0,15 m/s];
- Reducción de la corriente de entrada:
  - Para los ríos y los arroyos de agua dulce, a un caudal suficiente para mantener el uso de los recursos (es decir, irrigación y pesca), así como la biodiversidad durante las condiciones anuales con un promedio de caudal bajo[20];
  - Para los lagos o embalses, la corriente de entrada no debe alterar la estratificación térmica o el patrón de reposición de agua de abastecimiento;
  - Para los estuarios y desembocaduras de ríos, reducción de la corriente de entrada al 1% del volumen de la amplitud de marea.
- Si existen especies amenazadas, en peligro o protegidas o bancos de pesca dentro de la zona hidrográfica de influencia de la corriente de entrada, reducir la inserción y la captura de peces y moluscos mediante la instalación de tecnologías como redes (estacionales o todo el año), sistemas de manejo y devolución de peces, pantallas de malla fina, pantallas de alambre en forma de cuña y sistemas de barreras de filtrado acuático. Algunos ejemplos de medidas operacionales para reducir la inserción y la captura incluyen las vedas estacionales, si fueran necesarias, o la reducción del flujo y el uso continuado de las pantallas. El cambio de dirección o el movimiento hacia dentro de la estructura de abastecimiento también pueden reducir la inserción y la captura.

Efluentes

Efluentes procedentes de las plantas de energía térmica incluyen los vertidos térmicos, los efluentes de aguas residuales y los residuos sanitarios.

Vertidos térmicos

Como se señaló anteriormente, las plantas de energía térmica con generadores de vapor y sistemas de refrigeración abiertos sin recirculación utilizan una cantidad considerable de agua para enfriar y condensar el vapor para reciclarlo a la caldera. El agua calentada se vierte normalmente en la fuente original (es decir, río, lago, estuario u océano) o el acuífero más cercano. En general, el vertido térmico debe realizarse de manera que la temperatura del agua no supere los criterios para la calidad del agua ambiente fuera de una zona de vertido determinada científicamente. Por "zona de vertido" se entiende normalmente la zona en la que se produce la disolución inicial del vertido, en la que se pueden superar las normas sobre la temperatura del agua y se tienen en cuenta, entre otras cosas, el impacto acumulado de las variaciones estacionales, la calidad del agua ambiente, el uso del agua receptora, los posibles receptores y la capacidad de asimilación. La ubicación de dicha zona depende de cada proyecto y puede depender de la decisión de los organismos reguladores locales, que el proceso de evaluación ambiental del

[20] Los requisitos de caudal pueden basarse en el flujo promedio anual o el flujo bajo promedio. Los reglamentos pueden fijar un 5% o más para el flujo promedio anual y del 10% al 25% para el flujo bajo promedio. Su aplicabilidad debe comprobarse in situ teniendo en cuenta las necesidades de recursos y de la biodiversidad.

proyecto puede confirmar o actualizar posteriormente. Cuando no exista un reglamento, se determinará el cambio aceptable de temperatura del agua ambiente mediante el proceso de evaluación ambiental. En el diseño de los vertidos térmicos se deben prevenir los impactos negativos sobre el agua receptora teniendo en cuenta los siguientes criterios:

- Las zonas con temperaturas elevadas como consecuencia del vertido térmico del proyecto no deben afectar la integridad del conjunto de masas de agua o áreas protegidas (como las zonas recreativas, los criaderos o las zonas con biota sensible);
- No debe producirse la muerte o un impacto significativo sobre las costumbres de cría y alimentación de los organismos que transiten por las zonas con temperaturas elevadas;
- No debe existir un riesgo importante para la salud humana o el medio ambiente debido a la temperatura elevada o los niveles residuales de productos químicos para el tratamiento del agua.

Si se utiliza un sistema abierto sin recirculación en proyectos grandes (es decir, una planta con una capacidad de generación de vapor > 1.200 MWth), la EA debe examinar los impactos de los vertidos térmicos con un modelo matemático e hidrodinámico de pluma, que puede ser un método relativamente eficaz para determinar las temperaturas máximas y los caudales del vertido térmico compatibles con los objetivos ambientales para el agua receptora[21]. Las recomendaciones para prevenir, minimizar y controlar los vertidos térmicos incluyen:

- Usar difusores múltiples;
- Ajustar la temperatura, el caudal, la ubicación y el diseño del punto de descarga para minimizar los impactos hasta un nivel aceptable (es decir, extender la longitud del conducto para que el vertido se enfríe antes de caer al agua o cambiar el punto de descarga para minimizar las zonas con temperaturas elevadas);
- Usar un sistema cerrado de refrigeración con recirculación como el descrito anteriormente (por ejemplo, torre de refrigeración de tiro natural o mecánico), o un circuito cerrado de refrigeración con aire seco (por ejemplo, condensadores enfriados con aire) si fuera necesario para prevenir impactos negativos inaceptables. Los estanques o las torres de refrigeración son las principales tecnologías para un sistema de refrigeración con recirculación de agua.

Residuos líquidos

Las corrientes de aguas residuales de una planta de energía térmica incluyen el escape de la torre de refrigeración; las aguas residuales del tratamiento de la ceniza, los vertidos húmedos del sistema de DGC; las escorrentías del material almacenado; las aguas residuales de la limpieza de metales, y las aguas residuales de bajo volumen, como las aguas de limpieza de los calentadores de aire y los precipitadores, el agua de purga de la caldera, el residuo de la limpieza química de la caldera, el alcantarillado y los sumideros, los residuos de laboratorio y el flujo inverso del intercambio de iones proveniente de las unidades de destilación del agua de las calderas. Todas estas aguas residuales suelen estar presentes en plantas de carbón o biomasa; la presencia de algunas de estas corrientes (por ejemplo, las aguas residuales del tratamiento de la ceniza) puede ser reducida o nula en las plantas de generación de energía con petróleo o gas. Las características de las aguas residuales generadas dependen del uso que se haya hecho del agua. Las fuentes de contaminación son los desmineralizadores; los aceites lubricantes y auxiliares; los contaminantes depositados en los combustibles (a través de las aguas residuales del tratamiento de

[21] CORMIX (Cornell Mixing Zone Expert System) es un ejemplo de modelo de simulación informática de los procesos de mezcla hidrodinámica, que ha sido desarrollado por la Agencia de Protección Ambiental de los Estados Unidos. Este modelo se centra en la predicción de la geometría específica de la dispersión y las características de la dilución para valorar los efectos ambientales de un posible vertido.

cenizas y los vertidos húmedos del sistema de DGC), y el cloro, los biocidas y otras sustancias químicas utilizadas para la gestión de la calidad del agua de los sistemas de refrigeración. Los escapes de las torres de refrigeración suelen tener un contenido muy alto de sólidos totales en disolución, aunque suelen clasificarse como aguas refrigerantes sin contacto directo y, por lo tanto, están sometidos a los límites de pH, cloro residual y sustancias químicas tóxicas presentes en los aditivos de las torres de refrigeración (lo que incluye sustancias químicas anticorrosión con cromo y zinc, cuyo uso debe eliminarse).

En las secciones 1.3 y 1.4 de las **guías generales sobre MASS** se explican los métodos recomendados, respectivamente, para el tratamiento de agua y el reciclaje del agua residual. Además, las medidas recomendadas para prevenir, minimizar y controlar los efluentes de aguas residuales de las plantas de energía térmica incluyen:

- Reciclar las aguas residuales de las plantas de carbón para su uso en la DGC. Esta práctica contribuye a la conservación de agua y reduce el número de corrientes de agua que necesitan tratarse o verterse[22];
- En las plantas de generación de energía mediante carbón sin sistemas de DGC, tratar las aguas residuales del proceso con sistemas convencionales de tratamiento fisicoquímico para el ajuste del pH y eliminar como mínimo el total de sólidos en suspensión (TSS), y el aceite/la grasa. Dependiendo de los reglamentos locales, estos sistemas de tratamiento también se pueden emplear para reducir la presencia de metales pesados hasta una escala de partes por mil millones mediante el precipitado químico con hidróxidos u organosulfuros metálicos;
- Recolectar las cenizas volantes en estado seco y las cenizas depositadas en cintas transportadoras en las nuevas plantas de generación de energía con carbón;
- Considerar el uso de sopladores de hollín y otros métodos de eliminación en seco de los residuos de las superficies de transmisión de calor con el fin de minimizar la frecuencia y la cantidad de agua empleada en estas limpiezas;
- Usar medidas de control de la infiltración y las escorrentías de las pilas de carbón como compactación de tierra, barreras de contención y controles de la sedimentación;
- Vaporizar las pilas de carbón con detergentes aniónicos para detener el crecimiento de bacterias y minimizar la acidez de la lixiviación[23];
- Usar sistemas de eliminación de SO_X que generen menos aguas residuales, cuando sea factible; no obstante, se deben analizar en cada caso las características ambientales y el costo tanto de los materiales básicos como de los residuos;
- Tratar las aguas residuales poco caudalosas de los sumideros de las salas de calderas y de turbinas con separadores convencionales del petróleo y el agua antes de su vertido;
- Tratar las aguas residuales ácidas poco caudalosas, como las regeneradas por los sistemas de desmineralización y purificación en lecho profundo, mediante la neutralización química in situ antes del vertido;
- Tratar previamente el agua de las torres de refrigeración, instalar controladores automáticos de sangrado/alimentación, y usar materiales inertes de construcción para reducir los requisitos de tratamiento químico de las torres de refrigeración;
- Eliminar metales como el cromo y el zinc de los aditivos químicos empleados para controlar las incrustaciones y la corrosión en las torres de refrigeración;

[22] Entre los caudales que pueden reciclarse están las aguas derivadas de la limpieza del yeso, que proceden de un caudal diferente que las aguas de la DGC. En las plantas en las que se produce el yeso comercial, éste se enjuaga para eliminar el cloro y otros restos indeseables.

[23] Si se utiliza la escorrentía del carbón apilado para el sistema de DGC, los detergentes aniónicos pueden aumentar o crear la espuma en el sistema de depuración por vía húmeda. Por lo tanto, el uso de agentes emulsionantes en el

- Usar las cantidades mínimas requeridas de biocidas clorados en lugar de biocidas con bromo, o aplicar alternativamente dosis intermitentes de cloro, en lugar de un flujo constante.

Aguas residuales sanitarias

Las aguas de alcantarillado y otras aguas residuales generadas por los baños, etc. son similares a las aguas residuales residenciales. La Sección 1.3 de las **guías generales sobre MASS** se ocupa de los impactos y el manejo de las aguas residuales sanitarias.

Residuos sólidos

Las plantas de energía térmica de combustión de carbón y biomasa son las que generan más cantidad de desechos sólidos debido al porcentaje relativamente elevado de cenizas en estos combustibles[24]. Los residuos de la combustión del carbón (RCC) más voluminosos son las cenizas volantes, las cenizas depositadas, la escoria de las calderas y el lodo de la DGC. La biomasa contiene menos azufre, por lo que puede no ser necesaria la DGC. Las calderas de combustión en lecho fluido (CLF) generan cenizas volantes y cenizas depositadas, lo que se denomina lecho de cenizas. Las cenizas volantes procedentes de los gases de escape constituyen entre el 60% y el 85% del residuo de las calderas de carbón pulverizado y el 20% en el caso de las calderas secundarias. Las cenizas depositadas contienen escoria y partículas más gruesas y pesadas que las cenizas volantes. Los residuos de las CLF tienen mayor contenido de calcio y sulfato y menor contenido de sílice y alúmina que los residuos de la combustión de carbón, debido a la presencia de material absorbente. Las plantas de energía térmica de carbón y otras plantas generan pequeñas cantidades de otros residuos sólidos como desechos de la pulverización del carbón/piritas y lodos de la torre de refrigeración, el tratamiento de aguas residuales y el tratamiento del agua.

Los residuos procedentes de la combustión del petróleo incluyen cenizas volantes y cenizas depositadas, que normalmente sólo se generan en grandes cantidades durante la quema de fuel oil residual en calderas eléctricas de vapor. Otras tecnologías (por ejemplo, turbinas de combustión y motores diésel) y combustibles (por ejemplo, petróleo destilado) tienen una generación de residuos sólidos escasa o nula. En general, la combustión de petróleo genera mucha menos cantidad de residuos, con respecto a las grandes cantidades de RCC antes mencionados. Las plantas de energía térmica de combustión de gas no generan esencialmente ningún residuo sólido debido a la cantidad insignificante de cenizas, independientemente de la tecnología de combustión.

Los metales son motivo de preocupación tanto en los RCC como en los desechos sólidos de bajo volumen. Por ejemplo, los residuos de las cenizas y el polvo eliminados de los gases de escape pueden contener importantes niveles de metales pesados y algunos componentes orgánicos, además de materiales inertes.

Los residuos de las cenizas no se clasifican habitualmente como desechos peligrosos por su carácter inerte[25]. No obstante, cuando se prevea que los residuos de las cenizas pueden contener elevados niveles de metales pesados, radioactividad y otros materiales potencialmente peligrosos, estos componentes se deben analizar al inicio de las operaciones de la planta para comprobar su clasificación como peligrosos o no peligrosos en función de los reglamentos locales y las normas internacionalmente reconocidas. La Sección 1.6 de las **guías generales sobre MASS** contiene información adicional sobre la clasificación y el manejo de residuos peligrosos y no peligrosos.

carbón apilado debe evaluarse caso por caso.

[24] Por ejemplo, una planta de 500 MW que utilice carbón con un 2,5% de azufre (S), un 16% de ceniza y un contenido calórico de 30.000 kilojulios por kilo (kJ/Kg) generará unas 500 toneladas de residuos sólidos al día.

[25] Algunos países pueden considerar peligrosas las cenizas volantes debido a la presencia de arsénico o la radioactividad, y prohíben su uso como material de construcción.

Los RCC de gran volumen suelen gestionarse en vertederos, sistemas de lagunaje o, cada vez más, se pueden utilizar con fines útiles, Los desechos de poco volumen también se gestionan en vertederos o sistemas de lagunaje, aunque lo más frecuente es lo segundo. En muchas plantas de carbón se gestionan conjuntamente los residuos de gran volumen y bajo volumen.

Las medidas recomendadas para prevenir, minimizar y controlar el volumen de desechos sólidos de las plantas de energía térmica incluyen:

- Manejar en seco los residuos de la combustión del carbón, en particular las cenizas volantes. Estos métodos no conllevan el lagunaje y, por lo tanto, no plantean los riesgos ecológicos asociados con el lagunaje (por ejemplo, transmisión de metales a la flora y fauna);
- Reciclar los RCC para usos tales como el cemento y otros productos de concreto, rellenos de construcción (como rellenos estructurales, rellenos de densidad y bases para carreteras), usos agrícolas como los fertilizantes de calcio (siempre que el contenido de metales residuales y otros materiales potencialmente peligrosos se encuentre en niveles aceptables), manejo de residuos, minería y materiales construcción (por ejemplo, yeso sintético para las placas de escayola), e incorporación en otros productos siempre que los residuos (como los metales residuales y los materiales radioactivos) no se consideren peligrosos. La garantía de la calidad constante de los combustibles y los aditivos contribuye a asegurar que se puedan reciclar los RCC. Cuando no sea viable el reciclaje, se recomienda el desecho de los RCC en vertederos autorizados con controles ambientales tales como contenedores, barreras de contención, sistemas de recolección de la lixiviación, seguimiento de las aguas subterráneas, controles de los cierres, cobertura diaria (y otras coberturas operativas) y controles del polvo fugitivo;
- Recolectar en seco las cenizas depositadas y volantes de las plantas de combustión de fuel oil pesado que contengan altos niveles de metales con alto valor económico como el vanadio y reciclar el vanadio (cuando sea económicamente viable) o desecharlas en vertederos autorizados con controles ambientales;
- Manejar el desecho y la recuperación de cenizas para minimizar los impactos ambientales, especialmente la migración de metales tóxicos, cuando haya presencia de ellos, a las aguas superficiales y freáticas cercanas, además del arrastre de sólidos en suspensión en las escorrentías debido a las precipitaciones y las inundaciones. En particular, la construcción, la operación y el mantenimiento de los lagunajes se debe realizar de acuerdo con las normas internacionalmente reconocidas[26, 27].
- Reutilizar el lodo procedente del tratamiento de las aguas residuales en las instalaciones de DGC. Este lodo se puede reutilizar en las plantas de DGC debido a los componentes de calcio. También se puede usar como aditivo en las plantas de combustión de carbón para cambiar las características de disolución de las cenizas.

Materiales peligrosos y petróleo

Los materiales peligrosos que se utilizan o almacenan en instalaciones de combustión incluyen combustibles residuales sólidos, líquidos y gaseosos; sustancias químicas para el tratamiento del aire, el agua y las aguas residuales, y productos químicos para el mantenimiento del equipo y las instalaciones (por ejemplo, pintura, ciertos tipos de lubricantes y limpiadores). Las secciones 1.5 y 3.7 de las **guías generales sobre MASS** tratan la prevención de los derrames y ofrecen orientaciones para responder a ellos.

[26] Véase, por ejemplo, los reglamentos sobre salud y seguridad en las minas del Departamento de Trabajo de Estados Unidos (U.S. Department of Labor, Mine Safety and Health Administration regulations at 30 CFR §§ 77.214 - 77.216).

[27] Las Guías sobre MASS del Grupo del Banco Mundial para el manejo de residuos sólidos contienen orientaciones detalladas sobre la prevención y el

Además, las medidas recomendadas para prevenir, minimizar y controlar los riesgos asociados con el almacenamiento y el manejo de materiales peligrosos en las plantas de energía térmica incluyen el uso de depósitos a presión subterráneos de doble cámara para el almacenamiento de amoniaco puro licuado (por ejemplo, como reactivo en la RCS) en cantidades superiores a 100 m^3; se deben fabricar depósitos con menor capacidad mediante técnicas de recocido (CE, 2006).

Ruido

Entre las principales fuentes de ruido en las plantas de energía térmica se encuentran los generadores y los elementos auxiliares de las turbinas; las calderas y los elementos auxiliares como los pulverizadores de carbón; los motores de explosión; los ventiladores y las conducciones; las bombas; los compresores; los condensadores; los precipitadores, por golpeo o vibración; las tuberías y las válvulas; los motores; los transformadores; los interruptores, y las torres de refrigeración. Las plantas de energía térmica de carga básica pueden operar constantemente, mientras que las plantas más pequeñas pueden funcionar con menos frecuencia, aunque siguen generando una cantidad significativa de ruido cuando están ubicadas en zonas urbanas.

En la Sección 1.7 de las **guías generales sobre MASS** se explican los impactos acústicos, las medidas de control y los niveles de ruido ambiental recomendables. Las medidas adicionales recomendadas para prevenir, minimizar y controlar el ruido procedente de las plantas de energía térmica incluyen:

- Ubicar las nuevas instalaciones teniendo en cuenta la distancia entre el origen del ruido y los receptores (por ejemplo, receptores residenciales, escuelas, hospitales, centros religiosos) en la medida de lo posible. Si no hay una zonificación de los terrenos locales o no se aplica efectivamente dicha zonificación, examinar la posibilidad de que haya receptores residenciales fuera de los limites de los terrenos adquiridos para la planta. En los casos en que sea posible, puede ser más eficaz en relación con los costos adquirir terrenos adicionales como zona de contención que utilizar técnicas de control del ruido;
- Usar técnicas de control del ruido como: aislamientos acústicos de la maquinaria; selección de estructuras en función de su efecto de aislamiento del ruido para revestir la edificación; silenciadores en las vías de entrada y escape; materiales que absorban el ruido en paredes y techos; aisladores de las vibraciones y conexiones flexibles (por ejemplo, resortes de acero y elementos de caucho); aplicación de un diseño que tenga muy en cuenta la prevención de los escapes de ruido a través de aberturas o minimización de las variaciones de presión en las tuberías;
- Modificar la configuración de la planta o usar barreras contra el ruido de tierra o de vegetación para limitar el ruido ambiente en las demarcaciones de la planta, especialmente cuando pueda haber presencia de receptores sensibles.

Los modelos de propagación del ruido pueden ser un instrumento útil para evaluar las opciones de gestión del ruido como las ubicaciones alternativas de la planta, la disposición general de la planta y el equipo auxiliar, el diseño de los cerramientos y, partiendo de los resultados de una evaluación de los ruidos básicos, medidas para el cumplimiento de los requisitos sobre ruido en la comunidad.

1.2 Higiene y seguridad en el trabajo

Los riesgos que la construcción, el funcionamiento y el desmantelamiento de las plantas de generación de energía térmica entrañan para la higiene y la seguridad en el trabajo son similares a los que se producen en la mayoría de las instalaciones industriales, y se tratan en la Sección 2.0 de las **guías generales sobre MASS**. Además, los siguientes impactos sobre la salud y la

control de los impactos sobre el suelo y los recursos acuíferos del vertido de residuos sólidos peligrosos y no peligrosos.

seguridad son especialmente preocupantes durante el funcionamiento de las plantas de energía térmica:

- Radiación no ionizante
- Calor
- Ruido
- Espacios cerrados
- Riesgos de origen eléctrico
- Riesgos de incendio y explosión
- Riesgos de origen químico
- Polvo

Radiación no ionizante

Los trabajadores de las instalaciones de combustión pueden estar más expuestos a los campos eléctricos y magnéticos (CEM) que la población general debido a que trabajan cerca de generadores de energía, equipos y líneas de transmisión de alta tensión. La exposición a los CEM en el trabajo debe prevenirse o minimizarse mediante la preparación e implementación de un programa de seguridad sobre CEM que incluya los siguientes elementos:

- Identificación de los posibles niveles de exposición en el lugar de trabajo, lo que incluye estudios de dichos niveles en nuevos proyectos y el uso de dispositivos personales durante las actividades laborales;
- Capacitación de los trabajadores acerca de la detección de los niveles y los riesgos de CEM en el trabajo;
- Establecimiento e identificación de zonas seguras para diferenciar las áreas de trabajo con niveles previstos elevados de CEM en comparación con los niveles aceptables para la población general, con acceso limitado a los trabajadores con la capacitación adecuada;
- Implementación de planes de acción para abordar niveles de exposición posibles o registrados por encima de los niveles de exposición en el trabajo establecidos por organismos internacionales como la Comisión Internacional para la Protección contra las Radiaciones No Ionizantes (ICNIRP, en inglés) y el Instituto de Ingenieros Eléctricos y Electrónicos (IEEE, en inglés)[28]. La alarma del equipo de control de la exposición personal debe fijarse en un nivel inferior a los niveles de referencia para la exposición en el trabajo (por ejemplo, 50%). Los planes de acción para abordar la exposición en el trabajo pueden incluir la limitación de tiempo de exposición mediante rotación en el puesto, el aumento de la distancia entre la fuente y el trabajador, cuando sea posible, y el uso de materiales de protección.

Calor

La exposición al calor en el trabajo se produce durante la operación y el mantenimiento de unidades de combustión, tuberías y materiales calientes relacionados. Entre las medidas de prevención y control recomendadas en relación con la exposición al calor en las plantas de energía térmica se cuentan las siguientes:

- Inspeccionar y mantener periódicamente las válvulas de presión y las tuberías;
- Contar con ventilación adecuada en las zonas de trabajo para reducir el calor y la humedad;
- Reducir el tiempo requerido para trabajar en entornos a elevadas temperaturas y garantizar el acceso al agua potable;
- Proteger las superficies donde los trabajadores entren en contacto con equipos calientes, incluidos los equipos generadores, conductos, etc.;
- Usar señales de advertencia cerca de las superficies con temperaturas elevadas y equipos de protección individual (EPI) adecuados, incluidos guantes y calzado aislantes.

[28] Las directrices de la ICNIRP sobre salud en el trabajo aparecen en la sección 2.2 de estas guías.

Ruido

En las instalaciones de combustión, el ruido proviene de los generadores y los elementos auxiliares de las turbinas; las calderas y los elementos auxiliares como los pulverizadores de carbón; los motores de explosión; los ventiladores y las conducciones; las bombas; los compresores; los condensadores; los precipitadores, por golpeo o vibración; las tuberías y las válvulas; los motores; los transformadores; los interruptores, y las torres de refrigeración. En la anterior Sección 1.1 se ofrecen recomendaciones para reducir el ruido y las vibraciones. Las recomendaciones adicionales para prevenir, minimizar y controlar la exposición al ruido en el trabajo en las plantas de energía térmica incluyen:

- Instalar aislamientos del sonido en las salas de control con niveles de ruido inferiores a 60 dB[29];
- Diseñar generadores que cumplan los niveles de ruido en el trabajo aplicables;
- Identificar y demarcar las zonas con mucho ruido y exigir el uso de equipo protector contra el ruido siempre que se trabaje en dichas zonas (normalmente con niveles de ruido > 85 dB).

Espacios cerrados

Los elementos específicos que pueden conllevar el ingreso a espacios cerrados son los contenedores de cenizas de carbón, las turbinas, los condensadores y las torres de refrigeración (durante las actividades de mantenimiento). Los procedimientos recomendados para el ingreso a espacios cerrados se describen en la Sección 2.8 de las **guías generales sobre MASS**.

Riesgos de origen eléctrico

El equipo de transmisión de energía y las líneas de tensión conllevan riesgos de origen eléctrico para los trabajadores de las plantas de energía térmica. Las medidas recomendadas para prevenir, minimizar y controlar los riesgos de origen eléctrico en las plantas de energía térmica incluyen:

- Considerar la instalación de luces de advertencia de peligros dentro de los espacios interiores de los equipos eléctricos para advertir de subidas inesperadas de energía;
- Usar sensores del voltaje antes y durante el ingreso de trabajadores a espacios cerrados con componentes eléctricos;
- Desactivar y conectar a tierra de la debida manera las líneas vivas de distribución de energía eléctrica antes de realizar trabajos en las líneas o en sus proximidades;
- Proporcionar capacitación especializada sobre seguridad en el trabajo eléctrico a los trabajadores que manipulen componentes abiertos de circuitos eléctricos o trabajen cerca de ellos. Esta capacitación debe incluir, entre otras cosas, formación sobre la teoría fundamental de la electricidad, procedimientos adecuados para la seguridad en el trabajo, conocimiento e identificación de riesgos, uso adecuado del EPI, procedimientos adecuados de bloqueo y etiquetado, primeros auxilios, incluida la RCP, y procedimientos adecuados de salvamento. Se debe disponer una nueva capacitación periódica en función de las necesidades.

Riesgos de incendio y explosión

En las plantas de energía térmica se almacenan, trasladan y usan grandes cantidades de combustible; por lo tanto, es necesario manejarlo cuidadosamente para mitigar los riesgos de incendio y explosión. En particular, los riesgos de incendio y explosión

[29] La distancia entre la sala de control y las fuentes de emisión de ruido varía dependiendo del tipo y tamaño de las plantas de energía térmica. CSA Z107.58 contiene guías de diseño para salas de control con niveles inferiores a 60 dB. El nivel de ruido generado en las grandes plantas de energía térmica que emplean calderas de vapor o turbinas de combustión suele estar por debajo de 60 dB. Los fabricantes de motores de combustión interna recomiendan entre 65 y 70 dB, en lugar de 60 dB (Posición de Euromot al 9 de mayo de 2008). En estas guías se recomiendan como PIRIC 60 dB, dando por entendido que se pueden aceptar 65 dB para las plantas de generación de energía mediante motores de combustión interna, cuando existan dificultades económicas para mantener el nivel por debajo de 60 dB.

aumentan con la reducción del tamaño de las partículas de carbón. Los tamaños de las partículas de carbón que pueden generar una explosión por propagación se encuentran dentro de las secadoras térmicas, los ciclones, los filtros de mangas, los sistemas de combustible pulverizado, las moliendas, y en otros procesos y equipos de transporte. Las secciones 2.1 y 2.4 de las **guías generales sobre MASS** contienen orientaciones sobre la gestión de la prevención de incendios y explosiones. Las medidas recomendadas para prevenir, minimizar y controlar los riesgos de origen físico en las plantas de energía térmica:

- Usar controles de combustión y de seguridad automáticos;
- Mantener adecuadamente los controles de seguridad de la caldera;
- Implementar procedimientos de encendido y apagado que minimicen el riesgo de partículas de carbón en suspensión (por ejemplo, en el pulverizador, la molienda y el ciclón) durante la puesta en marcha;
- Limpiar regularmente las instalaciones para prevenir la acumulación de polvo de carbón (por ejemplo, en los suelos, los estantes, las vigas y el equipo);
- Eliminar los puntos calientes de las pilas de carbón (provocados por combustión espontánea) y extenderlos hasta que se enfríen, sin cargar nunca carbón caliente al sistema de combustible pulverizado;
- Usar sistemas automáticos como medidores de temperatura o sensores de monóxido de carbono para examinar las zonas de almacenamiento de combustible sólido con el fin de detectar los fuegos por combustión espontánea o identificar puntos peligrosos.

Riesgos de origen químico

Los materiales peligrosos empleados en las plantas de energía térmica incluyen el amoniaco para los sistemas de control de NO_X y el cloro gaseoso para el tratamiento del agua de refrigeración y de la caldera. La Sección 2.4 de las **guías generales sobre MASS** contiene orientaciones sobre el manejo de riesgos de origen químico. Las medidas adicionales recomendadas para prevenir, minimizar y controlar los riesgos de origen físico en las plantas de energía térmica incluyen:

- Considerar la generación de amoniaco a partir de urea dentro de las instalaciones y el uso de amoniaco acuoso en lugar de amoniaco puro licuado;
- Considerar el uso de hipocloruro de sodio en lugar de cloro gaseoso.

Polvo

El manejo de combustibles sólidos, aditivos y desechos sólidos (por ejemplo, cenizas) genera polvo. El polvo puede contener sílice (asociado con la silicosis), arsénico (cáncer de piel y de pulmones), polvo de carbón (antracosis) y otras sustancias que pueden ser dañinas. Las secciones 2.1 y 2.4 de las **guías generales sobre MASS** ofrecen orientaciones sobre el manejo del polvo. Las medidas recomendadas para prevenir, minimizar y controlar la exposición al polvo en el trabajo en las plantas de energía térmica incluyen:

- Usar controles del polvo (por ejemplo, ventilación hacia el exterior) para que se mantenga por debajo de los niveles aplicables (véase la Sección 2) o siempre que el nivel de sílice del polvo aéreo supere el 1%;
- Inspeccionar y mantener regularmente los materiales que contengan asbesto (por ejemplo, el aislamiento de las plantas más antiguas puede contener asbesto) para prevenir la presencia de partículas de asbesto en el aire.

1.3 Higiene y seguridad en la comunidad

Muchos impactos en la higiene y seguridad de la comunidad durante la construcción, la puesta en funcionamiento y el

desmantelamiento de los proyectos de plantas de energía térmica son comunes a los de la mayoría de las demás instalaciones industriales y se analizan en la Sección 3.0 de las **guías generales sobre MASS**. Además de estos y otros aspectos tratados en la Sección 1.1, los siguientes impactos para la higiene y la seguridad en la comunidad pueden ser particularmente preocupantes en el caso de los proyectos de plantas de energía térmica:

- Consumo de agua;
- Seguridad vial.

Consumo de agua

Las calderas requieren grandes cantidades de agua refrigerante para la condensación del vapor y la operación térmica eficiente. El caudal de agua refrigerante a través del condensador es el más grande con mucha diferencia, y equivale a cerca del 98% del flujo total de agua para toda la unidad. En un sistema de refrigeración abierto sin recirculación del agua, se suele extraer el agua de fuentes superficiales, aunque a veces se usan aguas freáticas o la red de abastecimiento municipal. Como se señala en la Sección 3.1 de las **guías generales sobre MASS,** se deben evaluar los posibles efectos del consumo del agua, para asegurar que el proyecto no comprometa la disponibilidad de agua para la higiene personal, la agricultura, las actividades recreativas y otras necesidades comunitarias.

Seguridad vial

El funcionamiento de una planta de energía térmica aumentará el volumen de tráfico, especialmente en las instalaciones con transporte de combustible por aire o mar, lo que incluye el transporte pesado por carretera de combustibles, aditivos, etc. El incremento del tráfico puede ser especialmente significativo en las zonas poco pobladas donde se encuentran algunas plantas de energía térmica. La Sección 3.4 de las **guías generales sobre MASS** se ocupa de la prevención y el control de las lesiones relacionadas con el tráfico por carretera. Las **guías sobre MASS en el transporte de mercancías por mar** tratan la seguridad en el transporte por agua.

2.0 Indicadores y seguimiento del desempeño

2.1 Medio ambiente

Guías sobre emisiones y efluentes

El Cuadro 5 contiene las guías sobre efluentes y el Cuadro 6, las guías sobre emisiones. Las guías sobre efluentes son aplicables a los vertidos directos de efluentes del tratamiento a las aguas superficiales de uso general. Se pueden establecer los niveles específicos de vertido de cada ubicación en función de la disponibilidad y las condiciones de uso del alcantarillado y los sistemas de recolección públicos o, si se vierten directamente a las aguas superficiales, en función de la clasificación de las aguas receptoras de acuerdo con las **guías generales sobre MASS.** Los valores de referencia de las emisiones y los efluentes de este sector son indicativos de las buenas prácticas internacionales de la industria, recogidas en las normas de países con marcos regulatorios reconocidos. Estos niveles deben lograrse, sin dilución, al menos durante el 95% del tiempo de funcionamiento de la planta o la unidad, lo cual se calculará como proporción del total anual de horas de operación. En la evaluación ambiental se deben justificar las desviaciones de estos niveles debidas a las condiciones específicas locales del proyecto.

Cuadro 5 - Guías sobre efluentes
(Aplicables a las corrientes de aguas residuales relevantes, procedentes, por ejemplo, del sistema de DGC, el transporte de cenizas húmedas, la limpieza de la caldera/el precalentador de aire y el precipitador, la limpieza ácida de la caldera, la regeneración de destiladores y resinas de filtración, el agua separada del aceite, el sistema de drenaje, las escorrentías del carbón apilado y el agua refrigerante)

Parámetro	mg/L, salvo pH y temp.
pH	6-9
TSS	50
Aceite y grasa	10
Cloro residual total	0,2
Cromo - Total (Cr)	0,5
Cobre (Cu)	0,5
Hierro (Fe)	1,0
Zinc (Zn)	1,0
Plomo (Pb)	0,5
Cadmio (Cd)	0,1
Mercurio (Hg)	0,005
Arsénico (As)	0,5
Aumento de la temperatura por la descarga térmica del sistema de refrigeración	• La EA determinará los requisitos específicos para la instalación. • Se deben minimizar las zonas con temperaturas elevadas debido al vertido de aguas refrigerantes de sistemas abiertos (por ejemplo, 1 grado Celsius por encima, 2 grados por encima, 3 grados por encima de la temperatura del agua del entorno) ajustando el diseño de la entrada y la salida en función de los ecosistemas acuáticos afectados alrededor del punto de vertido, mediante una EA específica para el proyecto.

Nota: La EA debe determinar la aplicabilidad a los metales pesados. Los límites orientativos del cuadro proceden de varias referencias de desempeño de los efluentes derivados de plantas de energía térmica.

Los niveles de emisiones para el diseño y el funcionamiento de cada proyecto deben establecerse mediante un proceso de EA basado en la legislación nacional y las recomendaciones de estas guías, adaptadas a las condiciones locales. Los niveles de emisiones seleccionados deben justificarse en la EA[30]. Los niveles de emisiones máximos fijados en estas guías pueden cumplirse constantemente mediante un buen diseño, funcionamiento y mantenimiento de los sistemas de control de la contaminación. En cambio, los procedimientos deficientes de operación o mantenimiento afectan la eficiencia real de remoción de contaminantes y pueden hacerla caer muy por debajo de la especificación del diseño. No es aceptable la dilución de estas emisiones a la atmósfera para lograr los niveles aceptables. El cumplimiento de las guías sobre calidad del aire ambiente debe evaluarse en función de las prácticas internacionales recomendadas para la industria en cuestión (PIRIC).

Como se señala en las **guías generales sobre MASS**, las emisiones no deben producir concentraciones de contaminantes equivalentes o por encima de las guías y normas relevantes sobre

[30] Por ejemplo, en los casos en que la EA haya detectado un riesgo significativo de vertidos ácidos, el diseño y el funcionamiento de la planta deben garantizar la reducción efectiva de la carga de masa de las emisiones para prevenir o minimizar dichos impactos.

calidad del aire[31] de acuerdo con la legislación nacional o, en su ausencia, las actuales Guías de calidad del aire ambiente de la OMS[32], u otras normativas internacionalmente reconocidas[33]. Además, las emisiones de un solo proyecto no deben contribuir en más del 25% a los niveles aplicables de calidad del aire ambiente, para permitir el futuro desarrollo sostenible de la misma cuenca atmosférica [34].

Como se describe en las **guías generales sobre MASS**, las instalaciones y los proyectos ubicados dentro de cuencas atmosféricas de mala calidad[35], o en el interior o las cercanías de zonas consideradas ecológicamente sensibles (por ejemplo, parques nacionales), deben asegurar que todo aumento en los niveles de contaminación sea lo menor posible, y constituya solamente una fracción del promedio a corto plazo y anual de las guías y normas sobre calidad del aire, según las especificaciones de la evaluación ambiental del proyecto.

Seguimiento ambiental

En el Cuadro 7 se presentan los programas de seguimiento ambiental para este sector. Los datos de seguimiento se analizarán y revisarán con regularidad, y se compararán con las normas vigentes para así adoptar las medidas correctivas necesarias. En el Cuadro 7 se ofrecen recomendaciones sobre las emisiones, las pruebas de las chimeneas, la calidad del aire ambiente y el control del ruido aplicables a las plantas de generación de energía. Las **guías generales sobre MASS** contienen orientaciones adicionales sobre los métodos de muestreo y análisis de emisiones y efluentes.

[31] Las normas sobre calidad del aire ambiente consisten en los niveles de calidad del aire ambiente establecidos y publicados mediante procesos nacionales legislativos y reglamentarios, y las guías de calidad del aire ambiente se refieren a los niveles de calidad del aire ambiente determinados mediante pruebas clínicas, toxicológicas y epidemiológicas (como las publicadas por la Organización Mundial de la Salud).

[32] Disponible en la Organización Mundial de la Salud (OMS). http://www.who.int/es/index.html

[33] Por ejemplo, las Normas de calidad del aire ambiente de los Estados Unidos (NAAQS, en inglés) (http://www.epa.gov/air/criteria.html) y las directivas relevantes del Consejo Europeo (Directiva del Consejo 1999/30/EC del 22 de abril de 1999/Directiva del Consejo 2002/3/EC del 12 de febrero de 2002).

[34] EE. UU. EPA, *Prevention of Significant Deterioration Increments Limits applicable to non-degraded airsheds.*

[35] La calidad del aire de las cuencas atmosféricas se considera deficiente si supera significativamente los niveles fijados por las normas nacionales o las Guías de calidad del aire de la OMS.

Cuadro 6 (A) – Guías sobre emisiones (en mg/Nm³ o según se indique) para motores de combustión interna

Nota:

- **Las guías son aplicables a las nuevas instalaciones.**
- **La EA puede justificar límites más o menos estrictos en función de consideraciones ambientales, técnicas o económicas, siempre que se cumplan las normas aplicables sobre la calidad del aire ambiente y se minimice el incremento de los impactos.**
- **Para los proyectos de rehabilitación de instalaciones existentes, la EA debe establecer requisitos de emisiones para cada caso teniendo en cuenta i) los niveles de emisiones existentes y los impactos sobre el medio ambiente y la salud comunitaria, y ii) el costo y la viabilidad técnica de que los niveles de emisiones existentes en las nuevas instalaciones cumplan estos límites.**
- **La EA debe demostrar que las emisiones no constituyen una parte significativa del cumplimiento de las orientaciones o normas de calidad del aire ambiente, y podría tener que aplicar límites más estrictos.**

Tecnología de combustión/combustible	Material particulado (MP)		Dióxido de azufre (SO_2)		Óxidos de nitrógeno (NOx)		Gas seco, exceso de contenido de O_2 (%)
Motor de combustión interna	CAND	CAD	CAND	CAD	CAND	CAD	
Gas natural	N/A	N/A	N/A	N/A	200 (encendido de chispa) 400 (combustible dual) (a)	200 (ECH) 400 (combustible dual/EC)	15%
Combustibles líquidos (planta > 50 MWth a < 300 MWth)	50	30	1.170 o uso de combustible con 2% o menos de S	0,5% S	1.460 (encendido de compresión, cilindrada [mm] < 400) 1.850 (encendido de compresión, cilindrada [mm] ≥ 400) 2.000 (combustible dual)	400	15%
Combustibles líquidos (planta >/= 300 MWth)	50	30	585 o Uso de combustible con 1% o menos de S	0,2% S	740 (según la disponibilidad de agua para la inyección)	400	15%
Biocombustibles/combustibles gaseosos diferentes del gas natural	50	30	N/A	N/A	Límites un 30% superiores a los dispuestos anteriormente para el gas natural y los combustibles líquidos	200 (ECH, gas natural), 400 (otro)	15%

Notas generales:

- MWth = potencia térmica basada en PCS; N/A = no aplicable; CAND = cuenca atmosférica no degradada; CAD = cuenca atmosférica degradada (mala calidad del aire); las cuencas atmosféricas deben considerarse degradadas cuando se superan los niveles de calidad del aire establecidos en la legislación nacional o, en ausencia de dichas leyes, cuando exceden considerablemente las Guías de calidad del aire de la OMS; S = contenido de azufre (expresado como porcentaje de la masa); Nm³ a una atmósfera de presión y 0 grados Celsius; la categoría de MWth se aplica a toda la instalación compuesta por múltiples unidades que razonablemente puedan considerarse procedentes de un almacenamiento común. Los límites de las guías se aplican a instalaciones que operan más de 500 horas al año. Los niveles de emisiones deben evaluarse en períodos de una hora y deben cumplirse durante el 95% de las horas de funcionamiento en un año.
- (a) Los motores con encendido de compresión (EC) pueden exigir diferentes valores para las emisiones que deben evaluarse en cada caso mediante el proceso de EA.

Comparación de los límites de las guías con las normas de ciertos países/regiones (a agosto de 2008):

- Motor de combustión interna de gas – NOx
  - Límites de las guías: 200 (ECH), 400 (CD)
  - RU: 100 (EC), EE. UU.: reducir a 90% o más, o alternativamente 1,6 g/kWh
- Motor de combustión interna de combustibles líquidos – NOx (planta > 50 MWth a < 300 MWth)
  - Límites de las guías: 1.460 (EC, cilindrada < 400 mm), 1.850 (EC, cilindrada ≥ 400 mm), 2.000 (CD)
  - RU: 300 (> 25 MWth), India: 1.460 (áreas urbanas & ≤ 75 MWe (≈ 190 MWth), áreas rurales & ≤ 150 MWe (≈ 380 MWth))
- Motor de combustión interna de combustibles líquidos – NOx (planta ≥ 300 MWth)
  - Límites de las guías: 740 (según la disponibilidad de agua para la inyección)
  - RU: 300 (> 25 MWth), India: 740 (áreas urbanas & > 75MWe (≈ 190 MWth), áreas rurales & > 150 MWe (≈ 380 MWth))
- Motor de combustión interna de combustibles líquidos – SO_2
  - Límites de las guías: 1.170 o uso de ≤ 2% S (planta > 50 MWth a < 300 MWth), 585 o uso de ≤ 1% S (planta ≥ 300 MWth)
  - UE: uso de fuel oil con bajo contenido de S o DGC secundaria (IPCC LCP BREF), contenido de S en FOP ≤ 1% (Directiva sobre calidad del combustible líquido), EE. UU.: uso de combustible diésel con máximo de 500 ppm de S (0,05%); UE: contenido de S en FOP para barcos ≤ 1,5% (Directiva sobre calidad del combustible líquido) utilizado en zonas de control de las emisiones de SOx; India: urbano (< 2% S), rural (< 4% S), sólo se deben usar combustibles diésel (DAV, CDL) en áreas urbanas.

Fuentes: RU (S2 1.03 *Combustion Processes: Compression Ignition Engines, 50 MWth and over*), India (SOx/NOx *Emission Standards for Diesel Engines* ≥ 0.8 MW), UE (IPCC LCP BREF, julio de 2006), UE (Directiva sobre combustibles líquidos 1999/32/EC, modificada por 2005/33/EC), EE. UU. (*NSPS for Stationary Compression Ignition Internal Combustion Engine* – Final Rule – 11 de julio de 2006).

Cuadro 6 (B) - Guías sobre emisiones (en mg/Nm³ o según se indique) para turbinas de combustión

Nota:

- **Las guías son aplicables a las nuevas instalaciones.**
- **La EA puede justificar límites más o menos estrictos en función de consideraciones ambientales, técnicas o económicas, siempre que se cumplan las normas aplicables sobre la calidad del aire ambiente y se minimice el incremento de los impactos.**
- **Para los proyectos de rehabilitación de instalaciones existentes, la EA debe establecer requisitos de emisiones para cada caso teniendo en cuenta i) los niveles de emisiones existentes y los impactos sobre el medio ambiente y la salud comunitaria, y ii) el costo y la viabilidad técnica de que los niveles de emisiones existentes en las nuevas instalaciones cumplan estos límites.**
- **La EA debe demostrar que las emisiones no constituyen una parte significativa del cumplimiento de las orientaciones o normas de calidad del aire ambiente, y podría tener que aplicar límites más estrictos.**

Tecnología de combustión/combustible	Material particulado (MP)		Dióxido de azufre (SO_2)		Óxidos de nitrógeno (NOx)	Gas seco, exceso de contenido de O_2 (%)
Turbina de combustión	CAND/CAD				CAND/CAD	
Gas natural (todos los tipos de turbinas de una unidad > 50MWth)	N/A	N/A	N/A	N/A	51 (25 ppm)	15%
Otros combustibles diferentes del gas natural (unidad > 50MWth)	50	30	Uso de combustible con 1% o menos de S	Uso de combustible con 0,5% o menos de S	152 (74 ppm)[a]	15%

Notas generales:

- MWth = potencia térmica basada en PCS; N/A = no aplicable; CAND = cuenca atmosférica no degradada; CAD = cuenca atmosférica degradada (mala calidad del aire); las cuencas atmosféricas deben considerarse degradadas cuando se superan los niveles de calidad del aire establecidos en la legislación nacional o, en ausencia de dichas leyes, cuando exceden considerablemente las Guías de calidad del aire de la OMS; S = contenido de azufre (expresado como porcentaje de la masa); Nm³ a una atmósfera de presión y 0 grados Celsius; la categoría de MWth se aplica unidades individuales. Los límites de las guías se aplican a instalaciones que operan más de 500 horas al año. Los niveles de emisiones deben evaluarse en períodos de una hora y deben cumplirse durante el 95% de las horas de funcionamiento en un año.
- Si se utilizan quemadores suplementarios en el sistema de turbina de gas de ciclo combinado, se deben cumplir los límites aplicables a las turbinas de combustión, incluso en el caso de las emisiones procedentes de estos quemadores suplementarios (por ejemplo, quemadores de tubo).
- [a] Las diferencias tecnológicas (por ejemplo, el uso de turbinas aeroderivadas) pueden exigir diferentes valores para las emisiones que deben evaluarse en cada caso mediante el proceso de EA, aunque no deben superar los 200 mg/Nm3.

Comparación de los límites de las guías con las normas de ciertos países/regiones (a agosto de 2008):

- Turbina de combustión de gas natural – NOx
  - Límites de las guías: 51 (25 ppm)
  - UE: 50 (24 ppm), 75 (37 ppm) (si la eficiencia del ciclo combinado es > 55%), 50*η/35 (η = eficiencia del ciclo simple)
  - EE. UU.: 25 ppm (> 50 MMBtu/h (≈ 14,6 MWth) y ≤ 850 MMBtu/h (≈ 249 MWth)), 15 ppm (> 850 MMBtu/h (≈ 249 MWth))
  - (Nota: Los requisitos para el aire ambiente exigen normalmente una reducción adicional del NOx ppm a un nivel de 2 a 9 ppm)
- Turbina de combustión de combustible líquido – NOx
  - Límites de las guías: 152 (74 ppm) – Turbinas de alto rendimiento y FOL/FOP, 300 (146 ppm) – Aeroderivadas y FOP, 200 (97 ppm) – Aeroderivadas y FOL
  - UE: 120 (58 ppm), EE. UU.: 74 ppm (> 50 MMBtu/h (≈ 14,6 MWth) y ≤ 850 MMBtu/h (≈ 249MWth)), 42 ppm (> 850 MMBtu/h (≈ 249 MWth))
- Turbina de combustión de combustible líquido – SOx
  - Límites de las guías: uso de combustible con 1% o menos de S
  - UE: contenido de S en el fuel oil ligero para las turbinas de gas por debajo del 0,1%; EE. UU.: contenido de S alrededor del 0,05% (zona continental) y 0,4% (zona no continental)

Fuentes: UE (Directiva sobre GIC 2001/80/EC del 23 de octubre de 2001), UE (Directiva sobre combustibles líquidos 1999/32/EC, modificada por 2005/33/EC), EE. UU. (*NSPS for Stationary Combustion Turbines*, Final Rule – 6 de julio de 2006)

Cuadro 6 (C) - Guías sobre emisiones (en mg/Nm³ o según se indique) para calderas

Nota:

- **Las guías son aplicables a las nuevas instalaciones.**
- **La EA puede justificar límites más o menos estrictos en función de consideraciones ambientales, técnicas o económicas, siempre que se cumplan las normas aplicables sobre la calidad del aire ambiente y se minimice el incremento de los impactos.**
- **Para los proyectos de rehabilitación de instalaciones existentes, la EA debe establecer requisitos de emisiones para cada caso teniendo en cuenta i) los niveles de emisiones existentes y los impactos sobre el medio ambiente y la salud comunitaria, y ii) el costo y la viabilidad técnica de que los niveles de emisiones existentes en las nuevas instalaciones cumplan estos límites.**
- **La EA debe demostrar que las emisiones no constituyen una parte significativa del cumplimiento de las orientaciones o normas de calidad del aire ambiente, y podría tener que aplicar límites más estrictos.**

Tecnología de combustión/combustible	Material particulado (MP)		Dióxido de azufre (SO_2)		Óxidos de nitrógeno (NOx)		Gas seco, exceso de contenido de O_2 (%)
Caldera	CAND	CAD	CAND	CAD	CAND	CAD	
Gas natural	N/A	N/A	N/A	N/A	240	240	3%
Otros combustibles gaseosos	50	30	400	400	240	240	3%
Combustibles líquidos (planta > 50 MWth a < 600 MWth)	50	30	900–1.500[a]	400	400	200	3%
Combustibles líquidos (planta >/= 600 MWth)	50	30	200–850[b]	200	400	200	3%
Combustibles sólidos (planta > 50 MWth a < 600 MWth)	50	30	900–1.500[a]	400	510[c] o hasta 1.100 si el material volátil es combustible < 10%	200	6%
Combustibles sólidos (planta >/= 600 MWth)	50	30	200–850[b]	200			6%

Notas generales:

- MWth = potencia térmica basada en PCS; N/A = no aplicable; CAND = cuenca atmosférica no degradada; CAD = cuenca atmosférica degradada (mala calidad del aire); las cuencas atmosféricas deben considerarse degradadas cuando se superan los niveles de calidad del aire establecidos en la legislación nacional o, en ausencia de dichas leyes, cuando exceden considerablemente las Guías de calidad del aire de la OMS; S = contenido de azufre (expresado como porcentaje de la masa); Nm³ a una atmósfera de presión y 0 grados Celsius; la categoría de MWth se aplica a toda la instalación compuesta por múltiples unidades que razonablemente puedan considerarse procedentes de un almacenamiento común. Los límites de las guías se aplican a instalaciones que operan más de 500 horas al año. Los niveles de emisiones deben evaluarse en períodos de una hora y deben cumplirse durante el 95% de las horas de funcionamiento en un año.
- [a] Marcándose como objetivo valores orientativos inferiores y reconocer los problemas derivados de la calidad del combustible disponible, la eficacia en función de los costos de los controles en las unidades más pequeñas y la posibilidad de aumentar la eficiencia de la conversión de energía (la DGC puede consumir entre 0,5% y 1,6% de la electricidad generada por la planta). [b] Marcándose como objetivo valores orientativos inferiores y reconociendo la diversidad de estrategias para la gestión de las emisiones de SO_2 (calidad del combustible versus uso de controles secundarios) y la posibilidad de aumentar la eficiencia de la conversión de energía (la DGC puede consumir entre 0,5% y 1,6% de la electricidad generada por la planta). Se espera que las plantas más grandes tengan medidas adicionales de control de las emisiones. La EA determinará la franja del nivel de emisiones en función de la sostenibilidad del proyecto, el impacto sobre el desarrollo y la eficiencia en función de los costos del control de la contaminación. [c] Las calderas secundarias pueden requerir diferentes valores para las emisiones que deben evaluarse en cada caso mediante el proceso de EA.

Comparación de los límites de las guías con las normas de ciertos países/regiones (a agosto de 2008):

- Calderas de gas natural – NOx
  - Límites de las guías: 240
  - UE: 150 (50 a 300 MWth), 200 (> 300 MWth)
- Calderas de combustible sólido – MP
  - Límites de las guías: 50
  - UE: 50 (50 a 100 MWth), 30 (> 100 MWth), China: 50, India: 100-150
- Calderas de combustible sólido – SO_2
  - Límites de las guías: 900-1.500 (planta > 50 MWth a < 600 MWth), 200-850 (planta ≥ 600 MWth)
  - UE: 850 (50-100 MWth), 200 (> 100 MWth)
  - EE. UU.: 180 ng/J energía bruta producida O reducción del 95% (≈ 200 mg/Nm3 con 6% O_2 asumiendo una eficiencia de PCS de 38%)
  - China: 400 (general), 800 (con carbón < 12.550 kJ/Kg), 1.200 (si la boca de la mina que suministra la planta no se encuentra en una zona de control doble de la región occidental y quema carbón con bajo contenido de S (< 0,5%))

Fuentes: UE (Directiva sobre GIC 2001/80/EC del 23 de octubre de 2001), EE. UU. *(NSPS for Electric Utility Steam Generating Units (Subpart Da), Final Rule* – 13 de junio de 2007), China (GB 13223-2003)

Cuadro 7 – Parámetros/frecuencia habitual de control de las emisiones procedentes de las plantas de energía térmica (Nota: Los detalles de los programas de control deben determinarse en función de la EA).

Tecnología de combustión/combustible	Control de las emisiones: Material particulado (MP)	Control de las emisiones: Dióxido de azufre (SO_2)	Control de las emisiones: Óxidos de nitrógeno (NOx)	Pruebas de emisiones de chimenea: MP	Pruebas de emisiones de chimenea: SO_2	Pruebas de emisiones de chimenea: NOx	Pruebas de emisiones de chimenea: Metales pesados	Calidad del aire ambiente	Ruido
Motor de combustión interna								Si la EA prevé un aumento a corto plazo del impacto >/= 25% con respecto a las normas sobre calidad del aire ambiente o si la planta >/= 1.200 MWth: - Comprobar los parámetros (por ejemplo, $MP_{10}/MP_{2.5}/SO_2/NOx$ compatibles con las normas relevantes sobre calidad del aire ambiente) mediante un sistema de control constante (normalmente un mínimo de dos sistemas para poder cubrir el punto de concentración máxima prevista a nivel del suelo/el receptor sensible/el punto secundario). Si la EA prevé un aumento a corto plazo del impacto >/= 25% con respecto a las normas sobre calidad del aire ambiente y si la planta < 1.200 MWth pero >/= 100 MWth: - Comprobar los parámetros mediante muestreos pasivos (promedio mensual) o mediante muestreos manuales estacionales (por ejemplo, una semana/estación) para los parámetros compatibles con las normas relevantes sobre la calidad del aire. Se debe comprobar regularmente la eficacia del programa de control de la calidad del aire ambiente. Se puede simplificar o reducir si se desarrolla un programa alternativo (por ejemplo, red de controles del gobierno local). Se recomienda la continuación del programa durante el funcionamiento del proyecto si existen receptores sensibles o si los niveles registrados están ligeramente por debajo de las normas relevantes sobre la calidad del aire.	Si la EA prevé niveles de ruido en receptores residenciales u otros receptores sensibles cercanos a las normas/guías relevantes sobre el ruido ambiental, o si dichos receptores se encuentran en las inmediaciones de la planta (por ejemplo, a menos de 100 m) se deben realizar controles del ruido ambiental cada uno, dos o tres años, según las circunstancias del proyecto. Se puede aceptar la eliminación de los controles del ruido si un estudio integral demuestra que el proyecto no afecta a ningún receptor o los niveles de ruido están muy por debajo de las normas/guías relevantes sobre el ruido ambiental.
Gas natural (planta > 50 MWth a < 300 MWth)	N/A	N/A	Constante o indicativo	N/A	N/A	Anual	N/A		
Gas natural (planta >/= 300 MWth)	N/A	N/A	Constante	N/A	N/A	Anual	N/A		
Líquido (planta > 50 MWth a < 300 MWth)	Constante o indicativo	Constante si se usa o controla el contenido de S mediante DGC	Constante o indicativo	Anual					
Líquido (planta >/= 300 MWth)	Constante o indicativo		Constante						
Biomasa	Constante o indicativo	N/A	Constante o indicativo	Anual	N/A	Anual	N/A		
Turbina de combustión									
Gas natural (todos los tipos de turbinas de unidades de > 50MWth)	N/A	N/A	Constante o indicativo	N/A	N/A	Anual	N/A		
Otros combustibles diferentes del gas natural (unidad de > 50MWth)	Constante o indicativo	Constante si se usa o controla el contenido de S mediante DGC	Constante o indicativo	Anual					
Caldera									
Gas natural	N/A	N/A	Constante o indicativo	N/A	N/A	Anual	N/A		
				Anual	Anual	Anual	N/A		
Otros combustibles gaseosos	Indicativo	Indicativo	Constante o indicativo	Anual					
Líquido (planta > 50 MWth a < 600 MWth)	Constante o indicativo	Constante si se usa o controla el contenido de S mediante DGC	Constante o indicativo						
Líquido (planta >/= 600 MWth)		Constante							
Sólido (planta > 50 MWth a < 600 MWth)		Constante si se usa o controla el contenido de S mediante DGC	Constante o indicativo						
Sólido (planta >/= 600 MWth)		Constante							

Nota: Constante o indicativo significa "seguimiento constante de las emisiones o seguimiento constante de parámetros indicativos". Las pruebas de las emisiones de la chimenea sirven para obtener una medición directa de los niveles de emisiones para cotejarla con los registros del sistema de control de emisiones.

2.2 Higiene y seguridad en el trabajo

Guía sobre higiene y seguridad en el trabajo

Para evaluar el desempeño en materia de higiene y seguridad en el trabajo deben utilizarse las guías sobre exposición que se publican en el ámbito internacional, entre ellas: las guías sobre la concentración máxima admisible de exposición profesional (TLV®) y los índices biológicos de exposición (BEIs®) publicados por la American Conference of Governmental Industrial Hygienists (ACGIH)[36], la Guía de bolsillo sobre riesgos químicos publicada por el Instituto Nacional de Higiene y Seguridad del Trabajo de los Estados Unidos (NIOSH)[37], los límites permisibles de exposición publicados por la Administración de Seguridad e Higiene en el Trabajo de los Estados Unidos (OSHA)[38], los valores límite indicativos de exposición profesional publicados por los Estados miembros de la Unión Europea[39], u otras fuentes similares.

Entre los indicadores adicionales específicos para las actividades del sector de la energía eléctrica se encuentran los límites de exposición en el trabajo de la ICNIRP a los campos eléctricos y magnéticos que se recogen en el Cuadro 8. En la Sección 2.0 de las **guías generales sobre MASS** se ofrecen indicadores adicionales aplicables al ruido, los riesgos de origen eléctrico, la calidad del aire, etc.

Cuadro 8 – Límites de la ICNIRP de exposición a los campos eléctricos y magnéticos en el trabajo

Frecuencia	Campo eléctrico (V/m)	Campo magnético (μT)
50 Hz	10.000	500
60 Hz	8.300	415

Fuente: ICNIRP (1998): "*Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)*"

Tasas de accidentes y letalidad

Deben adoptarse medidas para reducir a cero el número de accidentes entre los trabajadores del proyecto (sean empleados directos o personal subcontratado), especialmente los accidentes que pueden causar una pérdida de horas de trabajo, diversos niveles de discapacidad o incluso la muerte. Como punto de referencia para evaluar las tasas del proyecto puede utilizarse el desempeño de instalaciones en este sector en países desarrollados, que se obtiene consultando las fuentes publicadas (por ejemplo, a través de la Oficina de Estadísticas Laborales de los Estados Unidos y el Comité Ejecutivo de Salud y Seguridad del Reino Unido)[40].

Seguimiento de la higiene y la seguridad en el trabajo

Es preciso realizar un seguimiento de los riesgos que pueden correr los trabajadores en el entorno laboral del proyecto concreto. Las actividades de seguimiento deben ser diseñadas y realizadas por profesionales acreditados[41] como parte de un programa de seguimiento de la higiene y la seguridad en el trabajo. En las instalaciones, además, debe llevarse un registro

36 Disponibles en http://www.acgih.org/TLV/ y http://www.acgih.org/store/.

37 Disponible en http://www.cdc.gov/niosh/npg/.

38 Disponibles en http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992.

39 Disponibles en http://europe.osha.eu.int/good_practice/risks/ds/oel/.

40 Disponibles en: http://www.bls.gov/iif/ y http://www.hse.gov.uk/statistics/index.htm.

41 Los profesionales acreditados pueden incluir higienistas industriales certificados, higienistas ocupacionales diplomados o profesionales de la seguridad certificados o su equivalente.

de los accidentes y enfermedades laborales así como de los sucesos y accidentes peligrosos. Las **guías generales sobre MASS** contienen orientaciones adicionales sobre los programas de seguimiento de la higiene y la seguridad en el trabajo.

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Anexo A: Descripción general de las actividades de la industria

En las plantas de energía térmica se queman combustibles fósiles o biomasa para generar energía eléctrica o calor. Un motor de calor produce energía mecánica, que transforma la energía térmica procedente la combustión de un combustible fósil en energía rotacional. Un generador convierte esta energía mecánica en energía eléctrica mediante la creación de una corriente relativa entre un campo magnético y un conductor. En el Gráfico A-1 se presenta un diagrama de flujo general de una planta de energía térmica con calderas y sus operaciones asociadas.

De acuerdo con la segunda ley de la termodinámica, no toda la energía térmica puede transformarse en energía mecánica. Por lo tanto, las plantas de energía térmica también producen calor de baja temperatura. El calor que no se recicla se pierde en el medio ambiente. Si el calor desprendido se reutiliza (por ejemplo, en procesos industriales o calefacción del distrito), la planta se denomina una planta de cogeneración.

Tipos de plantas de energía térmica

Las plantas de energía térmica se pueden clasificar según el tipo de combustión o gasificación: calderas, motores de combustión interna y turbinas de combustión. Además, los sistemas de ciclo combinado y cogeneración aumentan la eficiencia con la utilización del calor desprendido por los sistemas convencionales de combustión. El tipo de sistema se elige en función de las cargas, la disponibilidad de combustibles y los requisitos energéticos de la instalación de generación de electricidad. También se deben realizar otros procesos secundarios, como el procesamiento del carbón y el control de la contaminación, para apoyar la generación de electricidad. En las siguientes subsecciones se describe cada sistema y se analizan los procesos secundarios de la instalación (EPA de los EE. UU., 1997).

Calderas (turbinas de vapor)

Las plantas convencionales de energía térmica que producen vapor generan electricidad en varias fases de conversión de energía: se quema combustible en las calderas para convertir el agua en vapor a alta presión, que se utiliza a su vez para mover una turbina de vapor que genera electricidad. El calor del sistema suele provenir de la combustión del carbón, el gas natural, el petróleo o la biomasa, además de otros tipos de combustibles residuales o reciclados. La caldera genera el vapor a alta temperatura y presión que entra en la turbina. En el otro extremo de la turbina está el condensador, que se mantiene a presión y temperatura bajas. El vapor que pasa de la caldera de alta presión al condensador de baja presión mueve las aspas de la turbina, que alimentan el generador de electricidad.

El vapor a baja presión que sale de la turbina entra en la carcasa del condensador y se condensa en los tubos, que se mantienen a baja temperatura mediante una corriente de agua refrigerante. Cuando el vapor se enfría, el sistema de recirculación de agua de la caldera transporta el vapor condensado para usarlo de nuevo. Es necesario un flujo constante de agua refrigerante a baja temperatura en los tubos del condensador para mantener la presión adecuada en la carcasa (receptora del vapor) y garantizar la eficiencia de la generación de energía. El agua refrigerante se calienta en el proceso de condensación. Si el sistema de refrigeración es abierto y sin recirculación, esta agua templada se vierte de nuevo en la fuente original[42]. En un sistema cerrado, el agua templada se enfría mediante su recirculación en torres de refrigeración, lagos o estanques, y el calor se desprende a la atmósfera mediante evaporación y/o transferencia por contacto.

[42] Si se emplean aguas freáticas para el enfriado, el agua refrigerante suele verterse a un acuífero superficial.

Si se utiliza un sistema de refrigeración con recirculación, sólo es necesario agregar una pequeña cantidad de agua para compensar las pérdidas por evaporación y las descargas de la torre de refrigeración que deben realizarse periódicamente para controlar la acumulación de sólidos. Un sistema de recirculación usa alrededor de una veinteava parte del agua que un sistema abierto sin recirculación.

Las turbinas de vapor suelen tener una eficiencia térmica del 35%, lo que significa que el 35% del calor producido por la combustión se transforma en electricidad. El 65% restante sale por la chimenea (habitualmente el 10%) o se descarga al condensador de agua refrigerante (habitualmente el 55%).

El carbón y el lignito son los combustibles más habituales de las plantas de energía térmica, aunque también se utiliza fuel oil pesado. Los sistemas de generación de vapor mediante carbón están diseñados para el uso de carbón pulverizado o molido. Se utilizan varios tipos de generadores de vapor mediante carbón, que se clasifican generalmente en función de las características del carbón que alimenta los quemadores y el tipo de combustión del carbón. En las calderas con lecho fluido, los materiales son empujados por gas hidrostático. La cámara de gas entre los sólidos hace que las partículas se muevan libremente y fluyan como un líquido. El uso de esta tecnología permite la reducción de las emisiones de SO_2 y NO_X debido al uso eficiente de un absorbente del SO_2, como la piedra caliza. Además, dada la baja temperatura, la formación de gases de NO_X es menor que con tecnología convencional.

El gas natural y los combustibles líquidos se transportan normalmente a las plantas de energía térmica a través de conductos. El carbón y la biomasa pueden transportarse por tren, barcaza o camión. En algunos casos, el carbón se mezcla con agua y se bombea a la planta de energía térmica a través de tuberías. Una vez que el carbón llega a la planta, se lo descarga para pasar a almacenaje o se lo coloca directamente en el fogonero o la tolva. Durante los meses más cálidos y en los climas secos, puede ser necesario eliminar el polvo en el transporte de carbón.

El carbón se puede limpiar y preparar antes de molerlo o pulverizarlo. Las impurezas del carbón como las cenizas, los metales, la sílice y el azufre pueden provocar la acumulación de materiales indeseados y escoria en la caldera. Se puede limpiar el carbón para reducir el contenido de azufre con el fin de cumplir los reglamentos sobre emisiones de dióxido de azufre (SO_2), el contenido de cenizas y la cantidad de metales pesados. La limpieza del carbón tiene un costo elevado, aunque puede compensarse en parte por el aumento de la eficiencia del combustible, la reducción de los requisitos de control de las emisiones y la reducción del costo del manejo de residuos. La limpieza del carbón se realiza habitualmente en la mina mediante concentración por gravedad, flotación o desaguado.

El carbón se transporta a una fosa o silo donde se tritura, muele y seca antes de introducirlo en el quemador o el sistema de combustión. Se puede utilizar múltiples mecanismos para moler el carbón y prepararlo para la combustión. Se utilizan pulverizadores, ciclones y hornos para triturar y secar el carbón. Se aumenta el nivel de partículas de carbón en superficie y se reduce la humedad para potenciar considerablemente su capacidad calorífica. Una vez preparado, el carbón se transporta al sistema de combustión dentro de la planta. Los dispositivos del fondo de la caldera capturan las cenizas y/o la escoria.

Motores de combustión interna

Los motores de combustión interna transforman la energía química de los combustibles (normalmente diésel o fuel oil pesado) en energía mecánica con un sistema similar al de los motores de los camiones, y esta energía mecánica se usa para hacer girar un generador. Normalmente se utilizan dos tipos de motores: motores de pistones de cuatro fases y velocidad

media, y motores de cruceta de dos fases y velocidad baja. Ambos tipos de motores funcionan con el ciclo termodinámico diésel. El aire se absorbe o introduce en un cilindro, donde se comprime mediante un pistón. El combustible se inyecta en un cilindro, donde se enciende mediante el calor generado por la compresión del aire. La mezcla de combustible y aire se expande y empuja el pistón. Los productos de la combustión se extraen del cilindro para completar el ciclo.

Los gases de escape de un motor se ven afectados por el perfil de carga del motor impulsor; las condiciones ambientales, como la humedad y la temperatura del aire; la calidad del fuel oil, como el contenido de azufre, el contenido de nitrógeno, la viscosidad, la capacidad de encendido, la densidad y el contenido de ceniza, y las condiciones de las instalaciones y el equipo auxiliar asociado con el impulsor principal, como las propiedades de refrigeración y la presión del gas de escape. Los parámetros del motor que afectan a las emisiones de NO_X son los tiempos, la duración y la atomización del combustible de inyección; las condiciones del aire de combustión, asociadas a los tiempos de la válvula, el sistema de carga de aire y el enfriamiento del aire antes de entrar a los cilindros, y el proceso de combustión, asociado a la mezcla de aire y combustible, el diseño de la cámara de combustión y la tasa de compresión[43]. Las emisiones de material particulado dependen de las condiciones generales del motor, especialmente el sistema de inyección de combustible y su mantenimiento, además del contenido de ceniza, que puede oscilar entre el 0,05% y el 0,2%. Las emisiones de SOx dependen directamente del contenido de azufre en el combustible. El fuel oil puede contener desde 0,3% de azufre hasta 5% de azufre en algunos casos.

Los motores diésel pueden emplear diversos combustibles como diésel, fuel oil pesado, gas natural, petróleo crudo, biocombustibles (como aceite de palma, etc.) y combustibles emulsionados (como Orimulsion, etcétera).

Las eficiencias eléctricas habituales en una fase van del 40% para los motores de media velocidad al 50% para motores grandes, e incluso mayores en el caso del ciclo combinado. La eficiencia total de la cogeneración en funcionamiento líquido llega a entre el 60% y el 80% y aún más con combustión de gas, según la aplicación. La proporción de calor por energía es normalmente de 0,5 a 1,3 en instalaciones de cogeneración, según la aplicación.

Motores de mezcla pobre de gas

Las eficiencias eléctricas habituales de los motores estacionarios más grandes con velocidades medias en ciclo simple suelen ser del 40% al 47% hasta 50% en ciclo combinado. La eficiencia total de las instalaciones de cogeneración suele llegar hasta el 90%, según la aplicación. La proporción de calor por energía es normalmente de 0,5 a 1,3 en instalaciones de cogeneración, según la aplicación.

Encendido de chispa (EC)

Es frecuente que los motores de gas con encendido de chispa funcionen de acuerdo con la técnica de mezcla pobre, lo que significa que se quema una mezcla pobre de aire y combustible dentro del cilindro (es decir, mucho más aire que el necesario para la combustión). En los motores más grandes, se utiliza un inyector con una mezcla más rica de aire y combustible para estabilizar el encendido y la combustión de la mezcla pobre. El encendido se genera con una bujía o algún otro dispositivo situado en el inyector, lo que produce una fuente de encendido con mucha energía para la carga principal de combustible del cilindro. El parámetro más importante que influye en la tasa de formación de NOx en los motores de combustión interna es la

[43] Si se inyecta el combustible demasiado pronto, aumentará la presión del cilindro, lo que incrementará la formación de óxido de nitrógeno. Si la inyección se produce demasiado tarde, aumentará el consumo de combustible y la velocidad del turbocompresor. Se pueden reducir las emisiones de NO_X retrasando la inyección, aunque esto aumentará el material particulado y los componentes no quemados.

temperatura de combustión; cuanto más elevada sea la temperatura mayor será el contenido de NOx en los gases de escape. Una manera de controlarla es disminuir la proporción de combustible/aire en la mezcla. Con la misma cantidad específica de calor desprendida por la combustión se puede calentar una mayor cantidad de gases de escape y reducir la temperatura máxima de combustión. Este método se denomina "combustión de mezcla pobre estratificada" y contribuye a la reducción eficiente del NOx. Por lo tanto, el motor de mezcla pobre con encendido de chispa genera pocas emisiones de NOx. Se trata de un motor puramente de gas, que sólo funciona con combustibles gaseosos.

Motores de combustible dual (CD)

Algunos tipos de motores de CD se adaptan a diversos combustibles y pueden funcionar con gas natural a baja presión o combustibles líquidos como el diésel (como combustible de apoyo, etc.), fuel oil pesado, etc. Este tipo de motor puede funcionar a pleno rendimiento en ambos modos. Los motores de CD también se pueden diseñar para que funcionen solamente en modo de gas con un combustible líquido para el encendido.

Turbinas de combustión

Los sistemas de turbinas de gas funcionan de manera similar a los sistemas de turbinas de vapor, con la diferencia de que se utilizan gases de combustión para hacer girar las aspas en lugar de vapor. Además del generador eléctrico, la turbina también hace girar un compresor de presurización del aire, que se mezcla con el gas o el combustible líquido en una cámara de combustión. Cuanta mayor sea la compresión, mayores serán la temperatura y la eficiencia alcanzables en la turbina de gas. Sin embargo, el aumento de la temperatura suele provocar incrementos de las emisiones de NO_X. La turbina emite gases de escape a la atmósfera. A diferencia de los sistemas de turbinas de vapor, los sistemas de turbinas de gas no tienen calderas ni entrada de vapor, condensadores ni un sistema de desecho del calor residual. Por lo tanto, los costos de capital son mucho más bajos para un sistema de turbina de gas que para un sistema de vapor.

Las turbinas de gas suelen emplearse para los picos de generación eléctrica, en los que se requieren encendidos rápidos y períodos de funcionamiento cortos. La mayoría de las turbinas de gas simples sin controles sólo tienen una eficiencia del 20% al 30%.

Ciclo combinado

En el ciclo combinado se utilizan tanto turbinas de gas como generadores de vapor. En una turbina de gas de ciclo combinado (TGCC) se aprovecha una parte o todos los gases de escape para calentar la caldera, que produce vapor para la turbina de vapor. Esta combinación aumenta la eficiencia térmica hasta alrededor del 50% al 60%. En los sistemas de ciclo combinado se puede alimentar una turbina de vapor con múltiples turbinas de gas. A veces también se usan motores diésel y generadores de vapor en los sistemas de ciclo combinado.

Además, se están desarrollando nuevas tecnologías de ciclo combinado con gasificación integrada (CCGI) En un sistema de CCGI se genera y se limpia el carbón gaseoso en un "gasificador" a presión, lo que reduce las emisiones y el material particulado[44]. En el sistema de generación de energía con TGCC se quema el gas del carbón.

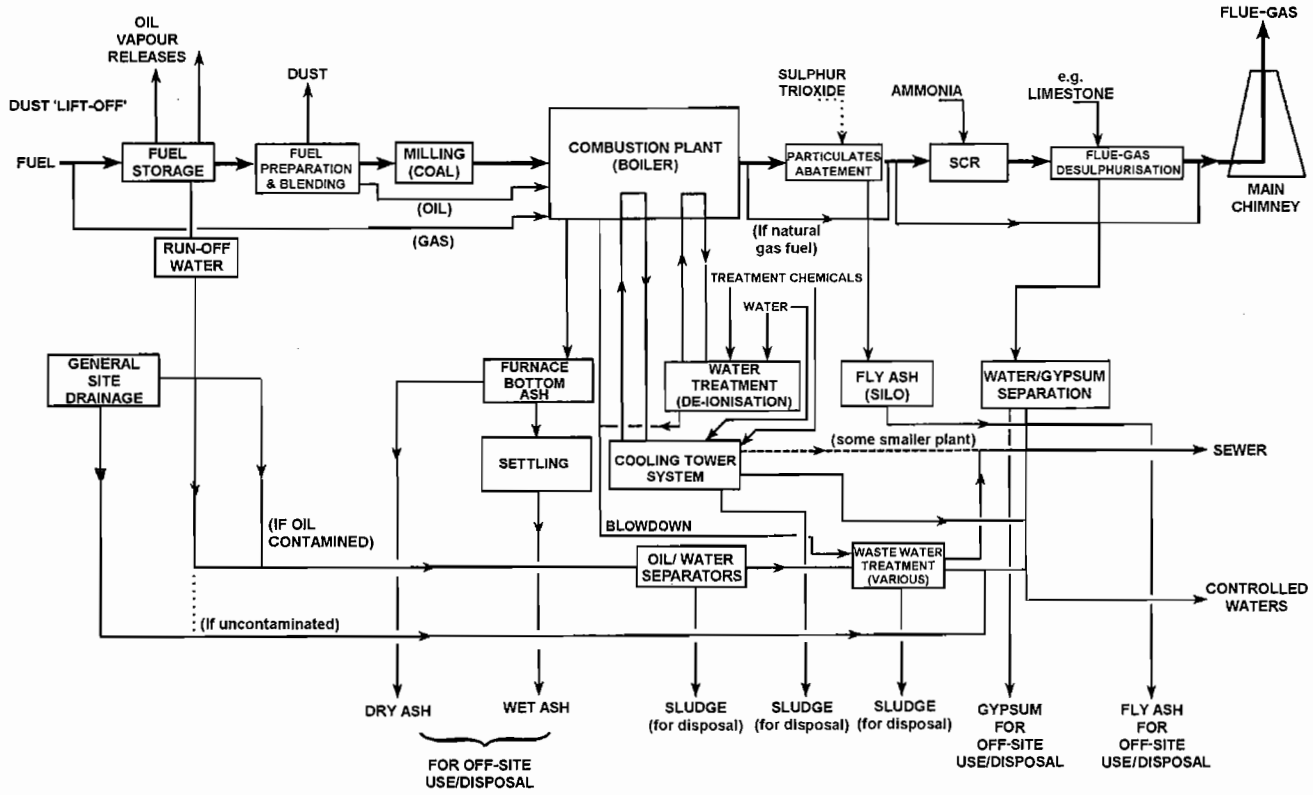
Cogeneración

La cogeneración consiste en la combinación de un sistema de producción de energía eléctrica con un sistema de producción de calor y vapor para la industria y/o la calefacción municipal. Se trata de una manera más eficiente de aprovechar los aportes

[44] La gasificación es un proceso que consiste en la transformación del carbón en gas mediante oxígeno, aire o vapor.

de energía y permite la recuperación para un proceso industrial de una energía térmica que se desaprovecharía de otro modo. Las tecnologías de cogeneración se clasifican en sistemas de ciclo superior y de ciclo inferior, según se genere primero energía eléctrica (ciclo superior) o térmica (ciclo inferior). La mayoría de los sistemas de cogeneración son de ciclo superior.

Gráfico A-1
Diagrama de flujo general de una planta de energía térmica[45] y operaciones asociadas



Fuente: CE, 2006.

[45] Sólo es aplicable a una planta de calderas con torre de refrigeración. Este diagrama no es aplicable a motores y turbinas con una configuración completamente diferente.

Anexo B: Orientaciones para la evaluación ambiental de proyectos de energía térmica

El desarrollo de una evaluación ambiental (EA) de un proyecto de energía térmica debe tener en cuenta todas las políticas y estrategias oficiales sobre energía y/o medio ambiente, incluidos aspectos estratégicos tales como la mejora de la eficiencia energética en los sistemas existentes de generación, transmisión y distribución, la gestión de la demanda, la ubicación del proyecto, la elección de combustibles y la tecnología, y el desempeño ambiental.

Nuevas instalaciones y ampliación de las instalaciones existentes

La EA de nuevas instalaciones o la evaluación y auditoría ambiental de instalaciones existentes debe realizarse en una fase temprana del ciclo del proyecto, para poder establecer los niveles de emisiones para cada instalación y otras medidas para las plantas nuevas o la ampliación de plantas existentes. En el Cuadro B-1 se presentan los elementos esenciales recomendados de la EA, cuyo alcance dependerá de las circunstancias de cada proyecto.

Cuadro B-1 – Elementos esenciales de MASS recomendados para una EA de una nueva planta de energía térmica

Análisis de alternativas	• Selección de combustibles, que incluye opciones no fósiles (carbón, petróleo, gas, biomasa, otras opciones renovables como energía eólica, solar, geotérmica, hidro), fuentes de abastecimiento de combustible • Tecnología de generación de energía o Eficiencia de la generación térmica (PCS-bruto, PEC-bruto, PCS-neto, PEC-neto) o Costo o Desempeño de las emisiones de CO_2 (gCO2/kWh) • Reducción de las emisiones de GEI/opciones de compensación o Eficiencia de la conversión de energía o Mecanismo de compensación o Uso de fuentes de energía renovables, etc. • Calidad básica de los acuíferos receptores • Suministro de agua o Aguas superficiales, freáticas o desalinización • Sistema de refrigeración o Sistema abierto sin recirculación, húmedo de circuito cerrado, de aire seco de circuito cerrado • Sistema de desecho de cenizas: por vía húmeda versus en seco • Control de la contaminación o Emisiones a la atmósfera: tratamiento primario versus secundario del gas de combustión (costo, desempeño) o Efluentes (costo, desempeño) • Vertido de efluentes o Aguas superficiales o Evaporación o Reciclaje sin vertido • Ubicación o Consideración de la adquisición de terrenos o Acceso a combustible/red eléctrica o Designación zonal actual y futura del terreno o Base ambiental existente y previsible (aire, agua, ruido)
Evaluación del impacto	• Evaluación de las emisiones de GEI (tCO_2/año, gCO_2/kWh) • Impacto sobre la calidad del aire o SO_2, NO_2, MP_{10}, $MP_{2.5}$, metales pesados cuando sea apropiado y lluvia ácida si es pertinente o Incremento de los impactos para el cumplimiento de las normas relevantes sobre calidad del aire o Superposición de isolíneas de concentración (a corto plazo, promedio anual, lo que sea más adecuado) en los mapas de uso del terreno y topográficos

	○ Impactos acumulados de las fuentes existentes/futuros proyectos, cuando se conozcan ○ Determinación de la altura de la chimenea ○ Consideración del impacto sobre la salud • Impacto sobre la calidad/el abastecimiento de agua ○ Vertido térmico si se usa un sistema abierto sin recirculación ○ Otros contaminantes esenciales cuando sea apropiado ○ Impacto sobre el abastecimiento de agua • Impacto acústico ○ Superposición de las delimitaciones del ruido en el mapa de uso del terreno y ubicación de los receptores • Determinación de las medidas de prevención y reducción de la contaminación
Medidas de mitigación/programa de gestión	• Aire (altura de la chimenea, medidas de control de la contaminación, costo) • Efluentes (medidas de tratamiento de las aguas residuales, costos) • Ruido (medidas de control del ruido, costo) • Reciclaje/eliminación de desechos (por ejemplo, cenizas, derivados de la DGC, petróleo usado) ○ Plan de manejo de las cenizas (equilibrio cuantitativo de la generación de cenizas, desecho, utilización, tamaño del vertedero de cenizas, sistema de transporte de cenizas) • Sistema de abastecimiento de combustible • Plan de preparación y respuesta ante emergencias • Evaluación del riesgo industrial, si procede
Programa de seguimiento	• Parámetros • Frecuencia de muestreo • Criterios de evaluación • Superposición de los puntos de muestreo en los mapas relevantes de la instalación/alrededores • Costo

Las tareas relacionadas con el análisis del impacto de la calidad de la EA deben incluir:

- Recolección de información básica que abarque desde información cualitativa relativamente simple (para los proyectos más pequeños) a datos cuantitativos más exhaustivos (para proyectos más grandes) sobre ciertos parámetros de concentración en la atmósfera y temporales compatibles con las normas relevantes sobre calidad del aire del país en cuestión (por ejemplo, parámetros tales como MP_{10}, $MP_{2.5}$, SO_2 (para las plantas de petróleo y carbón), NO_X y ozono a nivel terrestre, y promedios de tiempo máximo de una hora a 24 horas, y promedios anuales), dentro de una cuenca atmosférica afectada por el proyecto propuesto[46];
- Evaluación de la calidad básica de la cuenca atmosférica (por ejemplo, degradada o no degradada);
- Evaluación de la calidad básica del agua, cuando sea relevante;
- Uso de modelos matemáticos o físicos apropiados de la dispersión de la calidad del aire para estimar el impacto del proyecto en las concentraciones de estos contaminantes en la atmósfera;
- Cuando se considere que la lluvia ácida puede tener un impacto significativo, uso de modelos adecuados sobre la calidad del aire para evaluar los efectos de larga distancia y transfronterizos de la lluvia ácida;
- El alcance de la información básica recabada y la evaluación del impacto sobre la calidad del aire dependerá de las circunstancias del proyecto (es decir, tamaño del proyecto, cantidad de emisiones a la atmósfera y los

[46] Por "cuenca atmosférica" se entiende la zona local que rodea la planta cuya calidad del aire está directamente afectada por las emisiones de la planta. El tamaño de la cuenca atmosférica en cuestión dependerá de las características de la planta, como la altura de la chimenea y las condiciones meteorológicas y topográficas locales. En algunos casos, la legislación o las autoridades ambientales competentes definen las cuencas atmosféricas. En caso contrario, la EA debe definir claramente la cuenca atmosférica sobre la base de consultas con los responsables locales de la gestión ambiental.

posibles impactos en la cuenca atmosférica). En el Cuadro B-2 se ofrecen ejemplos de prácticas recomendadas.

Cuadro B-2 – Estrategia de evaluación recomendada del impacto sobre la calidad del aire	
Datos básicos sobre calidad del aire	• Información cualitativa (para proyectos pequeños, por ejemplo, < 100MWth) • Muestreo manual estacional (para proyectos de tamaño medio, por ejemplo, < 1.200MWth) • Muestreo constante automático (para proyectos grandes, por ejemplo, >/= 1.200MWth) • Modelización de fuentes existentes
Datos básicos meteorológicos	• Datos continuados de un año sobre el modelo de dispersión obtenidos en una estación meteorológica cercana (por ejemplo, aeropuerto, estación meteorológica) o una estación dentro de las instalaciones de proyectos medianos o grandes
Evaluación de la calidad de la cuenca atmosférica	• Determinar si la cuenca está degradada (es decir, si no se cumplen las normas de calidad del aire) o no degradada (es decir, se cumplen las normas de calidad del aire)
Evaluación del impacto sobre la calidad del aire	• Evaluar los incrementos y los niveles resultantes mediante modelos de selección (para pequeños proyectos) • Evaluar los incrementos y los niveles resultantes mediante modelos de refinado (para proyectos medianos o grandes, o para modelos pequeños, si se determina la necesidad después de aplicar el modelo de selección)[47] • Si fuera necesario, modificar los niveles de emisiones para garantizar que el incremento del impacto sea pequeño (por ejemplo, 25% de los niveles de las normas relevantes sobre calidad del aire) y que no se degrade la cuenca atmosférica

Cuando existan probabilidades razonables de expansión de la planta de energía o incremento significativo de otras fuentes de contaminación a mediano o largo plazo, el análisis debe tener en cuenta el impacto del diseño propuesto tanto inmediatamente como después de la ampliación de la capacidad y el aumento de otras fuentes de contaminación. El diseño de la planta debe contemplar la posibilidad de instalar equipos adicionales de control de la contaminación en el futuro, si resultara necesario o deseable en función de los impactos previstos en la calidad del aire y/o cambios en las normas sobre emisiones (por ejemplo, para los países que van a formar parte de la UE). La EA debe abordar también otras preocupaciones ambientales específicas del proyecto, como el combustible y las emisiones procedentes de las impurezas del combustible. En los casos en que estas impurezas provoquen emisiones que se sepa que son peligrosas, la EA debe estimar la cantidad de emisiones, evaluar los impactos y proponer medidas de mitigación para reducirlas[48]. Entre los componentes que pueden estar presentes en ciertos tipos de carbón, fuel oil pesado, coque de petróleo, etcétera, están el cadmio, el mercurio y otros metales pesados.

Rehabilitación de las instalaciones existentes

Se debe llevar a cabo una evaluación ambiental del proyecto de rehabilitación propuesto en una fase temprana del proceso de preparación para poder tener la oportunidad de valorar opciones alternativas antes de adoptar decisiones fundamentales. La evaluación debe incluir una auditoría ambiental en la que se examinen los impactos de las

[47] Para obtener más información sobre modelos de refinado/selección, véase el apéndice W de la Parte 51 de las Directrices sobre modelos de calidad del aire de la EE. UU. EPA (Decisión final del 9 de noviembre de 2005).

[48] Varios estados de los Estados Unidos han adoptado reglamentos que ofrecen a las plantas de generación de energía mediante carbón la opción de cumplir una norma sobre emisiones de mercurio basada en la energía producida o en las medidas de control. Por ejemplo, el estado de Illinois exige a las plantas termoeléctricas con una capacidad de producción igual o superior a 25 MW que no sobrepasen un nivel de emisiones de 0,0080 lbs de mercurio por gigavatio por hora (GWh) de producción de electricidad bruta o que las emisiones de mercurio no superen el 90% del mercurio procesado.

operaciones existentes en la planta en las poblaciones y los ecosistemas cercanos, complementada con una EA que examine los diferentes impactos resultantes de un diseño alternativo de la rehabilitación, y los costos estimados de capital y explotación asociados a cada opción. En función de la escala y las características de la rehabilitación, la evaluación/auditoría ambiental puede tener un alcance relativamente limitado y concentrarse solamente en un número reducido de aspectos afectados por el proyecto, o puede ser tan extensa como la necesaria para la construcción de una nueva instalación en el mismo lugar. Normalmente, se ocupará de los siguientes aspectos:

- Calidad ambiental de la cuenca atmosférica o hidrográfica afectada por la planta, junto con estimaciones aproximadas de la contribución de la planta a la carga total de emisiones de los contaminantes más preocupantes;
- El impacto de la planta, en las condiciones de funcionamiento actual y con diferentes alternativas de rehabilitación, en la calidad del aire y el agua asociados con poblaciones y ecosistemas sensibles cercanos;
- Los posibles costos que conlleva el cumplimiento de normas alternativas sobre emisiones u otros objetivos ambientales para el conjunto o actividades específicas de la planta;
- Recomendación de una serie de medidas eficaces en función de los costos para mejorar el desempeño ambiental de la planta, en el contexto del proyecto de rehabilitación, y las normas sobre emisiones y otros requisitos relacionados con la adopción de medidas específicas.

Estas cuestiones deben tratarse con un nivel de detalle adecuado a las características y la escala del proyecto propuesto. Si la planta está ubicada en una cuenca atmosférica o hidrográfica contaminada como consecuencia de las emisiones procedentes de diferentes fuentes, entre ellas, la propia planta, se deben comparar los costos relativos de la reducción de las emisiones de la planta con los de la reducción de las emisiones de otras fuentes para mejorar la calidad del aire y el agua.

Dust "Lift-off"	Levantamiento de polvo
Oil Vapour Releases	Emisiones de vapor de petróleo
Fuel	Combustible
Fuel Storage	Almacenamiento de combustible
Fuel Preparation & Blending	Preparación y mezcla de combustible
Dust	Polvo
Milling (Coal)	Molido (carbón)
(Oil)	(Petróleo)
Combustion Plant (Boiler)	Planta de combustión (caldera)
Particulates Abatement	Reducción de partículas
Sulphur Trioxide	Trióxido de azufre
SCR	RCS
Ammonia	Amoníaco
Flue-Gas Desulphurisation	Desulfurización del gas de combustión
e.g. Limestone	Por ejemplo, piedra caliza
Main Chimney	Chimenea principal
Flue-Gas	Gas de combustión
Run-off Water	Agua de escorrentía
(Gas)	(gas)
(If natural gas fuel)	(si el combustible es gas natural)
Treatment Chemicals	Sustancias químicas para tratamiento
Water	Agua
General site drainage	Drenaje general de las instalaciones
Furnace bottom ash	Cenizas depositadas en el horno
Water treatment (de-ionisation)	Tratamiento del agua (desionización)
Fly ash (silo)	Cenizas volantes (silo)
Water/gypsum separation	Separación de agua y yeso
Settling	Estabilización
Cooling tower system	Sistema de torre de refrigeración
(some smaller plant)	(alguna planta más pequeña)
Sewer	Alcantarillado
(If oil contaminated)	(Si está contaminado con petróleo)
Blowdown	Escape de agua
Oil/water separators	Separadores de agua y aceite
Waste water treatment (various)	Tratamiento de aguas residuales (varios)
Controlled waters	Aguas controladas
Dry ash	Cenizas secas
Wet ash	Cenizas húmedas
For off-site use/disposal	Para su uso/desecho fuera de las instalaciones
Sludge (for disposal)	Lodos (para desecho)
Sludge (for disposal)	Lodos (para desecho)
Sludge (for disposal)	Lodos (para desecho)
Gypsum for off-site use/disposal	Yeso para uso/desecho fuera de las instalaciones
Fly ash for off-site use/disposal	Cenizas volantes para uso/desecho fuera de las instalaciones

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Using CALPUFF to evaluate the impacts of power plant emissions in Illinois: model sensitivity and implications

Jonathan I. Levy[a,*], John D. Spengler[a], Dennis Hlinka[b], David Sullivan[b], Dennis Moon[c]

[a] *Department of Environmental Health, Harvard School of Public Health, Landmark Center, P.O. Box 15677, Boston, MA 02115, USA*
[b] *Sullivan Environmental Consulting, 1900 Elkin St. Suite 240, Alexandria, VA 22308, USA*
[c] *SSESCO, 3490 Lexington Ave. N. Suite 110, Shoreview, MN 55126, USA*

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Abstract

Air pollution emissions from older fossil-fueled power plants are often much greater than emissions from newer facilities, in part because older plants are exempt from modern emission standards required of new plants under the Clean Air Act. To quantify potential health benefits of emission reductions, there is a need to apply atmospheric dispersion models that can estimate the incremental contributions of power plants to ambient concentrations with reasonable accuracy over long distances. We apply the CALPUFF atmospheric dispersion model with meteorological data derived from NOAA's Rapid Update Cycle model to a set of nine power plants in Illinois to evaluate primary and secondary particulate matter impacts across a grid in the Midwest. In total, the population-weighted annual average concentration increments associated with current emissions are estimated to be $0.04\,\mu g\,m^{-3}$ of primary fine particulate matter ($PM_{2.5}$), $0.13\,\mu g\,m^{-3}$ of secondary sulfate particles, and $0.10\,\mu g\,m^{-3}$ of secondary nitrate particles (maximum impacts of 0.3, 0.2, and $0.2\,\mu g\,m^{-3}$, respectively). The aggregate impact estimates are moderately insensitive to parametric assumptions about chemical mechanism, wet/dry deposition, background ammonia concentrations, and size of the receptor region, with the largest uncertainties related to nitrate particles and long-range transport issues. Additional uncertainties may be associated with inherent limitations of CALPUFF, but it appears likely that the degree of uncertainty in atmospheric modeling will not dominate the total uncertainty associated with health impact or benefit estimation. Although the annual average concentration increments from a limited number of sources are relatively small, the large population affected by long-range transport and the number of power plant sources around the US imply potentially significant public health impacts using standard epidemiological assumptions. Our analysis demonstrates an approach that is applicable in any setting where source controls are being evaluated from a public health or benefit-cost perspective. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Health effects; Particulate matter; Meteorological modeling; Power plants; Uncertainty analysis

1. Introduction

Under the Clean Air Act, older power plants have not been compelled to meet the same requirements as new facilities, based in part on the assumption that control costs would be excessive and older plants would soon be phased out (Ackerman et al., 1999). However, the unintended consequence of this "grandfathering" has been reduced capital turnover and an extended lifetime for older facilities (Maloney and Brady, 1988; Nelson et al., 1993). As a result, pre-1980 coal-fired power plants currently contribute about half of the electricity generation in the US and are responsible for 97% of power plant sulfur dioxide (SO_2) and 85% of power

*Corresponding author. Tel.: +1-617-384-8808; fax: +1-617-384-8859.
E-mail address: jilevy@hsph.harvard.edu (J.I. Levy).

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Estimating population exposure to power plant emissions using CALPUFF: a case study in Beijing, China

Ying Zhou[a,*], Jonathan I. Levy[b], James K. Hammitt[c], John S. Evans[c]

[a] 6900 Strathmore Street, #125, Chevy Chase, MD 20815, USA
[b] Harvard School of Public Health, Landmark Center, Room 404 K, P.O. Box 15677, Boston, MA 02215, USA
[c] Harvard Center for Risk Analysis, 718 Huntington Ave., Boston, MA 02115, USA

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Abstract

Epidemiological studies have shown a significant association between ambient particulate matter (PM) exposures and increased mortality and morbidity risk. Power plants are significant emitters of precursor gases of fine particulate matter. To evaluate the public health risk posed by power plants, it is necessary to evaluate population exposure to different pollutants. The concept of intake fraction (the fraction of a pollutant emitted that is eventually inhaled or ingested by a population) has been proposed to provide a simple summary measure of the relationship between emissions and exposure. Currently available intake fraction estimates from developing countries used models that look only at the near field impacts, which may not capture the full impact of a pollution source. This case study demonstrated how the intake fraction of power plant emissions in China can be calculated using a detailed long-range atmospheric dispersion model—CALPUFF. We found that the intake fraction of primary fine particles is roughly on the order of 10^{-5}, while the intake fractions of sulfur dioxide, sulfate and nitrate are on the order of 10^{-6}. These estimates are an order of magnitude higher than the US estimates. We also tested how sensitive the results were to key assumptions within the model. The size distribution of primary particles has a large impact on the intake fraction for primary particles while the background ammonia concentration is an important factor influencing the intake fraction of nitrate. The background ozone concentration has a moderate impact on the intake fraction of sulfate and nitrate. Our analysis shows that this approach is applicable to a developing country and it provides reasonable population exposure estimates.

Keywords: Intake fraction; Atmospheric dispersion modeling; Particulate matter; Power plants; Air pollution; China

1. Introduction

Epidemiological studies have shown a significant association between both short- and long-term ambient particulate matter (PM) exposures and increased mortality (e.g., death due to heart and lung disease) and morbidity risk (e.g., cardiovascular disease, pneumonia, chronic obstructive pulmonary disease) (Pope et al., 2002; Samet et al., 2000; Dockery et al., 1993).

Power plants are significant emitters of sulfur dioxide (SO_2) and nitrogen oxides (NO_x), which are harmful at high concentrations and contribute to the formation of atmospheric fine particulates. For example, an estimated 12 million tons of SO_2 was emitted from coal-fired power plants in the US in 1996, which accounts for about 65 percent of the total estimated SO_2 emissions in the US (EPA, 1999). In China, an estimated 7 million tons of SO_2 was emitted from coal-fired power plants in 1996, which accounts for 35 percent of SO_2 emissions

*Corresponding author. Present address. Harvard University Center for the Environment, China Project, Cruft Lab. 212, 19 Oxford Street, Cambridge, MA 02138, USA.
E-mail address: yzhou@hsph.harvard.edu (Y. Zhou).

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Air quality impacts of power plant emissions in Beijing

Jiming Hao*, Litao Wang, Minjia Shen, Lin Li, Jingnan Hu

Department of Environmental Science and Engineering, Tsinghua University, Beijing 100084, P.R. China

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CALMET/CALPUFF modeling estimates sizeable reductions in SO_2, PM_{10} and NO_x pollution from power plants by 2008 for Beijing.

Abstract

The CALMET/CALPUFF modeling system was applied to estimate the air quality impacts of power plants in 2000 and 2008 in Beijing, and the intake fractions (IF) were calculated to see the public health risks posed. Results show that in 2000 the high emission contribution induced a relatively small contribution to average ambient concentration and a significant impact on the urban area (9.52 μg/m^3 of SO_2 and 5.29 μg/m^3 of NO_x). The IF of SO_2, NO_x and PM_{10} are 7.4×10^{-6}, 7.4×10^{-6} and 8.7×10^{-5}, respectively. Control measures such as fuel substitution, flue gas desulfurization, dust control improvement and flue gas denitration planned before 2008 will greatly mitigate the SO_2 and PM_{10} pollution, especially alleviating the pressure on the urban area to reach the National Ambient Air Quality Standard (NAAQS). NO_x pollution will be mitigated with 34% decrease in concentration but further controls are still needed.

Keywords: Power plants; Air quality; Beijing; CALPUFF; Intake fraction

1. Introduction

Although air pollution in Beijing has obviously been mitigated since 1998, it still faces a long way and big challenges in air quality improvement (Hao and Wang, 2005). Coal-dominated energy structure is one of the major causes of air pollution in Beijing and power plants take about one third of the total coal consumptions. It is estimated that Beijing's power plants emitted 49% of the total SO_2 emission and those of NO_x and PM_{10} are 27% and 11%, respectively (He et al., 2003). Evaluating the air quality impact of these power plants is a necessary step in the design of a comprehensive cost-effective air pollution control strategy in Beijing. There are several relevant pieces of research into this area (Hao et al., 2002; Xue et al., 2003a,b). In the studies of Xue et al. (2003a,b), a single power plant was evaluated which showed the power plant induced high SO_2 and NO_x concentrations in the near area but had a small influence to the central urban area of Beijing. In the study of Hao et al. (2002) air pollution of SO_2, NO_x and PM_{10} from all the anthropogenic sources was modeled but only the urban area, 11% of whole Beijing area, was covered. All the studies applied the ISC model with meteorological data from one station. The impact of this large-emission sector on Beijing's air quality needs further assessment.

Air pollution in Beijing has been a high-profile issue for the local and national government especially since it was selected to host the 2008 Olympics. Since December 1998 the Beijing municipal government has implemented 10 stages of comprehensive emergency control measures and a series of new local emission standards were promulgated and implemented to mitigate the SO_2, NO_x and PM pollution from coal burning, industry, vehicle exhaust and fugitive dust (Hao and Wang, 2005). From then on the cleaner combustion and flue gas treatment in power plants have been taken step by step, including dust control improvement, closure of high-pollution small

* Corresponding author. Tel.: +86 10 6278 2195; fax: +86 10 6277 3650.
E-mail address: hjm-den@mail.tsinghua.edu.cn (J. Hao).

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Primary air pollutant emissions of coal-fired power plants in China: Current status and future prediction

Yu Zhao, Shuxiao Wang, Lei Duan, Yu Lei, Pengfei Cao, Jiming Hao*

Department of Environmental Science and Engineering, Tsinghua University, Beijing 100084, China

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ABSTRACT

To explore the atmospheric emissions of coal-fired power sector in China, a unit-based method was developed based on detailed information of unit type, fuel quality, emission control technology, and geographical location. During 2000–2005, the period when power sector developed fastest in the past 20 years, SO_2, NO_x and PM emissions of coal-fired power plants increased by 1.5, 1.7 and 1.2 times, respectively. The SO_2, emission of coal-fired power sector was estimated to be 16097 kt in 2005, and would decrease to 11801 kt in 2010, attributed mainly to the wide application of the flue gas desulfurization (FGD) technology. The NO_x emission, however, would increase from 6965 kt in 2005 to 9680 kt in 2010, since few NO_x control measures would be taken during the five years. The TSP, PM_{10}, and $PM_{2.5}$ emissions in 2005 were estimated to be 2774, 1842 and 994 kt, and the values would be 2540, 1824 and 1090 kt in 2010 respectively. The wet FGD would play an important role on dust emission removal. Through faithful implementation of closing small units and emission control policies in the acid rain and sulfur dioxide control zones, approximately 33%, 6% and 25% of SO_2, NO_x, and TSP emissions respectively could be further reduced in 2010. Emissions in 2015 and 2020 of coal-fired power plants were predicted applying scenario analysis. For SO_2 and TSP, optimistic situation can be achieved through reasonable control policies; in contrast, NO_x would probably be a more serious issue in future.

1. Introduction

Coal-fired power plant has been considered as a very important source of regional air pollution and ecosystem acidification, due to its huge emissions of acidic pollutants. A series of studies have used top-down method to estimate the emissions of SO_2 (Wang, 2001; Streets et al., 2003; Ohara et al., 2007), NO_x (Hao et al., 2002; Tian, 2003; Streets et al., 2003; Ohara et al., 2007; Zhang et al., 2007a) and PM (Zhang et al., 2007b; Yi, 2006a) from Chinese power sector around year 2000 or before. On one hand, most of those studies treated power plant as one single sector in an anthropogenic emission inventory framework. They generally ignored the discrepancy of technology and fuel characters among power units of different types, which can be of great effect on emission levels. On the other hand, those studies did not reflect the rapid increase of coal consumption and electricity generation since 2000, and the results were no longer applicable for policy making in the future. With increasing environmental pressure, Chinese government has made the decision that coal-fired power sector would be the most important source of regional atmospheric emission abatement in the near future, and power plants are thus anticipated to face more stringent environmental regulations related to siting and operation. To supply a clear emission picture of power sectors for policy making, this study explored the current and historical emissions of power plants as well as the emission

* Corresponding author. Tel.: +86 10 62782195; fax: +86 10 62773650.
E-mail address: hjm-den@tsinghua.edu.cn (J. Hao).

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Atmospheric environmental protection in China: Current status, developmental trend and research emphasis

Honghong Yi[a,*], Jiming Hao[a,*], Xiaolong Tang[b]

[a]Department of Environmental Science and Engineering, Tsinghua University, 100084 Beijing, China
[b]School of Science and Technology, Beijing Institute of Technology, 100081 Beijing, China

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Abstract

Atmospheric environmental quality in China has been improving due to a variety of programs implemented by the Chinese government in recent decades. However, air pollution is still serious because of rapid socioeconomic development and increased energy consumption. Atmospheric environmental problems appear to be complex and regional in nature, and China's climate is aggravated by global climatic change. Air pollution originates from multiple sources and the effect on public human health will increase. The influence of acid rain in southern China will be long term, and the impact of climate change will rise. In order to reduce the adverse effects of air pollutants on the environment, the total number of emission sources from major industry, fine particle pollutants, SO_2 emissions from power plants and the vehicle exhaust must be lowered and strictly controlled. The energy structure will affect the quality of the atmosphere for a long time. Increased energy efficiency, optimization of energy structure and the generation of a sustainable consumption and production patterns will provide opportunities to resolve regional and the global environmental problems.

Keywords: Atmosphere; Environmental protection; China

1. Introduction

Air pollution is a serious environmental problem worldwide, especially in the developing countries like China. Most cities suffer from poor air quality, which has received increasing attention in the past decade (Mayer, 1999). Since the late 1970s when China started its economic reform, it has achieved rapid socioeconomic growth, industrialization, increased energy consumption and urbanization. The urban population increased by 15% from 1990 to 2004 (NBSC, 2005a). The total energy consumption of China increased about 200% from 1980 to 2004, as shown in Fig. 1 (NBSC, 2005b). Urbanization has improved societal development, industrialization and the modernization of the nation; however, it has led to substantial pressure on public facilities and natural resources. As a result, air pollution in many cities has deteriorated since the 1980s. To prevent the urban atmospheric environment from worsening, a variety of abatement strategies have been implemented by the Chinese government and the air quality standards (Chinese National Ambient Air Quality Standards—CNAAQS) have become more stringent. Compared with the National Ambient Air Quality Standards (NAAQS) of the US Environmental Protection Agency (EPA), generally, the revised monitoring standard used in the US was found to be more frequent and the standard values for the mass concentration are higher as compared to those used in China. However, the control of particulate matter (PM) is more stringent in the US. The detailed comparison is given in Table 1.

Although control measures have mitigated air quality deterioration in China, air pollution remains a serious environmental concern having been transformed from traditional coal-burning pollution to mixed source pollution. This paper discusses the current status and future trends of air quality in China and identifies the research emphasis for atmospheric environmental protection.

*Corresponding authors. Tel.: +86 10 62794369, +86 10 62782195.
E-mail addresses: yhh02@mails.tsinghua.edu.cn (H. Yi), hjm-den@tsinghua.edu.cn (J. Hao).

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Anthropogenic mercury emissions in China

David G. Streets[a,*], Jiming Hao[b], Ye Wu[c], Jingkun Jiang[b], Melissa Chan[d], Hezhong Tian[b], Xinbin Feng[e]

[a]*Decision and Information Sciences Division, Argonne National Laboratory, Argonne, IL 60439, USA*
[b]*Department of Environmental Science and Engineering, Tsinghua University, Beijing 100084, PR China*
[c]*Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, Argonne, IL 60439, USA*
[d]*National Energy Technology Laboratory, Pittsburgh, PA 15236, USA*
[e]*State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550002, PR China*

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Abstract

An inventory of mercury emissions from anthropogenic activities in China is compiled for the year 1999 from official statistical data. We estimate that China's emissions were 536 ($\pm$236) t of total mercury. This value includes open biomass burning, but does not include natural sources or re-emission of previously deposited mercury. Approximately 45% of the Hg comes from non-ferrous metals smelting, 38% from coal combustion, and 17% from miscellaneous activities, of which battery and fluorescent lamp production and cement production are the largest. Emissions are heaviest in Liaoning and Guangdong Provinces, where extensive smelting occurs, and in Guizhou Province, where there is much small-scale combustion of high-Hg coal without emission control devices. Emissions are gridded at 30 × 30 min spatial resolution. We estimate that 56% of the Hg in China is released as Hg^0, 32% as Hg^{2+}, and 12% as Hg^p. Particulate mercury emissions are high in China due to heavy burning of coal in residential and small industrial settings without PM controls. Emissions of Hg^{2+} from coal-fired power plants are high due to the absence of flue-gas desulfurization units, which tend to dissolve the soluble divalent mercury. Metals smelting operations favor the production of elemental mercury. Much of the Hg is released from small-scale activities in rather remote areas, and therefore the activity levels are quite uncertain. Also, emissions test data for Chinese sources are lacking, causing uncertainties in Hg emission factors and removal efficiencies. Overall, we calculate an uncertainty level of $\pm$44% (95% confidence interval) in the estimate of total emissions. We recommend field testing of coal combustors and smelters in China to improve the accuracy of these estimates.

Keywords: Speciated mercury; Emission inventory; Coal combustion; Metals smelting; China

1. Introduction

Concern about mercury in the environment has grown to the point where action is believed to be warranted to reduce the risks to humans and wildlife (US EPA, 1997; UNEP, 2002). Environmental mercury levels have increased considerably in recent years; and even regions with no significant emissions, such as the Arctic, are affected by the transcontinental transport of mercury. Modeling studies have confirmed the ability of elemental

*Corresponding author. Tel.: +1 630 252 3448; fax: +1 630 252 5217.
E-mail address: dstreets@anl.gov (D.G. Streets).

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The influence of geographic location on population exposure to emissions from power plants throughout China

Ying Zhou [a,*], Jonathan I. Levy [b], John S. Evans [c], James K. Hammitt [c]

[a] Harvard School of Public Health, Landmark Center, 401 Park Drive, Room 404, Boston, MA 02216, USA
[b] Harvard School of Public Health, Landmark Center, Room 404K, P.O. Box 15677, Boston, MA 02215, USA
[c] Harvard Center for Risk Analysis, 718 Huntington Ave., Boston, MA 02115, USA

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Abstract

This analysis seeks to evaluate the influence of emission source location on population exposure in China to fine particles and sulfur dioxide. We use the concept of intake fraction, defined as the fraction of material or its precursor released from a source that is eventually inhaled or ingested by a population. We select 29 power-plant sites throughout China and estimate annual average intake fractions at each site, using identical source characteristics to isolate the influence of geographic location. In addition, we develop regression models to interpret the intake fraction values and allow for extrapolation to other sites. To model the concentration increase due to emissions from selected power plants, we used a detailed long-range atmospheric dispersion model, CALPUFF. Primary fine particles have the highest average intake fraction (1×10^{-5}), followed by sulfur dioxide (5×10^{-6}), sulfate from sulfur dioxide (4×10^{-6}), and nitrate from nitrogen oxides (4×10^{-6}). For all pollutants, the intake fractions span approximately an order of magnitude across sites. In the regression analysis, the independent variables are meteorological proxies (such as climate region and precipitation) and population at various distances from the source. We find that population terms can explain a substantial percentage of variability in the intake fraction for all pollutants (R^2 between 0.86 and 0.95 across pollutants), with a significant modifying influence of meteorological regime. Near-source population is more important for primary coarse particles while population at medium to long distance is more important for primary fine particles and secondary particles. A significant portion of intake fraction (especially for secondary particles and primary fine particles) occurs beyond 500 km of the source, emphasizing the need for detailed long-range dispersion modeling. These findings demonstrate that intake fractions for power plants in China can be estimated with reasonable precision and summarized using simple regression models. The results should be useful for informing future decisions about power-plant locations and controls.

Keywords: Intake fraction; Particulate matter; Atmospheric dispersion modeling; Air pollution; Power plant; China

1. Introduction

As in many rapidly developing countries, energy generation capacity and consumption in China have increased tremendously over the past 25 years. Between 1978 and 2000, for example, power generation capacity increased nearly six-fold from 57 to 319 GW (Chinese Power Sector Publishing House, 1998, 2001). With the rapid increases in energy generation and consumption, and the use of coal for the majority of power generated, many cities in China are experiencing severe levels of air pollution (World Bank, 1997) and decision-makers are faced with the difficult task of mitigating air pollution while supporting continued economic growth. Methods to quantify the public health benefits of pollution control can allow decision makers to determine optimal control strategies balancing benefits and costs.

Estimating the benefits of air pollution control (or the reduction in human health damage from energy generation) involves four main steps: estimation of the quantities of various pollutants emitted from energy generation activities, the impact of these emissions on ambient concentrations and hence on population exposure to the pollutants, the incremental human health damage (e.g., mortality and morbidity) due to the exposure; and the monetary or other value of the resulting health damage. This analysis focuses on the second of these four components—estimating the impact of power plant

* Corresponding author. Tel.: +1 617 384 8528.
E-mail address: yzhou@hsph.harvard.edu (Y. Zhou).

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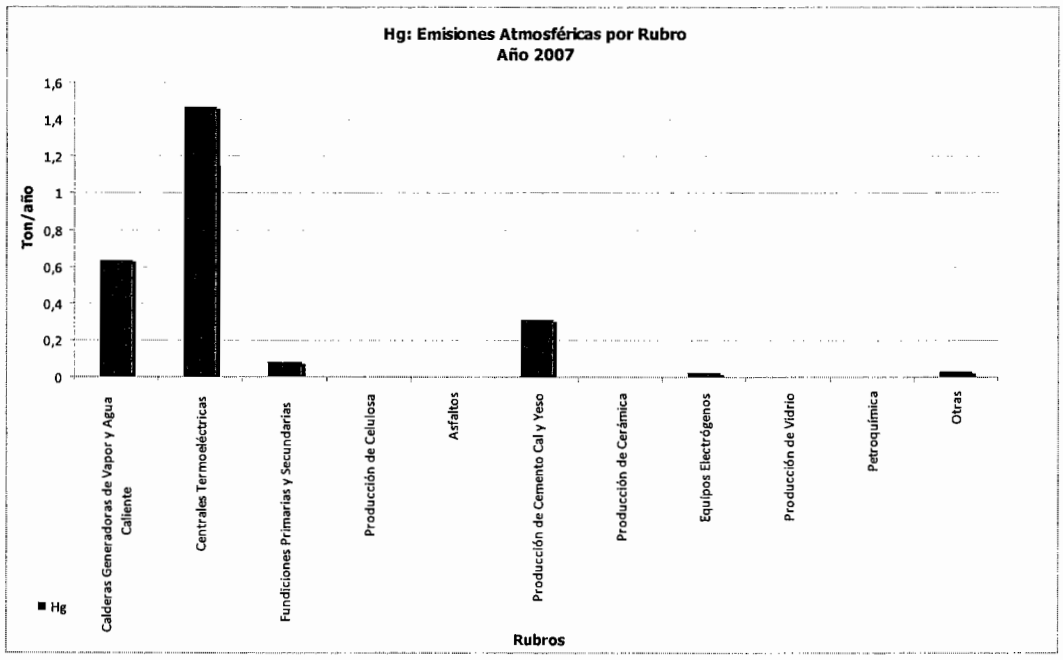
Se adjunta:

Copia de Acuerdo del Consejo Directivo de CONAMA N° 415 del 25 de Agosto de 2009, el cual aprueba Plan de Gestión de Riesgos del Mercurio y la creación e integración de Comité Operativo para su coordinación.

Cabe destacar que el Acuerdo estipula lo siguiente: en su Numeral 4.1, Línea de Acción: Adoptar normativas nacionales basadas en recomendaciones internacionales. 4.1.1 en su Plan de Acción de Corto Plazo: Estudiar la posibilidad de incorporar al Mercurio como parámetro en la norma de Centrales Termoeléctricas y la exigencia de caracterización de contenido de Mercurio en el carbón.

Por otra parte, el Estado en su gestión está llamado a ser eficiente y que por tal motivo se analizaran detenidamente todos los aspectos y fundamentos que permitan evaluar regular las emisiones de mercurio (Hg) a la atmósfera de las termoeléctricas que usan carbón. Análisis que se realizarán en el estudio que realiza KAS Ingeniería y GeoAire y a través del contacto con especialistas de oficinas internacionales.

Finalmente, cabe destacar que en el último reporte del RETC para el año 2007, las centrales termoeléctricas aportan las mayores emisiones de mercurio al aire.



Contacto en CONAMA D.E.:
Carmen Gloria Contreras Fierro
cgcontreras@conama.cl
fono: 240 5772

REPÚBLICA DE CHILE
COMISIÓN NACIONAL DEL MEDIO AMBIENTE
RGR/HVA

APRUEBA PLAN DE GESTIÓN DE RIESGOS DEL MERCURIO Y LA CREACIÓN E INTEGRACIÓN DE COMITÉ OPERATIVO PARA SU COORDINACIÓN.

En sesión ordinaria, de fecha 25 de agosto de 2009, el Consejo Directivo de la Comisión Nacional del Medio Ambiente ha adoptado el siguiente:

ACUERDO Nº 415/2009

VISTOS Y CONSIDERANDO:

Lo dispuesto en los artículos 70 letra a), 72 letra y 74 ter letra f), 76, letra b) y 77, todos de la ley Nº 19.300, sobre Bases Generales del Medio Ambiente; y los antecedentes tenidos a la vista por el Consejo Directivo en la presente sesión,

SE ACUERDA:

1.- Aprobar la Plan de Gestión de Riesgos del Mercurio y la creación e integración de un Comité Operativo para la implementación de la misma, que estará integrado del modo siguiente:

a) Ministerio de Salud
b) Ministerio de Minería
c) Ministerio de Educación
d) Ministerio de Agricultura
e) Ministerio de Relaciones Exteriores
f) Servicio Nacional de Aduanas
g) Comisión Chilena del Cobre
h) Servicio Nacional de Geología y Minería
i) Instituto Nacional de Estadísticas
j) Servicio Nacional del Consumidor
k) Superintendencia de Electricidad y Combustibles
l) Comisión Nacional de Energía
m) Programa País de Eficiencia Energética
n) Superintendencia de Servicios Sanitarios
ñ) Dirección General del Territorio Marítimo y de Marina Mercante
o) Comisión Nacional de Medio Ambiente

2.- Facultar al Director Ejecutivo de la Comisión Nacional del Medio Ambiente para que en la resolución que formalice el presente acuerdo, corrija los errores de tipeo, redacción y otras de carácter formal que se contengan en la presente Acta.

ANA LYA URIARTE RODRÍGUEZ
Presidenta del Consejo Directivo
Ministra Presidenta
Comisión de la Nacional del Medio Ambiente

ÁLVARO SAPAG RAJEVIC
Director Ejecutivo
Secretario Consejo Directivo
Comisión Nacional del Medio Ambiente

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GOBIERNO DE CHILE
COMISIÓN NACIONAL
DEL MEDIO AMBIENTE

Plan Nacional para la Gestión de los Riesgos del Mercurio

Julio 2009

Índice

Listado de Acrónimos

CNE: Comisión Nacional de Energía

COCHILCO: Comisión Chilena del Cobre

CONAMA: Comisión Nacional del Medio Ambiente

CPIP: Centro de Perfeccionamiento, Experimentación e Investigaciones Pedagógicas

ENAMI: Empresa Nacional de Minería

ENAP: Empresa Nacional del Petróleo

EPA: Environmental Protection Agency (USA)

MINEDUC: Ministerio de Educación

MINSAL: Ministerio de Salud

PPEE: Programa País Eficiencia Energética

PNUMA: Programa de Naciones Unidas para el Medio Ambiente

RETC: Registro de Emisiones y Transferencia de Contaminantes.

SAG: Servicio Agrícola y Ganadero

SEC: Superintendencia de Electricidad y Combustibles

SERNAC: Servicio Nacional del Consumidor

SERNAGEOMIN: Servicio Nacional de Geología y Minería

SISS: Superintendencia de Servicios Sanitarios

UNITAR: Instituto de las Naciones Unidas para la Investigación y Formación

1 Introducción

El Consejo de Administración del PNUMA en su sesión 22 celebrada el 2003, decidió que para el metal mercurio (Hg) existían pruebas suficientes de consecuencias nocivas importantes a nivel mundial, que justificaban la adopción de medidas a nivel internacional (Decisión 22/4 V). En respuesta a dicha decisión, el PNUMA en su División de Productos Químicos, estableció un Programa sobre el Mercurio. Este programa, en cooperación y consulta con otras organizaciones competentes, facilita y presta asistencia técnica y desarrolla actividades de creación de capacidad en apoyo de las actividades nacionales encaminadas a adoptar medidas sobre la contaminación causada por este metal.

Asimismo, el Consejo de Administración del PNUMA, en su 23º período de sesiones, celebrado el 2005, encargó al Director Ejecutivo instar a los gobiernos, organizaciones intergubernamentales, organizaciones no gubernamentales y sector privado a crear y establecer asociaciones de manera clara, transparente y responsable, como uno de los enfoques para reducir los riesgos para la salud humana y el medio ambiente procedentes de la liberación del mercurio y sus componentes (Decisión 23/9 IV).

El Consejo de Administración examinará nuevamente los progresos realizados y evaluará, en su 24º período de sesiones, la necesidad de adoptar medidas adicionales respecto del mercurio, considerando una amplia gama de opciones, incluida la posibilidad de un instrumento jurídicamente vinculante, asociaciones y otras medidas. Además, se estudiará un informe sobre la aplicación de la presente decisión en lo que se refiere a los exámenes de la información científica sobre el plomo y el cadmio.

De forma paralela, a nivel nacional se han desarrollado algunas iniciativas para abordar el problema del mercurio, un ejemplo de ello es el sector minero que, a través del Ministerio de Minería, ha implementado el "Programa de Manejo Integral de la Variable Ambiental de la Pequeña Minería" y el "Programa de Asistencia y Modernización de la Minería Artesanal, PAMMA", cuyos principales objetivos y actividades están enfocados a mejorar las condiciones de vida y de trabajo del minero artesanal y de su grupo familiar, a través de cursos como el "uso de retortas de amalgamación" dirigidos a la minería artesanal, que representa una pequeña fracción de la minería nacional.

Por su parte, el 16 de junio de 2004, el Ministerio de Salud publicó en el Diario Oficial el Decreto Supremo Nº 148 que aprueba el "Reglamento Sanitario sobre Manejo de Residuos Peligrosos". El Reglamento establece las condiciones sanitarias y de seguridad mínimas que se relacionan directamente con la generación, tenencia, almacenamiento, transporte, tratamiento, reuso, reciclaje, disposición final y otras formas de eliminación de los residuos peligrosos.

Sin embargo, a pesar de que el mercurio está incluido como un residuo peligroso dentro de este reglamento, no existe obligación de medir ni de comprobar su existencia. Asimismo, la mayoría de los hospitales públicos del país y, posiblemente, también las clínicas particulares, aún utilizan instrumental médico como termómetros y manómetros de presión, además de amalgamas dentales con mercurio con una disposición final inadecuada para este tipo de residuos.

En consecuencia, a pesar de los avances anteriormente descritos, no se considera en el país al mercurio como una sustancia de gran prioridad. Lo anterior, puesto que aún no existe conciencia de la problemática real que genera la presencia de este contaminante en los seres humanos y en el medio ambiente.

No obstante lo anterior, nuestro país considera necesario investigar cuáles son los usos y consumos de mercurio en el país, además de la cantidad de sitios contaminados con este metal que pudieran existir en el territorio nacional. Así, se espera conocer su alcance real, que permita definir un programa integrado de gestión de mercurio, acorde a nuestra realidad nacional, que cubra a todo el país y que integre diversos ámbitos de acción.

Para avanzar en esta problemática, CONAMA recibió apoyo técnico y financiero de PNUMA y UNITAR para la elaboración del proyecto "Desarrollo de un Inventario y un Plan de Gestión de Riesgos para el Mercurio: una Contribución a la Alianza Global sobre el Mercurio". Este proyecto comenzó en junio del año 2007 y finaliza en octubre del presente año.

Adicionalmente, se utilizarán los esfuerzos realizados en la implementación de un Registro de Emisiones y Transferencia de Contaminantes, RETC[1]. De esta forma, se pretende institucionalizar el inventario de emisiones y los productos con contenido de mercurio en dicho instrumento.

Para la elaboración del proyecto se creó un "Comité Técnico Nacional" de carácter multisectorial (sector público, privado y ONGs) cuya función principal fue apoyar y asesorar técnicamente el proceso de ejecución del mismo.

Para la confección de este Plan de Gestión, como primera etapa, se priorizó como un elemento relevante para la gestión del mercurio en nuestro país, mejorar el inventario de liberaciones de mercurio, con el objetivo de permitir una clara identificación de las responsabilidades de los distintos sectores, antes de pasar a una etapa de incorporación de medidas de fondo.

Para ello se distinguieron varias líneas de acción, destacando la mejora en la información de actividad de las fuentes mediante el fortalecimiento de la infraestructura y normativa requerida, para generar mejor información base, desarrollo de campañas de medición de mercurio que entreguen valores representativos de la realidad local, a través de acuerdos voluntarios con los sectores que según el instrumental aportarían grandes cantidades de mercurio pero que según la información local disponible estos aportes no serían coincidentes con la realidad del país.

Es importante mencionar que, dentro de la discusión generada por el PNUMA en torno al tema del Mercurio, existe la posibilidad de crear un instrumento vinculante (obligatorio) para este metal, lo cuál podría concretarse a través de algún Convenio Internacional en el largo plazo.

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[1] El RETC es un catálogo que contiene información actualizada sobre sustancias químicas contaminantes o potencialmente dañinas para la salud y el medio ambiente, que son emitidas directamente al suelo, al aire o al agua por establecimientos industriales u otras actividades como el transporte y la agricultura. Además, incluye información sobre el tratamiento o eliminación de residuos contaminantes peligrosos (transferencias). Esta es una herramienta que permite recopilar, integrar y difundir periódicamente estos datos, de este modo es posible monitorear el desempeño ambiental, poner a disposición de la ciudadanía antecedentes para prevenir riesgos y promover políticas efectivas de protección ambiental y de la salud.

2 Diagnóstico

El mercurio es un metal pesado, que se presenta de forma natural en el medio ambiente bajo distintas formas químicas. La forma pura, mercurio elemental, es líquida a temperatura ambiente aunque lentamente tiende a evaporarse. Las formas que se encuentran más comúnmente en la naturaleza son el mercurio inorgánico y el mercurio orgánico.

Además, el mercurio es el único metal líquido a temperatura ambiente. Se comporta como un buen conductor eléctrico, posee alta densidad y tensión superficial, se expande y contrae de forma uniforme cuando la presión y la temperatura cambian, y puede matar microorganismos como organismos patógenos y otras plagas.

El mercurio es tóxico, persistente y tiene un ciclo global, lo cual se traduce en que las emisiones en cualquier continente pueden contribuir a la deposición en otros. Por ello, las emisiones de mercurio son un problema de preocupación mundial. Además, debido a su capacidad de transporte a largo alcance, incluso naciones con mínimas emisiones de mercurio, y otras regiones alejadas de la actividad industrial, pueden verse adversamente afectadas por este contaminante.

Asimismo, estudios de numerosas áreas geográficas indican que una significativa porción de humanos, flora y fauna en todo el mundo, están expuestos a niveles preocupantes de metilmercurio.

El metilmercurio es considerado el compuesto orgánico de mercurio de principal importancia a nivel toxicológico, pues gran parte de la población se encuentra expuesta a éste por la ingesta de alimentos que lo contienen (presente en todo el mundo en peces y mamíferos marinos). Es particularmente preocupante su alta neurotoxicidad, en especial para el caso del sistema nervioso central en desarrollo.

El mercurio puede resultar más problemático en las regiones menos desarrolladas (creciente demanda de energía, instalaciones de tratamiento de residuos precarias, minería de oro artesanal, etc.). Sus usos se han reducido progresivamente en los países desarrollados, pero pueden seguir vigentes en países en desarrollo.

Dependiendo de su forma, ciertas emisiones de mercurio pueden ser controladas más fácilmente que otras (en plantas industriales, por ejemplo). Así, el mercurio inorgánico puede ser fácilmente eliminado del aire contaminado, mientras que las emisiones de mercurio elemental son más difíciles de capturar y eliminar.

2.1 Análisis de los Riesgos de exposición a las diferentes especies de Mercurio

El mercurio se encuentra en forma natural en la corteza terrestre en una concentración de 0.5 ppm aproximadamente. Las personas en general, pueden estar expuestas a concentraciones muy bajas de este metal en el aire, agua, y en los alimentos. Sin embargo, incluso en bajas concentraciones, el mercurio puede ser considerado potencialmente tóxico para el organismo humano[2].

Al combinarse con azufre, el mercurio puede formar una gran cantidad de compuestos. De estos compuestos, el más importante en forma comercial es el sulfuro rojo (HgS) conocido como cinabrio. De este mineral se obtiene el mercurio metálico, pues contiene aproximadamente 86.2 % de mercurio y 13.8 % de azufre.

Dentro de las características físico-químicas del mercurio, se destacan las siguientes:

- Los estados de oxidación de las sales de mercurio, son Mercúricas (Hg^{+2}) y Mercuriosas (Hg^{+1}).
- Las sales inorgánicas del mercurio son generalmente coloridas, los óxidos y yoduros son amarillos, mientras que los sulfuros pueden ser negros o cafés.
- El mercurio puede biotransformarse, principalmente en ambientes acuáticos, para formar derivados orgánicos como el metilmercurio, catalogada como la forma más peligrosa de mercurio.
- Los compuestos de mercurio pueden ser insolubles en agua y son muy tóxicos por ingestión o inhalación de sus polvos.

Por otra parte, la absorción, distribución, metabolismo, excreción y consecuentemente, la toxicidad del mercurio dependen del estado de oxidación y de la forma química en el organismo afectado (ATSDR, 1994).

En el organismo humano, el mercurio se convierte en diferentes formas químicas y estados de oxidación que actuarán de forma diferenciada en lo que se refiere a toxicidad y efectos adversos. A través de procesos enzimáticos, el mercurio elemental puede ser oxidado y convertido en formas inorgánicas, de la misma forma que los compuestos de mercurio orgánicos pueden ser llevados a mercurio inorgánicos en el organismo (ASTDR, 1994).

Por lo tanto, el riesgo del mercurio viene determinado por los siguientes factores:

- El tipo de exposición al mercurio.
- La especie de mercurio presente (algunas son más tóxicas que otras).
- Los factores geoquímicos y ecológicos que influencian la forma de migración del mercurio en el medio ambiente, y los cambios que puede sufrir durante dicha migración.

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2 Hursh et al., 1980; ATSDR,1989

2.1.1 Riesgos a la salud y al Medio ambiente[3]

El mercurio metálico, como sus sales orgánicas e inorgánicas son venenos protoplásmicos fatales para humanos, animales y plantas. Los más tóxicos son los compuestos orgánicos y de ellos, los derivados alquilados.

Los factores que determinan los efectos tóxicos en humanos son la velocidad y la cantidad absorbida, las propiedades fisicoquímicas de los compuestos, y la susceptibilidad del individuo. El mercurio y sus compuestos pueden ingresar al cuerpo a través de la piel, y los tractos gastrointestinal y respiratorio. En el caso del mercurio metálico, la principal vía de ingreso al organismo es a través del sistema respiratorio en forma de vapor, pues la cantidad que se absorbe a través de la piel, en su forma líquida, es mínima.

Los compuestos inorgánicos de mercurio, después de ingresar al organismo, son absorbidos y disociados por los fluidos corporales y la sangre, siendo distribuidos al plasma y eritrocitos. Los aril-compuestos y los alcoxi derivados se descomponen en iones mercurio y sufren el mismo proceso antes mencionado. Estos compuestos inorgánicos afectan el sistema nervioso central y se acumulan en el cerebro, siendo eliminados del organismo con mayor lentitud que los aril y alcoxi derivados.

Los compuestos alquilados tienen una vida media de eliminación de 50-60 días mientras que para los demás compuestos se tiene un valor de 30- 60 días. Estos valores dependen de la naturaleza del compuesto, la dosis, el modo y la velocidad de entrada al organismo, como ya se mencionó.

Las sales solubles en agua producen severos efectos corrosivos en la piel y membranas mucosas, provocando náusea severa, vómito, dolor abdominal, diarrea con sangre, daño a los riñones; pudiendo provocar la muerte en los siguientes 10 días a su exposición.

Una exposición crónica provoca inflamación de la boca, salivación excesiva, pérdida de los dientes, daño a los riñones, temblores musculares, espasmos de las extremidades, cambios de personalidad, depresión e irritabilidad.

Generalmente los compuestos de mercurio presentan bajas presiones de vapor, por lo que no contribuyen a la presencia de vapores tóxicos en áreas de uso, contrario a lo que sucede con el mercurio metálico (ejemplo: derrame por rompimiento de termómetros, esfigmomanómetros, y en general productos con contenido de mercurio metálico).

La exposición al vapor de este metal provoca irritación de los ojos, membranas mucosas y tracto respiratorio superior y, dependiendo de la sensibilidad del individuo, puede causar reacciones alérgicas y alteraciones del sistema nervioso.

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[3] Hoja de seguridad XXI mercurio y sales de mercurio.

2.1.2 Rutas de Entrada y efectos en el organismo

2.1.2.1 Inhalación

La inhalación constituye la principal ruta de ingreso al organismo para mercurio elemental. Esto, debido a que se vaporiza a temperatura ambiente y es absorbido por los pulmones para luego ser distribuido por la sangre. Aproximadamente el 1 % del metal absorbido se almacena en el cerebro de los mamíferos, en donde puede permanecer por mucho tiempo, mientras que el mercurio restante se distribuye en hígado y riñones en donde es secretado a través de la bilis y orina.

La inhalación de los vapores de mercurio está asociada con la toxicidad sistémica en humanos y animales. Debido a su alta difusibilidad y liposolubilidad, que facilita su distribución y movimiento a través del organismo, cerca del 80% del vapor de mercurio es absorbido por los pulmones y alcanza rápidamente la corriente sanguínea[4].

La inhalación en concentraciones altas causa edema pulmonar agudo y neumonitis intersticial, produciendo efectos tales como salivación, dolor abdominal, dolor en el pecho, náusea, vómito y diarrea.

Al generarse daño crónico, los síntomas se traducen en cambios en el comportamiento, tales como depresión e irritabilidad, temblores, y pérdida de apetito y peso.

El mercurio se absorbe a través de la piel en muy pocas cantidades, causando síntomas como irritación de ojos y piel. Se han detectado casos de dermatitis por contacto y sensibilidad a este metal.

Por otra parte, la velocidad de entrada de los vapores de mercurio a través de la piel es de 2,2 % de aquella absorbida por pulmones, por lo que el peligro por absorción por medio de la piel es mínimo.

2.1.2.2 Ingestión

La peligrosidad de la ingesta de mercurio reviste en su ingreso al organismo como metilmercurio, a través de alimentos que lo contengan.

El metilmercurio es uno de los metales más peligrosos para la salud (IPCS, 1991). Diversos incidentes de exposición humana al metilmercurio han demostrado sus efectos neurotóxicos.

Los efectos del metilmercurio varían, como se dijo anteriormente, según la dosis, la respuesta, y los síntomas asociados. Los grupos más vulnerables a la exposición del metilmercurio son los niños, el feto y la madre (US EPA, 1995). El metilmercurio pasa a través de la barrera sanguínea, cerebro y alcanza el Sistema Nervioso Central (SNC). El feto es particularmente sensible a la exposición al metilmercurio y sus efectos durante el desarrollo de la infancia han sido asociado con elevados

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[4] WHO, 1991.

índices de metilmercurio y con los efectos neuro comportamentales (Gilbert and Grant-Webster, 1995).

Los síntomas clínicos de intoxicación por metilmercurio en niños y adultos incluyen: parestesia (extremidades y alrededores de la boca adormecidos), ataxia (dificultad al caminar), disartria (dificultas en hablar), disminución del campo visual, sordera, temblores, deficiencia intelectual y en algunos casos, paralización motora (WHO, 1990).

En síntesis, de todas las especies de mercurio conocidas la más peligrosa es sin duda el metilmercurio (CH_3Hg). Aunque la forma exacta en que se produce la metilación del mercurio se desconoce, se sabe que en el proceso intervienen bacterias que participan en el ciclo SO_4^{2-} - S^{2-}. Estas bacterias, que por ende contendrán metilmercurio, son consumidas por el peldaño superior de la cadena trófica, o bien lo excretarán. En este último caso el metilmercurio puede ser rápidamente adsorbido por el fitoplancton y de ahí pasar a los organismos superiores.

Debido a que los animales acumulan metilmercurio más rápido de lo que pueden excretarlo, se produce un incremento sostenido de las concentraciones en la cadena trófica (biomagnificación). Así, aunque las concentraciones iniciales de metilmercurio en el agua sean bajas o muy bajas, los procesos biomagnificadores acaban por convertir el metilmercurio en una amenaza real para la salud humana.

En síntesis el riesgo del mercurio va a estar determinado por el tipo de exposición al mercurio, la especie de mercurio, los factores geoquímicos y ecológicos que influencian la forma de migración del mercurio en el medioambiente, los cambios que puede sufrir durante dicha migración, la ruta de entrada al organismo (ingestión, inhalación, contacto), la dosis y el tiempo de exposición.

En nuestro país la exposición de la población al mercurio metálico, estaría principalmente presente en la pequeña minería del oro para aquellos trabajadores que no toman las medidas adecuadas en su manipulación, en las personas que tienen obturaciones dentales con amalgamas de mercurio y en el mal uso, manipulación y disposición de los productos con contenido de mercurio, tales como termómetros, pilas, tubos fluorescentes, lámparas de ahorro de energía, interruptores eléctricos, etc.

Otras fuentes precursoras de mercurio metálico que tenemos presente en Chile, son aquella provenientes de liberaciones secundarias, a través de procesos tales como la combustión de carbón, procesamiento de crudo, combustión de hidrocarburos, combustión de biomasa, producción de cemento, procesos con gas natural, extracción primaria de metales y producción de metales reciclados.

Para el caso de mercurio inorgánico, se encontraría presente en algunos productos farmacéuticos y desinfectantes que aún se comercializan. En cuanto al etil mercurio, aún se usa el timerosal como preservante de algunas vacunas y para el metil mercurio, estaría presente por liberaciones de mercurio al agua, el cual sería producido por microorganismos y bacterias.

En la tabla siguiente se resume el riesgo de exposición a las diferentes especies de mercurio, a través de los usos, consumos y emisiones de este contaminante.

Tabla 1 Características de la exposición, según especie de mercurio, por subcategoría identificadas en Chile

Origen del Mercurio	*Mercurio Elemental*	*Mercurio Inorgánicos (sales)*	*Orgánico (metil-mercurio)*	*Orgánico (etil-mercurio)*
Uso Principal	Amalgamas dentales	Productos cosméticos y farmacéuticos (usado como preservante)	Liberaciones de mercurio al agua se transforma en el medio en metil-mercurio por microorganismos y bacterias	En vacunas como preservativo (el timerosal corresponde a un 49% de etil-mercurio)
Otros Usos	Minería del Oro Productos (pilas, lámparas, aparatos de medición) Dispositivos médicos (termómetros, esfigmomanómetros)	Desinfectantes y antimicrobianos Equipos eléctricos Equipos fotográficos		
Liberaciones Secundarias, a través de procesos	Combustión de Carbón Combustión de Aceites minerales Combustión de biomasa Producción de cemento Procesos con gas natural Extracción primaria de metales Producción de metales reciclados Incineración de desechos médicos Crematorios y Cementerios Sistema de tratamiento de aguas residuales			
Fuente de Exposición	Derrames hospitalarios o domiciliarios Amalgamas dentales		Consumo de pescados	
Vía de Exposición	80% mediante inhalación 0.01% mediante ingestión Absorción mínima por la piel	Menor al 10% mediante la ingestión Pueden absorberse dosis letales mediante la piel	Gran absorción mediante la inhalación Mediante ingestión se absorbe entre 90 y 100%	Por ser vacuna se absorbe el 100 % del contenido mercurio por la inyección de la sustancia
Toxicidad Primaria	Para la Piel, Ojos, Pulmones, Encías	Tracto intestinal, riñones	Sistema nervioso central	Aún en estudio
Toxicidad Secundaria	Sistema nervioso central, Riñones	Sistema nervioso central	En estudio efectos en el sistema cardio-vascular	
Transporte dentro del cuerpo	Se ha encontrado en leche materna Cruza a través de la placenta Atraviesa por el flujo sanguíneo la barrera del cerebro	No llega fácilmente al cerebro, así como tampoco cruza con facilidad la placenta		Se ha encontrado en leche materna Cruza a través de la placenta Atraviesa por el flujo sanguíneo la barrera del cerebro

Nota: No considera dosis ni tiempo de exposición

2.2 Análisis de la Situación Actual en el País

Para la elaboración del presente análisis, se tomaron en consideración el resumen de los resultados del Inventario de "Usos, consumos y liberaciones de mercurio" y del "Catastro de sitios potencialmente contaminados"; la revisión de la "Normativa Chilena" referida a los sectores que cuentan con alguna regulación respecto al mercurio; el análisis comparativo con la legislación existente en Estados Unidos, Canadá y la Unión Europea; y los vacíos detectados en la normativa existente.

A partir de los resultados obtenidos del inventario realizado utilizando el instrumental del PNUMA, la mayor fuente emisora de mercurio en el país corresponde a la categoría "Producción primaria (virgen) de metales", representada por la "Extracción y procesamiento inicial de oro mediante procesos distintos de la amalgamación de mercurio", la "Extracción de oro y plata con amalgamación de Mercurio", ya sea por el mercurio natural presente en este tipo de yacimientos, y/o debido a que este elemento es utilizado en el proceso de obtención del oro (amalgamación); y la " Extracción y procesamiento inicial del cobre" debido a las fundiciones primarias que procesan el cobre y la gran cantidad de relaves generados, ya que Chile es el primer productor a nivel mundial de Cobre.

Es relevante señalar que para el Servicio Nacional de Geología y Minería, los resultados obtenidos del instrumental del PNUMA, estarían sobrestimados para el sector minero, dado que se toman datos de producción total de cobre y oro (Anuario de SERNAGEOMIN), que no necesariamente representan la presencia de mercurio en todos los yacimientos o procesos involucrados. Lo anterior se basa en la génesis de los yacimientos "epitermales" de oro y plata (de baja temperatura de formación) presentan el mayor potencial para contener mercurio. Los grandes yacimientos de cobre (pórfidos cupríferos) existentes en el país, por su alta temperatura de formación presentan una baja potencialidad en términos de su contenido de mercurio.

Las tablas que se presentan a continuación indican las liberaciones mínimas y máximas para la categoría "Producción primaria (virgen) de metales

Tabla 2 Liberaciones mínimas de la categoría

		Mercurio, Kg/año						
	Categoría de Fuente	Aire	Agua	Suelo	Productos	Desechos Generales	Tratamiento específico	Total
5.2	Producción primaria (virgen) de metales	611,65	35,97	119437,00	1187,73	0,00	434,39	121.706,74

Tabla 3 Liberaciones máximas de la categoría

		Mercurio, Kg/año						
	Categoría de Fuente	Aire	Agua	Suelo	Productos	Desechos Generales	Tratamiento específico	Total
5.2	Producción primaria (virgen) de metales	4117,88	539,57	335320,18	11259,71	0,00	6529,60	357.766,95

El análisis comparativo de los resultados obtenidos, sin considerar la "Producción primaria (virgen) de metales en base a los factores de entrada aplicados (mínimos y máximos), sugeridas por el instrumental indica que cinco de las diez categorías estudiadas muestran las mayores liberaciones de mercurio, tal como se puede apreciar en las siguientes tablas:

Tabla 4 Liberaciones mínimas por categoría de Fuente

		Mercurio, Kg/año						
	Categoría de Fuente	Aire	Agua	Suelo	Productos	Desechos Generales	Tratamiento específico	Total
5.5	Productos de Consumo con uso deliberado de mercurio	107,04	222,98	32,53	0,00	1888,32	0,00	2250,87
5.6	Otros usos deliberados de mercurio en Productos/procesos	16,27	115,07	0,00	488,02	98,80	99,20	817,36
5.1	Extracción y uso de combustibles/fuentes de energía	503,09	30,96	7,74	0,00	41,28	19,29	602,36
5.3	Producción de otros minerales	444	0	0	0	8	0	452
5.9	Disposición de desechos/rellenos sanitarios y tratamiento de aguas servidas	12,08	225,91	4,01	0,00	98,07	61,16	401,23

Tabla 5 Liberaciones máximas por categoría de Fuente:

		Mercurio, Kg/año						
	Categoría de Fuente	Aire	Agua	Suelo	Productos	Desechos Generales	Tratamiento específico	Total
5.5	Productos de Consumo con uso deliberado de mercurio	619,13	636,81	406,68	0,00	7368,15	0,00	9030,77
5.9	Disposición de desechos/rellenos sanitarios y tratamiento de aguas servidas	120,84	778,28	120,22	0,00	5019,60	1864,70	7903,64
5.1	Extracción y uso de combustibles/fuentes de energía	3794,89	30,96	7,74	0,00	437,17	53,6	4324,36
5.6	Otros usos deliberados de mercurio en Productos/procesos	65,07	456,68	0,00	1952,07	391,61	392,01	3257,44
5.3	Producción de otros minerales	593,89	0	0	0	7,88	0	601,77

En la categoría "Productos de Consumo con uso deliberado de mercurio", destacan principalmente los termómetros, pilas, tubos fluorescentes, lámparas de ahorro de energía, interruptores eléctricos y productos farmacéuticos de uso humano y veterinario.

La categoría "Disposición de desechos/rellenos sanitarios y tratamiento de aguas servidas", está compuesta principalmente por los rellenos sanitarios, depósitos controlados, vertederos informales de desechos y los sistemas de tratamiento de aguas residuales.

La categoría "Extracción y uso de combustibles/fuentes de energía", está compuesta por la combustión de carbón en grandes centrales de energía, usos de carbón en calderas y extracción, quema de biomasa domiciliaria, incendios forestales y refinación de crudos.

La categoría "Otros usos deliberados de mercurio en Productos/procesos", la componen principalmente la producción de cemento, cal, yeso, pulpa y papel y fabricación de cerámicas.

Finalmente la categoría "Otros usos deliberados de mercurio en Productos/procesos", está representada por las amalgamas dentales de mercurio, manómetros, medidores, químicos, equipos de laboratorio y productos misceláneos (juguetes, pantallas lcd, sensores, etc.)

Respecto a las diferentes vías de liberación asociadas a las categorías estudiadas, la principal vía corresponde a la tierra, en cuyo caso la categoría de mayor contribución es la "Producción primaria (virgen) de metales", seguida por disposición general como consecuencia de los productos desechados con contenido de mercurio, tales como pilas, termómetros, lámparas y otros, para los cuales no existe un tratamiento previo, seguidos por las emisiones al aire, debido a los sectores productivos de mayor contribución, tales como las centrales termoeléctricas de energía en base a carbón, biomasa, petróleo diesel, gas natural; combustión con destilados del petróleo, las fundiciones mineras[5] e incineración de residuos médicos, luego siguen las impurezas en productos, liberaciones al agua y el sector de tratamiento específico.

En lo que concierne al "Catastro de sitios potencialmente contaminados", se seleccionaron las regiones que poseen antecedentes con los mayores problemas con el contaminante, estas fueron las de: Atacama, Coquimbo, Valparaíso, Metropolitana, Bío Bío y Los Lagos, en donde se priorizaron 29 sitios, sobre la base de la aplicación de unas fichas de inspección en terreno de carácter cualitativo, en donde se identificaron los puntos de exposición de mayor riesgo; las vías de exposición más probables (ingestión, inhalación, contacto directo, absorción de raíz, etc.); y, por último, la población potencialmente receptora de la(s) sustancia(s) involucrada(s).

La revisión de la situación actual del mercurio en Chile, se realizó en base a la guía otorgada por la agencia UNITAR, denominada "Desarrollo de un Análisis Situacional y Evaluación de Capacidades en apoyo del Desarrollo de Inventarios y Toma de Decisiones sobre los Riesgos del Mercurio".

Vacíos Legales Detectados

En lo que concierne a productos con contenido de mercurio, hasta el momento no existen iniciativas legislativas y normativas relacionadas con la importación y/o exportación de productos que contienen mercurio ni tampoco una normativa que regule el contenido de mercurio presente en ellos.

En Chile actualmente no se producen productos con contenido de mercurio, por lo tanto, el mayor problema radica en la importación de éstos. Los principales productos importados y que contienen mercurio son pilas, termómetros, manómetros, medidores, barómetros, sensores, interruptores, fuentes de luz con mercurio, productos farmacéuticos de uso humano y veterinario, químicos y equipos de laboratorio. En todos los casos, no existe regulación para el ingreso y/o contenido de este metal.

Para las fuentes de emisiones asociadas a la refinación y producción de crudo, no existe normativa que limite la emisión de mercurio por las diferentes vías de liberación (aire, agua, tierra, desechos generales, tratamiento de sector específico, impureza en productos).

Por otra parte, no existe una norma de emisión en centrales termoeléctricas y procesos de combustión en general, sin embargo, en este momento se está trabajando en la elaboración de una

[5] Los factores de estimación utilizados presentan incertidumbre.

norma de emisión para centrales termoeléctricas y para ello el comité operativo que trabaja en su elaboración, estudiará la posibilidad de incorporar al Mercurio como parámetro y la exigencia de caracterización de contenido de Mercurio en el carbón.

De forma similar, para el caso de otros usos deliberados de mercurio en productos/procesos, como es el empleo de amalgamas en obturaciones dentales, no existe ninguna regulación.

En el sector minero, específicamente en la pequeña minería, no existe regulación del uso del mercurio en el proceso extractivo, ni en su eliminación, sin embargo, es necesario señalar que el principal proceso extractivo en la pequeña minería, es de cobre el cual no usa mercurio. Asimismo, hay un gran número de joyeros que utilizan el mercurio proveniente de los procesos mineros, formando parte de un mercado informal que tampoco cuenta algún tipo de regulación.

En cuanto a la minería del cobre, al igual que en los casos antes descritos, no hay una normativa que establezca los límites máximos de contenido de mercurio generado en los residuos masivos mineros que se obtienen del proceso de extracción.

Iniciativas Legislativas y Normativas Actuales

Respecto al ámbito de la seguridad y salud ocupacional, existe el Decreto Supremo 594 de 1999 del Ministerio de Salud, "Reglamento sobre condiciones sanitarias y ambientales básicas en los lugares de trabajo", en donde se establecen límites de tolerancia biológica y niveles máximos de exposición al mercurio.

Para el medio acuático existen un conjunto de normativas que limitan las emisiones de mercurio, el Decreto Supremo Nº 609 de 1998 del Ministerio de Obras Públicas, que establece la "Norma de emisión para la regulación de contaminantes asociados a las descargas de residuos industriales líquidos a sistemas de alcantarillado", el Decreto Supremo Nº 90 del 2000 del Ministerio Secretaría General de la Presidencia, que establece la "Norma de emisión para la regulación de contaminantes asociados a descargas de residuos líquidos a aguas marinas y continentales superficiales", y el Decreto Supremo Nº 46 del 2002 del Ministerio Secretaría General de la Presidencia que establece la "Norma de emisión de residuos líquidos a aguas subterráneas".

También existen iniciativas legislativas o normativas relacionadas con los desechos de mercurio y su almacenamiento. Esto, a través del Decreto Supremo Nº 148 del 16 de Junio del 2004, "Reglamento sanitario sobre manejo de residuos peligrosos", del Ministerio de Salud, en el cual se considera al Hg como sustancia tóxica aguda y residuo peligroso, estableciendo las condiciones sanitarias y de seguridad mínimas a que deberá someterse la generación, tenencia, almacenamiento, transporte, tratamiento, reuso, reciclaje, disposición final y otras forma de eliminación de los residuos peligrosos.

Por otra parte, dicho Decreto obliga a un manejo de residuos en instalaciones, establecimientos o actividades que anualmente den origen a más de 12 Kg. de residuos tóxicos agudos o a más de 12 toneladas de residuos peligrosos que presenten cualquier otra característica de peligrosidad, y considera al mercurio como un elemento tóxico agudo.

La Ley Nº 19.300 sobre Bases Generales del Medio Ambiente, regula los proyectos o actividades que son susceptibles de causar impacto ambiental en cualquiera de sus fases, por lo que requieren

someterse al Sistema de Evaluación de Impacto Ambiental. Dentro de estas actividades están las plantas de disposición de residuos y estériles, la producción, almacenamiento, transporte, disposición o reutilización habituales de sustancias tóxicas, explosivas, radioactivas, inflamables, corrosivas o reactivas y aquellos proyectos de saneamiento ambiental como las plantas de tratamiento de aguas o de residuos sólidos de origen domiciliario, rellenos sanitarios, emisarios submarinos, sistemas de tratamiento y disposición de residuos industriales líquidos o sólidos.

El Reglamento del Sistema de Evaluación de Impacto Ambiental, DS MINSEGPRES N° 95/2001, obliga a someter a revisión de la CONAMA y de los distintos servicios que coordina, a los proyectos relacionados con las plantas de tratamiento de residuos sólidos domiciliarios y los rellenos sanitarios, sobre la base de Estudios de Impacto Ambiental.

El Decreto Nº 45, publicado en el Diario Oficial el 5 de Octubre del 2007, del Ministerio Secretaría General de la República, establece "Norma de Incineración y Coincineración", que regula las emisiones atmosféricas, productos de la incineración y coincineración a todas las instalaciones de incineración y coincineración que correspondan a hornos de cemento, hornos rotatorios de cal e instalaciones forestales. La norma aplicable en el territorio nacional, establece valores límites de emisión de mercurio para la incineración. En lo referido a la metodología de medición, para el caso del mercurio, estipula el método "EPA Method 29, Determination of Metals Emissions from Stationary Sources".

Recientemente, el Decreto Supremo Nº 189/2005, que aprueba "Reglamento Sobre Condiciones sanitarias y de seguridad básicas en los Rellenos Sanitarios", publicado por el Ministerio de Salud con fecha 5 de Enero del 2008, entre otros deberes, obliga a todo proyecto de relleno sanitario a que debe incorporar una estimación de la generación de lixiviados y un sistema de impermeabilización de acuerdo a las condiciones definidas en el reglamento. Cuando se considere el uso de los lixiviados o su descarga a cursos o masas de agua, se deberá incluir tratamiento de estos líquidos y cumplir las normas de emisión vigentes, además se deberá enviar mensualmente a la autoridad sanitaria regional un informe de la operación del relleno.

Entre los productos con uso deliberado de mercurio que están regulados en el país, se encuentran los pesticidas con contenido de mercurio, a través de la Resolución Exenta Nº 996 de 1993 del Servicio Agrícola y Ganadero (SAG). En esta resolución se prohíbe la importación, fabricación, distribución, venta y uso de plaguicidas agrícolas que contengan sales orgánicas o inorgánicas de mercurio.

Para el caso de los cosméticos, el ingrediente "mercurio" presente en éstos también está regulado a través del Decreto Supremo del MINSAL Nº 239 del 2002, el cual entrega un listado de compuestos prohibidos en los cosméticos, incluidos los compuestos de mercurio.

A nivel regional, no hay políticas, regulaciones y/o normativas establecidas al respecto. Sin embargo, se han identificado Resoluciones de Calificación Ambiental en algunos sectores que se han sometido al Sistema de Evaluación de Impacto Ambiental, como es el caso del sector cementero.

A raíz de lo anteriormente expuesto, en primera instancia se puede considerar que el marco legislativo y normativo no es suficiente para la regulación del mercurio en el país, particularmente

para el caso de los productos que lo contienen. No obstante, la legislación existente se aplica de forma efectiva a través de fiscalizaciones, mediciones y reportes a las autoridades correspondientes.

Actualmente, la base de datos existente en el país para el registro de importaciones se realiza a través de las partidas aduaneras, las cuales son muy limitadas para la obtención de información de contenido de mercurio en los productos.

Respecto a las emisiones de mercurio, está considerado institucionalizar el inventario de emisiones y productos con contenido de mercurio en el Registro de Emisiones y Transferencia de Contaminantes (RETC) y, para ello ya existen avances significativos en el país, específicamente para el caso de tratamientos de aguas, la información se canaliza a través de la Superintendencia de Servicios Sanitarios (SISS) y de emisiones al mar por parte de la Dirección General del Territorio Marítimo y de Marina Mercante, los residuos peligrosos con contenido de mercurio, a partir del D.S. MINSAL 148 del 2004.

Programas e Iniciativas Voluntarias

En cuanto a los programas voluntarios para reducir el uso y/o emisiones de mercurio, se han iniciado e implementado Acuerdos de Producción Limpia (APL) en sectores del ámbito privado, es el caso del sector cementero y empresas químicas de la Región Metropolitana, a través de la Asociación de Industriales Químicos (ASIQUIM) quienes desarrollaron un APL con el objeto de eliminar las sales de mercurio en las pinturas que se elaboran.

En Chile, no existe un sistema especial para la disposición final de las pilas o de otros residuos domésticos peligrosos. Un ejemplo de iniciativa por parte del sector privado, es ubicar contenedores para la recolección de Pilas, los que han sido implementados, por parte de una entidad bancaria, una minera privada y algunas Municipalidades.

Asimismo, algunas Organizaciones no Gubernamentales, como el "Instituto de Ecología Política", han lanzado una campaña nacional de recolección de pilas para su posterior reciclaje. Es importante mencionar que el reciclaje de pilas en Chile es de muy elevado costo; por lo general las pilas y baterías se envían a una empresa especializada en manejo de residuos, en donde se procede a la encapsulación de sus compuestos peligrosos.

Por otra parte, transnacionales como la empresa General Motors, han incorporado planes de manejo para la disposición de lámparas con contenido de mercurio dentro de su organización.

Estudios e Investigaciones Realizadas

Se han desarrollado diversos estudios en Universidades para temas relacionados con el mercurio y sus problemas en el país (salud, ambientales y sociales).

La Universidad de Atacama y Universidad de la Serena han elaborado estudios en el sector minero, específicamente para sitios potencialmente contaminados con mercurio producto de las explotaciones mineras de oro y cobre en las zonas de Punitaqui y Andacollo. Además, se han desarrollado estudios de contaminación de aguas, producto de relaves y faenas abandonadas en el

Norte de Chile, con caracterizaciones en balsas de estériles en Quebrada Marquesa y Las Rojas, en el Valle del Elqui.

Los departamentos de Oceanología y Química Analítica de la Universidad de Concepción han realizado investigaciones sobre concentraciones de mercurio y cadmio en aguas superficiales (2-3 m de profundidad), obtenidas durante la primera fase del Programa de Vigilancia del CPPS-PNUMA[6] (1985-1988) en localidades del litoral de la región del Bío Bío. Los objetivos del estudio, insertos en el marco del "Plan de Acción Internacional para la Protección del Medio Ambiente", fueron los siguientes:

- Establecer la tendencia y cronología de las fluctuaciones de mercurio y cadmio en diferentes localidades del litoral de la región del Bío Bío.
- Identificar áreas contaminadas y no contaminadas en el litoral.

Otro estudio significativo fue realizado por la Universidad de Concepción, denominado, "Evaluación de Contaminación por Mercurio de Aguas, Sedimentos y Suelo en el Estuario Lenga Talcahuano".

Actualmente la Universidad de Concepción, centro EULA de Chile, y la Universidad Federal de Río de Janeiro, Instituto de Biofísica de Brasil, se encuentran realizando el proyecto "Análisis comparado de sistemas costeros impactados por mercurio: valoración química de Hg, metilmercurio en el ambiente y uso de biomarcadores de exposición y efectos".

La misma institución está terminando de redactar una publicación científica denominada: "Estudio de la Contaminación por Mercurio en peces y sedimentos del Estuario de Lenga (VIII Región-Chile)", la cuál será publicada prontamente en una revista científica especializada.

Un interesante estudio fue realizado en la Escuela de Salud Pública de la Universidad de Chile[7] , referido al contenido de mercurio en peces Chilenos y estimación de los niveles de ingesta; dicho trabajo corresponde a un estudio piloto (n=46, número de muestras), el cual fue diseñado para determinar las concentraciones de mercurio en algunos tipos de pescado y en un molusco bivalvo para el consumo nacional (jurel Chileno, merluza, mejillones chilenos, atún) y para la exportación (salmón, merluza patagónica, albacora, merluza del sur), a partir de las concentraciones determinadas se estima la exposición de la población en general.

Por su parte, la Fundación Banco Bilbao Vizcaya Argentaria (BBVA) está impulsando una investigación sobre el impacto de la contaminación por mercurio en zonas de alto valor ecológico[8].

Iniciativas Gubernamentales

En cuanto a iniciativas gubernamentales, respecto a la educación pública en materias relacionadas con el mercurio; a nivel nacional la Comisión Nacional del Medio Ambiente (CONAMA), está comenzando su difusión, a través de este proyecto en cuestión.

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[6] Comisión Permanente del Pacífico Sur – Programa de Naciones Unidas para el Medio Ambiente.

[7] Cortes, Sandra and Fortt, Antonia (2007) 'Mercury content in Chilean fish and estimated intake levels', Food Additives & Contaminants, 24:9, 955 - 959

[8] Para mayor información visitar http://www.chilebosque.cl/foro/viewtopic.php?p=2199

El Servicio Nacional de Geología y Minería (SERNAGEOMIN), el año 2003 preparó un curso denominado "Uso de retortas de amalgamación", que se ha dictado a los miembros beneficiarios del Programa de Asistencia y Modernización de la Minería Artesanal (PAMMA).

El Programa mencionado ha tenido una incidencia positiva en la pequeña minería del oro, en cuanto al manejo del mercurio, por lo que se pudo observar en terreno. Una de las barreras existentes hasta el momento, que limitan la habilidad del gobierno a nivel local, regional y nacional, es la falta de información respecto al tema.

Resultados de las gestiones actualmente desarrolladas

Hoy en día, los Acuerdos de Producción Limpia (APL) de la industria cementera y los industriales químicos, han contribuido a la reducción en el uso y la contaminación causada por el mercurio.

Por su parte, los programas de ONGs nacionales relacionados con el mercurio prácticamente no han tenido impacto, a excepción del reciclaje de pilas.

En cuanto a las investigaciones realizadas por ciertas universidades del país, éstas no han sido aún relevantes para el desarrollo de inventarios y toma de decisiones. La incipiente evaluación para la gestión de riesgos del mercurio ha permitido una contribución, hasta el momento parcial, por parte de dichas investigaciones.

En algunos sectores de gobierno existe mayor conocimiento del tema, como es el caso de una parte del sector minería, y del Servicio Agrícola y Ganadero (SAG), por el tema de los pesticidas.

En lo referido a las capacidades para medir el uso y emisiones de mercurio en el país, existen laboratorios certificados para realizar mediciones del contaminante en su estado metálico. Sin embargo, resulta necesario contar con laboratorios encargados de la especiación de mercurio, pues estos análisis se realizan actualmente en el extranjero.

En cuanto a instalaciones para almacenar y hacer una disposición final adecuada del mercurio y sus desechos, existen en el país instalaciones y empresas de tratamiento final de residuos peligrosos para el caso de los grandes generadores. Sin embargo, este esfuerzo requiere de su descentralización a nivel nacional, pues se genera un problema logístico para el traslado de residuos desde plantas en regiones.

La zona norte se encuentra desprovista de manejo de residuos peligrosos, principalmente porque existe poca difusión de la normativa (específicamente del D.S. MINSAL 148/2004).

La información que la CONAMA ha generado en el tema, ha permitido reforzar las capacidades nacionales para la facilitar la toma de decisiones en materia de riesgos. El primer paso fue la realización de un taller Internacional, con la participación de PNUMA, UNITAR, EPA y Environment Canada.

Lo anteriormente descrito en este análisis situacional a nivel país, permitió generar el objetivo general en que se basará el "Plan Nacional de Gestión de Riesgos del Mercurio", con los correspondientes objetivos específicos, para los cuales se plantean las líneas de acción a seguir a través de una serie de actividades propuestas con el propósito de poder gestionar la problemática del mercurio en Chile.

3 Objetivos

3.1 Objetivo General

Implementar las acciones prioritarias que permitan reducir los riesgos asociados al uso, consumos y emisiones del mercurio, a fin de proteger la salud humana y el medio ambiente.

3.2 Objetivos Específicos

1. Fortalecer la información base del Inventario de Usos, Consumos y Emisiones de mercurio.

2. Sensibilizar y generar capacidades en los actores involucrados en la gestión de los procesos y productos con contenido de mercurio, en el correcto uso, manipulación, disposición y los riesgos asociados a la exposición de este elemento.

3. Incentivar la generación y aplicación de instrumentos voluntarios y obligatorios de gestión ambiental para mejorar el manejo racional del mercurio.

4. Fortalecer y armonizar el Marco Normativo relativo al mercurio.

5. Gestionar de manera racional los sitios con presencia de mercurio

6. Institucionalizar el Inventario de Usos, Consumos y Emisiones de Mercurio en el RETC.

4 Líneas de Acción

Para concretar los objetivos enunciados anteriormente, se proponen las siguientes líneas de acción específicas, en base a los problemas detectados.

4.1 Establecimiento del problema que da origen al objetivo **Fortalecer la información base del Inventario de Usos, Consumos y Emisiones de mercurio** y las líneas de acción correspondientes.

Problema

Al evaluar la información disponible en el instrumental, se pudo constatar un alto nivel de incertidumbre en algunos factores de entrada y distribución de salida recomendada y/o disponible. Este hecho llevó a tomar la decisión de generar un inventario en base a intervalos, generando un inventario con valores máximos y mínimos, de igual forma se consideró la incorporación al análisis de antecedentes disponibles localmente en cuanto a factores de entrada y distribución de salida, provenientes de: otros estudios de liberaciones de mercurio manejados por los actores involucrados, consulta a expertos de los respectivos sectores y datos de mediciones disponibles. A la luz de los resultados, se priorizó como un elemento relevante para la gestión del mercurio en nuestro país en esta primera etapa, la mejora del inventario de liberaciones de mercurio, con el propósito de tener una clara identificación de las responsabilidades en los distintos sectores, antes de pasar a un etapa de incorporación de medidas de fondo.

Los problemas identificados son los siguientes:

- Gran variabilidad entre los valores máximos y mínimos del inventario, principalmente en los sectores del cemento, minería metálica, refinación de petróleo y generación eléctrica en base a carbón.
- Valores no necesariamente representativos de la realidad local.
- Para el caso de los productos con contenido de mercurio, difícil identificación debido a la falta de descriptores específicos para su ingreso al país, lo cual no permite conocer su número exacto.
- Mediciones disponibles poco representativas e insuficientes a nivel país.
- Escasas metodologías convenidas internacionalmente en cuanto a mediciones de mercurio.
- No existen apoyos metodológicos por parte de entidades regulatorias para la determinación de mercurio.

Para el cumplimiento del objetivo se propone:

- Validar las tasas de actividad definidas en el Inventario.
- Convenir métodos de entrega de información.

- Realizar mediciones de Mercurio en las corrientes de diversos procesos productivos.
- Estandarizar métodos y análisis de medición de Mercurio.
- Incentivar en las universidades y centros de investigación estudios relacionados con la problemática del mercurio.

4.2 Establecimiento del problema que da origen al objetivo **Sensibilizar y generar capacidades a los actores involucrados en la gestión de los procesos y productos con contenido de mercurio, en el correcto uso, manipulación, disposición y los riesgos asociados a la exposición de este elemento** y las líneas de acción correspondientes.

Problema

Cada año ingresa al país una gran cantidad de productos con contenido de mercurio, los cuales son usados en diferentes ámbitos de la población, destacando principalmente, los termómetros, pilas, lámparas fluorescentes y productos varios (interruptores, juguetes, esfigmomanómetros, pantallas lcd, etc.). En Chile no se fabrican productos, pero sí se importa una gran cantidad de estos, lo que genera que el problema de la exposición al mercurio, radique en el uso, manipulación y disposición del producto, sumado a los problemas identificados con el manejo de los desechos. Además es usado como insumo en la pequeña minería artesanal del oro y en obturaciones dentales.

Los problemas identificados son los siguientes:

- Alto desconocimiento en la población acerca de los riesgos que involucra un mal uso, manipulación y disposición de los productos que contienen mercurio.
- Falta de capacitación, información y difusión sobre los riesgos del consumo de productos con mercurio.
- Desconocimiento por parte de la población de los productos que contienen mercurio.
- Programas e iniciativas públicas, privadas y voluntarias insuficientes.
- Escasa iniciativa por parte de los importadores y distribuidores sobre manejo de productos que contienen mercurio.

Para el cumplimiento del objetivo se propone:

- Implementar campañas de educación respecto a los riesgos del consumo de productos con Mercurio.
- Incorporar en las mallas curriculares de la educación formal los riesgos de un mal uso, manipulación o disposición inadecuada de productos con Mercurio.
- Promover mesas de trabajo con diferentes sectores.

- Confeccionar programas para generar conciencia de los riesgos del uso de Mercurio en procesos productivos, particularmente en la pequeña y mediana minería.

4.3 Establecimiento del problema que da origen al objetivo **Incentivar la generación y aplicación de instrumentos voluntarios y obligatorios de gestión ambiental para mejorar el manejo racional del mercurio** y las líneas de acción correspondientes.

Problema

Los desechos de mercurio se originan principalmente de los productos que ingresan al país y son consumidos por la población en general y en los sectores de salud público y privado.

Por otra parte existen trabajadores de la pequeña y mediana minería que están expuestos a este metal.

Los problemas identificados son los siguientes:

- Escasa existencia de programas de gestión del mercurio en sectores de salud público y privado.
- El sector de salud privado no se ha incorporado en programas de gestión del mercurio a nivel gubernamental.
- Escaso seguimiento en programas de vigilancia para trabajadores expuestos a este metal.
- No hay instrucciones por parte de la Autoridad Sanitaria hacia las empresas de cómo deben informar la cantidad de mercurio en sus residuos.
- Los importadores no tienen ninguna responsabilidad en la disposición final de los productos con contenido de mercurio que ingresan al país.

Para el cumplimiento del objetivo se propone:

- Fortalecer las iniciativas voluntarias para la gestión del mercurio, en el sector público y privado.
- Promover la incorporación del mercurio en los instrumentos de gestión ambiental, y en el ámbito salud, y seguridad.

4.4 Establecimiento del problema que da origen al objetivo **Fortalecer y armonizar el Marco Normativo relativo al mercurio** y las líneas de acción correspondientes.

Problema

En Chile hay una gran cantidad de sectores productivos identificados que entre sus procesos está presente el mercurio, el cual es liberado por diferentes vías; de igual forma el uso y consumo de productos con contenido de este metal es masivo en el país.

Los problemas identificados son los siguientes:

- No existe norma asociada a la emisión de mercurio en centrales termoeléctricas.
- No está contemplado como parámetro el mercurio en la "Norma Chilena de Calidad de Combustibles".
- Falta de criterios uniformes en las exigencias, como en el caso del sector cementero.
- No existe normativa sobre ingreso, manejo y disposición para productos que contienen mercurio.

Para el cumplimiento del objetivo se propone:

- Definir normativas nacionales basadas en recomendaciones Internacionales.
- Mantener un registro actualizado de la legislación aplicable al mercurio.
- Revisar los vacíos legales relacionados con el mercurio.
- Potenciar la aplicación de la legislación vigente y en estudio.

4.5 Establecimiento del problema que da origen al objetivo **Gestionar de manera racional los sitios con presencia de mercurio** y las líneas de acción correspondientes.

Problema

En el Norte de Chile hay una gran cantidad de mercurio que se ha generado durante muchos años producto de las actividades mineras, este metal pesado al entrar en contacto con la fase acuosa se puede transformar en metil mercurio[9], comportándose como un contaminante orgánico persistente, presentando de ese modo características de bioacumulación, capacidad para trasladarse en grandes distancias además de su evidente y comprobada toxicidad para la población expuesta.

Los problemas identificados son los siguientes:

- No existe información en la población expuesta más cercana, sobre los riesgos que conlleva la contaminación con mercurio.
- Existe gran cantidad de sitios, que corresponden a relaves con presencia de mercurio abandonados cerca de poblaciones y plantaciones agrícolas.
- Falta de investigación sobre cantidades de mercurio en sitios, relaves, botaderos y efluentes del país.
- Existe gran cantidad de mercurio que es liberado a diferentes medios, por un mal uso del metal por parte de pirquineros.

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[9]La Conferencia de las Partes en el Convenio de Estocolmo, establece que el metil mercurio, tiene las características de un compuesto orgánico persistente y que todas las emisiones antropogénicas de mercurio pueden llegar a transformarse en metil mercurio.

- Se han realizado muy pocos exámenes de muestras biológicas a la población expuesta a sitios con presencia de mercurio.

Para el cumplimiento del objetivo se propone:

- Poner en marcha un programa piloto de caracterización de la problemática del mercurio en la comuna de Andacollo.
- Identificar otros sitios con potencial presencia del mercurio.

4.6 En relación con el objetivo **Institucionalizar el Inventario de Usos, Consumos y Emisiones en el RETC,** se propone:

Chile inició el diseño de su Registro de Emisiones y Transferencia de Contaminantes a finales del año 2002, a partir de las metodologías propuestas por UNITAR. El año 2005 el Consejo Directivo de CONAMA mediante Acuerdo N° 277, aprueba la Propuesta Nacional para la implementación del RETC en Chile.

A finales del año 2007, Chile publica el primer reporte del RETC, el cual se continuará publicando anualmente, pero no considera los productos con contenido de mercurio.

El problema identificado es el siguiente:

- En el diseño del RETC no se consideraron de productos con contenidos con mercurio.

Para el cumplimiento del objetivo se propone

- Complementar infraestructura existente.
- Generar una nueva infraestructura.

5 Plan de Acción

Objetivos Específicos	Nº	Líneas de Acción	Nº	Plan de Acción de corto plazo (2009-2010)	Indicadores	Responsable	Nº	Plan de Acción de mediano plazo (2010-2011)	Indicadores	Responsable	Nº	Plan de Acción de largo plazo (2011 en adelante)	Indicadores	Responsable
1. Fortalecer la información base del Inventario de Usos, Consumos y Emisiones de mercurio	1.1	Validar las tasas de actividad definidas en el Inventario	1.1.1	Incorporar descriptores de atributos específicos a la importación de determinados productos con Mercurio.	Porcentaje de productos importados a los que se le ha incorporado descriptores de atributos específicos, del total de productos importados con contenido de Hg	Servicio Nacional de Aduanas								
	1.2	Convenir métodos de entrega de información.					1.2.1	Ampliar Convenio de Cooperación CONAMA – Servicio Nacional de Aduanas para productos con contenido de mercurio	Número de productos con contenido de mercurio incorporados en la ampliación de nuevos convenios	CONAMA Servicio Nacional de Aduanas				
	1.3	Realizar mediciones de Mercurio en las corrientes de diversos procesos productivos.	1.3.1	Incentivar la realización de mediciones voluntarias de Mercurio en Centrales Termoeléctricas.	Porcentaje de centrales termoeléctricas que realizaron mediciones voluntarias de mercurio, del total de centrales termoeléctricas identificadas en el país.	CONAMA, CNE, MINSAL					1.3.1	Establecer un registro confiable y adecuado de las emisiones de Mercurio producto de centrales termoeléctricas.	Porcentaje de centrales termoeléctricas con registros de emisiones de Hg, del total de centrales termoeléctricas identificadas en el país.	CNE, CONAMA, MINSAL

			1.3.2	Apoyar metodológicamente campañas de mediciones voluntarias de Mercurio, en el marco de un convenio público - privado, en las distintas corrientes del proceso de producción de las grandes empresas mineras.	Porcentaje de grandes empresas mineras que han realizado campañas de medición voluntarias de mercurio en las distintas corrientes del proceso, del total de grandes empresas mineras identificadas en el país.	CONAMA, COCHILCO, SERNAGEOMIN	1.3.2	Promover un estudio piloto para establecer las cantidades de Mercurio por tipo de yacimiento, producto y subproducto	Porcentaje de yacimientos en los cuales se ha podido establecer las cantidades de mercurio como producto y subproducto, del total de yacimientos dentro del estudio piloto.	SERNAGEOMIN CONAMA	1.3.2	Realizar mediciones que permitan establecer una línea base geológica de los lugares identificados con potencial presencia de Mercurio, lo anterior supeditado a la disponibilidad presupuestaria de las instituciones responsables.	Porcentaje de sitios con potencial presencia de Hg con mediciones para la línea base geológica, del total de lugares identificados con potencial presencia del contaminante.	SERNAGEOMIN CONAMA

											1.3.3	Medir el contenido de mercurio en las corrientes de los procesos de las Refinerías.[10]	Porcentaje de refinerías en las que se ha medido contenido de mercurio en las distintas corrientes del proceso, del total de refinerías identificadas en el país.	CONAMA ENAP MINSAL
											1.3.4	Apoyar e incentivar la realización de mediciones voluntarias de Mercurio en los derivados del crudo, incluyendo emisiones en el proceso de producción.[11]	Porcentaje de mediciones voluntarias de mercurio realizadas en los derivados del crudo, incluyendo emisiones en el proceso de producción realizadas.	CONAMA ENAP MINSAL
	1.4	Estandarizar métodos y análisis de medición de Mercurio.	1.4.1	Lograr una estandarización de los datos obtenidos desde las distintas empresas cementeras.	Porcentaje de empresas cementeras con datos estandarizados, del total de cementeras identificadas en el país.	CONAMA POLPAICO LAFARGE								

[10] Será implementada en la medida que las normativas internacionales definidas por los Gobiernos, permitan el desarrollo de metodologías, procesos y estándares que permitan a la Industria Petrolera realizar este tipo de mediciones, sin afectar la seguridad de las personas que trabajan y viven cerca de las instalaciones.

[11] Existen procesos de alta temperatura y presión en los cuales es imposible realizar mediciones.

	1.5	Incentivar en las universidades y centros de investigación estudios relacionados con la problemática del mercurio.					1.5.1	Incentivar estudios de evaluación de carga y monitoreos de mercurio, por parte de las Universidades y Centros de Investigación.	Número de estudios de evaluación de carga y monitoreos de mercurio, por parte de las Universidades y Centros de Investigación.	CONAMA				

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2. Sensibilizar y generar capacidades a los actores involucrados en la gestión de los procesos y productos con contenido de mercurio, en el correcto uso, manipulación, disposición y los riesgos asociados a la exposición de este elemento.	2.1	Implementar campañas de capacitación respecto a los riesgos del consumo de productos con Mercurio.	2.1.1	Implementar el Programa "Hospitales sin Mercurio", en dos hospitales públicos considerando 5 etapas superpuestas: i. Evaluación del establecimiento ii. Evaluación de los planes/procedimientos existentes iii. Asistencia en la elaboración de nuevos planes iv. Evaluación post-implementación v. Capacitación	Porcentaje de cumplimiento de etapas del proyecto.	CONAMA MINSAL (Subsecretaría de Redes Asistenciales)	2.1.1	Diagnosticar y generar línea de base de instrumentos con contenido de mercurio a lo menos en un hospital por cada uno de los servicios de salud (adquisición, uso, protocolo de manejo y disposición final).	Porcentaje de hospitales de los servicios de salud con diagnóstico y generación de línea base del total de hospitales escogidos.	MINSAL (Subsecretaría de Redes Asistenciales)	2.1.1	Iniciar Campaña de Redes Públicas sin mercurio.	Porcentaje de Redes Públicas sin instrumentos con contenido de mercurio del total de redes existentes en el país.	MINSAL (Subsecretaría de Redes Asistenciales)
											2.1.2	Establecer los mecanismos necesarios para crear centros de recolección y disposición de residuos con mercurio.	Número de centros de recolección y disposición de residuos con mercurio implementados.	CONAMA
	2.2	Difundir en establecimientos educacionales información de los riesgos de un mal uso, manipulación o disposición de productos con Mercurio.					2.2.1	Incorporar el tema del Mercurio en las mallas curriculares de los cursos de capacitación a profesores impartidos por el CPEIP.	Número de cursos de capacitación que incorporaron el tema del mercurio dentro de sus mallas curriculares.	CPEIP, SERNAC	2.2.1	Incorporar en los planes y programas de educación el tema del consumo informado de productos con Mercurio.	Número de programas de educación en los cuales se ha incorporado el tema de consumo informado de productos con mercurio.	MINEDUC

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	2.3	Promover mesas de trabajo con diferentes sectores	2.3.1	Coordinar una mesa de trabajo con los productores, importadores y distribuidores de ampolletas eficientes, con el propósito de asegurar y educar en torno a su buen uso y disposición debido a sus contenidos de mercurio.	Número de actividades realizadas en torno a la mesa de trabajo (ejs: campaña educativa; revisión de tecnologías disponibles, entre otras)	CONAMA	2.3.1	Identificar mesas de trabajo con otros rubros.	Análisis Comparativo del número de rubros identificados que se van incorporando semestralmente.	CONAMA	2.3.1	Coordinar campañas educativas sobre los riesgos asociados a cada sector de mesas de trabajo.	Análisis comparativo de campañas educativas que, semestralmente, se van coordinando por sectores dentro de las mesas de trabajo.	CONAMA
	2.4	Confeccionar programas de gobierno para generar conciencia de los riesgos del uso y manejo inadecuado del Mercurio en procesos productivos, particularmente en la pequeña y mediana minería.	2.4.1	Optimizar un programa piloto en la ciudad de Andacollo, para la capacitación de la minería artesanal, abordando los riesgos asociados al uso del mercurio en el proceso de extracción de oro[12], y la incorporación de nuevas tecnologías que no utilicen mercurio en sus procesos y/o maximicen su reutilización.	Porcentaje de pirquineros en Andacollo, capacitados y utilizando nuevas tecnologías para la extracción del oro con uso eficiente del Hg, del total de pirquineros identificados en la zona.	MINERIA, CONAMA	2.4.1	Replicar programa de capacitación e incorporación de nuevas tecnologías en otras ciudades con presencia de esta actividad.	Número de programas de capacitación implementados a nivel nacional en zonas distintas a Andacollo,	MINERIA, CONAMA	2.4.1	Dar seguimiento a los programas de capacitación e incorporación de nuevas tecnologías, evaluando el impacto generado en la pequeña y mediana minería del oro.	Análisis comparativo de considerando la anterior y actual situación en las zonas capacitadas y en las que se introdujeron nuevas tecnologías.	MINERIA, CONAMA

[12] El Ministerio de Minería, en conjunto con ENAMI y SERNAGEOMIN, llevaron a cabo el Programa Ecomín entre los años 2000-2004. En este Programa se realizaron una serie de cursos de capacitación a la pequeña minería a nivel regional, incorporando el tema del uso del mercurio.

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3. Incentivar la generación y aplicación de instrumentos voluntarios y obligatorios de gestión para un manejo racional del mercurio.	3.1	Fortalecer las iniciativas voluntarias para la gestión del mercurio, en el sector público y privado.	3.1.1	Incentivar y apoyar técnicamente las iniciativas voluntarias del sector público y privado, en cuanto a la gestión del mercurio, a través de guías metodológicas.	Número de guías metodológicas de gestión de mercurio incorporadas en el sector público y privado.	CONAMA	3.1.1	Velar por el establecimiento de programas de vigilancia para determinar los niveles de Mercurio en trabajadores sobreexpuestos al metal.	Porcentaje de trabajadores sobreexpuestos al metal a los que se les ha realizado programas de vigilancia del total de trabajadores expuestos identificados.	MINSAL				
	3.2	Promover la incorporación del mercurio en los instrumentos de gestión,	3.2.1	Incorporar al sector privado de salud a las actuales iniciativas de gestión del mercurio, que se están realizando en el sector público de salud.	Porcentaje de instituciones de salud del sector privado que han incorporado iniciativas de gestión de mercurio del total de instituciones privadas identificadas.	CONAMA, MINSAL					3.2.1.	Generar un mecanismo de información que permita identificar en el sector privado de salud, la cantidad de productos con contenido de mercurio que son utilizados.	Cantidad de productos identificados con contenido de mercurio en el sector privado de salud que son utilizados.	CONAMA, MINSAL

		ambiental, y en el ámbito salud, y seguridad.	3.2.2	Disponer de la información que manejan los Organismos Administradores del Seguro de la ley 16.744 respecto a trabajadores expuestos al mercurio y los programas de vigilancia que se llevan a cabo.	Porcentaje de Organismos Administradores del Seguro de la ley 16.744 que traspasan información al MINSAL del Total de Organismos Administradores del Seguro de la ley 16.744.	MINSAL								
			3.2.3	Instruir por parte de la Autoridad Sanitaria, a las empresas respecto a cómo informar del contenido de mercurio en los residuos.	Número de empresas que la ASRM ha instruido de cómo informar el contenido de mercurio en los residuos.	MINSAL								
			3.2.4	Establecer la declaración de residuos con contenido de mercurio.	Número de declaraciones de residuos con contenido de mercurio.	MINSAL								
	3.3	Incentivar mecanismos de gestión en los sectores involucrados en la distribución de productos con mercurio.					3.3.1	Establecer un programa piloto para implementar la responsabilidad extendida del importador para las lámparas con Mercurio.	Porcentaje de importadores que han implementado programa de responsabilidad extendida del importador para las lámparas con mercurio del total de importadores identificados en el país.	CONAMA, PPEE	3.3.1	Implementar la responsabilidad extendida del importador en todos los sectores involucrados con productos con contenido de mercurio.	Porcentaje de importadores que han implementado programa de responsabilidad extendida para los productos con contenido de mercurio del total de importadores identificados en el país.	CONAMA, MINSAL, MINECON

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4. Fortalecer y armonizar el Marco Normativo relativo al mercurio.	4.1	Adoptar normativas nacionales basadas en recomendaciones Internacionales	4.1.1	Estudiar la posibilidad de incorporar al Mercurio como parámetro en la norma de Centrales Termoeléctricas y la exigencia de caracterización de contenido de Mercurio en el carbón.	Existencia de Norma que incorpora al mercurio como parámetro en la norma, con la exigencia de la caracterización del contenido de mercurio en el carbón.	CONAMA, CNE, SEC MINERÍA, ECONOMÍA, MINSAL MINAGRI								
			4.1.2	Modificar Norma Chilena de Calidad de los Combustibles.	Cantidad de tipos de combustible con norma de calidad.	SEC, CNE, CONAMA								
	4.2	Mantener un registro actualizado de la legislación aplicable al mercurio.	4.2.1	Analizar y definir criterios uniformes en las exigencias solicitadas a la industria del cemento.	Porcentaje de plantas cementeras con las exigencias uniformes solicitadas del total de plantas cementeras del país.	CONAMA								
	4.3	Revisar los vacíos legales relacionados con el mercurio.	4.3.1	Generar la regulación de todo el ciclo de vida del mercurio.	Cantidad de etapas del ciclo de vida del mercurio que han sido reguladas.	MINSAL	4.3.1	Generar la exigencia de un certificado que indique el contenido de Mercurio para determinados productos importados.	Cantidad de productos con certificados que indiquen el contenido de mercurio.	MINSAL				

							4.3.2	Establecer límites máximos de contenido de mercurio en los productos que ingresan al país y que no cuentan con sustitutos.	Porcentaje de productos con mercurio que ingresan al país (que no cuentan con sustitutos) y han sido regulados en su contenido, del total de estos productos identificados en el país.	MNSAL	4.3.2	Establecer la prohibición de productos con contenido de mercurio que cuenten con sustitutos en el mercado, de acuerdo a legislación internacional.	Porcentaje de productos con contenido de mercurio que cuenten con sustitutos en el mercado, y que han sido prohibidos en el país, del total de estos productos identificados en el país.	MINSAL y Otros Organismos
							4.3.3	Establecer un protocolo de Análisis para las mediciones de metil mercurio.	Existencia de un protocolo para el análisis de metilmercurio en distintos medios.	MINSAL				

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5.Gestionar de manera racional los sitios con presencia de mercurio	5.1	Poner en marcha un programa piloto de caracterización de la problemática del mercurio en la comuna de Andacollo.	5.1.1	Generar una mesa de trabajo intersectorial con los distintos actores involucrados.	Número de actividades realizadas en tomo a la mesa de trabajo.	CONAMA	5.1.1	Realizar estudios de monitoreo de mercurio en los diferentes componentes ambientales comprometidos.	Número de monitoreos realizados en los diferentes componentes ambientales.	CONAMA MINSAL SERNAGEOMIN	5.1.1	Difundir y sensibilizar a los actores pertinentes en base a los resultados de los estudios realizados.	Número de jornadas de trabajo para la difusión y sensibilización.	CONAMA
	5.2	Identificar otros sitios con potencial presencia del mercurio.					5.2.1	Levantar nueva información de sitios potencialmente contaminados con mercurio.	Cantidad de Información nueva recopilada.	CONAMA MINSAL SERNAGEOMIN	5.2.1	Aplicar metodología de identificación de sitios en base a la metodología existente.	Número de nuevos sitios identificados con aplicación de metodología.	CONAMA MINSAL SERNAGEOMIN

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6. Institucionalizar el Inventario de Usos, Consumos y Emisiones de Mercurio en el RETC.	6.1	Complementar infraestructura existente.	6.1.1	Incorporar el contaminante mercurio en la Circular MINSAL Nº B32/23 del 2006 que imparte instrucciones de aplicación del D.S MINSAL 138/2005, ampliar los sectores (extracción minera, rellenos sanitarios, etc.) y agregar información relativa al mercurio de manera que permita estimar sus emisiones, principalmente información de contenidos de mercurio en: materia prima, combustible, productos intermedios, productos finales, emisiones.	Porcentaje de Sectores Industriales que tienen liberaciones de mercurio incluidos en el Formulario Electrónico 138 / D.S. 138/2005 MINSAL, con los parámetros adecuados para la estimación de sus emisiones según la metodología del Instrumental, del total de sectores pertinentes identificados en el país.	MINSAL								
			6.1.2	Incorporar para el sector industrial, métodos de cálculo de emisiones al aire del instrumental del mercurio en el modelo de emisiones SAIE. Incorporar métodos de estimación del instrumental para fuentes areales en el SAIE.	Porcentaje de subcategorías de fuentes areales incluidas en el modelo de cálculo de emisiones.	CONAMA, MINSAL								

			6.1.3	Complementar en los residuos peligrosos la información de composición actualmente manejada por empresas de manejo (tratamiento específico).	Porcentaje de residuos sólidos con contenidos de mercurio incorporados al RETC, que cuentan con la cantidad de mercurio contenida en el residuo.	MINSAL								
							6.1.4	Mejorar la identificación y caracterización de nuevos productos que contienen mercurio, en trabajo conjunto con el Servicio Nacional de Aduanas.	Cantidad de productos nuevos con contenido de mercurio incorporados al RETC	Servicio Nacional de Aduanas, MINSAL, CONAMA				
	6.2	Generación de nueva infraestructura.	6.2.1								6.2.1	Generar sistema de seguimiento de la cadena de distribución para la establecer su disposición espacial.	Porcentaje de productos que contienen mercurio con exigencia de reportes y sistemas de administración.	MINSAL CONAMA

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GOBIERNO DE CHILE
COMISION NACIONAL
DEL MEDIO AMBIENTE

Carta D.E. N° 092967 /

Mat.: Asesoría para el análisis del impacto económico y social de la Norma de Emisión para Termoeléctricas en Chile

Santiago de Chile, 26 AGO. 2009

Señor
Greg Radford
Director Environment and Social Development Department
International Finance Corporation IFC - World Bank Group

De mi consideración,

Junto con saludarle, a través de la presente me es grato informar a usted que Chile inició el año 2006, el proceso de elaboración de una norma de emisión para termoeléctricas, trabajo que involucra a varios organismos del Estado y que es coordinado por la Comisión Nacional del Medio Ambiente (CONAMA).

La futura norma de emisión corresponde a un instrumento de prevención de la contaminación y de sus efectos, es decir, sus valores límites de emisión se fijarán con tal que respondan al mínimo posible de acuerdo a la factibilidad técnica, económica y social, donde se valorarán los beneficios derivados por las mejoras en la calidad del aire. Actualmente, se desarrolla la etapa de elaboración de anteproyecto y se preparan los antecedentes sobre la evaluación del impacto económico y social de la futura regulación.

Parte de los antecedentes importantes que se han integrado al análisis para el diseño de la norma de emisión, corresponden a los documentos del Banco Mundial: "Environmental, Health, and Safety Guidelines for Thermal Power Plants" (2008), "Thermal Power: Rehabilitation of Existing Plants Pollution Prevention and Abatement Handbook" (1998) y "Thermal Power Guidelines for New Plants" (1998). Al respecto, nuestros profesionales encargados del diseño regulatorio han tomado contacto con el especialista de su institución Sr. Alexander W. Indorf, quien ha tenido la cordialidad de responder diversas inquietudes del equipo Chileno.

Dado lo anterior, quisiera solicitar a usted evaluar la posibilidad de establecer una relación de colaboración entre nuestras instituciones o mejor aún generar una agenda formal de trabajo a través de un convenio de cooperación, que nos permita conocer y recibir la experiencia de ustedes en el diseño de las guías (ampliándolo a otros rubros y actividades), conocer los fundamentos y enfoques regulatorios, así como también, la evaluación económica de los costos de capital al introducir distintos tipos de tecnologías de abatimiento.

Por último y en particular, en el mes de noviembre se realizará un seminario en el que se dará a conocer el anteproyecto de norma de emisión para las termoeléctricas. Iniciándose con esto, de acuerdo a nuestro reglamento, una consulta pública nacional. Para esta actividad sería muy valioso poder contar con la participación de algún expositor del IFC - Banco Mundial, lo que dará relevancia a esta actividad.

Agradece su respuesta y saluda atentamente a usted,

COMISION NACIONAL DEL MEDIO AMBIENTE
DIRECTOR EJECUTIVO

ÁLVARO SAPAG RAJEVIC
DIRECTOR EJECUTIVO
COMISIÓN NACIONAL DE MEDIO AMBIENTE

HWA/GLS/MJG/CGCF/aat

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001627

Carmen Gloria Contreras Fierro

De: Carmen Gloria Contreras Fierro

Enviado el: miércoles, 19 de agosto de 2009 18:09

Para: 'Walter Folch'; 'Olga Espinoza'; 'jeanine.hermansen@sag.gob.cl'; 'tsaavedra@minvu.cl'; 'Carolina Gomez'; 'Jaime Bravo'; German Oyola; Ingrid Henriquez Cortez; Claudio Bonacic Fuica; Claudia Ferreiro; Sandra Carolina Briceño Pérez

CC: Priscila Andrea Ulloa Menare; Maritza Jadrijevic Girardi; Gonzalo Leon Silva; Hans Willumsen

Asunto: Cita Reunión Comité Operativo Termoeléctricas

Importancia: Alta

Datos adjuntos: anteproyecto Termoelectricas v05_agosto.doc

Estimados Integrantes Comité Operativo Norma Termoeléctricas

Se cita a reunión para el miércoles 2 de septiembre de 11:30 hrs. a 13:00 hrs.. Temas de la reunión:

- Comentarios y observaciones a versión borrador de anteproyecto (se adjunta).
- Avances del estudio AGIES desarrollado por KAS-GeoAire.

Por otro lado, se informa que:

1. A la fecha, se envío desde la D.E. de CONAMA carta formal a cada termoeléctrica solicitando respuesta a encuesta para estudio. La encuesta fue elaborada por las consultoras y revisada por CNE y CONAMA. Ya se recepcionó en un 98% la información, y ya está siendo procesada por el consultor.
2. Se han sostenido reuniones de trabajo internas de seguimiento y discusión al estudio, una de las reuniones se invitó a participar a representantes de CNE, MINAGRI (se excusó) y MINSAL.
3. Se contactó a Coordinador del IFC - Banco Mundial, con objeto de conocer e intercambiar experiencia sobre guías con recomendaciones para thermal power. Más información en la próxima reunión.
4. Se realizó reunión de Comité Ampliado, con el fin de presentar a nuevo grupo consultor y responder inquietudes sobre encuesta.

Atte.,

Carmen Gloria Contreras Fierro
Área Control de la Contaminación Atmosférica
Dpto. Control de la Contaminación
CONAMA Fono: 56 02 240 57 72

Acta reunión Comité Operativo Norma de Emisión para Termoeléctricas
2º de septiembre 2009 Inicio: 11:30 hrs. - Término: 13:00 hrs.

Temas:

1. Se reciben y analizan comentarios y observaciones a la versión borrador de anteproyecto.
2. Se entrega un avance del estudio AGIES desarrollado por KAS-GeoAire.
3. Se informa que:

- A la fecha, se envío desde la D.E. de CONAMA carta formal a cada termoeléctrica solicitando respuesta a encuesta para estudio. La encuesta fue elaborada por las consultoras y revisada por CNE y CONAMA. Ya se recepcionó en un 98% la información, y ya está siendo procesada por el consultor.
- Se han sostenido reuniones de trabajo internas de seguimiento y discusión al estudio, una de las reuniones se invitó a participar a representantes de CNE, MINAGRI (se excusó) y MINSAL.
- Se contactó a Coordinador de la guía para termoeléctricas Sr. Alexander Indorf del Internacional Finance Corporation IFC del Banco Mundial, con objeto de conocer e intercambiar experiencia sobre guías con recomendaciones para thermal power. Más información en la próxima reunión.
- Se realizó reunión de Comité Ampliado, con el fin de presentar a nuevo grupo consultor y atender a preguntas sobre la encuesta.

Acuerdos:

1. Se compartirá minuta sobre definición existente/nueva, donde se discuten términos como "puesta en servicio" y que se entiende por "modificación". El comité operativo se compromete a enviar aportes a la minuta.
2. Se simplificará la definición de fuente a regular y que esta sea consistente en todo el borrador. Además, se acuerda que la definición atenderá en forma genérica a la fuente a regular.
3. Se comparten visiones sobre la prioridad de los contaminantes a regular, de acuerdo a los problemas que actualmente enfrenta el país y con esto resolver qué es más importante regular.
4. MINVU entrega observaciones por escrito al anteproyecto.
5. CNE pide revisar los valores del ejemplo planteado. CONAMA explica que el estudio entregará finalmente qué valores son tecnológicamente y económicamente factibles de implementar.
6. Se revisará con ejemplos la aplicación de la exigencia de cumplimiento horario y considerar una base de datos con un 95%.
7. CNE pide se indique procedimiento de carácter obligatorio que asegure el cumplimiento de la gradualidad y la estabilidad del sistema
8. Se realizará reunión MINSAL y MINAGRI-SAG CONAMA con objeto de discutir sobre alcances y roles en la fiscalización, se pide que estén presentes los abogados de las instituciones respectivas.
9. Se adjunta y da conocer resumen de normativa internacional.

Contacto en CONAMA D.E.:
Carmen Gloria Contreras Fierro. cgcontreras@conama.cl. fono: 240 5772

ANTEPROYECTO
NORMA DE EMISIÓN A LA ATMOSFERA PARA TERMOELECTRICAS

Versión 05: Agosto, 2009

Vistos

Considerandos

Observaciones de CNE

Título I: Objetivo, aplicación territorial y definiciones

Artículo 1. El presente anteproyecto de norma de emisión para termoeléctricas es de cumplimiento obligatorio en todo el territorio nacional y tiene por objeto controlar las emisiones de Material Particulado (MP), Óxidos de Nitrógeno (NO_X), Dióxido de Azufre (SO_2), Mercurio (Hg), Níquel (Ni) y Vanadio (V), a fin de prevenir y proteger la salud de las personas, la flora y fauna u otros elementos del medio ambiente como áreas silvestres protegidas y monumentos, entre otros[1].

Artículo 2. El presente anteproyecto de norma de emisión regula termoeléctricas, existentes y nuevas, destinadas a la generación de energía eléctrica que utilizan algún combustible de origen fósil o de biomasa. En particular aplicará a instalaciones de calderas y turbinas y se exceptúa a los motores de combustión interna y a las instalaciones de cogeneración.

Comentario [G1]: Estaria aun en evaluacion por el consultor

Artículo 3. Para los efectos de lo dispuesto en este anteproyecto, se entenderá por:

a) Termoeléctrica[2]: instalación compuesta por una o más unidades destinadas a la generación de energía eléctrica, cuyo principio de funcionamiento se basa en la conversión de energía térmica a mecánica, y ésta a su vez, en energía eléctrica. La conversión de energía térmica a mecánica se produce a través del uso de un fluido que produce trabajo en su proceso de expansión. La conversión de energía mecánica en eléctrica se efectúa a través del accionamiento de un generador eléctrico acoplado al eje de una turbina.

Simplificar definición,

b) Unidad de generación: corresponde a aquella caldera y/o revisar turbina de generación que forma parte de una termoeléctrica, que utiliza algún combustible de origen fósil o de biomasa. aclarar.

Eliminado: aclarar

c) Fuente emisora existente: corresponde a aquella termoeléctrica que a la fecha de publicación que oficializa la presente norma de emisión se encuentra construida o en construcción. Se aclarará

[1] De acuerdo a lo indicado expresamente en el Decreto Supremo Nº 93/95 del Ministerio Secretaría General de la Presidencia, párrafo 3º. Artículo 34, letra d).
[2] Definición mejorada a partir de consulta a CNE, Of.Nº 001161/18.12.08. Expediente Público 1161-1162.

d) Fuente emisora nueva: corresponde a aquella termoeléctrica cuya construcción, ampliación o modificaciones se inicia con posterioridad a la fecha de publicación que oficializa la presente norma de emisión. Aclarar a que se refiere modificación

Combustible
Aumentar potencia
Repotenciar
Adicionar equipo de abatimiento

* que modificaciones se incluyen: que no implique aumento en las emisiones*

e) Medición continúa de emisiones: sistema constituido por el instrumental, el equipamiento y el software, destinado a monitorear en forma ininterrumpida las emisiones de partículas, gases y parámetros del proceso asociados a los gases de combustión.

Comentario [G2]: Se solicita analizar con mucho cuidado como quedan los incentivos al poner "modificaciones" en esta definición, ya que mejoras en unidades existentes les haría quedar como fuente nueva y puede ocurrir que el titular no quiera invertir en mejoras. Por ejemplo: SCR en central Renca, aumento de campos en PE de Guacolda 1 y 2

Con formato: Español (España - alfab. internacional)

Título II: Límites máximos de emisión y plazo para el cumplimiento

Artículo 4. Los límites de emisión para fuentes emisoras existentes y nuevas y los plazos para su cumplimiento se indican a continuación:

Ejemplo de valores en evaluación:

Tabla 1: Límites de emisión para calderas existentes y nuevas, mayor o igual a 50MWt (mg/Nm^3)

Combustible	Material Particulado (MP)		Dióxido de azufre (SO_2)		Óxidos de Nitrógeno (NO_X)	
	existente	nueva	existente	Nueva	existente	nueva
Carbón	50	30	400	200	400	200
Biomasa	50	30			400	200
Diesel	30	30	400	200	400	200
Gas					250	250

(1) 50MWt: capacidad total de potencia térmica en función del poder calorífico superior.
(2) Condiciones normales a 25 °C y 1 atmósfera.
(3) Corrección de O_2 en base seca de un 6% para combustibles sólidos y de un 3% para combustibles líquidos.

CNE: Los valores señalados en la tabla son los más restrictivos que se puedan exigir, estos corresponden a la publicación del Banco Mundial señalados para **unidades nuevas**, para el **año 2008** y para DA (Degraded airshed) cuyos valores son mas altos que para NDA (Non Degradades airshed) en los tres contaminantes. La publicación del Banco Mundial del año 1998 para **plantas nuevas** son 50 para MP, 2000 para SO2 y valores de 1500, 750, 460 y 320 para NO2. La norma de la Comunidad Europea también presenta valores menos estrictos. Se solicita que en el AGIES se evalúen también limites de emisión menos estrictos como son Banco Mundial 1998 y Norma de la Comunidad Europea.

Por otra parte se sugiere regular por contaminante: sólido, liquido y gaseoso, por futuros tipos y/o mezclas de combustibles.

Eliminado: revisar valores de referencia tomados Bco. Mundial

Con formato: Fuente: Negrita

Con formato: Fuente: Negrita

Con formato: Fuente: Sin Negrita

Con formato: Fuente: Sin Negrita

Con formato: Fuente: Negrita

Eliminado: ¶

Gradualidad por contaminante

Tabla 2: Límites de emisión para turbinas existentes y nuevas, mayor o igual a 50MWt (mg/Nm^3)

Combustible	Material Particulado (MP)		Dióxido de azufre (SO_2)		Óxidos de Nitrógeno (NO_X)	
	existente	nueva	existente	nueva	Existente	nueva
Gas Natural						
Otros combustibles distintos a gas natural						

(1) 50MWt: potencia térmica en función del poder calorífico superior.
(2) Condiciones normales a 25 °C y 1 atmósfera.
(3) Corrección de O_2 en base seca de un 15%.

Los valores límites de emisión de la tabla 1 y 2, se evaluarán en periodos de una hora y deberán cumplirse durante el 95% de las horas de funcionamiento en estado en régimen[3] durante un año calendario, el 5% 18 días 6 horas restante comprende las horas de funcionamiento de las etapas de encendido, apagado o probables fallas.
Revisar regulación española art.14. se excluye periodo de partida
Como funciona el mercado de generacion español
Revisar con ejemplos como aplicaría
Ejemplo con diesel

Tabla 3: Límites de emisión para metales pesados, calderas existentes y nuevas, mayor o igual a 50MWt , que usan carbón o pet-coke (mg/Nm^3)

Combustible	Mercurio (Hg)	Níquel (Ni)	Vanadio (V)
Carbón	0,1		
Pet-coke		0,5	1

(1) 50MWt: capacidad total de potencia térmica en función del poder calorífico superior.
(2) Condiciones normales a 25 °C y 1 atmósfera.
(3) Corrección de O_2 en base seca de un 16%.

Los valores limites de emisión de la tabla 3, se considerarán sobrepasados cuando cualquier valor de medición de concentración sea mayor al indicado.

Las fuentes emisoras existentes deberán cumplir con los valores límites de emisión en un plazo de cuatro años analisis de la gradualidad (generación seguridad), contado desde el inicio del año calendario siguiente de la fecha de entrada en vigencia de la presente norma. Las fuentes emisoras nuevas deberán cumplir desde la entrada en vigencia de la presente norma.

CNE: PROCEDIEMINTO DE control , cronograma, que asegure que se cumplirá y evite atochamiento. Posibilidad de que el CDEC presente el programa. Cronograma obligatorio. De que manera?

Con formato: Izquierda

[3] Estado en régimen o estacionario.

Ver norma incineración.

Título III: Fiscalización, metodología de medición y procedimiento de control

Artículo 5. Corresponderá el control y fiscalización del cumplimiento de las disposiciones señaladas en la presente norma a los respectivos Secretarías Regionales del Ministerio de Salud (SEREMI de Salud) y a los Servicios Agrícolas Ganaderos Regionales del país.

Artículo 6. Las termoeléctricas existentes y nuevas, mayor o igual a 50MWt, deberán implementar un sistema de medición continuo de emisiones en chimenea para material particulado (MP), dióxido de azufre (SO_2), óxidos de nitrógeno (NO_X) y de los parámetros de interés que se relacionan con las emisiones caudal, temperatura y oxigeno de los gases de salida.

Las termoeléctricas existentes tienen un plazo de dos años para implementar el sistema de medición continuo de emisiones, contado desde la fecha de entrada en vigencia de la presente norma. Las fuentes emisoras nuevas deberán incorporar el sistema desde la entrada en vigencia de la presente norma.

Para la implementación del sistema de medición continuo de emisiones se deberá contemplar:

i) Las termoeléctricas, existentes o nuevas, deberán presentar por única vez a la autoridad fiscalizadora regional para su aprobación mediante resolución fundada, un informe sobre el sistema de medición continuo de emisiones que se implementará.

ii) En el caso de las termoeléctricas existentes, el informe se presentará en el plazo de un año, contado desde la fecha de publicación que oficializa la presente Norma.

iii) El informe será aprobado si cumple con los criterios de exactitud relativa cuando se trate de gases y flujo, o de coeficiente de correlación cuando se trate de material particulado, así como también, con los criterios de rendimiento, fiabilidad, certeza y calidad requeridos por el fiscalizador. El informe debe indicar además el programa de aseguramiento de calidad y control que se implementará y la frecuencia de las respectivas calibraciones.

iv) El sistema de medición continúo de emisiones utilizará equipos que cuentan con la aprobación de la Agencia de Protección Ambiental de los Estados Unidos USEPA, o con la aprobación de la Unión Europea; y que se basen en uno de los principios de medición señalados en la Tabla Nº 4 u otros aprobados por la USEPA o la Unión Europea.

Tabla 4: Principios de medición continúa

Contaminante	Principio de Medición
Material Particulado (MP)	Scattering de luz Atenuación Beta Extinción de luz u opacimetría

Dióxido de Azufre (SO_2)	Absorción de Radiación Ultravioleta
Óxido de Nitrógeno (NOx)	Absorción de Radiación Infrarroja
	Fluorescencia Ultravioleta
	Quimiluminiscencia Ultravioleta
	Análisis de Transformada de Fourier de Radiación Infrarroja (FT-IR)

v) Generar valores horarios para cada contaminante medido, los cuales se utilizarán para la verificación del cumplimiento del valor límite máximo de emisión y generar valores horarios de los parámetros que se relacionan con las emisiones, tales como: oxígeno (O_2), flujo máximo de gases de salida (m^3/Nh), temperatura de combustión mínima y máxima (°C).

Una vez implementado el sistema de medición continuo de emisiones se deberá:

vi) Remitir reportes mensuales sobre los resultados de la medición a la Secretaria Regional de Salud respectiva.

vii) El MINSAL definirá y entregará por única vez, los requisitos y contenidos mínimos del reporte mensual, el que contendrá a lo menos lo siguiente: cuando corresponda las horas de encendido, estado en régimen y de apagado; detenciones programadas o por fallas, fallas de equipos de abatimiento e información relativa a la composición químico física del combustible, en particular: contenido de cenizas, de azufre, entre otros a definir por la autoridad fiscalizadora.

Artículo 7. Se eximen de medir en forma continua los contaminantes material particulado (MP) y dióxido de azufre (SO_2), aquella fuente emisora que utilizan sólo gas como combustible. A su vez, cuando se utilice sólo biomasa quedará eximida de medir en forma continua las emisiones de dióxido de azufre (SO_2).

Artículo 8. Las termoeléctricas existentes y nuevas, mayor o igual a 50MWt, que usen carbón o pet-coke, deberán implementar un monitoreo discreto para la verificación del cumplimiento del valor límite de emisión de metales pesados, de acuerdo a la metodología señalada en la tabla N° 5.

Tabla 5: Métodos de medición discreta para metales pesados

Contaminante	Método de medición
Mercurio (Hg) Níquel (Ni) Vanadio (V)	Método CH-29, Determinación de Emisión de Metales desde Fuentes Fijas.

Las mediciones deben ser realizadas por laboratorios autorizados de acuerdo con la normativa vigente. A falta de una metodología oficial de medición, se utilizará la metodología que establezca para tales efectos el Ministerio de Salud.

Artículo 9. Una vez que empieza a regir el artículo 4, todo regulado deberá presentar anualmente en el mes de enero, a la Secretaria Regional de Salud, un informe del año calendario anterior con la siguiente información:

a) Identificación de las instalaciones sometidas a control bajo esta norma: listado de termoeléctricas, su localización en coordenadas UTM, datum WGS-84, uso 19 o 18 según corresponda.

b) Listado de termoeléctricas, periodos de funcionamiento, horas de encendido, estado en régimen, horas de apagado, detenciones programadas y no programadas, el o los combustibles utilizados.

c) Listado de las chimeneas e identificación de la o a las termoeléctricas que evacuan en cada una de estas, localización en coordenadas en UTM, datum WGS-84, huso 19 o 18 según corresponda, la altura y diámetro interno a la salida de los gases, velocidad y temperatura a la salida de los gases.

d) En caso que corresponda informe del laboratorio de las mediciones discretas.

e) Los registros de las mediciones continúas de la instalación (en formato electrónico *.xls).

f) Combustible utilizado y consumo.

g) Un resumen de las situaciones anormales de funcionamiento y las medidas aplicadas.

h) Un análisis sobre el cumplimiento o no de la presente regulación, utilizando gráficas y tablas.

La información base que sirva de sustento al informe anual, deberá estar disponible en las instalaciones reguladas por este decreto, a lo menos por 3 años.

Artículo 10. Anualmente, el servicio fiscalizador deberá enviar a CONAMA Nacional, una copia del Informe técnico anual a que se refiere el artículo precedente. Dicho informe deberá ir acompañado de la siguiente información relativa a la fiscalización y cumplimiento de la norma:

a) Número de inspecciones realizadas a las instalaciones sometidas a control.

b) Principales dificultades encontradas en la implementación de la norma.

c) Resumen de la situación de cumplimiento de la norma.

Dicha información será utilizada por CONAMA para realizar un seguimiento a la implementación de la norma y evaluar futuras necesidades de modificación cuando se realice su correspondiente actualización.

Título IV: Entrada en Vigencia

Artículo 11. El presente decreto entrará en vigencia el día de su publicación en el Diario Oficial

..//

Observaciones de MINSAL al Borrador de Norma de Emisión para Termoeléctricas.

Artículo 2: ok!!

- Reemplazar en el 3er renglón la conjunción y por y/o.

Artículo 3: ok!!

- Nos parece adecuada la definición de termoeléctrica, sin embargo, de la definición y del resto de los artículos, en particular el artículo 4, se desprende que la norma se le aplica al establecimiento y no a cada una de las unidades que conforman la Termoeléctrica. Es necesario que se precise que son las unidades que conforman la termoeléctrica que deben cumplir con los límites. Lo anterior se lograría si se cambia el uso de fuente emisora por unidad de generación.

Artículo 4: ok!!

- Reemplazar la frese fuentes emisoras por "unidades de generación"
- Se propone modificar la redacción del párrafo siguiente a la tabla N°2, en lo siguiente: "..se evaluarán sobre la base de promedios horarios y deberán cumplirse..."
- Las emisiones de metales pesados en las termoeléctricas se deben principalmente al uso del carbón en cualquiera de sus formas, razón por la cual, no es necesario diferenciar entre uso de carbón y pet-coke, toda vez que ambos combustibles son responsables de la emisión metales pesados. La única diferencia es que por el proceso de obtención del pet coke éste concentra aun mas los metales pesados.

Artículo 6: ok!!

- Se propone complementar la redacción del artículo a partir del primer párrafo y a continuación del mismo en la siguiente forma: " ...oxígeno de los gases de salida. Dicho sistema deberá ser aprobado por resolución de los servicios fiscalizadores y deberá contener los resultados de exactitud relativa, coeficiente de correlación y otros parámetros que fijen para la aprobación, las autoridades fiscalizadoras."
- Eliminar el ordinal iii para compatibilizar con el punto anteriormente señalado.
- Modificar el ordinal iv en su redacción de la siguiente manera: "... cuenten con la certificación del cumplimiento del Estándar Europeo EN 14181- Emisiones de fuentes estacionarias - Aseguramiento de Calidad de los sistemas automatizados de medición, o de su similar exigido por las Agencias de Protección Ambiental de los Estados Unidos de Norte América, Canadá u otro país.
- Eliminar la tabla 4, debido a que los principios de medición cambian constantemente y el listado puede quedar obsoleto rápidamente.

MINUTA OBSERVACIONES MINVU
ANTEPROYECTO DE NORMA TERMOELECTRICA

Observaciones:

1. Precisar algunas definiciones y alcances de la norma con el fin de facilitar la comprensión de su aplicación en el territorio chileno.

   Ejemplos:
   - En el Artículo 1, se señala "Emisión para Termoeléctricas": especificar que se refiere a: Centrales de Generación, Instalaciones, o, Plantas. Delimitar el objeto a normar.
   - En el Artículo 2, se señala "Regula Termoeléctricas": precisar que corresponden a Instalaciones o Centrales. El término "termoeléctricas (a)" por sí sólo no parece apropiado para una norma de esta naturaleza.
   - Utilizar términos símiles y delimitados para identificar el objeto normado: Centrales Termoeléctricas, Fuentes Emisoras, Instalaciones Termoeléctricas. En la norma se señalan de diferente forma.

2. Incorporar vocablos en el Artículo 3: combustión de biomasa, combustión fósil, caldera, turbina, etc.
3. Incorporar límite de plazo a la definición de fuente emisora existente, en el sentido del plazo del proceso de "en fase de construcción". Se consulta que ocurre con los Proyectos de Centrales Termoeléctricas que poseen RCA favorable y no han iniciado la fase de construcción (con documento ratificatorio).
4. Aclarar en el Art. 2 letra b, si la Unidad de Generación lo componen la caldera y la turbina. La letra "o" confunde el vocablo de Unidad de Generación, considerando que la Plante Termoeléctrica la compone la turbina y la caldera, señalado en el párrafo final del Artículo segundo.
5. Precisar en el Artículo 2, la potencia térmica de las Plantas Termoeléctricas que son objeto de aplicación de la norma termoeléctrica, tal como se señala en las Tablas de Límites de Emisión del Artículo cuarto.
6. En la letra d del Artículo 3, precisar si las modificaciones de las instalaciones termoeléctricas se refieren a aquellas instalaciones existentes. En este caso, significa que cualquier Fuente Emisora existente se transforma en una nueva al ser modificada o ampliada.
7. En el último inciso del Artículo cuarto, corregir: "Las Fuentes emisoras nuevas deberán cumplir con los valores límites de emisión desde la entrada en vigencia de la presente norma".
8. Se consulta Artículo 8; a que se refiere "monitoreo discreto".
9. No se comprende Artículo 9:"todo regulado".

Consultas

- De acuerdo a lo señalado en el Título III de la Norma, Artículo 5, los entes fiscalizadores corresponderán a las Secretarías Regionales Ministeriales de Salud y a los Servicios Agrícolas Ganaderos.

  Al respecto se consulta la competencia administrativa y/o legal del SAG para ejercer la fiscalización de la aplicación de la norma en el territorio chileno, por cuanto este Servicio posee otras funciones asociadas al apoyo en el desarrollo de la agricultura, los bosques y la ganadería, a través de la protección y mejoramiento de la salud de los animales y vegetales. No se comprende una función directa del SAG en el control de la norma de regulación termoeléctrica: si fuera así podrían existir también otros Servicios vinculantes que puedan ejercer fiscalización como DIRECTEMAR, Gobierno Regional, etc.

  Además, se detecta en el Anteproyecto de la Norma, específicamente en los procedimientos de fiscalización, registro, monitoreo de su aplicación, que el único Servicio habilitado es la Secretaría Regional Ministerial de Salud.

DDU
TSM/ASH

Agosto 2009

Estados Referentes (D.S. Nº 95/2001)	Regulación	Aspectos Regulatorios				
		Fuentes Reguladas			Contaminantes Regulados	Unidad
		Fuente	Tamaño	Combustible		
Argentina [1]	Resolución Nº 108/2001SEyM	Nuevas Existentes	menor y mayor a 75 MW	Sólidos Líquidos Gases	MP, NOx, SO_2, O2	mg/m^3N
Brasil	Resolución Nº 8/1990 CONAMA [2]	Nuevas	menor y mayor a 70 MW (potencia nominal total)	Sólidos Líquidos Gases	MP, SO2	g/Gcal (térmico)
México	Regulación Nº 085/1994 SEMARNAT [3]	Nuevas Existentes (hasta el 31/12/1997)	> 30,5 MWt	Sólidos Líquidos Gases	MP, NOx, SO_2	mg/m3 (MP) kg/106kcal pMPv (gases)
Banco Mundial [1]	Thermal Power:Guidelines for New Plants 1998	Nuevas (desde 1998)	< 500 MWt > 500 MWt	Sólidos Líquidos Gases	MP, NOx, SO2	mg/m^3N
	Environmental, Health, and Safety Guidelines for Thermal Power, 2008	Nuevas (desde 2008)	> 50 MWt - < 300 MWt > /= 300 MWt Calderas (Tabla 6C): > 50 MWt y < 600 MWt >/= 600 MWt	Sólidos Líquidos Gases	MP, NOx, SO2	mg/m^3N
Comunidad Europea	Directiva 2001/80/CE	Nuevas Existentes	50-100 MWt 100-300 MWt > 300 MWt	Sólidos Líquidos Gases	MP, NOx, SO2	mg/m^3N
Alemania	Ordenanza 13-BImSchV/2004	Nuevas Existentes	> 50 MWt	Sólidos Líquidos Gases	MP, NOx, SO2, COV, CO, MP, D&F	mg/m^3
	Requisitos Técnicos TA Luft	Nuevas Existentes	< 50 MWt	Sólidos Líquidos Gases	MP (Org/Inorg), NOx, SO2, COV, CO	mg/m^3
España	Real Decreto Nº 430/2004 Ministerio de la Presidencia	Nuevas Existentes	< 500 MWt > 500 MWt	Sólidos Líquidos Gases	MP, NOx, SO_2	mg/m^3N
Paises Bajos	Boletín de Actas, Ordenanzas y Decretos Nº 167/1998	Nuevas Existentes	todas	Sólidos Líquidos Gases	MP, NOx, SO2	mg/m^3N
Japón	Control de la Contaminación del Aire Ley N° 32/1996 9	Nuevas Existentes	> 50 MW	Sólidos Líquidos Gases	MP, NOx, SO2 Parámetros de Chimenena Otros	g/m3N (MP) pMP (Nox) m3-N/h (SO2)
Suiza	Ordenanza OAPC Control de la Contaminación del Aire, 2000	Nuevas Existentes	> 0,5 MWt	Sólidos Líquidos Gases	MP, NOx, SOx, COV, CO, NH3 Parámetros de Chimenena Sust. Inorganicas gaseosas y en el particulado	mg/m^3N
EEUU [1]	CFR Titulo Nº 40, Parte 60, Sección Da A vapor	Nuevas (desde 28.02.2005) Regulación de Hg (30.01.2004) Existentes	>73 MWt	Enfoque Neutro	MP, NOx, SO_2, Hg	ng/J lb/MMBtu lb/MWh %
	CFR Titulo 40, Parte 60, Sección GG Turbinas a gas	Nuevas (desde el 3.10.1977)	> 2,97 MWt	Enfoque Neutro	NOx, SO_2	ng/J lb/MWh output
Estado de California [1]	Código de Regulaciones Titulo N° 17, Sección 93115	Nuevas Existentes	todas	Sólidos Líquidos Gases	MP, NOx, SO2, VOC, CO	lb/MMBtu lb/MWh %
Canadá [1]	New Source Emission Guidelines for Thermal Electricity Generation, 2003	Nuevas	> 73 MWt	Enfoque Neutro	MP, NOx, SO2 (o 99% de reducción mínima)	kg/MWh output ng/J input
	Recomendaciones de Emisión Nacional para Turbinas de Combustión, 1993	Existentes	todas	Sólidos Líquidos Gases	CO, NOx, SO_2	g/GJ

[1] Regulación para termoelectricas

[2] Regulación de Brasil distingue zonas:
Clase I: Zonas de conservación o preservación
Clase II: Zonas reguladas por normas de calidad secundaria
Clase III: Zonas reguladas por normas de calidad primaria

[3] Regulación de México distingue zonas en:
Zona ZMCM: Zona Metropolitana de la Ciudad de México
Zona ZC: Zonas Críticas
Zona Resto del País (RP)

Minuta para revisión: definición de la fuente a regular y distinción entre existente y nueva

Cgcf/Versión 01/Comité operativo. 3 de sept. 2009

1. Objeto de regulación

a) Central termoeléctrica

Una central termoeléctrica tiene por objeto generar electricidad, hay distintas tecnologías asociadas a una central termoeléctrica. En términos de emisiones atmosféricas es pertinente considerar dos tecnologías asociadas a unidades de generación: calderas y turbinas. Ambas tecnologías pueden utilizar combustibles de origen fósil (carbón, gas, diesel) o de biomasa para su proceso de combustión. Una termoeléctrica puede abastecer algún sistema eléctrico del país (SIC, SING, Edelmag) o autoabastecer a una empresa específica (minera, ENAP, etc.).

La aplicación y constatación del cumplimiento de la norma de emisión es en chimenea (efluente de la fuente emisora).

b) Central termoeléctrica existente

Es aquella que a la fecha de entrada en vigencia de la norma de emisión, se encuentra en servicio para algún sistema eléctrico o para el autoabastecimiento de alguna empresa en particular.

Se requiere definir de acuerdo a la reglamentación eléctrica "en servicio", a CONAMA/Comité Operativo le interesa distinguir como existente a aquella que está construidas y ha operado

c) Central termoeléctrica nueva

- Es aquella que a la fecha de entrada en vigencia de la norma de emisión no esta en servicio o siendo existente presenta una modificación.

d) Modificaciones a una central

En una termoeléctrica se pueden dar varios tipos de modificaciones, en el ámbito de esta futura norma de emisión interesa distinguir aquellas modificaciones que resulten también en una modificación en la cantidad y calidad de las emisiones (excluyendo a priori la incorporación de equipos de abatimiento). De esta forma, se identifican:

- Cambio de combustible.
- Ampliación en la generación, modificación que se realiza mediante la incorporación de una unidad de generación: caldera o turbina.

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GOBIERNO DE CHILE
CONAMA

"COMITÉ OPERATIVO DE NORMA DE EMISION PARA TERMOELECTRICAS"

FECHA : 02/09/2009
HORA INICIO : 11:30 hrs.
HORA TÉRMINO: _____
LUGAR : Sala de Reuniones del 6° piso

N°	NOMBRE	INSTITUCION	DIRECCION	FONO	E-MAIL
1.	CRISTIAN IBARRA	CONAMA			cibarra@conama.cl
2.	Ingrid Henríquez	CONAMA		2405698.	
3.	Claudio Bonacic	CONAMA		2411880	cbonacic@conama.cl
4.	SANDRA BRICEÑO	CONAMA		Ext. 878	sbriceno@conama.cl
5.	Alberto Gil	conama			agil@conama.cl.
6.	Angela Soriano	MINVU / DDU	Alameda 924 6º piso	3513641	asoriano@minvu.cl.
7.	TEO SAAVEDRA	MINVU.	"	3513633	

N°	NOMBRE	INSTITUCION	DIRECCION	FONO	E-MAIL
8.	Priscilla Ulloa	CONAMA	Teatinos 258.	2405787	pulloa@conama.cl.
9.	Cándida Gómez A	CNE	Alameda 1449 piso 14	3676376	cgomez@cne.cl
10.	Montserrat Jadrijevic	CONAMA	Teatinos 258	2405688	mjadrijevic@conama.cl
11.	Germán Oyola	CONAMA Biobío	Lincoyán 145	2791750	goyola.b@conama.cl
12.	Olga Espinoza M	SAG	AUDA. BULNES 140 - 5°	345-1535	olga.espinoza@sag.gob.cl
13.					
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20.					

Acta reunión Comité Operativo Norma de Emisión para Termoeléctricas
16 de septiembre 2009 Inicio: 9:30 hrs. - Término: 11:30 hrs.

Temas:

El consultor presenta:

- Un avance sobre el potencial de reducción de emisiones y el diseño de escenarios. Expositor: Carlos Barria
- Análisis sobre la fuente a regular, definición de fuente, hito entre existente y nueva. Expositora: Marcela Fernández

Acuerdos:

- Se debe mejorar y fundamentar lo presentado sobre potencial de reducción de emisiones.
- La revisión preliminar se debe ampliar a otros análisis, por ejemplo para NO_X, en cuanto a acciones de reftrofit o quemadores, que también logran de acuerdo a la literatura internacional y catálogos significativas reducciones de NO_X.
- Con respecto a la definición se prioriza que sea genérica, se comparte con Marcela F. que no es necesario distinguir entre si una unidad está puesta en servicio para el sistema o si autoabastece.
- Se acuerda diferenciar la regulación por combustible según clasificación en líquidos, gas y sólido.
- Para el caso de biomasa de origen vegetal, los contenidos de azufre son marginales.
- Se acuerda que el hito entre nuevas y existentes es puesta en servicio, de acuerdo al Reglamento eléctrico.
- Se pide al consultor que analice el tema de modificaciones, para zanjar una propuesta concreta y fundamentada. Se considera útil la propuesta de Pedro Sanhueza "tal que no aumente sus emisiones" y el aporte de Enzo Sauma "no es modificación tecnología de abatimientos".
- Se pide corroborar y completar la información recolectada a través de SEIA.

Contacto en CONAMA D.E.:
Carmen Gloria Contreras Fierro
cgcontreras@conama.cl
fono: 240 5772

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Reunión de Avance: Potencial de Reducción de Emisiones y Diseño de Escenarios

Preparado para CONAMA, en el marco del estudio "Análisis General del Impacto Económico y Social de una Norma de Emisión para Termoeléctricas"

GOBIERNO DE CHILE
COMISIÓN NACIONAL DEL MEDIO AMBIENTE

Santiago, Septiembre 2009

Contenidos

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Matriz SIC y SING

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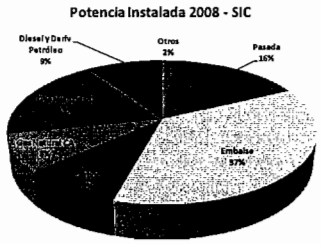

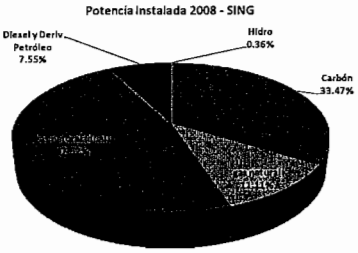

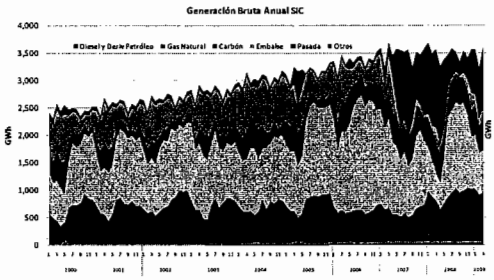

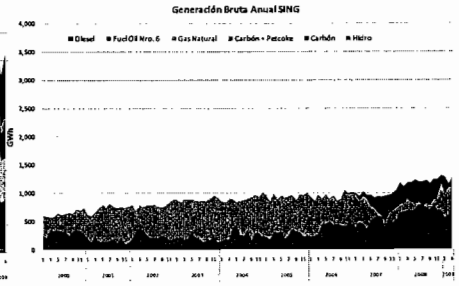

Fuente: CDEC, CNE/Elaboración: KAS

Centrales Termoeléctricas SIC y SING

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SIC

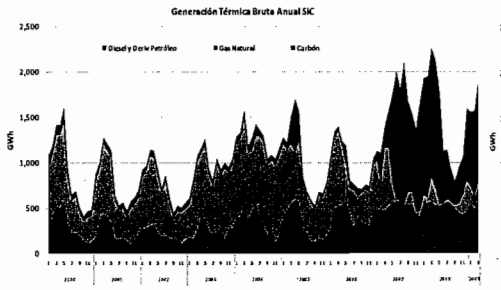
- Capacidad Instalada Termoeléctricas: 4458 MW (47.5% del total instalado)

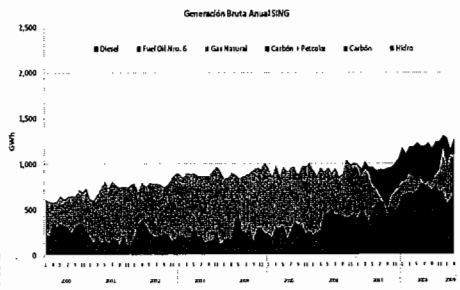
Tipo de Combustible	Potencia Bruta Instalada [MW]	Potencia Bruta Instalada [%]
vapor-licor negro	42	1%
vapor-carbón	837.7	19%
gas-diesel	767.292	17%
gas-IFO 180	64.23	1%
ciclo-abierto dual	784	18%
vapor-des.forest.	124.4	3%
ciclo-combinado dual	1763.3	40%
derivado del petróleo	75	2%
Potencia Termoeléctrica	4468	100%

SING

- Capacidad Instalada Termoeléctricas: 3289 MW (99% del total instalado)

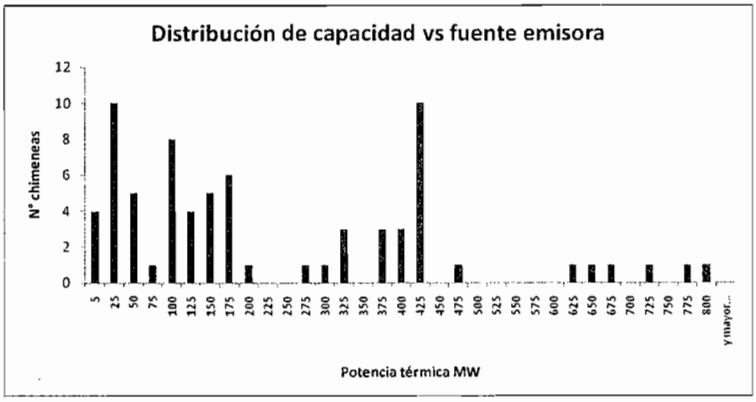
Tipo de Combustible	Potencia Bruta Instalada [MW]	Potencia Bruta Instalada [%]
Carbón (Incluye PetCoke)	1206	34%
Diesel	144	4%
Fuel Oil Nro. 6	128	4%
Gas Natural/Diesel	2112	59%
Potencia Termoeléctrica	3589	100%





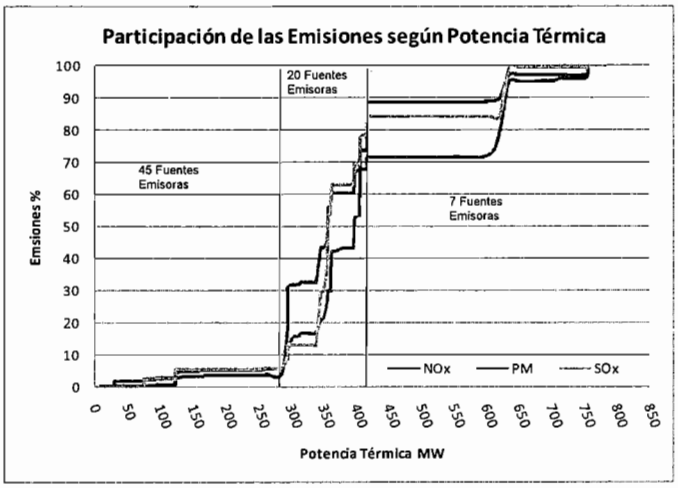
Fuente: CDEC, CNE/Elaboración: KAS

Potencia Térmica y Fuente Emisora



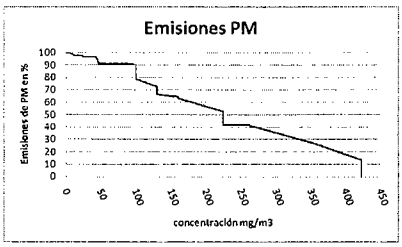
Participación de las fuentes emisoras según potencia térmica:
Entre 5 – 200 MWt -> 61%
Entre 275 – 475 MWt -> 28%
Sobre 625 MWt -> 11%

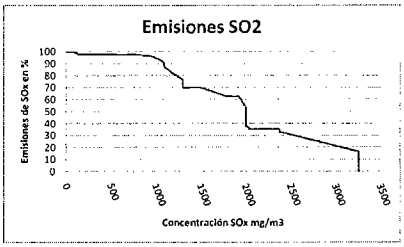
Emisiones y Potencia Térmica

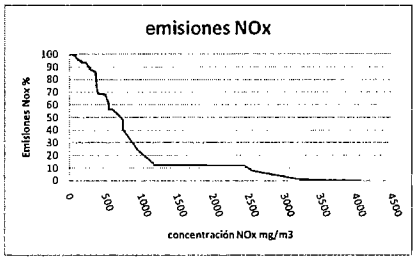


Entre 250 y 400 MWt es responsable del 85% del total de emisiones

Línea Base







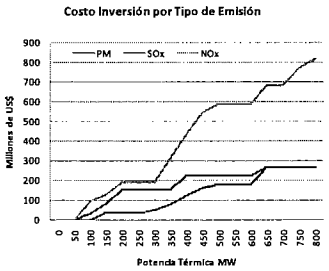
Línea base año 2008

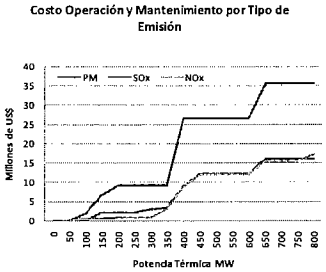
MP [ton/año]	SOx [ton/año]	NOx [ton/año]
7799	74148	33957

Revisión Preliminar de Costos

- Según Banco Mundial, para el año 2008.
  - Abatimiento en centrales que no cumplen la norma.
  - Fuentes de costos: Estudios previos, actualizados según índice "PPI Sheet Metal Works".
- Tecnologías de Abatimiento prevista
  - PM: filtros de mangas.
  - NOx: SCR.
  - SOx: DESOx con agua de mar y húmeda.
- Costos Totales para Cumplir Banco Mundial
  - Costo Inversión: 1347 [MUS$]
  - Costos de Operación y mantenimiento: 69 [MUS$]

Costos	Unidad	PM	SOx	NOx
Inversión	MMUS$	266	265	816
Operación y Mantenimiento	MMUS$	16	36	17





Centrales en Construcción (SIC)

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Central	Campiche	Santa María (Coronel 1)	Bocamina 2	Nueva Ventanas	Guacolda 3	Guacolda 4
Propietario	AES GENER S.A.	Colbún S.A.	Endesa Chile	AES Gener S.A.	Guacolda	Guacolda
Año puesta en Marcha	Fines primer semestre de 2011	Fase I: 1º semestre 2010 - Fase II: 2013	2010	Mediados de 2009	Unidad 3: 2009	Unidad 4: 2010
Tipo equipo/turbina	Caldera carbón pulverizado - Vapor	Caldera carbón pulverizado - Vapor	caldera carbón pulverizado - Vapor	Caldera Lecho Fluiudizado Cirulante (LFC) - Vapor	Caldera - Vapor	Caldera - Vapor
MW bruto	270	350	350	250	152	152
Abatimiento MP	Filtro de mangas (99% eficiencia)	Precipitador electroestático (96,5% - 99, 6%)	Filtro de mangas (98% eficiencia). Se utilizará para reducir emisiones de Unidad 1 y 2.	filtro de mangas o precipitador electroestático (ambas posibilidades mencionadas)	Precipitador Electrostático (99,8% eficiencia)	Precipitador Electrostático (99,8% eficiencia)
Abatimiento NOx	Quemadores tangenciales Low NOx	Quemadores Low NOx	Quemadores low NOx (40% reducción)	Reducción en LFC (bajas temperaturas)	Quemador low NOx	Quemador low NOx; SCR
Abatimiento SO2	Desulfurizador semi-seco (SDA)	Carbón con bajo Azufre	Desulfurizador (98% eficiencia)	Reducción en LFC (inyección de caliza)	Desulfurizador húmedo	No especifica
MP10 [mg/m3N]	47 (1,06 ton/día)	(1,3 ton/día)	(1,72 ton/día)	(1,25 ton/día)	43	63
Nox [mg/m3N]	513 (11,5 ton/día)	687 (19,4 ton/día)	(26,94 ton/día)	(7,78 ton/día)	570	60
SO2 [mg/m3N]	450 (10,1 ton/día)	917 (26 ton/día), hasta entrada en operación desulfurizador. Después 458 mg/Nm3	(21,55 ton/día)	(20,8 ton/día)	769	1928

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Reunión de Avance: Potencial de Reducción de Emisiones y Diseño de Escenarios

Preparado para CONAMA, en el marco del estudio "Análisis General del Impacto Económico y Social de una Norma de Emisión para Termoeléctricas"

GOBIERNO DE CHILE
COMISIÓN NACIONAL DEL MEDIO AMBIENTE

Santiago, Septiembre 2009

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Elaboración de Norma de Emisión para Termoeléctricas

GEOAIRE

Hacia una definición de Fuentes Nuevas y Existentes

Estudio "Análisis General de Impacto Económico y Social de la norma de emisión para termoeléctricas"

Marcela Fernández Rojas
Abogado
15 septiembre 2009

KAS Ingeniería SA - GEOAIRE

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- CONSIDERACIONES JURÍDICAS PREVIAS
- FUENTE REGULADA
- FUENTE REGULADA NUEVA Y EXISTENTE
- FUENTES QUE SE EXCLUYEN

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Consideraciones Previas:

- Igualdad ante la ley y no discriminación arbitraria en el trato que debe dar el Estado en el ejercicio de una actividad económica

- No vulnerar los derecho en su esencia

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Consideraciones Previas:

- Artículo 5º, Ley 19.300: Las medidas de protección ambiental que, conforme a sus facultades, dispongan ejecutar las autoridades no podrán imponer diferencias arbitrarias en materia de plazos o exigencias.

- DS Nº93 de 1995 MINSEGPRES, Reglamento para elaboración normas de calidad y emisión

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Consideraciones Previas:

Para ello:

Importancia fundamentos técnicos que justifiquen la fuente regulada y la distinción entre fuentes nuevas y existentes

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FUENTE REGULADA

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ELEMENTOS DEFINICIÓN FUENTE REGULADA

Expediente de Norma:

Fs 218: por combustible y por tecnología utilizada
Fs 366: fuente a regular
Fs 561: tipo de termoeléctricas: turbina vapor, turbina de gas, de ciclo combinado, motores de combustión interna
Fs 639: cómo regulan otros países
Fs 736: cómo se regulan

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ELEMENTOS DEFINICIÓN FUENTE REGULADA

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MINUTA CONAMA:

Elementos Esenciales:

- Central Termoeléctrica:
  - Obras de generación (materia): turbinas a vapor y a gas, y de ciclo combinado.
  - Destinadas a la generación eléctrica mediante un proceso térmico (fin)

Considerar si constituirían fuentes a regular individualmente en la norma termoeléctrica: las turbinas a vapor y a gas, y de ciclo combinado.

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ELEMENTOS DEFINICIÓN FUENTE REGULADA

GEOAIRE

MINUTA CONAMA:

Otros elementos a considerar en la definición:

- Combustibles utilizados:
    - de origen fósil (carbón, gas, diesel)
    - biomasa

- Acuerdo de Consejo Directivo nº 302 de 25 de mayo 1996 estableció que la norma termoeléctrica independientemente del combustible utilizado (antes asociada a combustible sólidos (fs1)

KAS INGENIERIA

ELEMENTOS DEFINICIÓN FUENTE REGULADA

GEOAIRE

MINUTA CONAMA:

Otros elementos a considerar en la definición:

- Capacidad instalada superior a xxx MW

- Aplicación y constatación del cumplimiento de la norma de emisión es en chimenea (efluente de la fuente emisora).

- Para abastecer algún sistema eléctrico del país (SIC, SING, Edelmag) o para abastecer consumos propios ó de terceros *(eliminado "o auto abastecer a una empresa específica").*

KAS INGENIERIA

GEOAIRE

FUENTE REGULADA NUEVA Y EXISTENTE

KAS INGENIERIA

GEOAIRE

ANTECEDENTES FUENTE REGULADA NUEVA Y EXISTENTE:

Expediente:

Se distingue fuentes nuevas y existentes en fs 221, 341, 342, 352 , fs 731, 737y ss
Fs 218: Por combustible y tecnología utilizada

Otras Normas de Emisión al Aire:

- Norma olores molestos: hito: en operación o no a la fecha entrada en vigencia del presente decreto

- Norma arsénico: hito: instalada o no a la fecha entrada en vigencia del presente decreto

- Co-Incineración : hito : que cuenta o no con autorización de la Autoridad Sanitaria otorgada con anterioridad a la entrada en vigencia del presente decreto
- Grupo electrógeno (en elaboración): hito: registrado o no en la Seremi de Salud a la fecha entrada en vigencia del presente decreto

KAS INGENIERIA

GEOAIRE

ELEMENTOS PARA UNA DEFINICION FUENTE REGULADA NUEVA

DEFINICION FUENTE REGULADA EXISTENTE

Fuente regulada existente (Central termoeléctrica existente)

"Aquella fuente regulada que a la fecha de entrada en vigencia de la presente norma de emisión, se encuentra en servicio"

eliminar: para algún sistema eléctrico o para el autoabastecimiento de alguna empresa en particular".

ELEMENTOS PARA UNA DEFINICION
FUENTE REGULADA NUEVA

Fuente Regulada Nueva (Central termoeléctrica nueva)

"Aquella que a la fecha de entrada en vigencia de la presente norma de emisión **no** se encuentra **en servicio** o aquella fuente regulada existente que ha sido **modificada**."

Modificación de una fuente regulada existente

Aquella en la que se efectúen cambios en los sistemas de combustión, ya sea por aumento de capacidad de generación, por cambio de combustible, o por cambio tecnológico en el sistema de combustión y control de emisiones"

KAS INGENIERIA

ELEMENTOS PARA UNA DEFINICION FUENTE REGULADA NUEVA

GEOAIRE

"En servicio": Artículo 215, Reglamento de Ley Eléctrica, DS N°327 del Ministerio de Economía, Fomento y Reconstrucción:

"Para los efectos de este artículo**, se entenderá por puesta en servicio, la energización de las instalaciones" (inciso 2°)**

"La puesta en servicio de las obras de generación, transporte y distribución o partes de ellas, deberán ser comunicadas a la superintendencia con a lo menos 15 días de anticipación. En dicha comunicación se deberá indicar a lo menos, una descripción general de las obras que se ponen en servicio, una relación de los principales equipos y materiales, sus características técnicas y la indicación de si son nuevos o reacondicionados. En el caso de concesionarios de servicio público de distribución, se deberá señalar, además, su costo, desglosado en el equipo o material y el de mano de obra." (inciso 1°)

¿Sólo para los conectados al SING Y SIC.?

KAS INGENIERIA

ELEMENTOS PARA UNA DEFINICION FUENTE REGULADA NUEVA

GEOAIRE

MINUTA CONAMA:

Respecto a Modificación fuentes regulada existente:

"En el ámbito de esta futura norma de emisión interesa distinguir aquellas modificaciones que resulten también en una **modificación en la cantidad y calidad de las emisiones (excluyendo a priori la incorporación de equipos de abatimiento**). De esta forma, se identifican: Cambio de combustible y ampliación en la generación, modificación que se realiza mediante la incorporación de una unidad de generación: caldera o turbina.

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FUENTES NO REGULADAS POR ESTA NORMA:

- Aquellas generen igual o inferior a xx MW
- Motores de combustión interna (otras normas) e instalaciones de cogeneración (anteproyecto)

KAS INGENIERIA

Elaboración de Norma de Emisión para Termoeléctricas

GEOAIRE

Hacia una definición de Fuentes Nuevas y Existentes

Estudio "Análisis General de Impacto Económico y Social de la norma de emisión para termoeléctricas"

Marcela Fernández Rojas
Abogado
15 septiembre 2009

KAS Ingeniería SA - GEOAIRE

GOBIERNO DE CHILE
CONAMA

"COMITÉ OPERATIVO DE NORMA DE EMISION PARA TERMOELECTRICAS"

FECHA : 16/09/2009
HORA INICIO : 09:30 hrs.
HORA TÉRMINO: _____
LUGAR : Sala de Reuniones del 6° piso

N°	NOMBRE	INSTITUCION	DIRECCION	FONO	E-MAIL
1.	PEDRO SANTIBAÑEZ	GORDAÍNE		2093838	PSANTIBAÑEZ@GORDAÍNE.cl
2.	PABLO GONZALEZ	KAS		2632040	pgonzalez@gmail.com
3.	ENZO SAUMA	KAS - PUC		354 4272	esauma@ing.puc.cl
4.	MARCELO MENA	KAS - U NAB		6618230	mmena@unab.cl
5.	CRISTIAN IBARRA	CONAMA			cibarra@conama.cl
6.	maría teresa Palma	KAS			teresa.palma@kasing.cl ~~mtpalma~~
7.	JAIME ORDENES G.	KAS			jaime.ordenes@kasing.cl

N°	NOMBRE	INSTITUCION	DIRECCION	FONO	E-MAIL
8.	Carmen G. Contreras				
9.	Cristina Gómez A	CNE	Alameda 1449 piso 14 Stgo Down Town II	3656876	cgomez@cne.cl
10.	Angela Soriano R	MINVU	Alameda 924, 6° p	3513641	asoriano@minvu.cl
11.	Sandra Briceño	Conama	—	Anex. 878	sbriceno@conama.cl
12.	alberto gil	Conama	—		agil@conama.cl
13.	Evelyn Salazar	GeoAire.			geoaire2@gmail.com
14.	Mª José Rodríguez	GeoAire.	—	—	geoairemsr@gmail.com
15.	Rodolfo Granifo	KAS			RODOLFO.GRANIFO@KASING.cl
16.	Marcela Jerardino	KAS Ingeniería			mjerardino@kasing.cl
17.	MARIA PIA BRAVO	KAS	—	—	PIA.BRAVO@KASING.cl
18.	Montserrat Rodríguez	CONAMA			mrodriguez@conama.cl
19.	Marcela Fernández	KAS	—	—	marcelafernandez@abogadosambiental.cl
20.	Manuel Jerardino	KAS			
	Pisailha Ulloa	CONAMA.		2405787.	pulloa@conama.cl.

C0166

Wrocław University of Technology

Ministry of the Environment

Energy Efficiency and Air Pollutant Control Conference

Under Patronage of the Polish Ministery of the Environment

Air & Waste Management Association

IEA Clean Coal Centre

Wrocław, Poland

September 21 - 25, 2009

The International Conference on Energy Efficiency and Control of Air Pollutants from Utilization of Fossil Fuels

CO-CHAIRS: **Dr. Nick Hutson,** US EPA, Research Triangle Park, NC, USA

Prof. Tomasz T. Suchecki, Wroclaw Univ.of Technology, Poland

SCIENTIFIC CHAIR: **Prof. Tim Keener,** University of Cincinnati, USA

Areas of Interest

Control of SO_2, NO_X, PM, mercury, CO_2 • Multipollutant control • Energy efficiency measures for industrial sectors and buildings • Combined heat and power systems • Indoor climate control systems • Climate change mitigation

Scope

Fundamental research • Pilot-scale testing • Demonstration • Commercial implementation

To check for updates go to:

www.energy-air-wroclaw.pwr.wroc.pl

Conference hosted by the Wroclaw University of Technology and organized by the Faculty of Environmental Engineering in Wroclaw http://www.wroclaw.pl/ms/english/

Wrocław University of Technology

Energy Efficiency and Air Pollutant Control Conference

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Under Patronage of the Polish Ministery of the Environment

Ministry of the Environment

Wroclaw, Poland
September 21 - 25, 2009

ISBN 978-83-929704-0-8

Energy Efficiency and Air Pollutant Control Conference
Wroclaw, Poland, September 21 – 25, 2009

Mercury Pollution and Human Welfare

J.M. Pacyna, E.G. Pacyna, and K. Sundseth
Center for Ecology and Economics
Norwegian Institute for Air Research, Kjeller, Norway

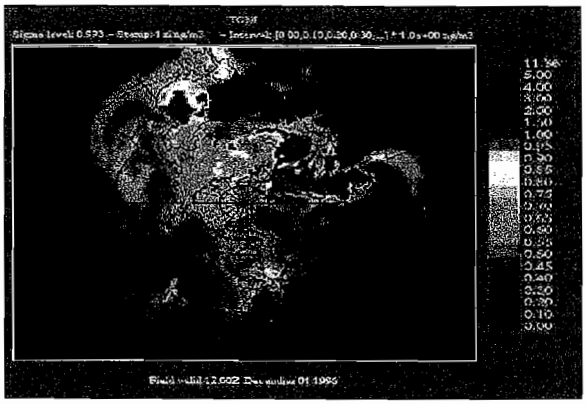
NILU

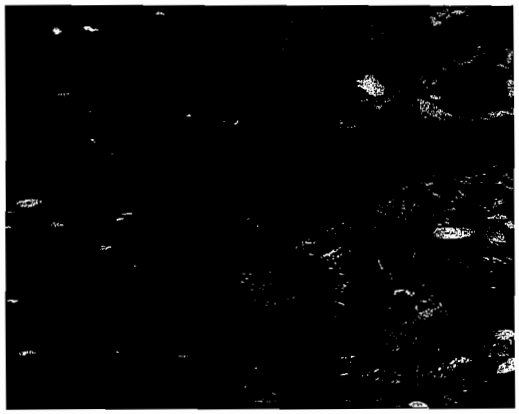
Presentation topics

- Introduction
- Sources and emissions
- Main transport pathways - modeling
- Contribution of global cycling to deposition on global scale
- Mercury in fish
- Impacts on ecosystems and human health
- Future emission control scenarios and their cost
- International agreements to limit exposure to mercury

The Mercury Problem

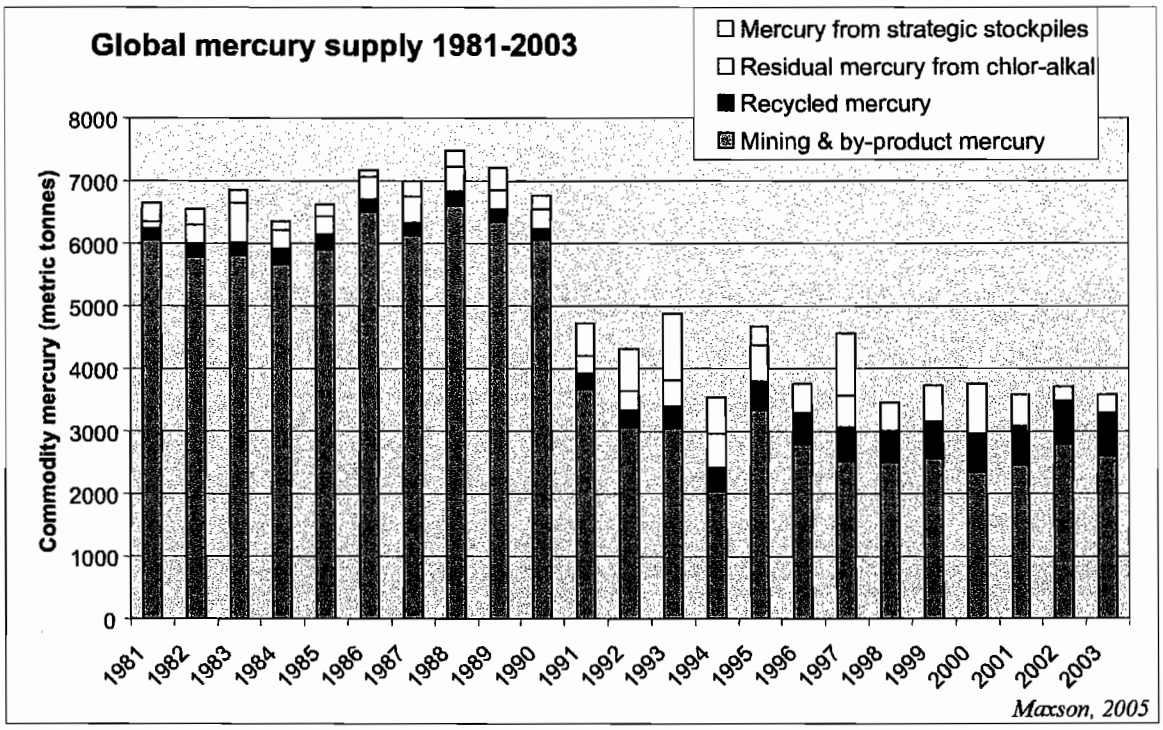
- Mercury is a toxic and persistent substance of global concern
- Environmental levels increasing in some regions
- Methylmercury bioaccumulates
- Impacts on wildlife and human health



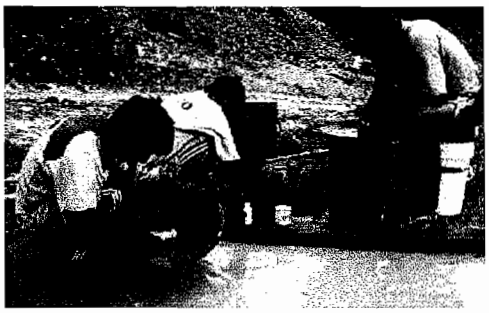


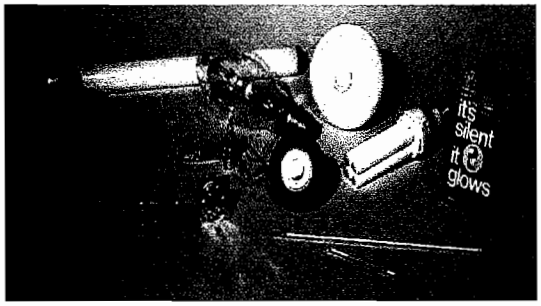
Methylmercury

- The most toxic form of mercury in the environment
- Present in air, water, soils, sediments as a small fraction of the total mercury (0.1 to 5 %)
- Methylmercury 90-100% of total mercury in fish
- Biotic formation e.g. via methylation of mercury by sulphate reducing bacteria



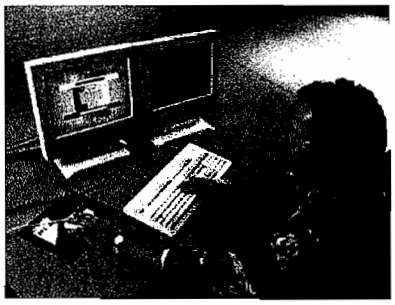
Emissions from product-use and disposal

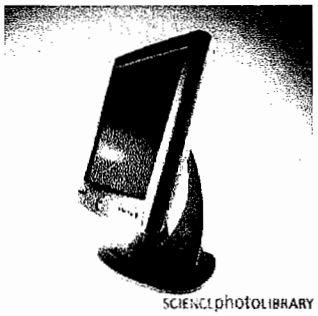




Hg in electronic and electrical components

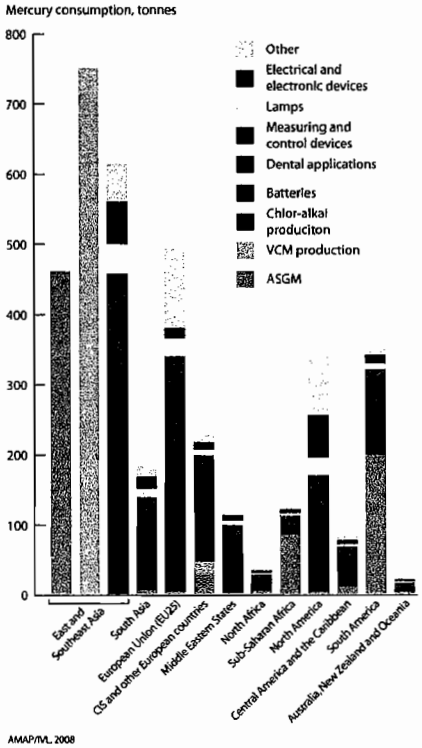
- Computers and electronic devices
  - Wiring devices and switches
  - Measuring and control instruments
  - Electronic and lighting devices
  - LCD in laptops, flat panel display, mobile phones and other LCD display panels (as in fluorescent lamps in display modules)





Emissions from product-use and disposal

Global mercury consumption by application and by region in 2005
(note: East and Southeast Asia bar is split)



AMAP/IVL, 2008

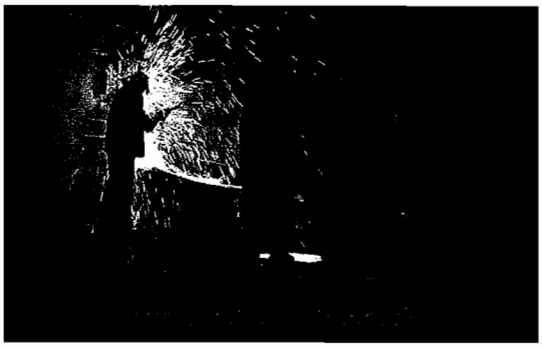
Emission due to mercury impurities in fuels and raw materials

Main sectors:

- **Fossil Fuel Combustion** (mainly coal) for heat and energy
- **Metals Production** (primary iron & steel; non-ferrous metals; large-scale gold; mercury production)
- **Cement Production**
- **Waste Incineration** (some countries)

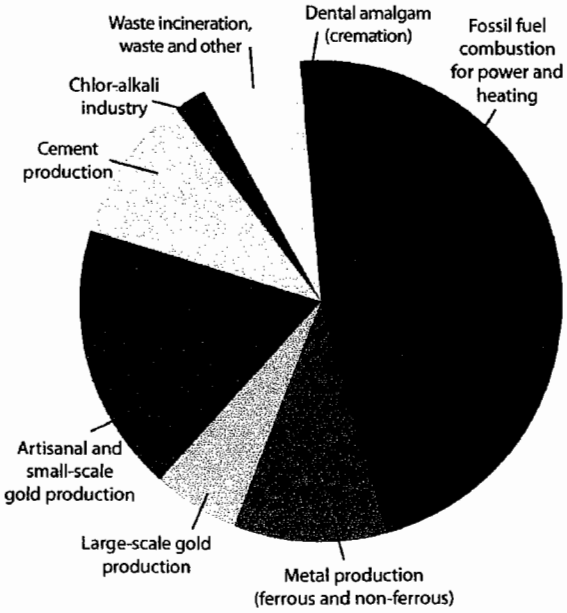
.. in addition one intentional use sector:

- **Chlor-alkali Industry**



2005 emissions by sector

- Combustion of fossil fuels (in particular coal): ca 45%
- Artisanal and small-scale gold mining: ca 20%
- Waste and Other figures are conservative estimates and highly uncertain

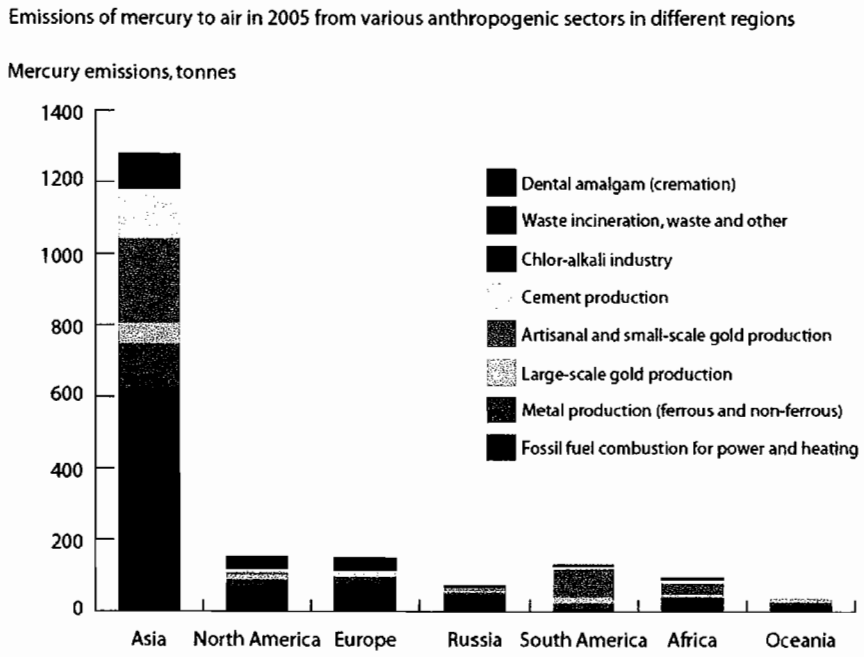


2005 emissions by region

Geographical distribution reflects economic activity and technology, and presence of ASGM

Two-thirds from Asian sources

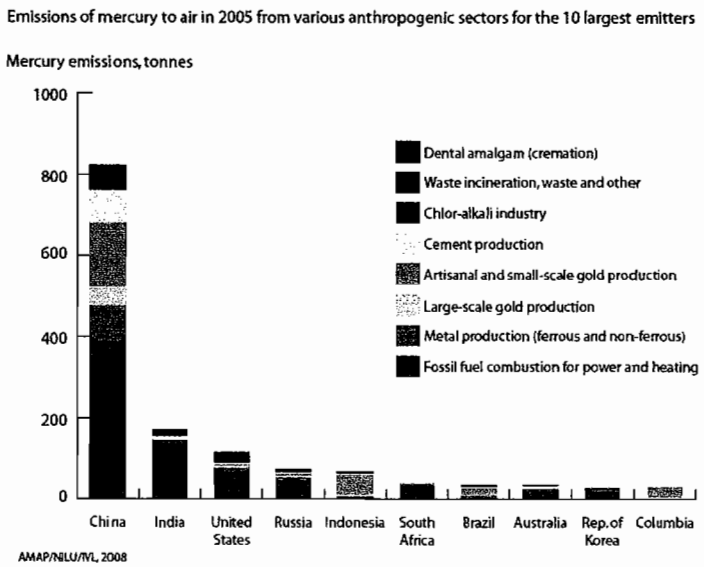
(mainly China and India)



2005 emissions from countries

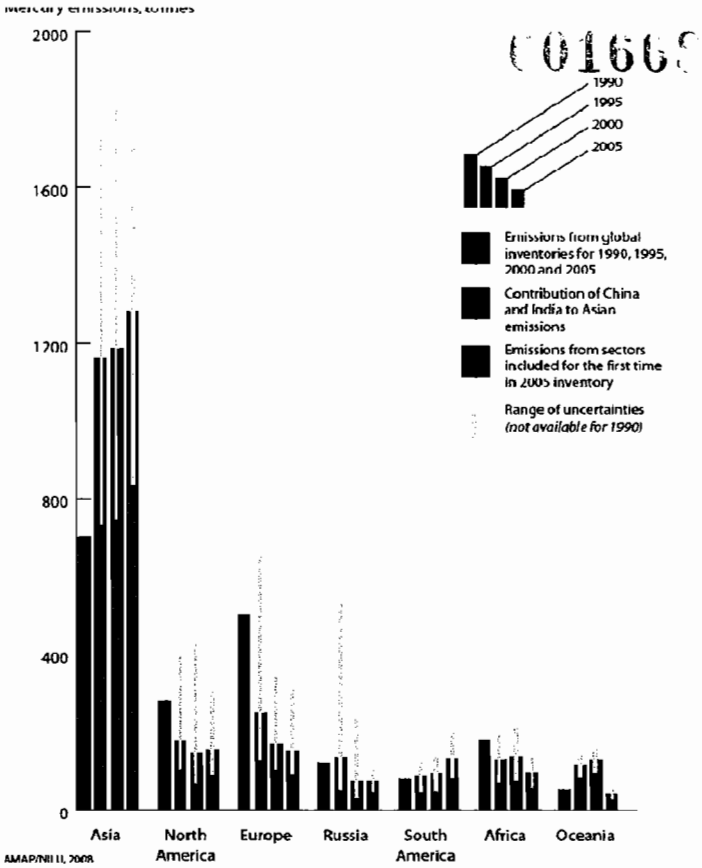
Different emission sectors contribute to emissions in the top-ten emitting countries

- By far the largest contribution to the estimated global anthropogenic emissions are from China
- Indonesia, Brazil and Columbia in the top 10 emitting countries due to ASGM

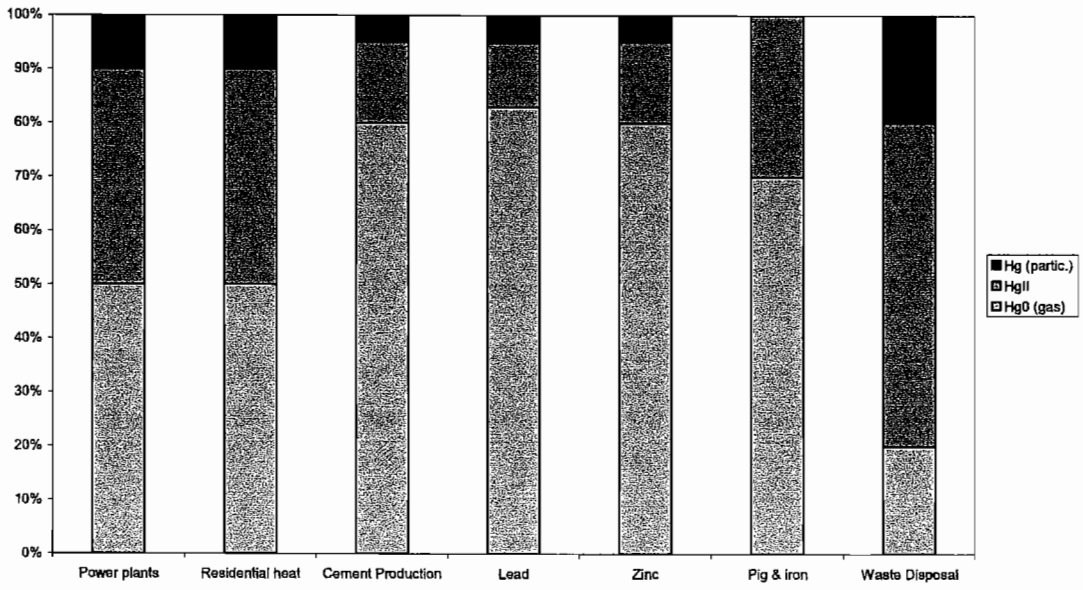


Trends in emissions (1995-2005)

- Decrease in ("by-product sector") emissions in Europe and North America due to introduction of control technologies
- Increasing emissions from 1990 to 2000 in most other regions
- Apparent decreases from 2000 to 2005 in Africa and Oceania partly due to improved data and information.
- Increasing emissions from some countries in Asia, partly offset by decreasing emissions in other countries (e.g. Japan)



Emission profiles for different chemical forms of mercury and various source categories



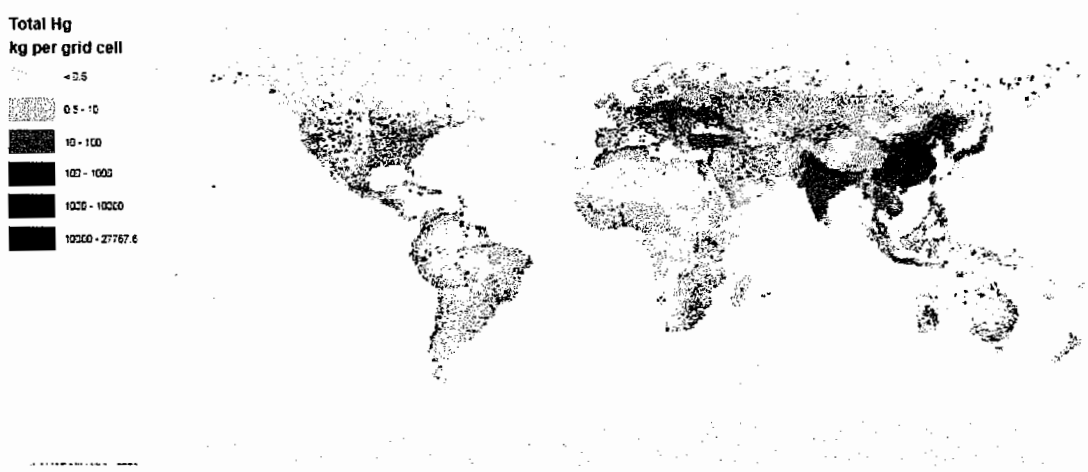
Natural sources and re-emissions

- Natural sources believed to be of the same order of magnitude as anthropogenic
- Main source areas associated with cinnabar deposits and other Hg-containing minerals, volcanos
- Re-emissions occur from water bodies as well as soils and vegetation
- For water surfaces, re-emissions may be of same magnitude as deposition
- Uncertainties very large for both natural emissions and re-emissions

2005 emissions inventory

Anthropogenic emissions to air

- Total global anthropogenic emissions to air in 2005 = 1930 tonnes
- Range based on estimated uncertainties = 1200 to 2900 tonnes
- Includes conservative estimates for product-use emissions
- National/sector based estimates geospatially distributed (0.5 degree lat/long grid) for use in modeling applications, etc.

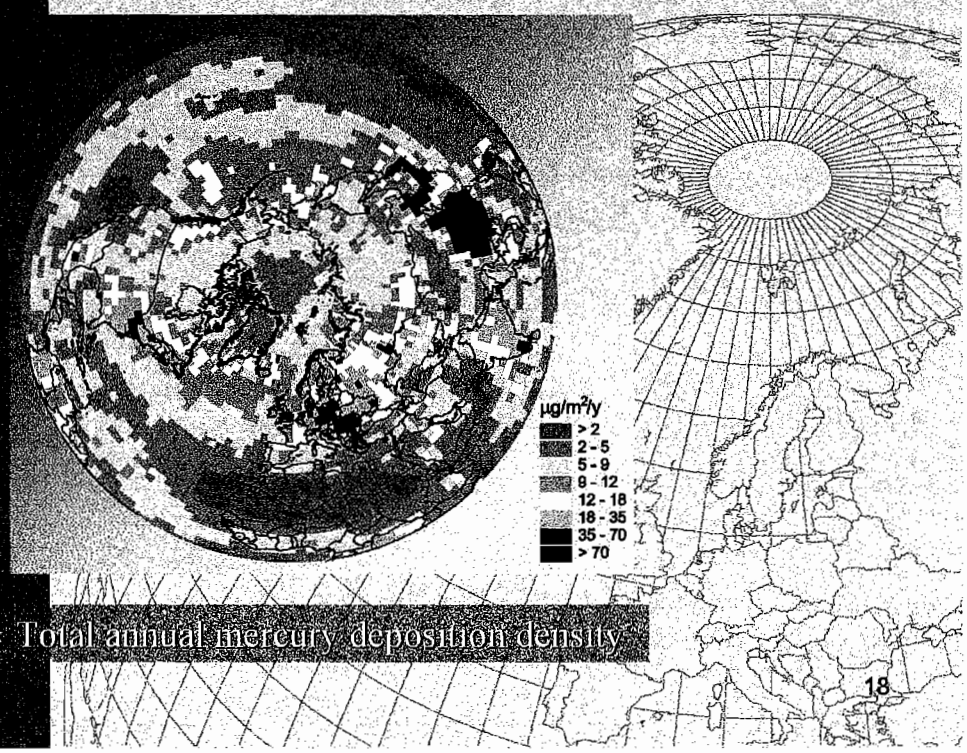


Global transport modelling

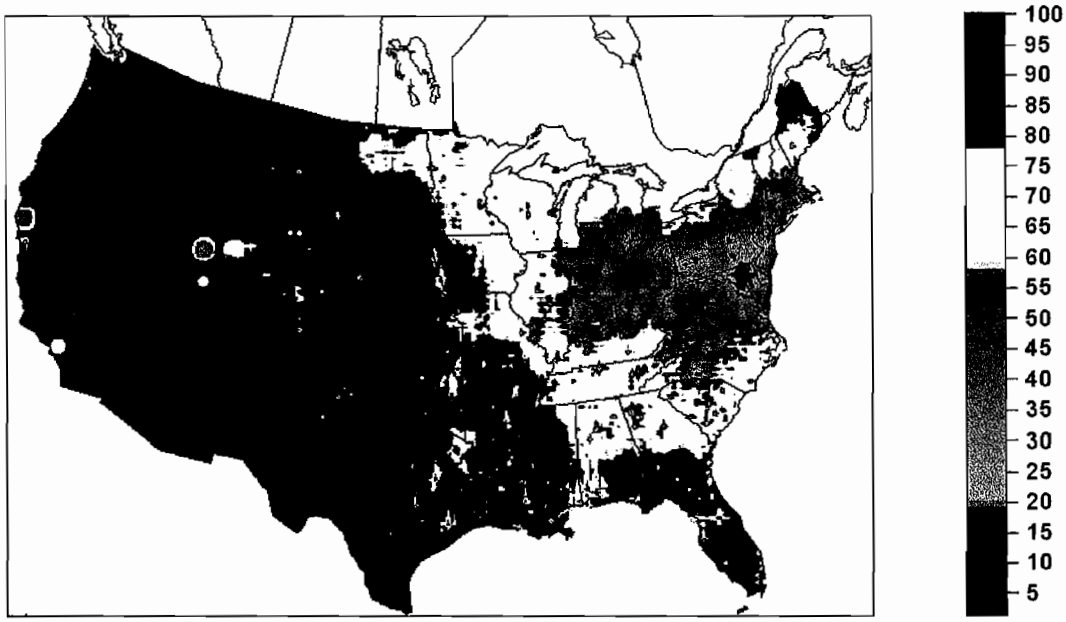
Average elemental mercury surface concentrations for July 2001 (ng/m3)

GRAHM (Global/Regional Atmospheric Heavy Metals Model) simulation – Ashu Dastoor, Meteorological Service of Canada, Environment Canada

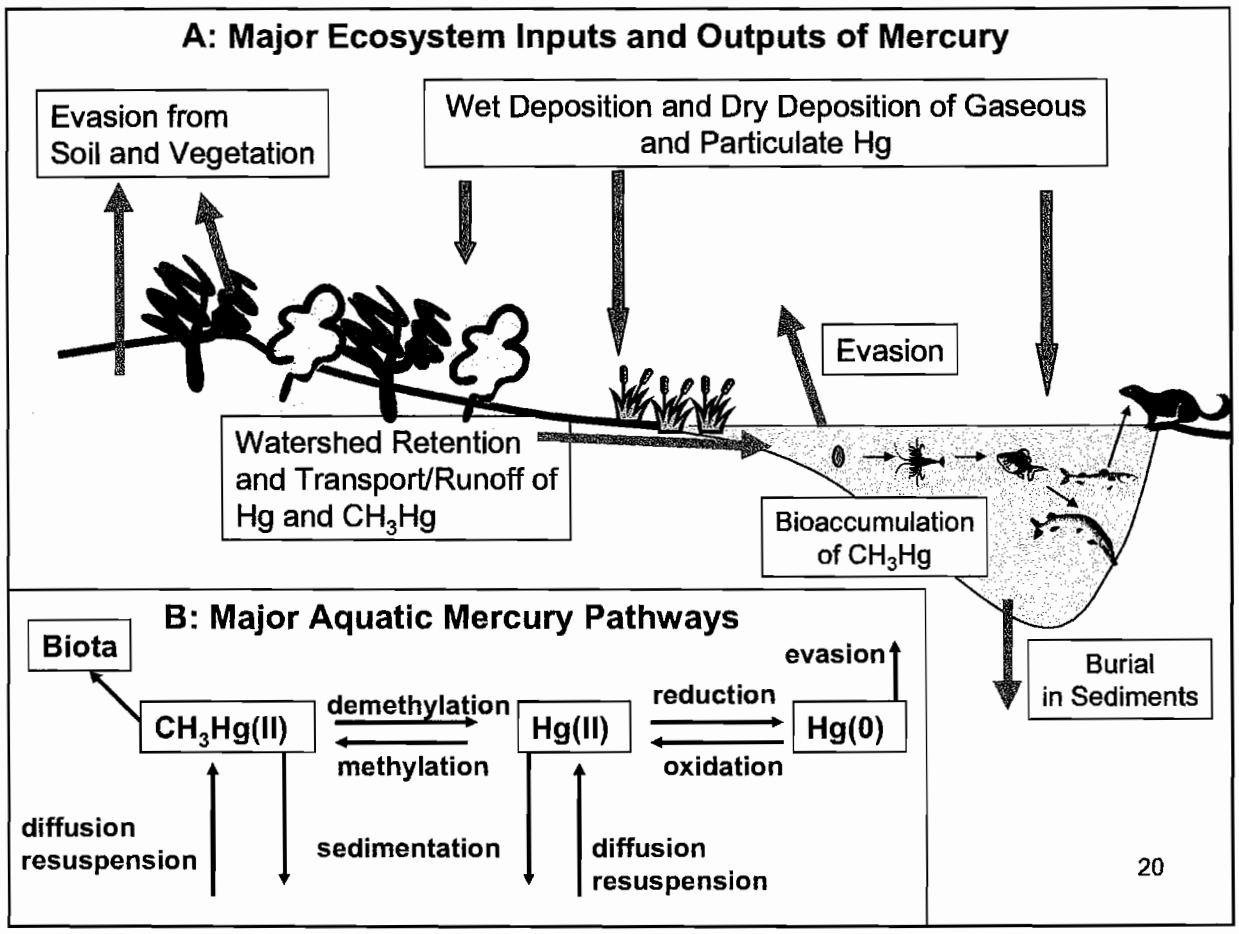
Mercury deposition in the NH

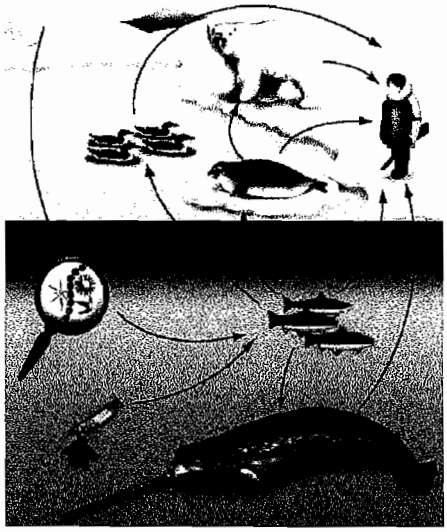


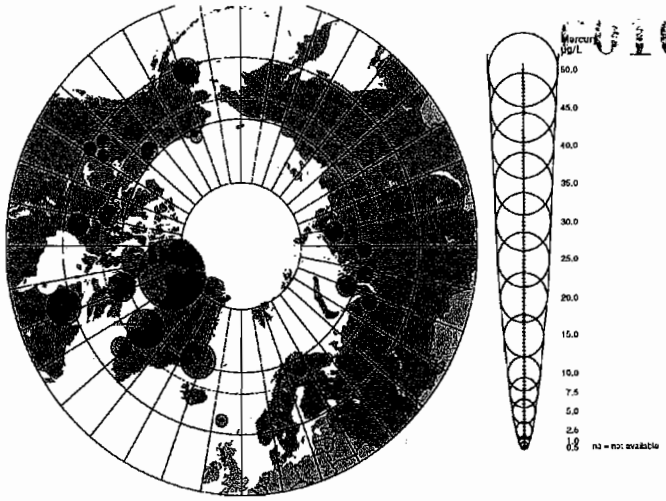
Contribution of sources other than U.S. anthropogenic sources to Hg deposition



AER/EPRI Modeling System for Atmospheric Mercury
Christian Seigneur

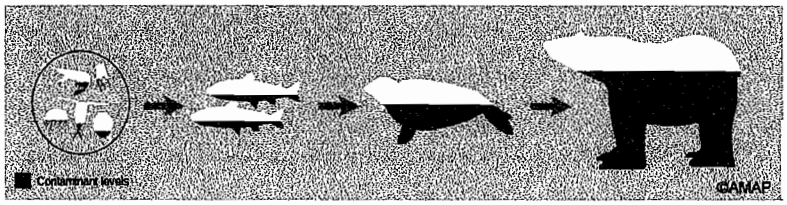






Hg in blood of women of reproductive age

Biomagnification and human exposure



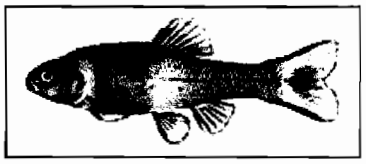
Arctic Monitoring and Assessment Programme

EXPOSURE

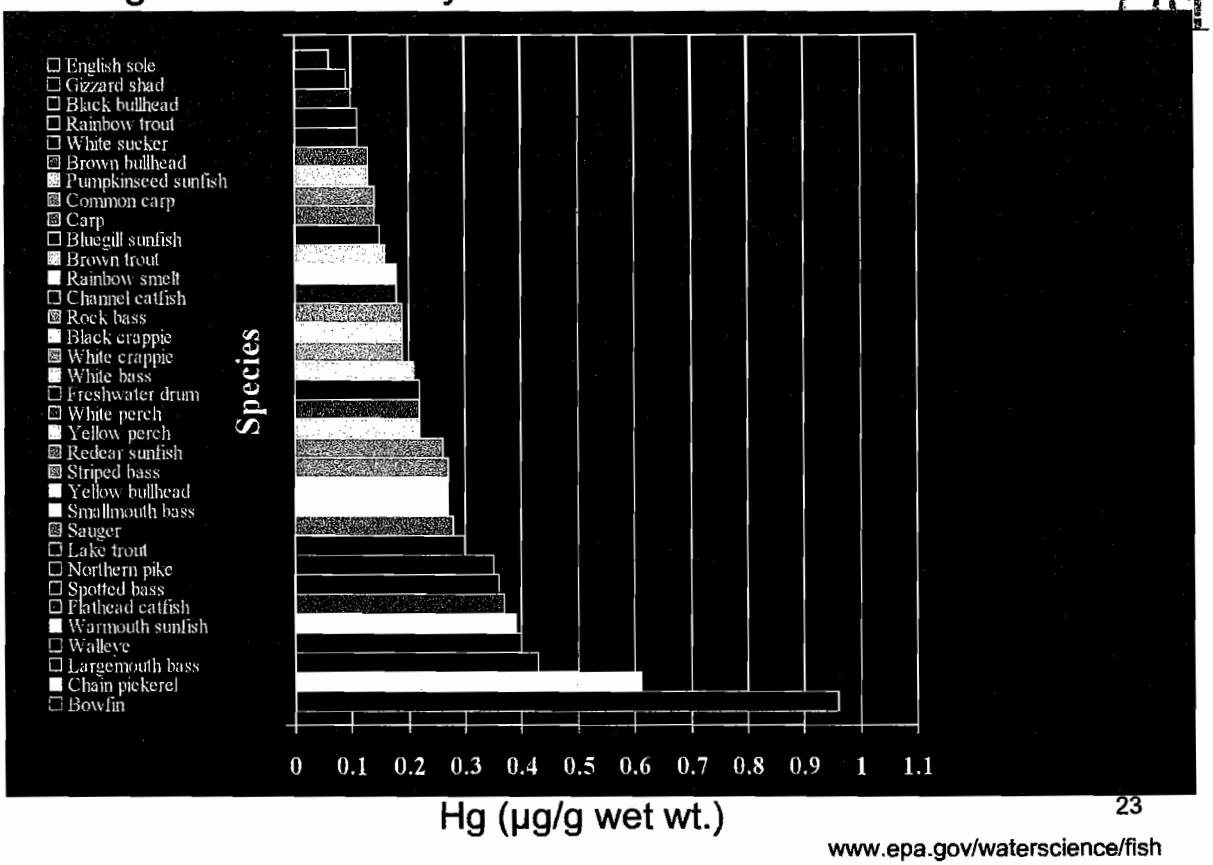
Fish and Fish-eating Wildlife

Piscivorous fish and wildlife experience the greatest exposure to methylmercury

Fish – pike, walleye, lake trout, bass, pickerel
Birds – loons, kingfishers, bald eagles, herons, osprey
Mammals – otter, mink, seal, polar bear, certain whales

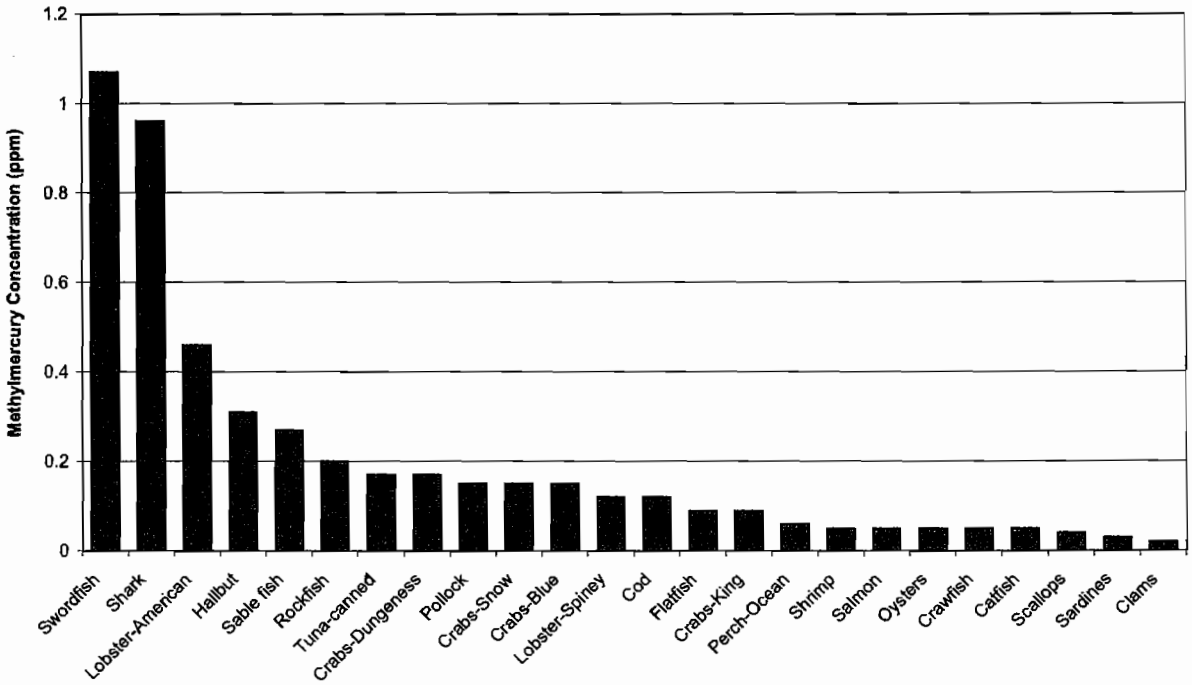


Average Tissue Mercury Concentrations in Noncommercial Fish



www.epa.gov/waterscience/fish

Average Mercury Concentrations for Top 24 Types of Fish Consumed in U.S. Commercial Seafood Market



*Includes both canned light and albacore tuna

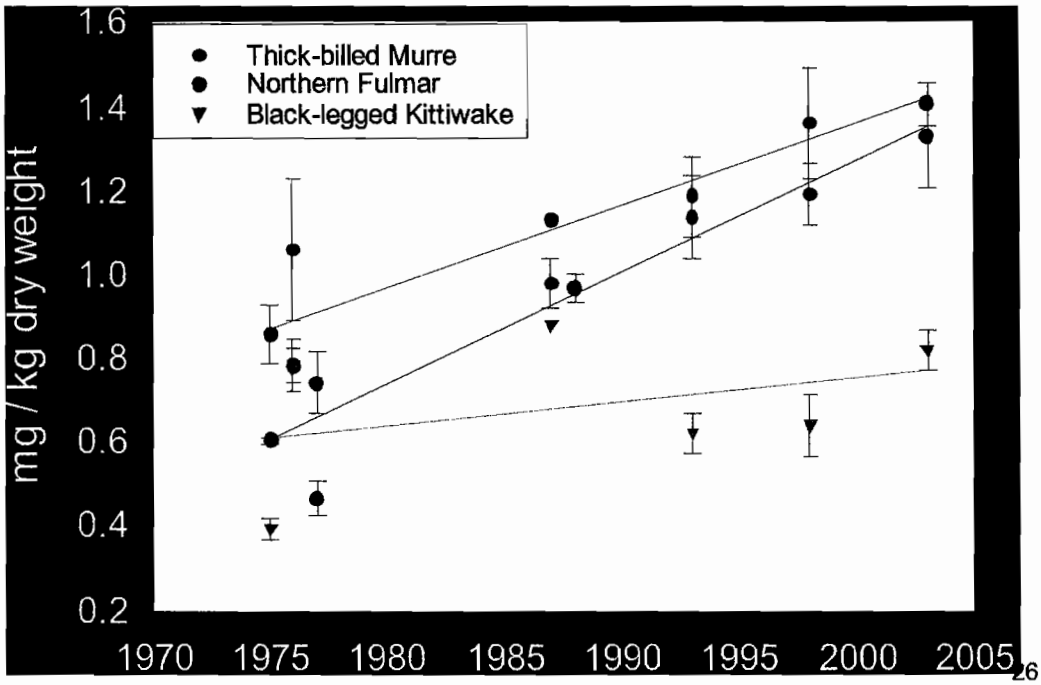
Source: Carrington and Bolger, 2002 cited in NESCAUM briefing to EPA

EPA's Reference Dose for Methylmercury

- **RfD = 0.1µg/kg/day** (about 1.1 ppm hair, 5.8 µg/L blood)
- Reference dose includes a uncertainty factor of 10 in converting the BMLD into the RfD
- This translates into a value of ~0.3 ppm in fish for a 60 kg person consuming 5 oz fish per week

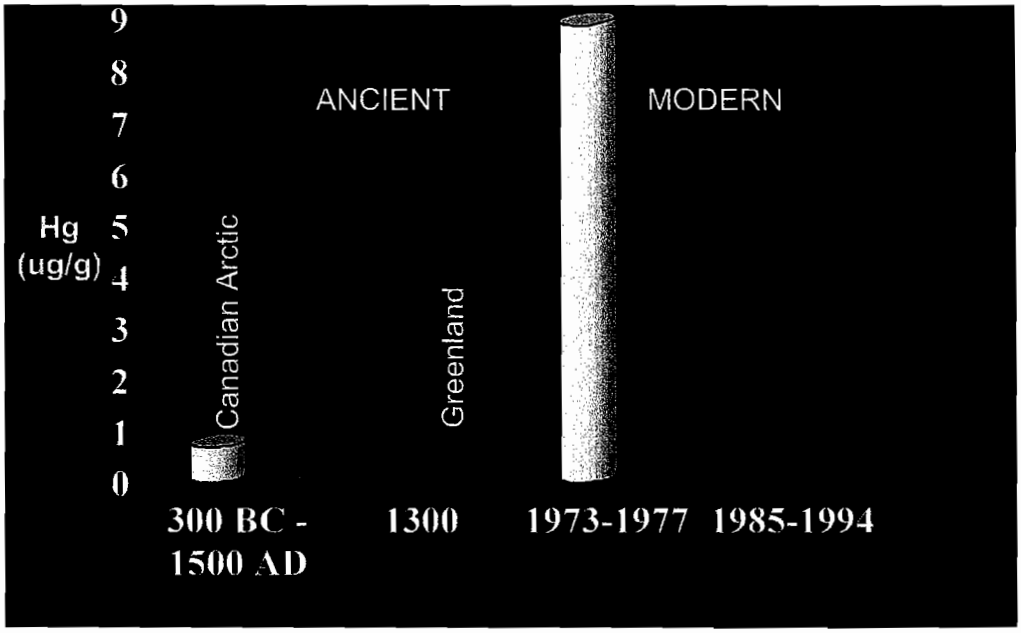
- **Similar to other regulatory or risk values**
  - EU - 0.1 µg/kg/day
  - Health Canada - 0.2 µg/kg/day
  - FDA - 0.4 µg/kg/day
  - WHO-FAO - 0.23 µg/kg/day

Mercury in Arctic Seabird Eggs, Prince Leopold Island, 1975 - 2003



Adapted from Braune et al (2005)

Historical Increases in Hg Concentration of Polar Bear Fur



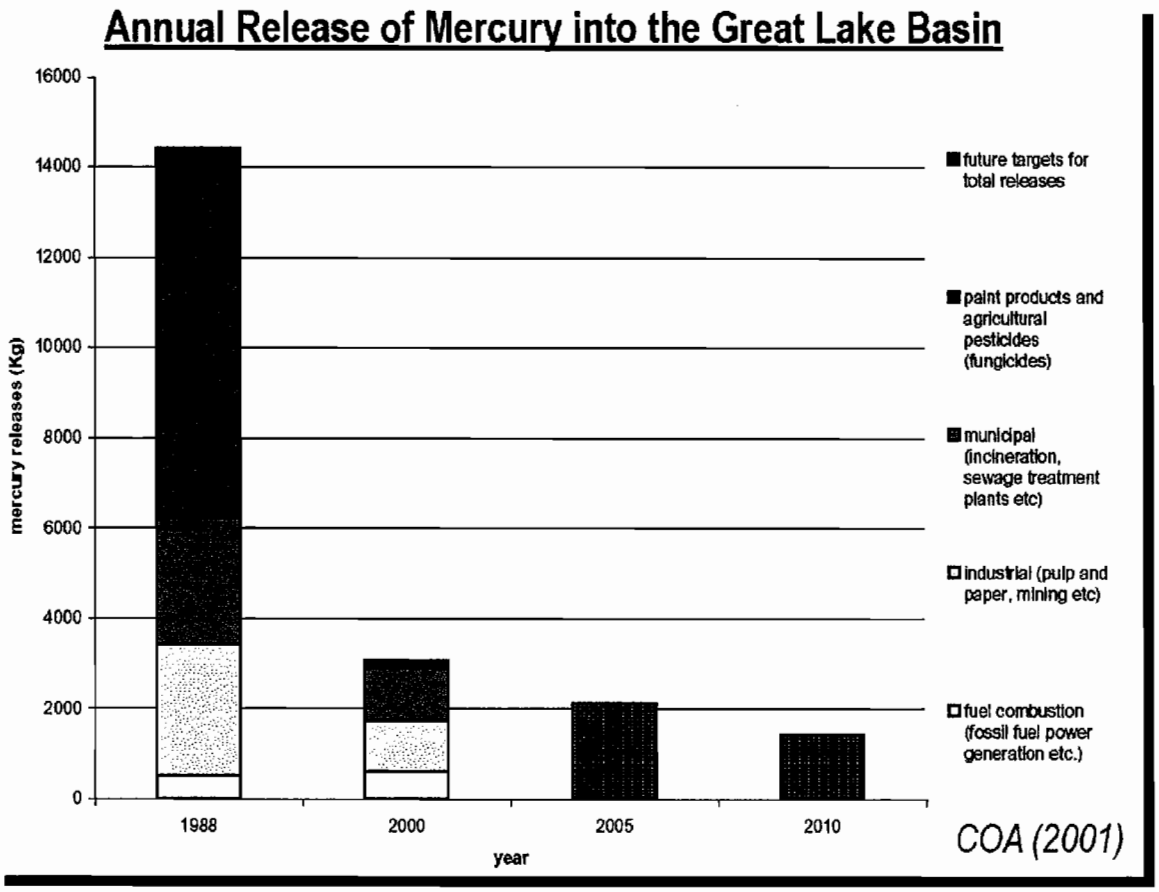
Adapted from Dietz et al (2005)

Hg Effects - Conclusions

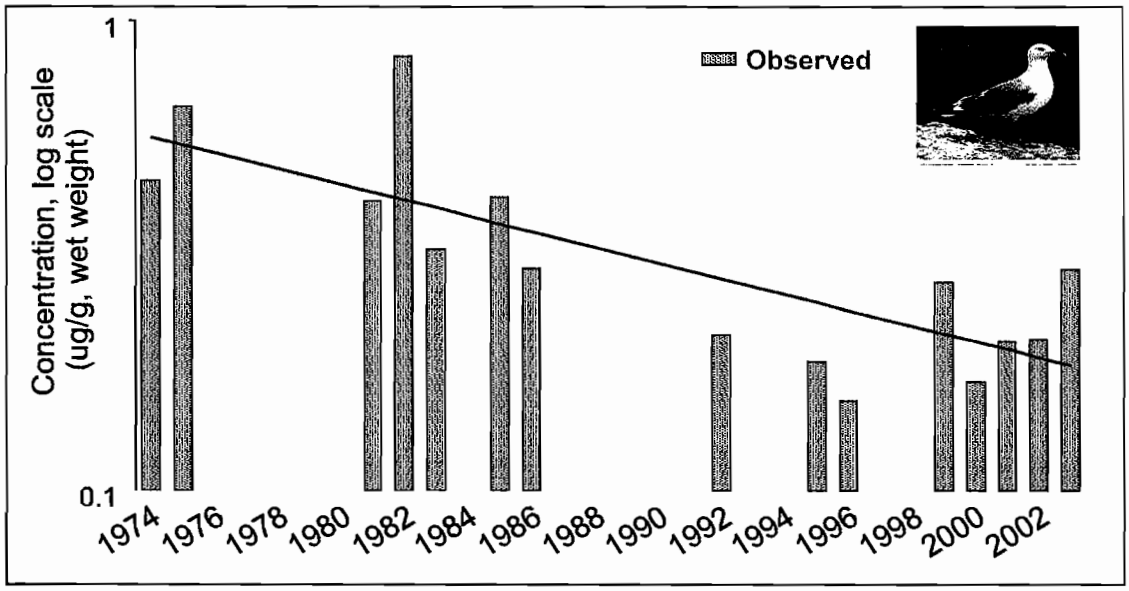
- Fish - dietary methylmercury could adversely affect reproduction in wild populations of fish in surface waters containing food webs with high concentrations of methylmercury.
- Mammals - significant neurochemical effects have been documented in both wild mink, and in captive mink fed with environmentally measured levels of methylmercury.
- Birds - impaired reproduction occurs at environmentally measured levels of dietary methylmercury intake. It is plausible that population level effects occur regionally, particularly in the most exposed cohorts of some piscivorous species.

Source-receptor relationship

- Is there a direct relationship between emissions of inorganic mercury from a coal-fired power plant and methylmercury concentration in fish?
- If yes, on which scale do we observe this relationship?



Mercury in Herring Gull Eggs, Snake Island, Lake Ontario, 1974 - 2003



From D.V. Weseloh, Canadian Wildlife Service

Scenarios

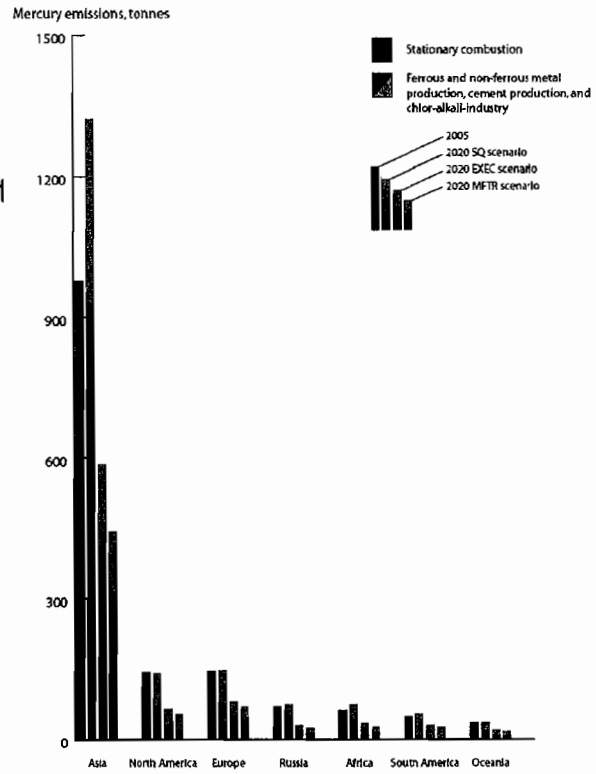
Three Scenarios to explore implications of 'no action' vs 'action'

- Target year 2020
- Status Quo (SQ): Do nothing, current technology, continued economic and population growth
- Extended Emissions Controls (EXEC): Apply controls currently implemented or planned for EU to all countries
- Maximum Feasible Technological Reductions (MFTR): Employ best technology currently available in all countries
- Includes 'by-product sectors' only (estimates for product use sectors considered too uncertain)

Scenario results

Considerably uncertainty in any projections

- SQ: Emissions from main 'by-product' sectors rise (from 1480 t to 1850 t)
- EXEC: Emissions from these sectors in 2020 could be 850 t
- MFTR: Emissions from these sectors in 2020 could be 670 t
- Emissions from product-use and ASGM not included in scenarios
- Climate change and actions to limit greenhouse gasses will impact future emissions



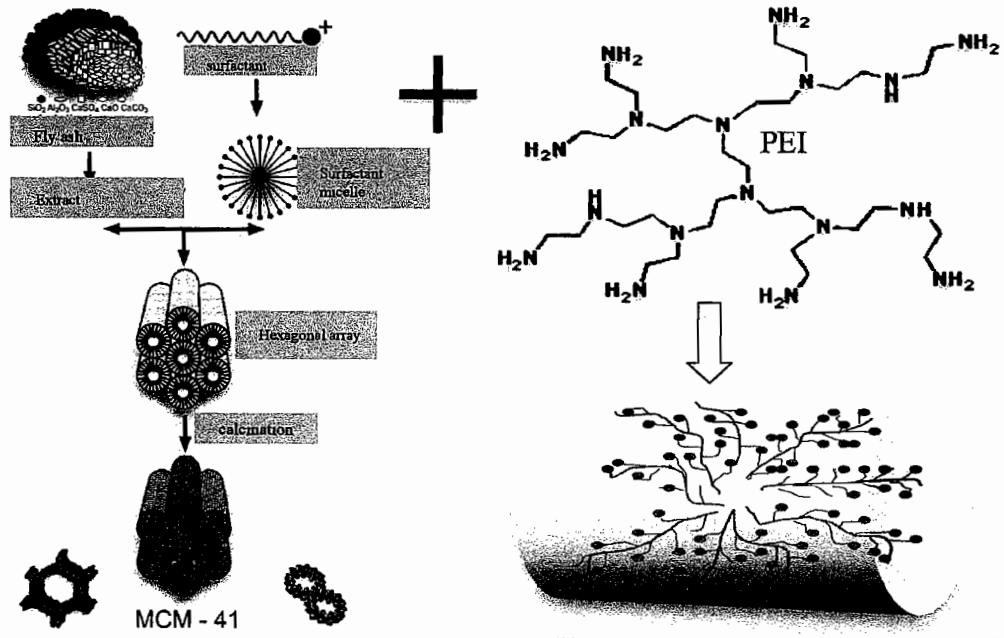
Non-technological Methods of Mercury Emission Reductions

- ***Energy conservation***
  - energy taxes
  - consumer information
  - restrictions and regulations
  - energy management
  - energy efficiency (up to 68%)
- ***Pollution prevention***
  - material separation
  - product content bans
  - input taxes on the use of mercury in products
  - labeling of products

Technological solutions

Method	Mercury content after cleaning, mg/m^3	Mercury removal efficiency, %
1. ESP or FF		10-30
2. Wet FGD + ESP or FF		30-85
3. Spray dry systems + FF		35-85
4. Selenium filter	<0.01	90+
5. Selenium scrubber	0.2	90-95
6. Carbon filter bed	0.01	90-95
7. Activated carbon injection	0.01	50-90+
8. Lead sulfide balls	0.01-0.05	99

Modified mesoporous materials from fly ash- -novel sorbents for post-combustion capture of CO2 and Hg



Modified mesoporous materials (MCM-41) from fly ash

Human exposure: sources

- Consumption of fish, high on the trophic chain, is the major source of MeHg exposure for humans
- For some populations, marine mammals are also a source of exposure
- Consumption of animals that have been nourished with fish feed may also contribute to body burden
- Recent studies suggest that in some regions, with high Hg contamination, rice may take up MeHg.

Conclusions - Humans
on the basis of current research

- Methylmercury is a developmental neurotoxicant at current environmental levels.
- In adults, neurobehavioral effects are observed at moderately elevated exposures.
- There is a body of evidence indicating elevated risk for cardiovascular disease, especially myocardial infarction.

Methods description – damage cost estimate assumptions

- IQ loss only.
- Based on methodology developed in DROPS project (http://www.nilu.no/DROPS/) and Spadaro and Rabl, 2008.
- Damage cost associated with IQ loss taken from literature, assumed to be 15 000 US$ (range in literature 11 000 to 22 000) representative for USA.

$$c_i = c_{USA} \frac{(GDP \quad / capita \quad)_i}{(GDP \quad / capita \quad)_{USA}}$$

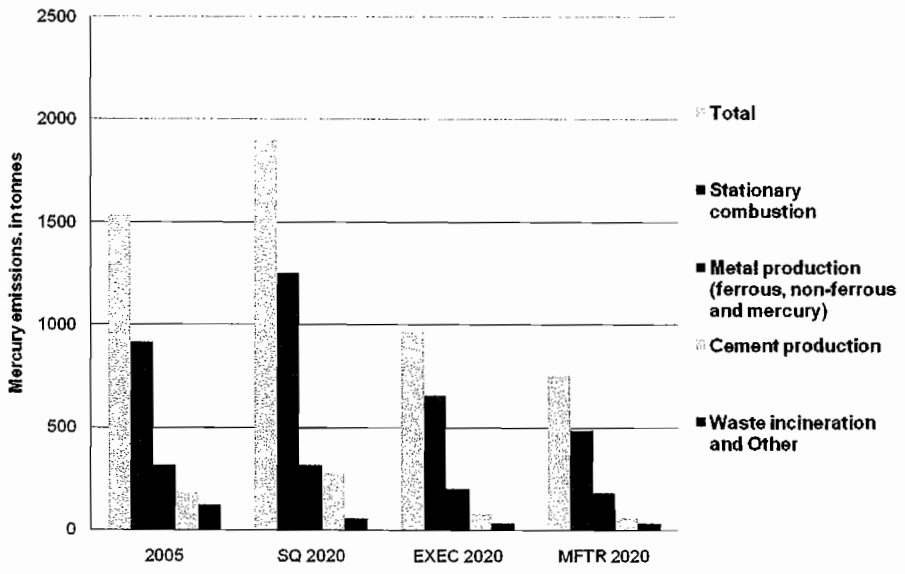
- USA costs estimate adjusted by country specific GDP (PPP).

Methods description – damage cost estimates by Spadaro and Rabl, 2008

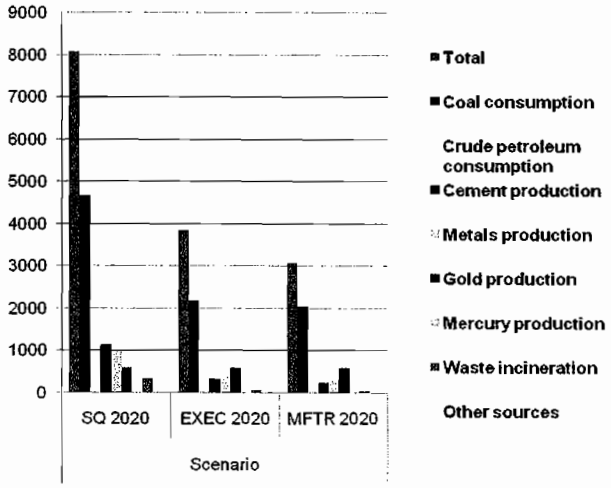
- Simplified globally averaged dose - response relationship for mercury based on observations of exposure (fish consumption) and neurotoxic impacts (IQ-loss) in empirical studies to find a slope factor due to daily (yearly) intake of MeHg.
- Simplified global transfer function to relate emissions of mercury to exposure to methylmercury.
- IQ-loss assumed to lead to societal costs mainly due to loss of earning and remedial education.

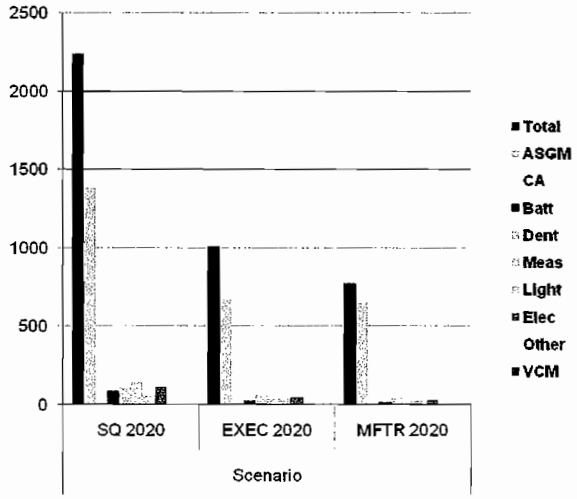
Spadaro and Rabl, Risk Analysis 28, 2008

A comparison of the 2020 emission data estimated for the EXEC and MFTR scenarios with emissions of the 2020 SQ scenario and the 2005 emission data for various source categories



Annual damage costs in the year 2020 due to IQ loss following ingestion and inhalation of mercury along the emission reduction assumptions within the SQ, EXEC, and MFTR scenarios for different sources (2005 US$), (in million US$)





Annual damage costs	SQ 2020	EXEC 2020	MFTR 2020
Total by-product	8082	3865	3077
Total intentional use	2239	1008	772
SUM	**10321**	**4873**	**3849**

Societal annual damage costs and benefits

	Societal damage costs			Societal benefits	
	SQ	EXEC	MFTR	EXEC	MFTR
Total by-product	8082	3865	3077	4217	5005
Total intentional use	2239	1008	772	1231	1467
Total	**10321**	**4873**	**3849**	**5448**	**6472**

In million 2005 US$, GDP (PPP) adjusted

Conclusions

- **If no further action is taken to reduce mercury emissions globally (the SQ scenario), loss of IQ will lead to annual damage costs of 10.3 Billion 2005 US$.**
- **The total damage costs to society of mercury pollution are likely to be considerably higher than the damage cost related to IQ-loss only.**
- **With introduction of policies to reduce emissions according to two scenario calculations, the emissions can be reduced by around 50% and 60% for the EXEC and MFTR scenarios, respectively, in comparison to the SQ scenario.**
- **The damage costs can be reduced significantly leading to annual benefits of approx. 5 billion US$ and 6 billion US$ for the two different emission scenarios, respectively.**

International efforts to help reduction of Hg releases

- The UNEP Partnership on Global Mercury reductions
- The UN ECE LRTAP Convention/ Aarhus protocol on heavy metals
- The EU European Mercury Strategy
- The International Joint Commission (IJC) in North America initiatives

The EU Strategy Concerning Mercury (since 2002)

Major objectives and action

- Banning mercury exports by 2011
- Global action – input to international activities and cooperation with other countries, e.g. to control mercury trade, emissions, and use in activities like gold mining.
- Reducing EU demand – restricting the marketing of measuring devices containing mercury (e.g. thermometers), and further investigation of remaining uses (e.g. dental amalgam).

The EU Strategy Concerning Mercury (since 2002)

Major objectives and action

- **Addressing EU surpluses – safe storage of mercury decommissioned by industry, and further study of mercury already circulating in society (e.g. In old products still in use).**
- **Reducing EU emissions – review of the effects of current EU law, provision of information to support further emission cuts in Member States, and study of additional control of releases from coal burning.**

Acknowledgements

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- **the Polish-Norwegian project SORBENT through the contribution from the Norwegian and EEA Financial Mechanisms,**
- **the UNEP GLOMER project, and**
- **The EU projects DROPS and ESPREME.**

The authors are grateful for this support.

Methods description – damage cost estimates by Spadaro and Rabl (2)

Factor	Unit	Mean
Emission rate, E	t/year	6000
Average dose, D_{av}	μg/day	2.40
Dose above threshold, $D_{av}(D_{th})/D_{av}$	–	0.44
s_{DR} based on Hg in hair	IQ point/ppm	0.18
Hair conc/cord blood conc	ppm/(μg/L_{cord})	0.20
Ratio of cord to maternal blood	(μg/L_{cord})/(μg/L_{mat})	1.65
Ratio of maternal blood to dose intake	(μg/L_{mat})/(μg/day)	0.61
Cost of IQ point in USA	\$/IQ point	18,000
f_{world} [Equation (21)]	1/year	0.00315
Discount factor, f_{disc}	–	0.64
World population, p_{world}	–	6.43E+09
Results for cost C	\$/kg	1,487

	Median	Mean
Results for cost C [\$/kg]	531	1487

$$C = s_{DR}[T_{av}\, D_{av}(D_{th})/D_{av}] \times f_{world}\, p_{world}\, c_{USA}\, f_{disc}$$

Tav=4E-07 ((µg/day)/(kg/year)) – Transfer factor

Spadaro and Rabl, Risk Analysis 28, 2008

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Global Health Impacts and Costs Due to Mercury Emissions

Joseph V. Spadaro[1] and Ari Rabl[1]*

Since much of the emission is in the form of metallic Hg whose atmospheric residence time is long enough to cause nearly uniform mixing in the hemisphere, much of the impact is global. This article presents a first estimate of global average neurotoxic impacts and costs by defining a comprehensive transfer factor for ingestion of methyl-Hg as ratio of global average dose rate and global emission rate. For the dose-response function (DRF) we use recent estimates of IQ decrement as function of Hg concentration in blood, as well as correlations between blood concentration and Hg ingestion. The cost of an IQ point is taken as $18,000 in the United States and applied in other countries in proportion to per capita GDP, adjusted for purchase power parity. The mean estimate of the global average of the marginal damage cost per emitted kg of Hg is about $1,500/kg, if one assumes a dose threshold of 6.7 μg/day of methyl-Hg per person, and $3,400/kg without threshold. The average global lifetime impact and cost per person at current emission levels are 0.02 IQ points lost and $78 with and 0.087 IQ points and $344 without threshold. These results are global averages; for any particular source and emission site the impacts can be quite different. An assessment of the overall uncertainties indicates that the damage cost could be a factor 4 smaller or larger than the median estimate (the uncertainty distribution is approximately log normal and the ratio median/mean is approximately 0.4).

KEY WORDS: Damage costs; dose distribution; dose-response function; global modeling; IQ decrement; mercury; methylmercury; transfer factor; uncertainty

1. INTRODUCTION

There has been much debate, especially in the United States, about proposed stricter regulations for the emission of Hg (in the United States the Clean Air Mercury Rule went into effect in 2005), and a large number of studies have been performed, for example, Lipfert *et al.* (1996), Trasande *et al.* (2005), Rice and Hammitt (2005), and Griffiths *et al.* (2007). An important consideration in this debate is the comparison of abatement costs and benefits. Estimating the benefits is challenging: the modeling of the environmental pathways is very complex and uncertain, and the dose-response functions (DRF) are poorly known. A further complication arises from the fact that Hg is a global pollutant (Lamborg *et al.*, 2002) and therefore the benefits should be evaluated at the global scale, something that has not been attempted before. More precisely, it is Hg(0), the gaseous metallic part of Hg emissions, that is dispersed globally because its effective atmospheric residence time (including resuspension) is about one to two years, long enough for the distribution in the hemisphere to become quite uniform. The other main species are RGM (reactive gaseous mercury Hg^{++}) and Hg_p (particulate mercury), and they deposit regionally rather than globally. The speciation of Hg emissions depends on the source, but the contribution of Hg(0) to the total is large.

Even if the United States or the EU were entirely selfish, it would be appropriate for them to consider the emissions from and impacts in other countries, for at least two reasons: first, since the problem is global,

[1] ARMINES/Ecole des Mines de Paris, Paris.
*Address correspondence to Ari Rabl, ARMINES/Ecole des Mines de Paris, 60 boul. St.-Michel, F-75272, Paris; tel: (33)6-3263-0431; ari.rabl@gmail.com.

emission reductions need to be negotiated by all concerned parties; second, the most certain contribution to the damage cost (the one evaluated in this article) is a reduction of the IQ, entailing a delay in economic and social development that leaves everybody worse off. Of course, for international agreements on emission reductions one would need an assessment of the contributions of the concerned countries to the impacts in other countries. Such an assessment would be difficult and far beyond the scope of this article, which intends only to highlight the importance of the problem by presenting a first order-of-magnitude estimate of the global average health damage costs of Hg emissions.

We argue that a global estimate is relatively simple because the dominant pathway is the ingestion of fish and seafood, and the transfer factor from emission to ingestion can be estimated by comparing the global average dose and emissions, both of which have been estimated in a number of studies. Such a comprehensive transfer factor is much easier to determine and less uncertain than a detailed calculation of all the individual transfer factors, in particular the fraction transformed to methyl-Hg (MeHg) and the bioconcentration factor in seafood. The most troubling and currently best understood health impacts of Hg are neurotoxic (see Axelrad *et al.*, 2007 and references therein), and we evaluate them using as proxy recent DRF data for IQ decrement due to MeHg ingestion. We neglect other forms of Hg because they are far less toxic, despite relatively high doses, for example, from dental amalgam (see, e.g., Bellinger *et al.*, 2006).

The main assumptions are the following.

(1) For an assessment of global impacts of Hg emissions to air the dependence on emission site can be neglected because the residence time of metallic Hg in the atmosphere is sufficiently large to imply a fairly uniform hemispherical distribution of the ingestion dose. Even though the actual distribution of ambient total Hg is not very uniform (because of the contribution of RGM and Hg_p), the ingestion dose of MeHg becomes far more uniform because of the wide international trading of fish.

(2) A comprehensive transfer factor, defined as incremental average dose due to an incremental emission, can be estimated as ratio of average dose and total (natural + anthropogenic) global emission at steady-state conditions.

(3) The worldwide average dose from fish and seafood is about 2.4 μg/day-person of MeHg as reported by UNEP (2002).

(4) The worldwide emission rate is about 6,000 tons/year, as estimated by the recent UN study (UNEP, 2002); about one-third of that is from natural sources.

(5) The DRF for IQ points lost can be approximated by a straight line with two possibilities for a threshold, either no threshold or a threshold corresponding to the reference dose RfD of EPA (2001); as slope of the DRF we take the value found by the integrative analysis of Axelrad *et al.* (2007) and we convert it to an ingestion dose using conversion factors from the literature.

(6) The neurotoxic impact on a population can be estimated by applying the DRF of Axelrad *et al.* to women of child-bearing age.

(7) The average ingestion dose of women of child-bearing age is equal to the average dose reported by UNEP (2002); for the threshold case we assume a distribution of worldwide doses similar to that in the United States (NCHS, 2005).

(8) The social cost of an IQ point lost in each country is calculated by modifying the value in the United States (for which we take $\$_{2005}$18,000/IQ point in proportion to the GDP/capita), adjusted for purchase power parity (PPP).

We believe that in view of the evidence these assumptions are the most plausible choice for calculating the global average Hg damage cost and that no better calculation is possible with the limited data currently available. An examination of the uncertainties suggests that the result estimates the global damage cost within a factor of about 4 (around the geometric mean).

2. THE COMPREHENSIVE TRANSFER FACTOR

Of course, the pathways of Hg in the environment are extremely complex and at the present state of knowledge a detailed modeling of global impacts would be difficult and very uncertain. The difficulties begin with the speciation during emission. The dominant species emitted from coal-fired power plants are Hg(0), RGM, and Hg_p, and typical percentages in the United States are around 58% for Hg(0), 40% for

RGM, and 2% for Hg_p, although highly variable from one plant to another (RGM from utility boilers in the United States can vary from 10% to 90%) (Sullivan *et al.*, 2003). Pirrone *et al.* (2001) report Hg speciation estimates for all anthropogenic sources as 64% Hg(0), 28.5% RGM, and 7.5% Hg_p. Natural emissions are mostly elemental mercury, according to EMEP [http://www.msceast.org].

RGM and Hg_p are water-soluble and deposit by wet and dry deposition (Rea *et al.*, 2000, 2001; Vette *et al.*, 2002; Landis *et al.*, 2002). Several recent articles (EPA, 1997; Rossler, 2002) indicate that in the United States about 60% of the Hg deposition is from local sources, the global reservoir contributing the rest. Hg(0) becomes part of the global mercury cycle. The effective lifetime of Hg(0) in the atmosphere is in the range of one to two years, long enough to cause mixing in the entire hemisphere (Lamborg *et al.*, 2002). Note that this life time is much longer than what would be implied by a simple consideration of the wet and dry deposition velocities because much of the deposited Hg(0) evaporates again for another deposition-volatization cycle. If natural emissions are one-third of the total with about 95% Hg(0), while anthropogenic emissions are two-thirds with about 64% Hg(0), it follows that about three-quarters of the total emitted mercury disperses globally—hence the importance of a global assessment of damage costs.

The dose from fish and seafood involves the transformation of Hg into MeHg by aquatic microorganisms. Even though only a small percentage of the Hg is thus transformed, MeHg is much more toxic than the other forms. Furthermore, the bioconcentration factor of MeHg is very large, leading to relatively high concentrations in seafood, especially among predatory fish. For these reasons the ingestion of fish and seafood is by far the most important pathway for human health impacts.

Trying to model the detailed pathways at the global scale would be most problematic because of the almost universal lack of data; the uncertainties would be enormous. As an alternative to detailed pathway modeling we use a comprehensive transfer factor T_{av}, defined as the ratio of the global average ingestion dose D_{av} per person and the global emission rate E,

$$T_{av} = D_{av}/E, \tag{1}$$

it has units of (μg_{MeHg}/year)/(kg_{Hg}/year). (The key symbols of our article and their definitions are summarized in Table I.) Estimates of global emissions and global ingestion dose have been reviewed in a major study by UNEP (2002). Based on this study we take a global emission rate of $E = 6{,}000$ tons/year (uncertainty range 3,000–9,000 tons/year). A large part of that, about one-third, is due to natural emissions; the anthropogenic part has been increasing steadily since the Industrial Revolution (Lamborg *et al.*, 2002). One of the difficulties of estimating global emissions lies in the fact that a significant fraction of the deposited Hg is later, possibly much later, reemitted to the atmosphere.

For the global average ingestion dose of MeHg we take $D_{av} = 2.4$ μg/day per person, based on a report of the WHO (World Health Organization) as cited in Table 4.3 of UNEP (2002). For comparison we note that in the United States the ATSDR dose estimate is 50 ng/kg_{bw}/day, implying 3.0 μg/day for a body weight of 70 kg_{bw} [http://www.atsdr.cdc.gov/toxprofiles/phs46.html], quite similar in view of the uncertainties. Data for the United Kingdom (2002) indicate intakes of about 3 μg/day for adults. With $D_{av} = 2.4$ μg/day per person we obtain a transfer factor of

$$T_{av} = 4.0\text{E} - 07(\mu\text{g/day})/(\text{kg/year}). \tag{2}$$

Table I. Definition of the Most Important Symbols

Symbol	Definition and Equation Where it is Defined
T_{av}	Transfer factor T_{av} = ratio of global average ingestion dose D_{av} per person and global emission rate E; Equation (1)
s_{DR}	Slope of dose-response function; Equation (5)
I_i	Lifetime impact for individual i exposed to dose D_i; Equation (6)
$\Delta D_{av}(D_{th})$	Dose above threshold D_{th} [μg/day per person], averaged over entire population; Equation (8)
$D_{av}(D_{th})$	Total dose of the individuals who are above D_{th}, averaged over entire population; Equation (11)
C	Marginal damage cost in €/kg emitted; Equation (17)
f_{world}	Fraction of world population p_{world} that is affected per year by Hg, weighted by GDP/capita; Equation (21)

The product of T_{av} and the world population, 6.4 billion (times the ratio of molecular weights Hg/MeHg) is the intake fraction, that is, the fraction of the emitted Hg that passes through a human body as MeHg on its way to the ultimate environmental sink, mostly ocean sediment (Lamborg *et al.*, 2002). Our result for intake fraction, 0.9E-03, is in the range of values found for other toxic metals (Spadaro & Rabl, 2004). Despite the low proportion of Hg that is transformed to MeHg we find such an intake fraction plausible because of the large bioconcentration factor in fish and seafood.

3. DRF

In this article we are only concerned with impacts at low doses. Among the various possible health impacts of Hg at low doses, the neurotoxic impacts on fetus and infants have been investigated most thoroughly and they appear to be the most worrisome and the least uncertain. The adult brain is far less sensitive to Hg and no significant association with neurotoxic impacts on adults has been found at low doses (Weil *et al.*, 2005). Evidence is also accumulating for another impact at low doses, coronary heart disease, see, for example, the review by Virtanen *et al.* (2007), although the case seems less clear and we do not consider it, noting only that Rice and Hammitt (2005) find that it can make a very large contribution to the damage cost. Measuring impacts at the low exposures of typical populations is in fact a great challenge. For instance, the study of neurotoxic effects of PCBs and Hg in the United States by Stewart *et al.* (2003) has not been very conclusive for Hg; however, the focus was on PCBs, Hg being examined only as an effect modifier. The most important studies on neurotoxic impacts have followed cohorts of children among three populations (New Zealand, the Seychelles, and the Faroe Islands) whose diet contains a particularly large portion of seafood; here significant associations between exposure and neurotoxic impacts have been observed.

Based on the findings in New Zealand, the Seychelles, and the Faroe Islands, Trasande *et al.* (2005) have estimated the social cost of the IQ decrement that can be attributed to Hg ingestion in the United States. In view of the large uncertainties, they consider several possible forms of the DRF, both linear and logarithmic, with a no-effect threshold of 8.2 μg/L_{cord} in the cord blood of the newborn infant. In a recent update (Trasande *et al.*, 2006) they revise their DRFs, the new ones being much lower than in their 2005 article.

In this article we take the DRF of Axelrad *et al.* (2007) because it is derived by an integrative analysis of the New Zealand, the Seychelles, and the Faroe Islands studies, with a method that uses the maximum of information from all three studies. Thus it holds promise to be much more reliable than any single study. They assume a linear DRF and their central estimate of the slope is 0.18 IQ points per ppm increase of maternal hair mercury (95% confidence interval 0.009 to 0.378). Sensitivity analyses produce estimates in the range from 0.13 to 0.25 IQ points per ppm, not very different.

To apply this DRF we need to relate the Hg concentration in maternal hair to the MeHg intake dose D by ingestion. Axelrad *et al.* indicate a concentration ratio hair/cord blood of 200. The concentration in cord blood is higher than in maternal blood, but there is considerable uncertainty about the ratio cord blood concentration/maternal blood concentration. In this article we assume a ratio of 1.65, the mean of the meta-analysis by Stern and Smith (2003). These authors find that the distribution of values for this ratio is lognormal with median (=geometric mean) of 1.45, which implies a geometric SD $\sigma_g = 1.66$ since one has (see, e.g., Spadaro & Rabl, 2008)

$$\sigma_g = \mathrm{Exp}[(2\mathrm{Ln}(\mathrm{mean/median}))^{0.5}] \qquad (3)$$

for the lognormal distribution.

To relate blood concentration to dietary intake, we note that according to UNEP (2002) the ratio of the steady-state blood concentration c[in μg/L_{mat}] and the average dietary MeHg intake D[in μg/day] is in the range $c/D = 0.3$ to 0.8. Here, we assume the model of Stern (2005) for the relation between intake dose D of MeHg and concentration c, namely,

$$c = 0.61 * D. \qquad (4)$$

The coefficient 0.61 μg/L_{mat}/(μg/day) accounts for blood volume, absorption, and elimination rate.

Multiplying these factors we obtain a DRF slope of

$$\begin{aligned} s_{DR} &= 0.18\,\mathrm{IQpoints/ppm_{hair}} * 0.2\mathrm{ppm_{hair}}/(\mu\mathrm{g/L_{cord}}) \\ &\quad * 1.65\,\mu\mathrm{g/L_{cord}}/(\mu\mathrm{g/L_{mat}}) \\ &\quad * 0.61\mu\mathrm{g/L_{mat}}/(\mu\mathrm{g/day}) \\ &= 0.036\,\mathrm{IQpoints}/(\mu\mathrm{g/day}). \end{aligned} \qquad (5)$$

As for a possible threshold, EPA (2001) noted that "*no evidence of a threshold arose for methylmercury-related neurotoxicity within the range of exposures*" Axelrad *et al.* (2007) also argue for linear DRF without threshold. We find the possibility of a straight

line without threshold not only plausible but probable. Hg is a neurotoxicant that damages the developing brain and reduces the IQ, just like Pb. Also, like Pb it is a substance that has only harmful effects, by contrast to other metals (for instance, Cr and Se) that are toxic at high doses but of which the organism needs a certain minimum to survive. Furthermore, whereas in the past the DRF for IQ decrement due to Pb was believed to have a threshold, more recent studies have found that at the lowest doses the DRF for Pb is at least as high as the extrapolation of the high dose points, and quite possibly even higher (Lanphear *et al.*, 2005). Nonetheless, we also evaluate the impacts if there is a no-effect threshold dose D_{th}, assuming the same slope s_{DR}. As threshold we take the oral reference dose RfD of EPA (2001), noting, however, that it is not a no-effect level but intended as a guideline for protecting the population with a sufficient margin of safety.

4. CALCULATION OF LIFETIME IMPACT

To apply the DRF, it might appear necessary to consider the time window during which the brain is affected by Hg. The sensitivity of the brain to Hg is greatest during the early development of the body, but the precise time distribution of the damage is not known. Whereas the damage is incurred only during early development, it is assumed permanent and measurable at the ages reported in the epidemiological studies. Since the DRF of Axelrad *et al.* is based on correlations between the maternal hair concentration and the IQ of the children, it implicitly includes also the effect of diet during early infancy before the IQ of the children was measured. One can assume that the diet of the infants is strongly correlated with that of the mothers. Thus the DRF slope of Equation (5) describes the total lifetime impact on children whose mothers are exposed to a specified steady-state ingestion dose, and the detailed time distribution of the sensitivity to Hg does not matter for the calculation of impacts.

If a particular mother i has had an ingestion dose D_i, the lifetime impact I_i on the offspring is an IQ loss of

$$I_i = \begin{cases} 0 & \text{if} \quad D_i < D_{th} \\ s_{DR}(D_i - D_{th}) & \text{if} \quad D_i \geq D_{th} \end{cases}, \tag{6}$$

where D_{th} is the threshold dose. Since everybody alive has or had a mother, the total impact in a population of p individuals is obtained by summing Equation (6) over the doses of the mothers:

$$I_{\text{tot}} = s_{DR} \sum_{i=p_{th}}^{p} (D_i - D_{th}), \tag{7}$$

where p_{th} is the number of individuals with maternal dose below D_{th} and the sum covers only the individuals with maternal dose above D_{th}. We find it convenient to express everything as impact per person, averaged over the entire population (men, women, all ages) rather than just the sensitive individuals. Using the notation $\Delta D_{av}(D_{th})$ for the positive differences $D_i - D_{th}$, averaged over the entire population,

$$\Delta D_{av}(D_{th}) = \frac{1}{p} \sum_{i=p_{th}}^{p} (D_i - D_{th}), \tag{8}$$

one can write the average lifetime IQ loss per person $I_{av} = I_{\text{tot}}/p$ as

$$I_{av} = s_{DR} \Delta D_{av}(D_{th}). \tag{9}$$

To calculate this quantity one needs data for the distribution of doses for the world population. For most countries that is unfortunately not available. The best data are the ones of NCHS (2005) (see also Mahaffey, 2005) for the fraction of women of child-bearing age in the United States that has various levels of MeHg concentration (as μg per L of maternal blood). This distribution is to a good approximation lognormal with geometric mean $\mu_g = 0.7$ μg/L and geometric SD $\sigma_g = 3.5$ (a distribution that is fairly similar to data of the United Kingdom, 2002). Using this lognormal distribution one can readily calculate the population averaged dose above D_{th} of Equation (8). Since the distribution is not weighted by the number of children, our calculations assume implicitly that the number of children per mother is independent of her dose.

The resulting mean dose in the United States is about 2.5 μg/day and very close to the UNEP (2002) estimate of the average dose of the entire world, 2.4 μg/day, the dose that we use as basis for our damage cost estimates. Lacking data for the dose distributions in other countries, we use the distribution of NCHS (2005) for the world and scale it down by a factor 2.4/2.5, assuming that the UNEP data also apply to women of child-bearing age.

Fig. 1 shows the resulting relation between threshold dose D_{th} and $\Delta D_{av}(D_{th})$ of Equation (8). The fraction $f(D_{th})$ of the population that is above threshold is indicated by the dashed line and the right-hand scale. The threshold RfD of EPA is 0.1 μg/day/kg$_{\text{bodyweight}}$, implying D_{th} = 6.7 μg/day for an average weight

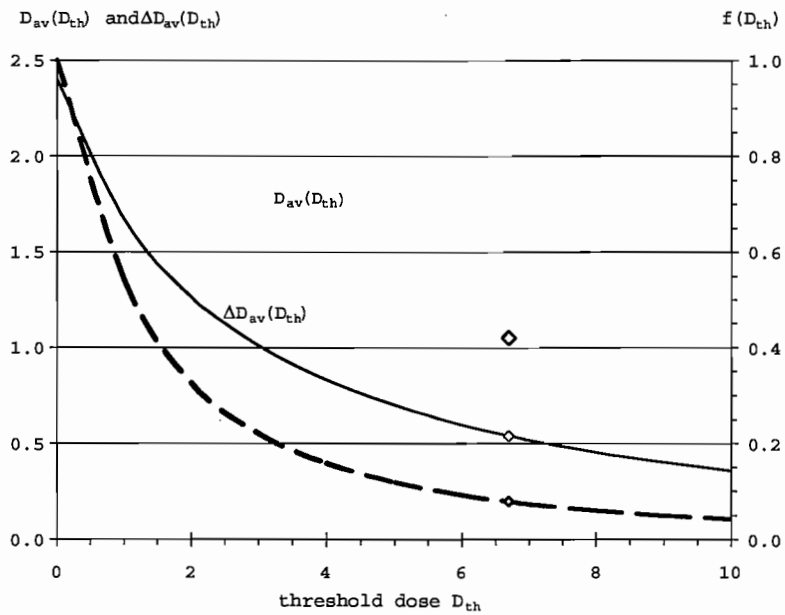

Fig. 1. Thin solid line shows relation between threshold dose D_{th} and dose $\Delta D_{av}(D_{th})$ above D_{th} per person averaged over entire population, Equation (8); this is needed for the total lifetime impact. Thick gray line shows the dose $D_{av}(D_{th})$ of Equation (11), needed for the marginal damage cost. Dashed line and right-hand scale shows the fraction $f(D_{th})$ of the population that is above threshold. Diamonds mark the EPA reference dose of 6.7 μg/day. Based on the distribution of NCHS (2005) and scaled to correspond to the UNEP dose of 2.4 μg/day.

of 67 $kg_{bodyweight}$; this is indicated by the diamonds. The graph also shows the quantity $D_{av}(D_{th})$ of Equation (11) in the next section, which will be needed for the marginal damage cost. Multiplying the dose $\Delta D_{av}(D_{th})$ by s_{DR} of Equation (5) one finds the corresponding average IQ loss is 0.020 IQ points if $D_{th} = 6.7$ μg/day. For zero threshold the loss is 0.087 IQ points.

5. MARGINAL IMPACTS AND COSTS PER KILOGRAM OF EMITTED HG

By contrast to the lifetime impact, the calculation of impact and cost of an additional kg of emitted Hg (also called marginal or incremental cost) requires consideration of the rate at which new individuals are affected, hence the birth rate b enters into the calculation. For the allocation of an additional impact δI to an additional emission δQ it may be helpful to assume that emission and impact are simultaneous and occur during a certain time interval for which one can arbitrarily take $\Delta t = 1$ year; in reality the impact occurs later, of course, but the delay does not change the magnitude of the impact. Only the $\Delta p = pb\Delta t$ individuals born during this time interval are affected, and the incremental impact on the total population is

$$\delta I_{tot} = pb\Delta t s_{DR} \delta \Delta D_{av}(D_{th}), \tag{10}$$

where $\delta\Delta D_{av}(D_{th})$ is the increment of $\Delta D_{av}(D_{th})$ of Equation (8) due to δQ. To find how an increase of the emission rate $\delta E = \delta Q/\Delta t$ changes the dose $\Delta D_{av}(D_{th})$, note that in the limit of small changes the number p_{th} of individuals above threshold does not change (a change in p_{th} would yield a term of order δE^2 in the incremental impact and is, by definition, neglected in the calculation of marginal costs). Whereas the doses D_i are proportional to the emission rate E, the quantity $\Delta D_{av}(D_{th})$ is not because it contains only the contributions above threshold. To find how $\Delta D_{av}(D_{th})$ changes, let us define the population-average of the total dose of the individuals who are above D_{th} as

$$D_{av}(D_{th}) = \frac{1}{p} \sum_{i=p_{th}}^{p} D_i, \tag{11}$$

and rewrite Equation (8) in the form

$$\Delta D_{av}(D_{th}) = D_{av}(D_{th}) - f(D_{th}) D_{th} \text{ with } f(D_{th}) = (1 - p_{th}/p). \tag{12}$$

To relate it to the emission rate E, we multiply $D_{av}(D_{th})$ by a factor $E\,T_{av}/D_{av}$, which is equal to unity by its definition in Equation (1):

$$\Delta D_{av}(D_{th}) = ET_{av}\, D_{av}(D_{th}) D_{av} - f(D_{th})\, D_{th}. \tag{13}$$

Since a small change in emission rate changes neither the transfer factor T_{av} nor the shape of the probability distribution of doses, the quantity $T_{av}\, D_{av}(D_{th})/D_{av}$ is independent of E. Hence, the increment $\delta\Delta D_{av}(D_{th})$ equals

$$\delta\Delta D_{av}(D_{th}) = \delta E T_{av} D_{av}(D_{th})/D_{av}. \quad (14)$$

Inserting this into Equation (10) and replacing the incremental emission rate by $\delta E = \delta Q/\Delta t$, we obtain

$$\delta I_{\text{tot}} = pb\Delta t\, s_{DR}(\delta Q/\Delta t)\, T_{av}\, D_{av}(D_{th})/D_{av}. \quad (15)$$

The time interval Δt is indeed arbitrary because it cancels out. The ratio of δI_{tot} and incremental emission δQ is the incremental impact per emitted Hg:

$$\text{incremental impact per emitted Hg} = s_{DR}[T_{av}\, D_{av}(D_{th})/D_{av}] \sum_k p_k b_k, \quad (16)$$

where $D_{av}(D_{th})$ is given by Equation (11), and we have replaced pb by a sum over countries k to allow for the fact that birth rates in different countries are different. Multiplying by the cost c_k per IQ point in country k, we obtain the marginal damage cost C in €/kg emitted,

$$C = s_{DR}[T_{av}\, D_{av}(D_{th})/D_{av}] \sum_k p_k b_k c_k f_{\text{disc}}. \quad (17)$$

We have included a factor f_{disc} to account for the time lag between a change in emissions and the impact

$$f_{\text{disc}} = (1 + r_{\text{disc}})^{-N}, \quad (18)$$

where r_{disc} is the discount rate and N the time lag; following Griffiths *et al.* (2007), we take $r_{\text{disc}} = 3\%$ and $N = 15$ year for the central value, resulting in $f_{\text{disc}} = 0.64$. Note that we apply this discount factor only to the marginal cost, not to the lifetime cost, since the latter corresponds to current exposure.

For the cost associated with the loss of an IQ point there is a range of estimates in the United States, mostly based on lost earnings or remedial education. In particular we cite

- Muir and Zegarac (2001) $\$_{1999}$14,700/IQ point,
- Grosse *et al.* (2002) $\$_{2000}$14,500/IQ point,
- Rice and Hammitt (2005) $\$_{2000}$16,500/IQ point,
- Trasande *et al.* (2005) $\$_{2000}$22,200/IQ point, and
- Griffiths *et al.* (2007) $\$_{2000}$11,245/IQ point.

Adjusting these figures to \$2005 by means of the CPI we obtain a mean of about $\$_{2005}$18,000/IQ point. To apply this cost in different countries we modify the cost in proportion to the GDP_{PPP}/capita, the per capita GDP adjusted for purchase power parity [http://www.cia.gov/cia/publications/factbook/]. So the cost of an IQ point in country k is

$$c_k = c_{\text{USA}} \frac{(GDP_{PPP}/capita)_k}{(GDP_{PPP}/capita)_{\text{USA}}}. \quad (19)$$

The worldwide average cost is

$$c_{av} = \sum_k c_k \frac{p_k}{p_{\text{world}}} = \$3,890/\text{IQpoint}. \quad (20)$$

Let us define a fraction f_{world} of the world's population p_{world} that is affected per year by Hg, weighted by GDP/capita, as

$$f_{\text{world}} = \sum_k b_k \frac{p_k}{p_{\text{world}}} \frac{(GDP_{PPP}/capita)_k}{(GDP_{PPP}/capita)_{\text{USA}}}, \quad (21)$$

its numerical value is 0.00315. Thus we can write C in the form

$$C = s_{DR}[T_{av}\, D_{av}(D_{th})/D_{av}] \times f_{\text{world}}\, p_{\text{world}}\, c_{\text{USA}}\, f_{\text{disc}} \text{ in \$/kg emitted.} \quad (22)$$

As shown in Table II, the marginal damage cost C per kg of emitted Hg is about \$1,500/kg for a threshold dose of 6.7 mg/day and \$3,400/kg for zero threshold. It is also interesting to look at the total average worldwide IQ loss per person due to current emissions (0.02 IQ points/person with and 0.087 IQ point/person without threshold) and the corresponding costs (\$78/person with and \$344/person without threshold). We note

Table II. Our Estimates of the Total Worldwide Lifetime Impact and Cost (Equations (8) and (20)), and of the Marginal Damage Cost C (Equation (22)) of Hg Emissions, for Two Assumptions about the Threshold Dose D_{th}

		Lifetime Impact and Cost			Marginal Damage Cost	
D_{th} (μg/day)	$f(D_{th}) = 1 - p_{th}/p$	$\Delta D_{av}(D_{th})$ (μg/day)	Lifetime Impact (IQ points/person)	Lifetime Cost (\$/person)	$D_{av}(D_{th})$ (μg/day)	C (\$/kg)
6.7	0.08	0.54	0.020	78	1.05	1,500
0	1	2.40	0.087	344	2.40	3,400

Note: $f(D_{th})$ is the fraction of the total population that is above threshold.

that the marginal damage cost for the case with threshold is appropriate only for small changes: for large changes the fraction of the population above threshold will also change.

6. ASSESSMENT OF UNCERTAINTIES

Uncertainty assessments for this kind of problem are usually done via a Monte Carlo analysis; the result is numerical and not very transparent. Instead, we apply the method of Rabl and Spadaro (1999) and Spadaro and Rabl (2008), which is appropriate in this case because the impact and cost are essentially a product of factors (the summation over countries introduces errors that are entirely negligible). This approach has the advantage of being simple and transparent, and its accuracy is sufficient because in any case an assessment of uncertainties involves subjective judgments and is very approximate. The uncertainty of each factor is characterized in terms of its geometric *SD*. Then the geometric *SD* σ_g of the product can readily be calculated from the geometric $SD\sigma_{gj}$ of the factors by the equation

$$[\ln(\sigma_g)]^2 = [\ln(\sigma_{g1})]^2 + [\ln(\sigma_{g2})]^2 + \cdots + [\ln(\sigma_{gn})]^2, \tag{23}$$

assuming that the distributions are statistically independent.

The central limit theorem implies that the distribution of the product is approximately lognormal in the limit where the number of factors becomes very large. In practice the distribution is close to lognormal even for a small number of factors, unless the distribution(s) with the largest width is (are) far from lognormal. For a lognormal distribution the geometric *SD* indicates multiplicative confidence intervals, analogous to the additive confidence intervals of the Gaussian distribution. One can show that for the lognormal distribution the geometric mean μ_g is equal to the median and the ratio of mean/geometric mean is given by

$$\mu/\mu_g = \exp\left(0.5 \ln^2(\sigma_g)\right). \tag{24}$$

If a quantity with a lognormal distribution has been found to have a geometric mean μ_g and a geometric *SD* σ_g, the probability is approximately 68% for the true value to be in the interval $[\mu_g/\sigma_g, \mu_g\,\sigma_g]$ and 95% for it to be in the interval $[\mu_g/\sigma_g^2, \mu_g\,\sigma_g^2]$. Our estimates of the uncertainties are listed in Table III for the case with threshold; without threshold the uncertainty is lower. We have taken the geometric $SD\sigma_{gi}$ of the individual factors as 4th root of the ratio's high value/low value, roughly interpreting the low to high range as width of the 95% confidence interval. For the estimation of the average dose above threshold we have considered a wide range of possible dose distributions and their effect on the ratio $D_{av}(D_{th})/D_{av}$; we believe that this accounts for the uncertainty. The uncertainty of f_{world} includes the GDP/capita adjustment of the cost of an IQ point in different countries. The resulting σ_g is 4.2.

Table III. Our Estimates of the Uncertainties of the Marginal Damage Cost for the Case with Threshold

Factor	Unit	Mean	Low	High	σ_{gi}	$\ln^2(\sigma_{gi})$
Emission rate, E	t/year	6000	3000	9000	1.32	*0.08*
Average dose, D_{av}	μg/day	2.40	0.60	4.00	1.61	*0.22*
Dose above threshold, $D_{av}(D_{th})/D_{av}$	–	0.44	0.20	1.20	1.57	*0.20*
s_{DR} based on Hg in hair	IQ point/ppm	0.18	0.009	0.38	2.55	*0.87*
Hair conc/cord blood conc	ppm/(μg/L_{cord})	0.20	0.10	0.30	1.32	*0.08*
Ratio of cord to maternal blood	(μg/L_{cord})/(μg/L_{mat})	1.65	0.41	3.14	1.66	*0.26*
Ratio of maternal blood to dose intake	(μg/L_{mat})/(μg/day)	0.61	0.40	1.00	1.26	*0.05*
Cost of IQ point in USA	\$/IQ point	18,000	10,000	25,000	1.26	*0.05*
f_{world} [Equation (21)]	1/year	0.00315	0.0014	0.0071	1.50	*0.16*
Discount factor, f_{disc}	–	0.64	0.30	0.82	1.29	*0.07*
World population, p_{world}	–	6.43*E*+09			1.00	*0.00*
Results for cost C	\$/kg	1,487			$\Sigma_i \ln^2(\sigma_{gi}) =$	*2.04*
			68% CI			
	Median	Mean	Low	High	σ_g	
Results for cost C [\$/kg]	531	1487	126	2230	4.2	

Note: The geometric *SD* σ_{gi} of the individual factors are the 4th root of the ratio's high/low. Some numbers for the results have been rounded in the text.

The lower part of the table lists the 68% confidence interval $[\mu_g/\sigma_g, \mu_g \sigma_g]$ of the result. To place the confidence intervals, one has to note the difference between mean and median. We have calculated the mean as product of the means of the factors. Since the distribution of the product is fairly close to lognormal, the ratio median/mean is 0.36 according to Equation (24) if $\sigma_g = 4.2$, and for the 68% confidence interval the ratio's lower bound/mean and upper bound/mean are 0.06 and 1.5. The placement of the confidence interval is very asymmetric because σ_g is so large.

Of course, estimating component uncertainties necessarily involves a certain amount of subjective judgment. Our choice of the σ_{gi} is somewhat arbitrary since the probability distributions of most of the parameters may be quite different from lognormal and our high and low values may not be the correct 95% confidence intervals, but even with different and equally plausible choices the σ_g of the result would not be very different as the reader can readily verify. Note that because of the quadratic combination of the individual terms (see last column of the table), terms with relatively small uncertainty make negligible contributions to the total. In view of the great uncertainty of the estimation of uncertainties we round the numbers to summarize by saying that σ_g is about 4 and the 68% confidence interval extends from about 0.1 to 1.5 times the mean.

7. CONCLUSIONS

Using a comprehensive transfer factor, defined as ratio of global Hg emissions and global average ingestion dose of MeHg, we have estimated the global average impact and cost. This includes local and regional impacts, but only as global averages. For a specific source and site the impact can be quite different. The ratio of local + regional/total impact can also be very different for different sources because much of the local and regional impact is due to RGM and Hg_p whereas metallic Hg(0) is dispersed globally.

Some people might argue that regional and local variability could invalidate our global approach. As far as environmental pathways are concerned, such variability arises only from the Hg_p and RGM component of the emissions, since Hg(0) disperses globally. Our model would be exact for Hg(0) emissions if we had exact data for the Hg(0) component of global emissions and for its contribution to the global average dose. Instead, our transfer factor includes the other components and thus our model combines global and regional impacts, the latter as global average. The other source of variability arises from the distributions of ingestion doses in different parts of the world. We believe that our uncertainty analysis of Section 6 adequately accounts for the possible effects of such variability by including a wide range of possible doses and dose distributions, and that therefore our results are valid within the uncertainty bounds we have estimated. Another possible criticism concerns our use of a steady state analysis whereas in reality emissions and doses have been changing. Here, too, our uncertainty analysis covers the ground because the range of emissions and doses is wide enough to account for changes during the past one or two decades (i.e., the time constant for the environmental pathways).

In terms of absolute magnitude the impacts and costs are small: 0.02 IQ points/person with and 0.087 IQ points/person without threshold, and \$78/person with and \$344/person without threshold; also one should note that about two-thirds of the current total emissions are anthropogenic. However, because of the small quantity of Hg that is involved, the marginal damage cost is high compared to other pollutants that have been evaluated, for example, by the ExternE project series of the EC [www.externe.info]; they are approximately \$1,500/kg if the threshold dose is 6.7 μg/day and about \$3,400/kg without threshold.

An examination of the uncertainties leads us to a geometric *SD* of about 4, in other words, the damage cost could be a factor 4 smaller or larger than the median estimate. However, the uncertainty about a possible threshold is difficult to capture because of the lack of information. As an indication one can consider the range of results between zero threshold and the RfD threshold of EPA, but the true threshold could be even higher: the RfD is a guideline for protecting public health and derived by including a large margin of safety (see also the discussion of thresholds by Lipfert *et al.* (1996)). Thus the impact and costs might even be an order of magnitude smaller than our estimate.

It is interesting to compare our marginal damage cost *C* with a recent study by Rice and Hammitt (2005), who estimate the benefit of the new regulation for Hg emissions by power plants in the United States. Of course, their numbers are not very comparable with ours because they consider only impacts within the United States, whereas our estimate is a simple global average. Due to local and regional variations in Hg speciation, dispersion, population, dietary habits, etc., a regional calculation such as that of Rice and Hammitt can find very different results. In particular, the speciation for the power plants considered

by Rice and Hammitt has a higher fraction of RGM and Hg_p than the global emissions we have assumed; thus they find a higher fraction of Hg deposited in the United States where the cost of an IQ point is higher than the global average. However, the threshold assumptions are the same.

To estimate what our model implies with the scope and assumptions of Rice and Hammitt, we multiply by the ratio of the United States cost and the global cost in our global calculation; that ratio is 0.207, relatively high because of the high cost of an IQ point in the United States compared to the rest of the world (in other words, the result of Rice and Hammitt would be a factor 1/0.207 larger if they had included global impacts and if the damage of U.S. power plant emissions were equal to our very simple global model). We also adjust for different assumptions about cost of IQ point ($16,500/IQ point for Rice and Hammitt vs. $18,000/IQ point for us, and DRF slope s_{DR} (0.12 IQ point/(μg/day) for Rice and Hammitt vs. 0.0362 IQ point/(μg/day) for us).

Finally, about 60% of U.S. emissions are deposited on U.S. soil (EPA, 1997) because of the large fraction of RGM in the speciation of power plant emissions in the United States; to convert from the typical speciation that we assume to power plant emissions in the United States we, therefore, have to multiply by a factor of 3. Combining these adjustment factors we multiply our global cost C (but without discount factor f_{disc} for consistency with Rice and Hammitt) by $0.207 * 3.0 * (0.12/0.0362) * (16.5/18) = 1.89$ to obtain our estimate for the United States. The result, $4,380/kg with and $9,993/kg without threshold, agrees with the corresponding numbers of Rice and Hammitt, $4,300/kg and $11,200/kg, within 12%, far closer than one could expect in view of the radically different approach.

Abatement of Hg emissions is cost effective if the marginal abatement cost is smaller than the marginal damage cost. Abatement costs are highly variable, depending on technologies and specific conditions. For example, Jones *et al.* (2007) evaluate the cost of Hg removal by activated carbon injection for six power plants, with several variations, and find a range of about $8,400 to $365,000/$kg_{Hg}$; in most cases the abatement would exceed by far the benefits we have calculated. Of course, the benefits may turn out much larger if other impacts, in particular cardiovascular, are included (Rice & Hammitt, 2005; Virtanen *et al.*, 2007).

But let us emphasize that for the formulation of new regulations there are other options besides reducing the emissions. In particular, a worldwide educational campaign to prevent pregnant woman and infants from eating fish and seafood with high Hg content may be far more cost effective in many regions and it is all the more relevant in view of the fact that a large part of the emissions is of natural origin. However, careful analysis of all relevant costs and benefits is required before formulating any such advisory because the large health benefits of seafood must not be overlooked (see Cohen *et al.*, 2005; Jorgensen *et al.*, 2007).

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Ad Hoc Open-ended Working Group on Mercury
Second meeting
Nairobi, Kenya
6–10 October 2008
Agenda item 3 of the provisional agenda*

Review and assessment of options for enhanced voluntary measures and new or existing international legal instruments

Report presenting the costs and benefits for each of the strategic objectives

Note by the secretariat

1. The Governing Council of the United Nations Environment Programme, in its decision 24/3 IV on chemicals management, established an ad hoc open-ended working group of Governments, regional economic integration organizations and stakeholder representatives to review and assess options for enhanced voluntary measures and new or existing international legal instruments for addressing the global challenges presented by mercury.

2. At its first meeting, the Ad Hoc Open-ended Working Group on Mercury requested the secretariat to undertake intersessional work in a number of areas in preparation for its second meeting.

3. The report annexed to the present note provides a general qualitative assessment of potential costs and benefits for each of the strategic objectives (classifying them as small, medium, large or not applicable). The assessment takes into account that the cost element is based on the overall costs associated with implementing each strategic objective, while the benefit element is based on the extent to which the strategy would reduce mercury-related risks on a global basis and distinguish between local and global risk-reduction benefits.

4. The secretariat was also requested to gather and present any available information on the social and economic costs of maintaining the status quo.

5. The secretariat requested information from Governments, intergovernmental organizations and non-governmental organizations. Information submitted has been made available on the website of the mercury programme (http://www.chem.unep.ch/mercury) and has been used in the preparation of the assessment. The work has also been built, where possible, on work undertaken for other forums that is directly relevant to this context.

* UNEP(DTIE)/Hg/OEWG.2/1.

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Suggested actions

6. The Ad Hoc Open-ended Working Group on Mercury may wish to draw on the report in considering the need for and relative priority of individual measures for inclusion within the options to be forwarded to the Governing Council.

UNEP Report

on

A general qualitative assessment of the potential costs and benefits associated with each of the strategic objectives set out in Annex 1 of the report of the first meeting of the Open Ended Working Group

June 30, 2008

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Executive Summary

Mercury is an important environmental contaminant. This contaminant is toxic, persistent, and long-lived in the atmosphere, and can be transported globally. International action is required to reduce environmental and health risks at local, regional, and global scale.

A new assessment of the emissions of mercury is underway. A draft version of the UNEP report on emissions will be available as a draft at the second meeting of the ad hoc open-ended working group. Information from the UNEP emissions report has been used in the preparation of this report on cost benefit analyses.

This report presents a qualitative assessment of potential costs and benefits associated with each of the strategic objectives set out in Annex 1 of the report of the first meeting of the Open Ended Working Group (OEWG 1) that met in Bangkok 12-16 November 2007.

Costs have been assessed as including the economic costs of introducing the necessary equipment or actions to obtain the mercury reduction. Costs are defined as being small, medium and large, based on the highest cost of abatement for a given strategy (emission category).

Benefits of reducing mercury emissions include social, economic, ecological and human health benefits. For ingested mercury, the benefits are estimated to be $12,500 USD per kg of mercury[1]. For inhaled mercury, the benefits are between $1.34 and $1.22 per kg of mercury.

In conducting the cost-benefit analysis, the benefits are assessed on the basis of the impact of the reduction of mercury releases, and are then related to costs. Statements regarding the benefits of activities are base on the assumption that that the benefits are large if they exceed the costs by at least a factor of 2. If the benefits are equal or lower than costs, then it was assumed that the benefits are small. Medium benefits are between the large and small benefits.

While all strategic objectives specified have been assessed, assessment in detail was possible only where information was available. In particular, the costs and benefits of reducing emissions from coal burning have been addressed in some detail in this report.

In assessing ways to reduce anthropogenic mercury emissions, technological and non-technological measures have been assessed. A number of technological measures are available for reducing mercury emissions from anthropogenic sources where mercury is a by-product (e.g. power plants, smelters, cement kilns, other industrial plants), waste disposal and other uses. These measures differ with regard to emission control efficiency, costs, and environmental benefits obtained through their implementation. Very often mercury emissions are substantially reduced by equipment employed to reduce emissions of other pollutants. The best example is the reduction of mercury emissions achieved through the application of desulfurization measures.

The analysis also took account of the range of efficient, non-technological measures and pre-treatment methods are also available for the reduction of mercury releases from various uses of products containing mercury. These measures include ban on use and substitution of products containing mercury, and cleaning of raw materials before their use (e.g. coal cleaning). These

[1] A conversion figure of 1 USD = 0.64 € has been used throughout this report.

measures also include energy conservation options, such as energy taxes, consumer information, energy management and improvement of efficiency of energy production through a co-generation of electricity and heat in coal-fired power plants.

The costs of reducing mercury emissions in this report are linked to the economic costs of introducing the necessary equipment or introducing other necessary actions to obtain the reduction. These costs include the investment costs and operational and maintenance costs.

A summary of the costs and benefits for each of the strategic objectives are presented in Table 1 below.

Table 1: Costs and benefits of Hg emission reduction for various reduction options

Reduction option		**Costs**	**Benefits**
1	Reduction from coal usage	Medium →Large	Large
2	Artisanal and small – scale gold mining	Small → Large	Small → Large
3	Reduction of Hg trade emissions	Small → Large	Small → Large
4	Reduction from industrial processes	Medium → Large	Medium → Large
5	Reduction of waste generation	Small → Large	Large
6	Promotion of Hg waste collection and treatment	Small → Medium	Large
7	Reduction from waste disposal	Medium → Large	Large
8	Reduction of Hg consumption in VCM and chlor-alkali production	Small → Large	Medium → Large
9	Reduction of Hg use in products	Small → Large	Small
10	Reduction from dental practice	Small → Large	Medium
11	Reduction of supply from mining and extraction	Small → Medium	Large
12	Reduction of supply from decommissioned cells and stockpiles	Small → Large	Large
13	Prevention of contamination from spreading	Large	Medium → Large
14	Control and remediation of contaminated sites	Small → Medium	Large
15	Increase of knowledge among states	Small → Large	Large
16	Increase of knowledge among users and consumers	Small	Large

It can be seen from this table that costs and benefits vary significantly between strategic objectives.

The final conclusion of the reported work is that there are benefits to investment in reducing mercury emissions and exposure in the future primarily for the sake of improvement of human health and more generally human welfare. Measures with the application of technology, such as implementation of installations to remove mercury from the flue gases in electric power plants,

waste incinerators, and smelters are rather expensive (medium to large costs) compared to non-technological measures, such as prevention activity, capacity building, and promotion of mercury-containing waste separation (small to medium costs). Both groups of measures would result in large benefits, and parallel application of these, depending on resources would be appropriate.

Introduction

Mercury is an important environmental contaminant requiring action from policy makers, industry, and the general public. This contaminant is toxic, persistent, and transported long distances in the atmosphere and food chain. Coal combustion is believed to be the main source of mercury emissions to the atmosphere.

During the last decade major progress has been made in the assessment of emissions of mercury from various anthropogenic sources in various parts of the world. This progress has been reviewed by Pacyna et al. (2006) and has been used to assess the past, current and future emissions of mercury. It is estimated that the total anthropogenic emission of Hg in the year 2005 was about 1960 tonnes, distributed along various categories.

The largest emissions of Hg to the global atmosphere occur from combustion of fossil fuels, mainly coal in utility, industrial, and residential boilers. As much as 46.5 % of the total emission of Hg emitted from all anthropogenic sources worldwide in 2005 came from combustion of fossil fuels. Emissions of Hg from coal combustion are between one and two orders of magnitude higher than emissions from oil combustion, depending on the country. Emissions during the artisanal small scale gold production contributed about 17 %, followed by non-ferrous metal manufacturing, including gold (about 10 %), and cement production (about 9 %) (UNEP 2008, in preparation).

Emission projections for mercury in 2020 were also estimated within this project (UNEP, 2008-in preparation) and another project GLOCBA-SE prepared for the Nordic Council of Ministers (Pacyna et al., 2008 – in preparation). Three scenarios were developed: Status quo scenario, Extended Emission Control scenario and Maximum Feasible Technological Reduction scenario. The status quo scenario assumes that current patterns, practises and uses that result in mercury emissions to air will continue. Economic activity is assumed to increase, including in those sectors that produce mercury emissions, but emission control practices remain unchanged. The extended emission control scenario assumes economic progress at a rate dependent on the future development of industrial technologies and emission control technologies, i.e. mercury-reducing technology currently generally employed throughout Europe and North America would be implemented elsewhere. It further assumes that emissions control measures currently implemented or committed to in Europe to reduce mercury emission to air or water would be implemented around the world. These include measures adopted under the LRTAP Convention, EU Directives, and also agreements to meet IPCC Kyoto targets on reduction of greenhouse gases causing climate change (which will cause reductions in mercury emissions). The maximum feasible technological reduction scenario assumes implementation of all solutions/ measures leading to the maximum degree of reduction of mercury emissions and its loads discharged to any environment; cost is taken into account but only as a secondary consideration.

It can be concluded from the scenario estimates that a significant increase of about one third of the 2005 Hg emissions is expected in 2020 in the case that no major change in the efficiency of emission control will be introduced (the status quo scenario). A decrease by one third of the total emissions of mercury in 2005 can be expected in 2020 if the assumptions of the extended emission control scenario are met. As much as a half of the 2005 total emission can be reduced by 2020 if the assumptions of the maximum feasible technological reduction scenario are met. These scenarios are used as the basis for discussion on the costs and benefits of taking action on mercury reduction.

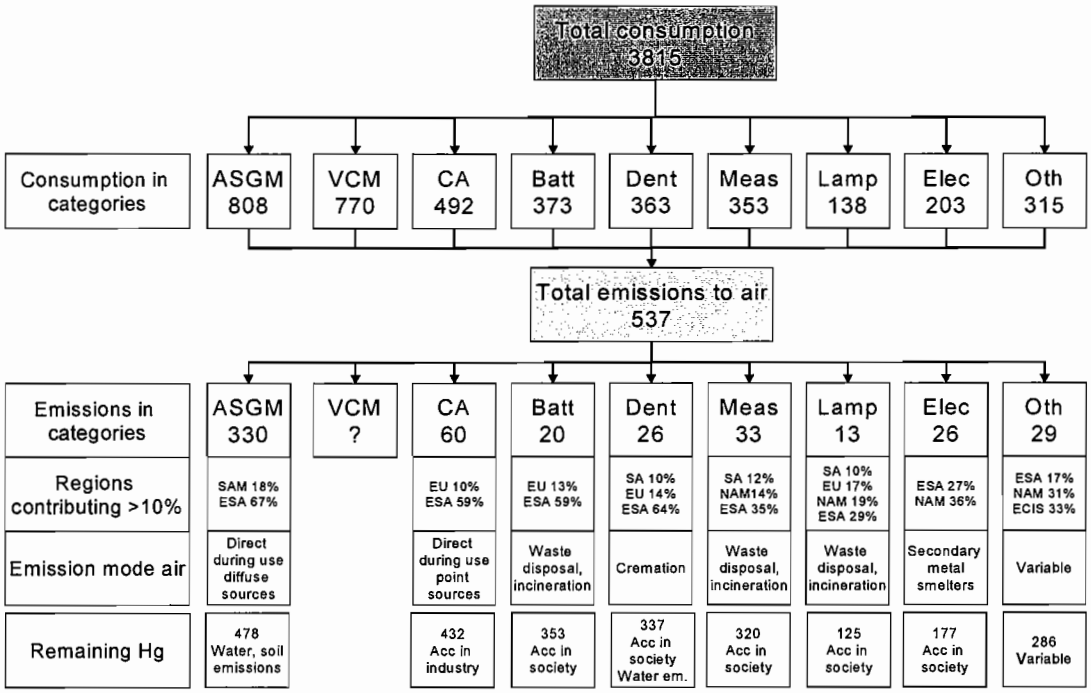
Mercury is intentionally used globally in a variety of industrial applications, products and other applications. Global consumption patterns have recently been assessed in UNEP (2008 – in preparation) where also emissions of mercury from intentional uses were estimated. Intentional uses of mercury were summarised by different geographical regions and by major use category. For purposes of estimating product related emissions, mercury 'consumption' was defined in terms of regional consumption of mercury products rather than overall regional 'demand'. For example, although most measuring and control devices are produced in China (reflected in Chinese 'demand' for mercury), many of them are exported, 'consumed' and disposed of in other countries.

The major mercury applications and intentional use sectors are:

- **Artisanal and small-scale gold mining (ASGM).** The largest global user of mercury, reportedly continues to increase with the upward trend in the price of gold, and is inextricably linked with issues of poverty and human health
- **Production of vinyl chloride monomer (VCM)**, especially in China, is another area of major concern, especially as it is not yet clear where much of the mercury – estimated to be several hundred tonnes – goes as the catalyst is depleted.
- **Chlor-alkali production (CA).** The chlor-alkali industry is the third major mercury user worldwide. The mercury based technology is being phased out in many regions but continues to be used in others.
- **Batteries** The use of mercury in batteries, while still considerable, continues to decline as many nations have implemented restricting policies. Large quantities of batteries with low mercury content are still produced as are button cell batteries, containing up to 2% mercury.
- **Dental applications**. Some countries have implemented measures to greatly reduce the use of dental amalgams containing mercury and dental use of mercury is declining. However, the speed of decline varies widely, so that mercury use is still significant in most countries.
- **Measuring and control devices**. There is a rather wide selection of mercury containing measuring and control devices, including thermometers, barometers, manometers, etc., still manufactured in various parts of the world, although most international suppliers now offer mercury-free alternatives.
- **Lamps.** Mercury containing (fluorescent tubes, compact fluorescent, HID, etc.) lamps remain the standard for energy-efficient lamps, where ongoing industry efforts to reduce the amount of mercury in each lamp are countered, to some extent, by the ever-increasing number of energy-efficient lamps purchased and installed around the world.
- **Electrical and electronic devices**. Due to the RoHS Directive in Europe, and similar initiatives in Japan, China and California, among others, mercury-free substitutes for mercury switches, relays, etc., are being actively encouraged, and mercury consumption has declined substantially in recent years. At the same time, the US-based Interstate Mercury Education and Reduction Clearinghouse (IMERC) database demonstrates that mercury use in these devices remains significant.
- **Other applications of mercury**. This category has traditionally included the use of mercury and mercury compounds in such diverse applications as pesticides, fungicides, laboratory chemicals, in pharmaceuticals, as a preservative in paints, traditional medicine, cultural and ritual uses, cosmetics, etc. However, there are some further applications that have recently come to light in which the consumption of mercury is also especially

significant such as the use of mercury catalysts in the production of polyurethane elastomers and the use of mercury in porosimetry.

In UNEP (2008 – in preparation) emissions of mercury from product categories have been calculated using distribution factors for the mercury consumed in the different products and emission factors to air for releases of mercury from the different paths of the mercury in the products. The general methodology is further described in Kindbom and Munthe (2007). In Figure 1, an overview of intentional mercury consumption and emissions is presented.



Abbreviations
Categories
ASGM: Artisanal and small scale gold mining
VCM: Vinyl chloride monomere production
CA: Chlor alkali production
Batt: Use and disposal of batteries
Dent: Dental amalgam (emissions only related to cremations)
Meas: Measurement and control devices
Lamp: Light sources
Elec: Electronic devices
Oth: Other uses e.g pesticides

Abbreviations
Regions
SAM: South America
SA: South Asia
EU: European Union
ESA: East and southeast Asia
NAM: North America
ECIS: Non EU European countries and CSI

Figure 1. Overview of intentional mercury use and emissions to air. Apart from the consumed and emitted amounts from different categories, information on the main regions where emissions occur, the main emission mode (i.e. source type) and an indication of the fate of the fraction of mercury consumed but not emitted to air ("Remaining Hg"). All figures expressed in tonnes

The overview presented in Fig. 1 provides a guide to the discussion of different management strategies discussed in the following chapters. The main point is that intentional mercury use can result in environmental emissions in various manners.

The costs of reducing Hg emissions is in this project linked to the economic costs of introducing the necessary equipment or introducing other necessary actions to obtain the reduction. In general, the term "cost" is often used when referring to both private cost and social cost, where the social cost is the sum of private- and external costs. When taking into account the social cost, this means that all costs in principle need to be internalised in the product price in order to give products their real price. Who is bearing this cost (the producer or the consumer) is determined by price- and market mechanisms often referred to as "elasticity" by economic theory. The effect of external factors such as pollution controls on production costs may either be absorbed by the producer, or passed on to the consumer, depending on this elasticity of the market

The benefits of reducing the Hg emissions include a spectrum of social, economic, ecological, and human health benefits. For example, mercury exposures through fish consumption (as well as other pathways), ,can cause a range of human health effects including neurological effects, including reductions in IQ (Intelligence Quotient) among children. Dietary methyl-mercury is almost completely absorbed into the blood and distributed to all tissues including the brain; it also readily passes through the placenta to the fetus and fetal brain. One of the measures of benefits is the prevention of IQ loss by reducing exposures. Other benefits to human health could include lower incidence of other types of neurological effects and lower incidence of some types of cardiovascular disease. Ecological benefits include less adverse effects to wildlife, while an economic benefit would be seen from fewer fish consumption advisories with a consequent boost for the recreational and commercial fishing industries. The benefits and costs of fish consumption advisories for mercury were discussed by Jakus et al. (2002).

Critical elements in estimating the cost of methyl-mercury exposure and risk from fish consumption would need to consider the species of fish consumed, the concentrations of methyl-mercury in the fish, the quantity of fish consumed, and how frequently fish is consumed. Those who regularly and frequently consume large amounts of fish -- either marine species that typically have much higher levels of methyl-mercury than the rest of seafood or freshwater fish that have been affected by mercury pollution -- are more highly exposed. Because the developing fetus may be the most sensitive to the effects from methyl-mercury, women of childbearing age are regarded as the population of greatest interest. In the United States, EPA believes that between 1 and 3 percent of women of childbearing age (i.e., between the ages of 15 and 44) eat sufficient amounts of fish to be at risk from methyl-mercury exposure, depending on the methyl-mercury concentrations in the fish. Advisories in the United States have been issued by 39 states and some Tribes.

The societal benefits due to the reduction of damage cost to the society from exposure to Hg pollution (societal cost) on global scale are now being studied within the GLOCBA-SE project (Pacyna et al., 2008 – in preparation). This project uses the results from the EU (European Union) DROPS project (DROPS D5.1 available from Pacyna, 2008). The overall objective of the DROPS project was to provide a full-chain analysis related to impact of health protection measures related to priority pollutants as identified by the EU Environment and Health Action Plan, in order to support the development of cost effective policy measures against pollution related diseases and their wider impacts. Mercury was one of the contaminants studied within the DROPS project. Neurotoxic impacts were found as the main human health end point for mercury. The damage cost data obtained in the DROPS project were estimated for inhalation of Hg polluted air and ingestion of Hg contaminated food, separately. The annual cost of $12,500 per kg of Hg was accepted for the

ingestion pathway. In the case of inhalation, the amount of $1.34 /kg of Hg (the case for Poland) was used for the countries in Asia (except Japan), Eastern Europe, Africa and South America, while $2.21/kg of Hg was used for the rest of the world. These values were used in the GLOCBA-SE project to estimate the total damage cost to the society, defined as the societal cost. This cost is related to IQ loss, through loss of earning, loss of education, and opportunity cost while at school. The social benefits associated with IQ increase were assessed for individual countries in the world taking into account the difference between the damage costs for the scenario with no improvement of Hg emission control (the status quo scenario) and the damage costs for the scenario with improvement of Hg emission control (the extended emission control Scenario. It was concluded that these social benefits can be as high as much as 187 billion US$ during the period from 2005 until 2020.

The benefits of reduced mercury releases can be significantly higher for certain subpopulations that are more likely to be affected by fish contamination (e.g., the Native Americans and Asian Americans whose cultures include larger consumption rates of fish compared to the average American). Also, it is important to keep in mind that the cost per tonne reduction and benefit estimates are strongly correlated with baseline air emissions situations in countries, as well as with source and population information. The U.S. or the European Union estimates cannot be transferred and applied to tonnage reductions in another country given variable baseline mercury levels. The population near coastal regions may be higher, and the fish consumption rate may be higher than in the United States or in the European Union. These factors would lower the cost/tonne estimate and raise the benefits.

The reductions of Hg emissions can be obtained within various economic sectors, generating these emissions. UNEP Governing Council Decision 24/3 IV established an ad hoc open-ended working group (OEWG) of Governments, regional economic integration organisations and stakeholder representatives that will review and assess options for enhanced voluntary measures and new or existing international legal instruments to reduce risks from releases of mercury for each of the priorities set out in GC 24/3 IV, paragraph 19. Decision 24/3 IV also requests UNEP Chemicals, in its service as secretariat for the OEWG, "to prepare the analytical and summary reports necessary for [the OEWG's] work." The first meeting of the OEWG (OEWG-1) took place in Bangkok 12-16 November 2007. OEWG-1 adopted a program of inter-sessional work for the Secretariat, including the elements addressed in this Memorandum.

The main objective of the project UNEP-CBA reported here is to prepare a qualitative assessment of potential costs and benefits associated with each of the strategic objectives set out in Annex 1 of the report of the first meeting of the Open Ended Working Group. It was agreed that this assessment will be general in nature quantifying costs and benefits as small, medium, and large for the following strategic objectives:

- reduce mercury emissions from coal usage,
- reduce mercury emissions from artisanal and small-scale gold mining,
- reduce mercury emissions from industrial processes,
- reduce generation of waste containing mercury,
- reduce emissions to air from incinerators and reduce migration and emission of mercury from landfills
- promote separate collection and treatment of mercury-containing wastes,
- reduce mercury consumption in VCM and chlor-alkali production,
- reduce mercury use in products, incl. Packaging,
- reduce mercury in dental practises
- reduce mercury supply from a hierarchy of sources,

- reduce international trade of mercury and mercury containing products, and
- increase knowledge of and capacity to manage mercury.

The purpose of this report is to provide qualitative assessment of costs and benefits. The costs defined as small, medium and large are related to the highest cost of abatement for a given strategy (emission category).

The benefits are then related to costs. It was assumed in this project that the benefits are large if they exceed the costs by at least a factor of 2. If the benefits are equal or lower than costs, then it was assumed that the benefits are small. Medium benefits are between the large and small benefits.

A recent review of socio-economic consequences of mercury use and pollution is presented in Appendix 1. This review has been published by Swain et al in Ambio, Vol. 36, No. 1 in February 2007 with a co-authorship of Jozef M. Pacyna (Swain et al., 2007). A summary of economic analyses that have been performed on the costs or benefits of reducing mercury emissions or just reducing exposure through fish consumption advisories is presented. This document can be regarded as a major introduction to the reported work.

1 Reduction of mercury emissions from coal usage

1.1 Overall assessment of costs and benefits

Qualitative Cost Assessment: Variable, ranging from small (if used as an incremental approach with other pollution reduction measures) to large.

Qualitative Benefit Assessment: Large emission reduction of mercury, both globally and locally with consequent health benefits; Reductions of other air pollutants.

1.2 Mercury emissions from coal combustion

Based on the latest inventories (particularly in UNEP, 2008 – in preparation), coal combustion is the largest emitting anthropogenic mercury source. The coal fired power sector is among the largest contributors to worldwide mercury emissions.

The Hg content in coal and the type and efficiency of emission control equipment are the most important parameters. The Hg content of coal varies from 0.01 to 1.0 ppm with an average of 0.1 ppm.

Various technologies within the same industry may generate different amounts of atmospheric emissions of mercury. It can be generalized for conventional thermal power plants that the plant design, particularly the burner configuration has an impact on the emission quantities. Wet bottom boilers produce the highest emissions among the coal-fired utility boilers, as they need to operate at the temperature above the ash -melting temperature (Pacyna, 1989).

Non-conventional methods of combustion, such as fluidized bed combustion (FBC) were found to generate comparable or slightly lower emissions of mercury and other trace elements than the conventional power plants (Carpenter, 1979; Abel et al., 1981). However, a long residence time of the bed material may result in increased fine particle production and thus more efficient condensation of gaseous mercury. Tests carried out in the former Federal Republic of Germany have shown that the residence time of the bed material can be regulated by changing the operating conditions of a given plant, the reduction of combustion temperature, coal size, moisture content, and bed flow rates (Munzner and Schilling, 1985). A literature review of information on the influence of various FBC techniques on emissions of trace elements has been presented by Sloss and Smith (2000).

The load of the burner affects the emissions of trace elements including mercury in such a way that for low load and full load the emissions are the largest (Bakkum and Veldt, 1986). For a 50 % load the emission rates can be lower by a factor of two.

1.3 Mercury from combustion of fuels other than coal

Major revision of recent data on the Hg content in crude oil indicates the concentration range from 0.01 to 0.5 ppm. It is expected that mercury concentrations in residual oil are higher than those in distillate oils being produced at an earlier stage in an oil refinery. Natural gas may contain small amounts of mercury, but the element should be removed from the raw gas during the recovery of

liquid constituents, as well as during the removal of hydrogen sulfide. Therefore, it is believed that mercury emissions during natural gas combustion are insignificant.

The influence of plant design or its size on atmospheric emissions of mercury from oil-fired boilers is not as clear as for the coal-fired boilers. Under similar conditions the emission rates for the two major types of oil-fired boilers: tangential and horizontal units are comparable (Pacyna, 1982).

1.4 Mercury abatement measures and their efficiency

1.4.1 Pre-treatment methods of Hg emission control during coal combustion

Fuel washing and fuel substitution are the major pre-treatment measures to reduce emissions of various pollutants from coal combustion processes, including reduction of mercury.

Coal washing

Commercial coal cleaning (or beneficiation) facilities, particularly in the United States (e.g. NAPAP, 1990) are physical cleaning techniques to reduce the mineral matter and pyritic sulfur content. As a result, the product coal has a higher energy density and less variability (compared to feedstock coal) so that power plant efficiency and reliability are improved. A side benefit to these processes is that emissions of sulfur dioxide, as well as other pollutants including mercury can be reduced. The efficiency of this removal depends on the cleaning process used, type of coal, and the contaminant content of coal. Basic physical coal cleaning techniques have been commercial for over 50 years.

The cleaning of coal takes place in water, in a dense medium, or in a dry medium. Physical cleaning processes are based on either the specific gravity or surface property differences between the coal and its impurities. Jigs, concentrating tables, hydrocyclones, and froth flotation cells are common devices used in current physical coal-cleaning facilities.

The mercury concentrations in the raw coal, the clean coal, and the present reduction achieved by cleaning have been presented by Akers et al. (1993) for coals from various regions in the United States. The removal efficiency ranged from 0 to 60 % with 21 % as average reduction. Kraus et al. (2006) indicate that typically 10 to 50 % of the mercury in coal can be removed by in the cleaning process alone. This efficiency is highly dependent on the type of coal.

Fuel switching

The following options of fuel substitution are often considered in the electric utilities:

- switching from high- to low-sulfur coal burnt in applicable coal-based generation (including switching directly from high-sulfur to low-sulfur supplies, blending high- and low-sulfur coal, cleaning high- and medium-sulfur coal, or a combination of cleaning and blending),
- increasing the use of natural gas, or oil, and
- increasing the use of alternate fuels or importing electricity to meet base load electric-generation requirements.

The two latter methods are the most interesting with respect to the reduction of mercury emissions. The substitution of coal by coal-bed methane to produce heat and electricity would result in decrease of emissions of various air pollutants, including mercury. The following action would be needed in the case of the substitution:

- the modernization of existing utility and industrial heat producing plants,
- the development of new methane burning boilers, and
- the modernization of coal mines with respect to the better exploitation of coal-bed methane.

1.4.2 Primary measures to reduce mercury emissions during coal combustion

Primary measures of emission reduction include solutions where emission reduction occurs at emission generation point, e.g. application of various modifications of combustion process may reduce emissions from a given burner.

Non-conventional combustion technologies

Non-conventional methods of combustion, such as fluidized bed combustion (FBC) were found to generate comparable or slightly lower emissions of mercury and other trace elements compared to the conventional power plants (e.g. Carpenter, 1979, Abel et al., 1981). However, a long residence time of the bed material may result in increased fine particle production and thus more efficient condensation of gaseous mercury. Tests carried out in Germany have shown that the residence time of the bed material can be regulated by changing the operating conditions of a given plant, the reduction of combustion temperature, coal size, moisture content, and bed flow rates (Munzner and Schilling, 1985). A literature review of information on the influence of various FBC techniques on emissions of trace metals, including mercury has been presented by Sloss and Smith (2000).

Low NOx burners

Low NO_X technologies are also likely to reduce mercury emission in the exhaust gases due to the lower operating temperatures. Very limited information on this subject is rather inconclusive. While some sources indicate that the reduction can be achieved, preliminary results of staged combustion in atmospheric fluidized bed combustion (AFBC) units indicated that low NO_X had only little effect on trace element emissions (Smith, 1987).

1.4.3 Secondary measures to reduce mercury emissions from coal combustion

Secondary measures include technological solutions to decrease concentrations of mercury in the flue gas leaving the combustion zone.

Mercury enters the atmosphere from coal combustion in a gaseous form. However, de-dusting installations, such as electrostatic precipitators (ESPs) and fabric filters (FFs) can also remove up to 30 % of Hg from exhaust gases. One should note that ESPs are now commonly used abatement measures in major electric power plants and central heating plants worldwide.

The application of flue gas desulfurization (FGD) has a very important impact on removal of not only sulfur dioxide but also mercury. A number of studies have been carried out to assess the extent of this removal and parameters having major impact on this removal. These studies were reviewed in connection with the preparation of the EU Position Paper on Ambient Air Pollution by Mercury (EC, 2004). It was concluded that the relatively low temperatures found in wet scrubber systems allow many of the more volatile trace elements to condense from the vapour phase and thus to be removed from the flue gases. In general, removal efficiency of FGD installations for mercury ranges from 30 to 50%. It was also concluded that the overall removal of mercury in various spray dry systems varies from about 35 to 90%. The highest removal efficiencies are achieved from spray dry systems fitted with downstream fabric filters.

Higher Hg emission control efficiencies, exceeding 95 %, can be obtained through a combination of FGD and ESP's with "add on" type of equipment including sorbent injection. Sorbent injection generically describes the injection of powdered activated carbon (PAC) or other non-carbon sorbents into the flue gas for mercury control, while mercury oxidation enhancements are intended to improve the mercury capture efficiency of conventional control installations or downstream air pollution control devices by converting elemental mercury to a more reactive oxidized state (e.g. Jones et al., 2006)

Selenium scrubber is a wet media process for removal of fairly large quantities of mercury from the flue gas. The gaseous mercury reacts with activated amorphous selenium, which is circulating in a scrubber with a 20.0 to 40.0 % sulfuric acid. The mercury removal efficiency is between 90.0 and 95.0 %.

Carbon filter bed is another dry media process. Carbon filter bed technology is assumed by the U.S. EPA to remove 80 to 90 % of the mercury in the flue gas.

Lead sulfide process has also been recommended for removal of mercury. The flue gas containing mercury passes through a tower packed with lead sulfide coated balls. The removal efficiency of 99.0 % has been measured.

A detailed review of the current and developing mercury technologies and the control effectiveness that can be achieved from these technologies in the U.S. coal-fired power plants has been presented by IEPA (2006). The study has confirmed that depending on several variables, including coal and boiler type, there are a number of control technologies that will achieve 90+ % removal of mercury. Mercury emissions control technology is a rapidly advancing field, with use of halogenated sorbents that are becoming an affordable and effective option for many applications.

1.4.4 Emission control measures suggested for use within the UN ECE LRTAP Convention

An assessment of technological developments and the best available techniques for the implementation of the heavy metal emission reduction Protocol of the UN ECE Convention on Long-range Transboundary Air Pollution (Kraus et al., 2006) has recently been prepared. It was found out that the ESPs or FFs operated in combination with FGD and sorbent injection techniques are capable of removing between 75% and 90 % of mercury from the flue gases in coal-fired power plants in the additional presence of selective catalytic reduction. The following conclusions were reached with regard to the least costly retrofit options for the control of mercury emissions from units with ESP or FF:

- The modification of dry FGD systems by the use of appropriate sorbents for the capture of mercury and other air toxics is considered to be the easiest retrofit problem to solve;
- Injection of a sorbent upstream of the ESP or FF. Cooling of the stack gas or modifications to the ducting may be needed to keep sorbent requirements at acceptable levels;
- Injection of a sorbent between the ESP and a pulse-jet FF retrofitted downstream of the ESP. This approach will increase capital costs but reduce sorbent costs;
- Installation of a semi-dray circulating fluidized-bed absorber (CFA) upstream of an existing ESP used in conjunction with sorbent injection. It is believed that CFAs can

potentially control mercury emissions at lower costs than those associated with the use of spray dryers.

1.5 Cost of mercury abatement

1.5.1 Incremental cost of Hg abatement

The incremental cost of mercury reduction, i.e. the cost (in US$/kg Hg removed) to achieve a specific reduction is impacted largely by the level of baseline mercury capture exhibited by the existing air pollution control devices (APCD) configuration and coal mercury content. For example, the incremental cost of mercury control will increase when: (1) baseline mercury capture by existing APCD is high; or (2) the coal mercury content is low, because a smaller quantity of mercury is removed from the flue gas for a given level of control. In terms of raw monetary cost, reducing mercury from coal combustion can be quite expensive. The incremental cost of Hg emission reduction varies substantially depending on factors such as the type of coal used, the type of combustion unit, the type of control devices already in place to control other pollutants, the facility configuration, and the percent reductions expected. For example, wet scrubbers installed primarily for mercury have been estimated to cost between US$76,000 and US$174,000 per pound of mercury removed (or between US$168,000 and US$384,000 per kg of mercury removed). This result is very close to the cost of $234,000 per kg of mercury removed, estimated and used in a study of the effectiveness of the UN ECE heavy metals (HM) Protocol and cost of additional measures (Visschedijk et al., 2006).

Some years ago, the U.S. Environmental Protection Agency (EPA) had estimated that it would cost between US$67,700 and US$70,000 per pound (or between US$149,300 and US$154,000 per kg) to achieve a 90 percent control level using sorbent injection (US EPA, 2005). Since 1997, Research, Development and Demonstration activities sponsored by the Department of Energy (DOE), vendors and utilities relating to sorbent injection for mercury removal have shown significant advances along with the potential for reductions in overall installation and operational costs. More information on the cost estimates is available from the DOE/NETL's Phase II Mercury Control Technology Field Testing Program (Jones et al. 2006), particularly with regard to the economic analysis of activated carbon injection method. This analysis was conducted on a plant-specific basis, meaning that the economics are dependent on the actual power plant operating conditions and coal properties observed during full scale field testing at each of the power plants taking part in the Program. Mercury control through activated carbon control was analysed. The 20-year levelized incremental cost of mercury control was found to vary from about US$ 8,400/kg Hg removed to about US$365,000/kg Hg removed.

1.5.2 Hg emission reduction as a co-benefit of reduction of emission of conventional pollutants

At present, it is uncommon for countries to invest in technologies to reduce only mercury from the emissions stream. Instead, countries usually use a multi-pollutant approach, which is much more cost effective. For example, approaches and technologies for controlling conventional air pollutants, including particulate matter, SO_2, and NO_x, typically result in some reduction of mercury emissions as a co-benefit, as mentioned earlier in this chapter. In most countries, mercury controls are contingent upon controls for conventional pollutants, although the degree of the mercury capture by various technologies varies widely. In this context, the incremental cost of adding a mercury reduction effort to a national strategy is much smaller.

Major review of information on the costs of abatement for combustion of coal and other economic sectors was carried out within the EU ESPREME (http://espreme.ier.uni-stuttgart.de) and DROPS (http://drops.nilu.no) projects. The annualized investment and operational costs for installations that are used to remove mercury, including ESPs, FFs, FGD, and "add on" measures just for mercury removal are presented in Table 1. These costs are given in relation to the production of 1 MWhe electricity in utility and large industrial boilers. The information on efficiency of Hg removal using these installations is also included in Table 1.

Table 1: Abatement cost for installations used to reduce Hg emissions from coal combustion processes (in US$/ MWhe) – selected technologies from the EU ESPREME project database (http://espreme.ier.uni-stuttgart.de)

Sector	Emission control technology	Hg reduction (%)	Annual costs (US$ 2008/MWhe)		
			Annual investment costs	Annual operating costs	Annual total costs
Hard and brown coal combustion	dry electrostatic precipitator (ESP) – medium emission control efficiency	24	0,45	0,90	1,35
	fabric filters (FF) – medium emission control efficiency	20	0,46	1,47	1,93
	dry ESP – retrofitted from medium to high control efficiency	32	0,92	0,52	1,44
	FF+wet or dry scrubbers+sorbent injection – state-of-the-art (BAT)	98	0,72	1,80	2,52
	dry ESP + wet or dry scrubber + dry injection --- state-of-the-art	98	2,73	2,40	5,13
	electro-catalytic oxidation – emerging method	80	8,55	11,76	20,31
	Integrated gasification combined cycle (IGCC) – emerging method	90			20,00

1.5.3 Examples of abatement cost estimates

The abatement cost, associated with the reduction of Hg emissions from coal combustion estimated in the 2020 SQ scenario to the emission level estimated in the 2020 EXEC scenario has been estimated by Pacyna et al. (2008 – in preparation) . This cost was estimated using the information on a difference between emissions in these two scenarios in the year 2020 for each country. The emission difference was then multiplied by the cost of 1 kg of Hg reduction being $234, 000.00. As a result it was estimated that as much as US$ 135 billion will be needed to meet the targets of the 2020 EXEC emission scenario for the coal combustion sector. This estimate should be regarded with caution. It was assumed that the cost of Hg emission reduction will not change significantly (within the accuracy limit being about 50 %) between 2005 and 2020. No discount or inflation rate was taken into account, which makes the estimated costs higher than expected otherwise. The operational cost was estimated in the basis of information from Europe. As personnel cost can be substantially higher in Europe than in other parts of the world, the cost rate used in the report can be lower at least in Asia, Africa, and South America. It can be concluded that overall costs for a country to implement a mercury reduction program will vary greatly.

In the United States, EPA promulgated a regulation in 2005 to reduce criteria air pollutant emissions from power plants, the Clean Air Interstate Rule (CAIR). The U.S. EPA calculated the estimated costs and some of the benefits of that regulation. The CAIR rule is primarily aimed at reducing emissions of SOx and NOx from large coal-fired power plants, but as a co-benefit will result in reductions of mercury emissions. The CAIR rule will achieve the majority of its mercury reductions as a co-benefit from controls for SO_2. Applying SO_2 controls (or other multi-pollutant approaches) are more cost-effective at reducing mercury than direct mercury control. EPA also promulgated the Clean Air Mercury Rule (CAMR) which was targeted to specifically further

reduce mercury emissions from coal-fired power plants. The co-benefits of CAIR were estimated to reduce mercury emissions to 34.5 metric tonnes in 2010; the specific requirements of CAMR were estimated to further reduce mercury emissions to 13.6 tonnes by 2020. This could cost the U.S. electric power industry about US$ 11.3 billion

1.6 Benefits of Hg emission abatement

Information on the benefits and costs of reduction of mercury emissions from the coal combustion was recently reviewed by NESCAUM (2005). The NESCAUM study describes the results of a comprehensive assessment of the health benefits of reducing mercury emissions from coal-fired power stations in the United States. It has been anticipated that reductions in mercury emissions from coal-fired power plants decrease methyl-mercury concentrations in fish. A model has been developed assuming that equilibrium currently exists between deposited mercury and fish methyl-mercury concentrations and between fish methyl-mercury concentrations and methyl-mercury exposures to individuals who consume these fish. Changes in the quantity of mercury deposited are assumed to lead to leaner and proportional changes in fish methyl-mercury concentrations, assuming that no other factors change. The model accounts for human exposure through commercially and non-commercially harvested fish. Two potential health effects were accounted: cognitive abilities and cardiovascular events. The results from epidemiological studies were used to develop association between methyl-mercury exposures in males and increased risks of myocardial infarction and premature mortality. Using a Willingness-to-Pay (WTP) approach it has been estimated that the value of premature fatality is approximately US$ 6.0 million (in 2000 US$) but it was indicated that this value should be taken with caution. The NESCAUM study (2005) also described the possible benefits of the U.S. power plant mercury emission controls in terms of IQ increases in the annual birth cohorts. The predicted annual benefit associated with IQ increases in the annual birth cohort ranged from US$ 75 million to US$ 288 million, estimated within two scenarios related to different emission projection in the U.S. power plants.

The societal benefits related to the Hg emission on global scale were estimated in by Pacyna et al. (2008-in preparation). These benefits were estimated as a difference between the damage costs estimated for the SQ scenario of emission reductions and the EXEC scenario. The two thirds of the societal costs due to Hg pollution are associated with the societal costs due to the Hg pollution of the environment by emissions from coal combustion. It should be noted, however, that only anthropogenic sources where mercury is emitted as a by-product were considered (e.g. no analysis for product use of mercury or artisanal gold mining). On annual basis, the social benefits associated with the IQ change due to Hg emission reductions from coal combustion worldwide were estimated to more than $9 billion. The U.S. benefits due to reduction of Hg were estimated to about $900 million US annually with about 50 % of this value assigned to benefits related to Hg emission from coal combustion. This value is comparable to the above mentioned NESCAUM (2005) estimates for the U.S. coal-fired power plants.

1.7 Summary of cost and benefits for coal combustion

An attempt was made to present the information on types and efficiency of emission reduction technologies for Hg in the coal combustion sector together with the investment and operational costs of these technologies and compared it with societal benefits due to the implementation of these technologies in the year 2020. The information needed for this comparison is presented in this chapter of the report. The results are presented in Table 2.

Table 2: Abatement costs and benefits in the year 2020 due to the reduction of Hg emissions from coal combustion using various emission control technologies, relative to the status quo scenario of pollution.

Efficiency of Hg emission reduction, %	**Abatement cost US$/g Hg abated**	**Societal benefits US$/g Hg abated**
0 - 30 (ESPs or FFs)	100	100
30 - 50 (ESPs or FFs + FGD)	190	320
50 - 99+ (ESPs or FFs + FGD + sorbent injection)	260	540

The benefits were estimated as the difference between the damage costs estimated for the SQ scenario of Hg emissions in the year 2020 (employment of ESPs or FFs only) and respectively the EXEC 2020 emission scenario (application of ESPs or FFs + FGD) and the MFTR 2020 emission scenario (application of ESPs or FFs + FGD + sorbent injection). The damage cost to the society due to exposure to Hg pollution (societal cost) was estimated on the basis of data available from the EU DROPS project (DROPS D5.1 available from Pacyna, 2008). These cost data were obtained in the DROPS project for inhalation of Hg polluted air and ingestion of Hg contaminated food, separately. The cost of $12,500.00 per 1 kg of Hg was accepted for the ingestion pathway.

Only neurotoxic impacts through the IQ loss were considered as the main human health end point for mercury. The total damage cost to the society, defined here as the societal cost, is related to IQ loss, through loss of earning, loss of education, and opportunity cost while at school.

The investment and operational costs were estimated using 1% discount rate. The comparison in Table 2 indicates that reduction of Hg emissions from coal combustion will result in benefits significantly higher than the cost of abatement. These benefits will be higher when the benefits other than the improvement of IQ are added.

2 Reduction of mercury emissions from artisanal and small-scale gold mining

2.1 Overall assessment of costs and benefits

There are a wide range of measures available within artisanal and small scale gold mining (ASGM) to reduce mercury emissions. An overview of the results is therefore presented after the overall assessments for costs and benefits of reduced emissions from ASGM.

Qualitative Cost Assessment: Variable, ranging from small to large.

There are several technical options available for the ASGM. The cost assessments of these measures are linked to the number of individuals affected by the option and the technical requirements of the options. Mercury vapour capture in gold shops is related to small costs thanks to the relatively small amount of gold shops and their immobility. The use of retorts in the mining process is related to medium costs since it affects a larger group of miners and requires educational efforts. To encourage mercury free sluice options is related to medium costs due to the technical requirement of the option.

Market mechanisms such as a decrease in gold prices or increase in mercury prices are associated with large costs since they will affect the economic situation for the miners. Micro credits given to miners that convert their mining activities into mercury free practices (where possible) may result in small costs overall as the credit is paid back.

Other mechanisms such as education of best practice and conversion to other livelihoods may incur large costs since they require much greater institutional efforts.

Qualitative Benefit Assessment: Variable, ranging from small to large

The benefit assessments of technical solutions are linked to the number of individuals affected by the option and whether the solution enables mercury free mining or not. Mercury vapour capture in gold shops is related to medium benefits since there is a large potential for mercury capture, from a relatively limit amount of emission sources. The use of retorts in the mining process has the potential to produce large benefits if broadly utilised, however the use of retorts has been related to small benefits since the adaptations are smaller in size and variable in quality. Retort use relies on individual mining communities being committed to reducing mercury emissions. The benefit from mercury free sluice solutions are related to large benefits since no mercury is required, although this benefit estimate may be reduced by mining situations where it is not feasible to use mercury free sluice solutions.

Market mechanisms such as decreases in gold prices or increases in mercury prices are estimated as giving small benefits since the price difference between gold and mercury is very large. This price difference reduces the motivation to altered mining technologies or reduced mining activities. Micro credits provided to facilitate the move to mercury-free technology may be related to large benefits since they would help in phasing out mercury use, however this may not be universally feasible.

Education is related to small benefits on a global scale since education in itself seems to need to be linked to other options and market mechanisms in order to be effective. It is difficult to quantify the

effects of education on community groups, where increased awareness of the hazards of mercury may result in more significant behaviour changes. Conversion to other livelihoods for miners is related to small benefits since other potential miners are likely to take the place of the miners moving to other sources of livelihood.

For all the measures aimed at abating the release of mercury from ASGM activities, the benefits are both local and global in their nature. In relation to other type of emission sources, the benefits from reducing mercury use and release in ASGM has a stronger emphasis on local benefits due to the reduction of high direct exposure to mercury air emissions and water pollution affecting the miners and the local population.

An overview of the cost-benefit of strategies to reduce mercury emissions is presented in Table 3.

Table 3: Overview of the cost-benefit of strategies to reduce mercury emissions

Strategy	*Preliminary Qualitative Cost Assessment*	*Preliminary Qualitative Benefit Assessment*
Technological solutions		
- Mercury vapour capture in gold shops	SMALL	MEDIUM
- Retort use in mining	MEDIUM	SMALL
- Sluice solutions	MEDIUM	LARGE
Market Mechanisms		
- decrease in gold price	LARGE	SMALL
- increase in mercury price	LARGE	SMALL
- micro credit to clean technologies	SMALL*	LARGE*
Other mechanisms		
- Education	LARGE	SMALL
- Conversion to other livelihoods	LARGE	SMALL

* No evaluated experiences on ASGM, but pilot studies are performed

2.2 Small Scale Gold Mining as a source of Hg emissions

The demand for mercury in Small Scale and Artisanal Gold Mining (ASGM) was for the year 2005 estimated to 1000 ton. The major part (650 to 1000 tons) of these 1000 tons is not recycled but rather released via gold mining processes to air and water, thereby causing adverse environmental effects and effects on human health. The environmental and human health effects are more of a local nature in relation to other types of mercury emissions, given the large impact on the gold miners, the local population and their local environment. Mercury pollution from ASGM cause global pollution effects due to the emissions to air from combustion of mercury in the gold mining process, but what is characteristic for ASGM (in contrast to other mercury emission sources) is the high local human exposure of highly concentrated mercury vapour in air and mercury residual in water. This extreme exposure is related to a number of medical conditions not common for other types of "more controlled" mercury emissions. Emissions from ASGM are responsible for approximately one third of all anthropogenic mercury emissions globally. ASGM involves some 10 to 15 million miners and produces roughly 20 to 30 % (500 - 800 tonnes per year) of the global gold production (Telmer 2007).

2.3 Hg abatement efficiency and costs

There are a number of technologies available to reduce the use or release of Hg associated with ASGM. The use of mercury vapour capture technologies in gold shops is estimated as rather efficient since it involves relatively large scale operations and allows for increased income for the users of the technology. The estimated costs are relatively low. A quick estimate is a cost less than US$ 19 / kg reduced mercury emission (not considering education or disposal costs). Telmer (2008) indicate that the installation of vapour capture equipment in a gold shop would cost US$ 35 and capture 90 % of the mercury vapour.

The use of Hg retorts by miners is based on information and education and there are a vast number of miners in need of education, so the use of retorts is estimated as costly, although the unit cost of each retort is low. The efficiency of the measure depends on the application of the retorts.

The use of some sluices can be advocated since experiments indicate a relatively high efficiency in recovering gold (Hylander et al. 2007) under certain circumstances. It is also a mercury free alternative, which further increases the efficiency. The costs associated with using the studied slurry techniques are stated as being more cost efficient than using mercury amalgamation techniques (Hylander 2007). However, investments will be required and the time preferences of local miners will have to be prolonged.

There are other more technology independent options that could decrease the Hg emissions from ASGM. A decrease in gold prices could result in a reduction in gold mining and Hg use. Given a recent price relation between gold and mercury of 1:1000 (ranging between 1:1650 to 1:125, Telmer 2008), it is quite plausible that it would require an extremely large reduction in gold price before gold production via ASGM technologies would become less profitable than alternative income sources for the community. Furthermore, if there were to be a large decrease in gold price, many poor populations would become even poorer.

If the prices for mercury were to increase, the demand should correspondingly decrease. Veiga and Baker (2004) indicate that mercury constitutes 1 - 30 % of the gold production costs for ASGM using mercury amalgamation techniques. All in all, although mercury is very cheap compared to the price of gold, the literature and experience supports that high mercury prices results in reduced mercury losses from ASGM. UNEP (2004) and Hylander (2007), for example, indicate a large demand effect of high mercury prices.

Micro credits have proven themselves as very effective as a tool to reduce poverty in other circumstances in the world (Yunus 2006, Grameen Bank). What this instrument would provide with respect to ASGM is the opportunity to the gold miners to increase their long term thinking when engaging in gold mining. Furthermore, given that this is a loan, implementation costs can be reduced as loans are repaid.

Education has been indicated as inefficient if not followed by increasing mercury prices (EC DG-ENV 2006). However, education of some sort will be needed for the application of any technology or other measure since the current market conditions for miners still encourage the use of mercury amalgamation. Using previous experiences, an estimate is that US$ ~1000 million would be needed to educate 10 million miners in the use of retorts. Mercury would still be used by these miners, although the emissions would be lower.

Conversion to other livelihoods for miners is most likely a very ineffective abatement option. To convert the livelihood of miners will have almost zero benefit since potential miners can fill the gap as long as there are high profits to be made and few alternative occupations in the regions where ASGM take place. A comparison using African conditions indicates that 42 % of the people in sub-Saharan Africa have earnings below US$ 1 / day, while miners earn US$ 3 - 15 per day. Similar estimates can be seen in many parts of the world (Handelsman and Veiga 2006).

2.4 Benefits of Hg emission abatement

Mercury vapour capture technology in gold shops is a relatively potent abatement solution both since the vapour can be condensed and re-sold as mercury and also since the solution is oriented towards the relatively large scale gold shops (large scale as in contrast to single person miners). Some 90 % of the emissions from gold shops can be reduced by this technology.

The reduced emissions from using retorts are uncertain and depend on local conditions.

In a 2-year project community mining groups have been trained and are purchasing and using retorts, each of which costs about $5 when purchased in bulk. 500 miners have been trained and to date, upwards of 80 percent, as self-reported by the miners, are using the retorts. A retort has a maximum potential of capturing 90 % of the mercury vapour A rough estimate, assuming that 10 million miners are using 1000 tonnes of Hg (10 kg / person year) indicates that mercury use could be reduced by around 7 kg mercury per person per year. The costs following this effort are constituted of US$ 5 per retort and US$ 100 per person for education (based on EU experience cited above), which gives a final rough estimate of US$ 15 / kg mercury captured in the retorts during the first year of use. The duration of the training efforts, the retort efficiency and the lifetime of the retort are central parameters for the cost estimates. The costs of training ($100 per person) could be averaged over five years, provided miners were continuing to use the same types of retorts, leading to an approximate cost of $3/kg mercury per year for those five years.

The use of modern sluices is the one of the technologies that is mercury-free. The use of mercury-free technology is more efficient than reducing emissions from mercury, which is the reason to why the benefit estimate is estimated as higher than other ASGM technologies where mercury is used but the emissions are reduced.

Given a recent price relation between gold and mercury of 1:1000, it would require an extremely large price reduction in gold before gold production via ASGM technologies would become less profitable than alternative income sources for the community. What would happen however is that the disposable income would become even smaller for the miners and their community. If the prices of mercury where to increase, the income would become smaller for the miners, resulting in a poorer financial situation.

The implementation of suitably designed micro credits could encourage the use of mercury-free technologies which increases the potential benefit of this abatement option, since no use of mercury has a higher benefit than control of mercury emissions via technical solutions.

Education has been indicated as inefficient if not followed by increasing mercury prices (EC DG-ENV 2006). The benefit estimate is very uncertain and variable, given that almost all of the above mentioned abatement options will require some sort of education to introduce the option. For

education efforts aimed at increased awareness and not specified towards any specific abatement option, the benefit estimate is therefore considered as small.

Conversion to other livelihoods for miners can be efficient for the miners considered for this action and their relatives. If other miners will fill the gap of the miners that have been converted into other occupations, this option will have zero effect on the mercury emissions. Given the potential profit to be made from ASGM, this dynamic seems very likely.

3 Reduction of mercury emissions from international trade

3.1 Overall assessment of costs and benefits

The potential effect on costs and benefits are presented for three cases; trade ban from EU; Seller-specified end-use restrictions; and disposal costs mandated via trade restrictions.

Qualitative Cost Assessment: Variable, ranging from small to large.

An export ban from the European Union is estimated as causing small costs since the total economic value of the ~800 tonnes mercury currently traded from EU corresponds to a relatively small economic value. Likewise, the cost estimate for end-use restrictions is small. These costs estimates do not include transactional costs, but an uncertain estimate of corresponding transactional costs indicates that these would constitute ~10% of the disposal costs.

Qualitative Benefit Assessment: Variable, ranging from small to large

An export ban from the European Union is estimated as having medium but variable benefits since reduced export from the European Union will result in reduced end use of mercury. The reduced use will be counteracted to some extent by increased production elsewhere. End-use restrictions are estimated as having medium benefits since they are focused on mercury uses with the worst environmental performance (ASGM).

Table 4 below presents a summary of available cost estimate for different final disposal solutions.

Table 4: Cost estimates for various disposal solutions. Information compiled from EC DG-ENV (2006a) and EC (2006)

Literature Source	Cost estimate	Estimate source
EC DG-ENV (2006)		
- Deep bedrock respitory	~US$ 220 / Hg / year	(SEPA)
- Permanent storage	~US$ 150 / tonne Hg / year	(SRIC)
- Surface storage	~US$ 300 / tonne Hg / year	(US DNSC)
- Disposal in monofill	~US$ 7 000 - 19 000 / tonne Hg / year	(SAIC)
EC (2006a)		
- Costs of storage	~US$ 300 / tonne Hg / year	

It can be seen that the cost estimates linked to disposal in mono-fills represents an outlier in the cost estimates for final disposal, and these results should be considered with some caution.

3.2 International trade as a source of Hg emissions

EC DG-ENV (2006) gives estimates on the direct costs for final storage of mercury that will be a result of the export ban from the European Union. These estimates are given in the Table 5 below.

Table 5: Estimates of cost for final storage of Hg due to export ban from the EU

EU chlor-alkali industry		
Years	2005 – 2010	2011 - 2015
Amount of Hg available	494 t/y to be sold	582 t/y to be stored
Income/costs of storage per tonne	US$ 10 / kg sold	US$ 306 /tonne /year
Total yearly income / cost	US$ 4,9 million / year	~ - US$ 180 000 / year

source: EC DG-ENV 2006

For our CBA purposes, the costs for the mercury producers of restricting trade are in principal made up out of two parts; foregone profits and costs of disposal. From a socioeconomic perspective however, the costs are only based upon the costs of disposal. The foregone profits are excluded from the socioeconomic costs estimates since they constitute restructuring costs. The economy will restructure from mercury trade into production and trade of a suitable substitute. The foregone profits will negatively affect chlor-alkali plants for example, but the foregone profits of the chlor-alkali industry induce increased profits in some other industry and are thereby offset. In this context, it should be mentioned that mercury trade is currently not a major source of income for any firm based in the EU (EC DG-ENV 2006).

It can be seen from Table 5 that the export ban will induce disposal costs corresponding to US$ 0.30 / kg per year for Europe. If putting these costs in comparison to the benefit estimates from the ESPREME study (Friedrich 2008), which presents external cost estimates of mercury to some US$ 12 500 / kg mercury emitted the net-benefit indicated is very large, ~ US$ 12 500 / kg. The benefit/cost ratio would equal 40 000, a very high number. However, the disposal costs are only related to the mercury stored and not to actual emissions to the environment so the comparison is not directly relevant.

In 2005, the global supply of mercury was 3690 tonnes (incl. 400 tonne from mercury stocks); the global demand was 3439 tonnes. For EU-25 the supply was 625 tonnes (incl. 0 tonne stock) and demand was 440 tonnes. For 2004, the import / export flows of 'elemental' mercury to and from EU-25 were 723 tonnes (US$ 3 615 000 - US$ 10 845 000) imported and 824 tonnes (US$ 4 120 000 - US$ 12 360 000) exported. The international market price for mercury has ranged between 5 and 15 US$ / kg mercury. The export flows from EU-25 were much smaller in 2004 (824 tonnes) than earlier (1658 tonnes in 2002, 1110 tonnes in 2003) due to new requirements on end-user specification from one of the main exporters of mercury. This requirement was installed to avoid exported mercury being used in ASGM in developing countries. The global trade patterns for 2004 are presented in Figure 2 below (EC DG-ENV 2006)

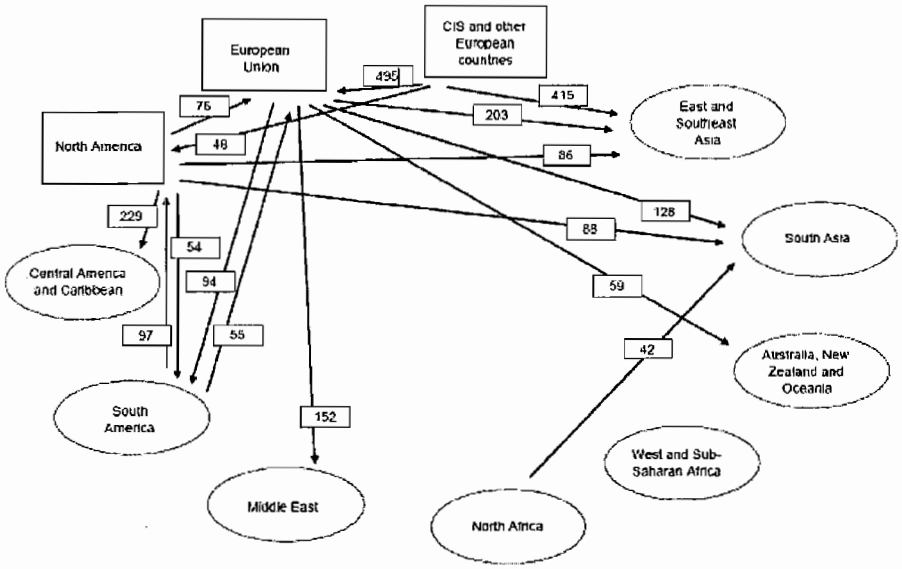


Figure 2: Global trade patterns for 2004 (EC DG-ENV 2006)

The countries, such as Spain, Netherlands, USA, United Kingdom, Germany, Belgium and Australia together exported more than 1325 tonnes of mercury to other than EU-25 in 2003 (EC DG-ENV 2006).

3.3 Hg abatement efficiency and costs

When the EU introduces a mercury export ban (scheduled to be adopted in September 2008 and enter into effect 15 March 2011) there will be an income loss corresponding to $6.25 million / year for specific European firms and disposal costs corresponding to $ 0.16 million /year. The income losses will be offset by income increases in other firms. Other costs would include restructuring costs for firms. Globally there is a potential mercury price increase, but this can be counteracted by the availability of substitutes for mercury and increased domestic production of mercury. However, the net trade and global supply of mercury should be reduced. As an additional remark, EC (2006) estimates that a trade ban will have a neutral economic impact on the current traders of mercury in the EU.

User restriction is a voluntary way used within the EU to avoid traded mercury ending up in e.g. small scale artisanal gold mining, which is usually the case with mercury exported from the EU (EC 2006). One of the major traders in the EU, MAYASA, decided in 2004 to restrict export to avoid exported mercury being used in ASGM in developing countries. The means used for enforcing this restriction is not specified (EC DG-ENV 2006). User restrictions involve a potential mercury price increase, but this can be counteracted by the availability of substitutes for mercury and increased domestic production of mercury. However, the net trade and global supply of mercury should be reduced due to the increased use of substitutes and increase in mercury prices.

Administrative costs related to a trade ban and disposal are very difficult to estimate, but estimates from EC (2006) indicate some 3 - 12 % of the disposal costs, or US$ 0.78 - 5 million for a ten year period.

This section has only addressed the impact of a ban on export by the EU, and only addressed direct costs involved in storage.

3.4 Benefits of Hg emission abatement

The benefit of an export ban is estimated as medium since the European Union currently supplies almost 1/4 of the global mercury traded globally, which indicates a large impact from an export ban. The benefit is also considered as medium since an export ban will reduce final use, which has a larger effect than reducing emissions and leakage from final use. The benefits are considered as variable since it is difficult to divine which trade flows that will be reduced and the environmental impacts vary over regions.

The total amount of mercury not traded according to the example on end-use restrictions in EC DG-ENV (2006) reduced the amount of export from EU by 30 %. The benefit can be large since they occur in hot spots where the negative impacts are very large from using mercury.

The impact of the expansion of such export limitations globally has not been further investigated.

4 Reduction of mercury from emissions from industrial processes, including use as a catalyst, by-production, contamination of component materials, and heat production

4.1 Overall assessment of costs and benefits

Qualitative Cost Assessment: Medium to Large
Cost Categories: Capital costs, operating costs

Qualitative Benefit Assessment: Medium to Large mercury emission reduction both globally and locally.

4.2 Industrial processes as a source of Hg emissions

Industrial processes contribute about 25 % to the total emissions of anthropogenic mercury to the atmosphere.

Emissions from non-ferrous and ferrous metal industry are estimated to contribute about 10 % to the total emissions. With regard to the Hg emissions from non-ferrous metal production, their amounts depend mainly on: 1) the content of Hg in non-ferrous metal ores used mostly in primary processes or scrap used in secondary non-ferrous production, 2) the type of industrial technology employed in the production of non-ferrous metals, and 3) the type and efficiency of emission control installations.

The content of Hg in ores varies substantially from one ore field to another (e.g. Pacyna, 1986, UN ECE, 2000) as does the Hg content in scrap. The Hg emissions from primary production using ores in non-ferrous smelters are between one and two orders of magnitude higher that the Hg emissions from secondary smelters with scrap as the main raw material, depending on the country. Pyro-metallurgical processes in primary production of non-ferrous metals, employing high temperature roasting and thermal smelting emit Hg and other raw material impurities mostly to the atmosphere. Non-ferrous metal production with electrolytic extraction is responsible more for risks of water contamination.

Major thermal non-ferrous metal smelters in developed countries employ ESPs and FGDs, working with efficiencies comparable with those for noted for energy production. This information has been obtained by the authors of the report (Pacyna et al. 2001) from:
- Cominco Ltd in Canada,
- Hudson Bay Mining and Smelting Co. Limited in Canada,
- Kennecott Utah Copper Corporation in the United States,
- Huttenwerke Kayser AG in Germany,
- Berzelius Metall GmbH in Germany,
- Norddeutsche Affinerie in Germany, and
- Metaleurop Weser Blei GmbH in Germany.

More details on individual non-ferrous metal works are available from metal Bulletin Books (see also www.icmm.com).

Among various steel making technologies the electric arc (EA) process produces the largest amounts of trace elements and their emission factors are about one order of magnitude higher than those for other techniques, e.g., basic oxygen (BO) and open hearth (OH) processes. The EA

furnaces are used primarily to produce special alloy steels or to melt large amounts of scrap for the reuse. The scrap which often contains trace elements, and on some occasions mercury, is processed in electric furnaces at very high temperatures resulting in volatilization of trace elements. This process is similar from the point of view of emission generation to the combustion of coal in power plants. Much less scrap is used in other furnaces, where mostly pig iron (molten blast-furnace metal) is charged. It should be noted, however, that the major source of atmospheric mercury related to the iron and steel industry is the production of metallurgical coke.

The primary sources of mercury emissions from portland cement manufacturing contribute with about 9 % to the total anthropogenic emissions of this element. These emissions are generated in the kiln and preheating/pre-calcining operations. The kiln operations consist of pyro-processing (thermal treatment) of raw materials which are transformed into clinkers. Raw material processing differs somewhat for the wet and dry processes. Mercury is introduced into the kiln with fuels such as coal and oil which are used to provide energy for calcination and sintering. Other fuels, such as shredded municipal garbage, chipped rubber, petroleum coke, and waste solvents are also being used frequently.

Occasionally, building companies mix cement with fly ash from coal combustion in proportion about 3:1 in order to produce concrete. Fly ash may contain mercury through the condensation of gaseous mercury on fine fly ash particles in the flue gas before the collection of fly ash on de-dusting devices, such as ESPs or FFs (Pacyna, 1980). However, it is difficult to assess how much of mercury enters the environment through this pathway.

Heat is produced in large and medium size central heating plants, as a co-generation product in large electric power stations, industrial boilers and small residential and commercial furnaces. Large industrial plants generate their own electric power or process steam. The process of generation of emissions of Hg from these plants is similar to the one for emissions from coal and oil combustion in electric utility plants, discussed in Chapter 2 in this report. Similar are also installations to control these emissions. The main difference is brought by the type of boiler employed, which is often stoker-type boiler. The pulverized and cyclone boiler units are generally associated with larger industrial complexes and are similar in design to those used in electric utilities.

Commercial and residential furnaces are mainly used for space heating. Small stoker-type boilers and hand-fired units are still used in many regions of the world. Emission control equipment is not generally used in these small furnaces.

4.3 Hg abatement efficiency and costs

Large non-ferrous smelters use high efficiency air pollution control devices to control particle and sulfur dioxide emissions from roasters, smelting furnaces, and convertors (e.g. Pacyna et al., 1981; Pacyna et al., 2001). ESPs are the most commonly used devices for removal of particles. Control of sulfur dioxide emissions is achieved by absorption to sulfuric acid in the sulfuric acid plants, which are commonly a part of the smelting plants. Mercury is emitted mostly in a gaseous form and therefore, the ESPs are not very effective in the element removal. The element does not end up in sulfuric acid plants and is instead emitted to the atmosphere from the smelter stacks. The amount of these emissions depends on the content of mercury in the ore. This content varies substantially from one ore field to another. Only limited information has been gathered on mercury emission rates from non-ferrous smelters by the U.S.EPA (1993).

Mercury can be emitted to the atmosphere during the production of metallurgical coke, which is used in iron and steel industry. ESPs or FFs and less frequently wet scrubbers are used in the coke production plants to control emissions, particularly those generated during quenching. This process is performed to cool down the coke and to prevent complete combustion of the coke upon exposure to air. Although no data are available for the performance of the ESPs or FFs in coke production plants it is expected that mercury removal is limited (U.S.EPA, 1993).

The U.S. EPA has some experience with quantifying the costs and benefits of reducing mercury emissions from various industrial sources. One such industry is secondary steel production. This category is a significant source of mercury air emissions largely because mercury-containing switches are in the scrap metal (such as cars) used to make steel. In the United States, a program was established in 2006 called the National Vehicle Mercury Switch Recovery Program (NVMSRP). The NVMSRP, along with a few state mercury switch programs, will reduce mercury emissions by about 34 tonnes over the next 15 years, which represents the mercury content in approximately 61 million switches. The program is designed to remove mercury-containing switches from scrap vehicles before they are recycled in secondary steel mills, therefore preventing mercury emissions At this time, the precise cost-effectiveness of this program is unknown, although components of the costs include: outreach and education, design efforts which are typically do not require significant ongoing monetary investment. However, the voluntary effort to remove switches provides an incentive of about US$1.00 per switch. While this may not reflect the actual cost of removing the switch (some states have proposed incentives of up to US$7.00 per switch), it still costs significantly less than installing end-of-pipe controls to capture mercury at the furnace. In December of 2007, EPA also promulgated the Electric Arc Furnace Rule which codifies and builds upon the voluntary program (EPA, 2007).

With regard to chlor-alkali plants, the EPA promulgated an emissions standard based on maximum control technology (MACT) in December of 2003 to limit mercury emissions from this industry. The MACT rule requires controls and emissions limits for process vents and relatively stringent work practice standards or a cell room monitoring program to minimize fugitive emissions from the cell rooms. The total estimated capital cost of the final rule for the nine mercury cell chlor-alkali plants was around US$1.6 million, and the total estimated annual cost is about US$1.4 million per year. Plant-specific annual costs in our estimate range from about US$130,000 for the least-impacted plant to about US$260,000 for the worst-impacted plant. The final rule will reduce mercury air emissions from existing emission points within mercury cell chlor-alkali plants by 675 kg per year, a 74 percent reduction from current levels. The final rule also requires rigorous work practice standards such as periodically washing down work floors and covering waste containers. These requirements will reduce mercury emissions from so called "fugitive sources" throughout the plants. Although EPA is not able to accurately quantify the reductions associated with these work practice standards, these requirements will reduce mercury air emissions industry wide. By any accounting, the costs of implementing the MACT rule are significantly less than facility conversion to non-mercury cell technologies.

Major review of information on the costs of abatement for combustion of coal and other economic sectors was carried out within the EU ESPREME (http://espreme.ier.uni-stuttgart.de) and DROPS (http://drops.nilu.no) projects. The annualized investment and operational costs for installations that are used to remove mercury, including ESPs, FFs, FGD, and "add on" measures just for mercury removal are presented in Table 5. These costs are given in relation to the production of 1 tonne of specific production, indicated as specific activity indicator. The information on efficiency of Hg removal using these installations is also included in Table 6.

Table 6: Abatement cost for installations used to reduce Hg emissions from various industrial processes (in US$ /tonne of specific production- SAI) – selected technologies from the EU ESPREME project database (http://espreme.ier.uni-stuttgart.de)

Sector	Specific activity indicator (SAI)	Emission control technology	Hg reduction (%)	Annual costs (US$ 2008/SAI)		
				Annual investment costs	Annual operating costs	Annual total costs
Sintering	tonne sinter	dry electrostatic precipitator (ESP) – medium efficiency of emission control	5	0,10	0,05	0,15
		dry ESP – optimized	70	0,21	0,20	0,41
		virgin activated carbon injection (SIC)+FF – optimized	80	2,10	1,12	3,22
		calcium hydroxide-impregnated adsorbents (SICa) – emerging method	100	1,05	1,24	2,29
Primary lead	tonne primary lead	dry ESP – medium efficiency of emission control	5	0,06	0,04	0,10
		fabric filters (FF) – state-of-the - art	10	0,12	1,12	1,24
		virgin activated carbon injection (SIC)+FF+FGD – optimized	90	2,48	1,32	3,80
Primary zinc	tonne primary zinc	dry ESP – medium efficiency of emission control	5	0,10	0,06	0,16
		fabric filters – state-of-the-art	10	4,50	1,12	5,62
Primary copper	tonne primary copper	fabric filters – medium efficiency of emission control	5	1,80	13,80	15,60
		fabric filters – state-of-the-art	10	3,87	25,65	29,52
Secondary lead	tonne secondary lead	dry ESP – medium efficiency of emission control	5	0,10	0,06	0,16
		fabric filters – state-of-the-art	10	6,75	1,12	7,87
Secondary zinc	tonne secondary zinc	dry ESP – state-of-the-art	5	0,10	0,06	0,16
		fabric filters – state-of-the-art	10	0,12	1,42	1,54
Secondary copper	tonne secondary copper	dry ESP – state-of-the-art	5	10,89	15,86	26,75
		fabric filters – state-of-the-art	10	6,64	43,97	50,61
Cement production	tonne cement	fabric filters – medium efficiency of emission control	5	0,20	0,22	0,42
		fabric filters – optimized	98	0,39	0,38	0,77
		wet FGD – optimized	90	1,35	0,45	1,80
Coke production	tonne coke	use of raw materials with low HM content – optimized	5	0,00	0,02	0,02
		fabric filters – medium efficiency of emission control	5	0,21	1,65	1,86
		fabric filters – optimized	5	0,46	3,08	3,54
		dry ESP – medium efficiency of emission control	5	0,76	1,11	1,87
		wet FGD – medium efficiency of emission control	30	2,80	1,91	4,71
		wet FGD – optimized	40	3,04	2,79	5,83
		dry ESP – optimized	70	1,40	1,57	2,97
Iron and steel foundring	tonne cast iron	fabric filters – medium efficiency of emission control	5	10,80	82,77	93,57
		dry ESP – medium efficiency of emission control	5	38,10	55,47	93,57
		fabric filters - retrofitted from medium method to state-of-the-art	98	12,46	71,10	83,56
		dry ESP – optimized	70	69,80	78,97	148,77

Sector	Specific activity indicator (SAI)	Emission control technology	Hg reduction (%)	Annual costs (US$ 2008/SAI)		
				Annual investment costs	Annual operating costs	Annual total costs
Pig iron production	tonne cast iron	fabric filters – medium efficiency of emission control	5	0,20	0,75	0,95
		dry ESP – medium efficiency of emission control	5	1,53	2,22	3,75
		dry ESP - retrofitted	72	1,28	0,94	2,22
		dry ESP – optimized	70	2,79	3,16	5,95
Basic oxygen furnace steel	tonne steel	dry ESP – medium efficiency of emission control	5	1,20	3,00	4,20
		wet scrubber Venturi – optimized	8	5,68	0,54	6,22
		dry ESP – optimized	70	4,32	4,50	8,82
Electric arc furnace steel	tonne steel	fabric filters – medium efficiency of emission control	5	0,21	1,65	1,86
		dry ESP – medium efficiency of emission control	5	0,76	1,11	1,87
		fabric filters - retrofitted	98	0,26	1,42	1,68
		dry ESP– optimized	70	1,40	1,57	2,97

Major assessment of costs and environmental effectiveness of options for reducing mercury emissions to air from small scale combustion installations, SCI, (<50 MWth) has been prepared for the European Commission by Pye et al. (2006). It was concluded that:

- One of the most cost-effective options were preventive options (e.g. options prior to combustion to minimize emissions), such as coal washing and fuel switching. Such options require the use of a better quality, cleaner fuel within the same fuel type, or the switching to an alternative fuel with lower emissions. Another preventive option is reduction in energy consumption through energy efficiency;
- Only limited technical abatement options (such as removal of mercury from flue gases after combustion) were identified for SCI.

An assessment of abatement costs for reduction of heavy metals, including mercury within various industries was carried out for the heavy metal emission reduction Protocol of the UN ECE Convention on Long-range Transboundary Air Pollution (Visschedijk et al., 2006). The results of this assessment are similar to the data presented in Table 6.

4.4 Benefits of emission reductions

Information on monetary valuation of environmental and human health benefits related to the reduction of Hg emissions from individual industrial sources is largely missing in the literature.

Societal benefits related to the decrease of the 2005 Hg emissions from industrial sources worldwide until the year 2020 are estimated by Pacyna et al as part of the UNEP report on air emissions, (2008-in preparation) as a part of an assessment of socio economic costs of continuing the status quo of mercury pollution from all major anthropogenic sources. The social benefits were estimated as a difference between the societal costs (damage costs) related to the emission reductions calculated for the scenario assuming the status quo of environmental pollution between the years 2005 and 2020 and the emission reductions projected in the scenario where application of modern emission control devices is employed (ESPs or FFs + FGD + absorbent injection).

It was estimated for the metal industry and cement manufacturing that the damage costs to society due to ingestion of Hg contaminated food in the year 2020 can be as high as US$ 6,300 million along the assumptions defined within the status quo scenario relating to pollution of environment by Hg since 2005 and US$ 2,800 million along the assumptions defined within the extended emission control scenario (UNEP, 2008-in preparation). The damage costs to society due to inhalation of Hg polluted air were estimated insignificant compared to the damage costs due to ingestion. Thus, the societal benefits due to reduction of Hg emissions from metal industry and cement manufacturing in the year 2020 were estimated to be about US$ 3,900 million.

5 Reduction of generation of wastes that contain mercury

5.1 Overall assessment of costs and benefits

Qualitative Cost Assessment: Variable depending on the management technique such as incineration and land filling

Qualitative Benefit Assessment: very high relative to the abatement costs if management is in place

5.2 Hg abatement efficiency and costs

The sources of waste containing Hg are several. These sources may differ from one region to another and the quantity of waste-Hg from different sources may be correlated with life style and the level of economic development in the different countries and regions as well. Since the sources are different and the emissions from these sources are local and region specific, the costs to reduce generation of wastes that contain mercury and the measures as well as their implementation to reduce the emissions from these sources differ depending on whether the source is in a developed country or in a less developed one.

Table 7 brings together some sources of mercury containing waste generated both in developed countries (DC) and in less developed countries (LDC) where most of the sources are related to certain level of economic development.

Table 7: Examples of different sources of waste

Wastes from natural gas purification and transportation - wastes containing mercury
Metal-containing wastes other than those mentioned in batteries and accumulators/wastes from the manufacture, formulation, supply and use (MFSU)/manufacture, formulation, supply and use/of salts and their solutions and metallic oxides/ - wastes containing mercury
End-of-life vehicles from different means of transport (including off-road machinery) and wastes from dismantling of end-of-life vehicles and vehicle maintenance - components containing mercury
Batteries and accumulators - mercury-containing batteries and lamps and electronic devices
Construction and demolition wastes - construction and demolition wastes containing mercury
Wastes from natal care, diagnosis, treatment or prevention of disease in humans – amalgam waste from dental care
Separately collected fractions - fluorescent tubes and other mercury-containing waste

Source: adapted from: http://ec.europa.eu/environment/chemicals/mercury/doc/czech_rep_1.doc

In order to reduce generation of waste that contains Hg in DC different policy instruments including regulations, market based instruments as well as information are used. The reason why these policy instruments are developed is based on the fact that Hg in waste is leading to externalities (both ecological and health) where the damage costs may be very high as in the case of ingestion of fish containing Hg and the implied reduction of IQ in the population of new natal. Hence, the policy instruments have led to the implementation of different measures and waste management of wastes containing Hg such as recycling, land filling and incineration (for more detail on related to the costs of these measures see section 7). However, whilst the use of regulations and market based instruments have led to different technical measures that are moderate in the case of landfills and high in the case of incineration (which has led in some cases to the export of hazardous waste to LDC), the most costs effective measures are non technical being the results of good information highlighting the consequences of Hg emissions on the environment and human health.

In LDC on the other hand, the environment issue became an interesting subject quite recently and many LDC lack well formulated guidelines and policy structures regarding waste in general and waste containing Hg in particular. However, whilst both technical and non technical measures are used in DC, the measures in LDC are most of the time artisanal and in many cases chaotic. Uncontrolled dumping of wastes on outskirts of towns and cities has created overflowing landfills, which are not only impossible to reclaim because of the haphazard manner of dumping, but also because they have serious environmental implications (http://cat.inist.fr/?aModele=afficheN&cpsidt=2384293).

Nevertheless, when it comes to abatement costs when policy instruments are in place these may be high if they are technical and if transaction costs including monitoring are included in the estimations. However, costs to reduce waste containing Hg may be low and cost effective if the policy instruments are based on guidelines and information.

At the global level, the international community is working to strengthen legislation on the use, movement and disposal of toxic and hazardous waste (http://www.marketresearch.com/product/display.asp?productid=1470786). Example of the international work is the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (in force since 1992). The transaction costs of these works are certainly efficient leading to lower global environmental as well as health damage.

6 Promotion of separate collection and treatment of mercury-containing wastes

6.1 Overall assessment of costs and benefits

Qualitative Cost Assessment: small to medium, at least in developed countries

Qualitative Benefit Assessment: relatively large

6.2 Hg abatement efficiency and costs

Outside the industrial sector which is responsible for high emissions/releases of Hg, several other products include Hg which should be managed appropriately e.g. recycled in order to prevent emissions of this pollutant. Some of the products containing and which can be recycled are shown in Table 8.

Table 8: Some products containing Hg

Fluorescent bulbs:	All fluorescent bulbs typically contain 10-40 milligrams of mercury (.01 - .04 grams of mercury). Nonetheless, these bulbs use up to 50-75% percent less electricity than incandescent bulbs, making them the environmentally preferred choice. Remember to keep fluorescent bulbs out of the trash, avoid breakage and contact a recycling service to remove them.
Thermometers	Mercury thermometers can be identified by the silver colored liquid in the bulb. -Thermometers typically contain 0.5 - 0.7 grams of mercury. Large thermometers can have as much as 3 grams of mercury. Alternatives: Replace with digital thermometers or alcohol (red bulb) thermometers.
Thermostats	Non-electronic thermostats contain an average of 5.25 grams of mercury. Alternatives: Replace with electronic thermostats.
Other sources of mercury	
Button cell batteries (some types) - like those used in watches	
Dental fillings	
-Mercury switches - silent light switches and tilt switches, found in automotive trunk and hood lights, clothes irons, and space heaters	
-Old pesticides, fungicides, paint	
-Electronic devices	
-Different equipment at different public units e.g. drinking water systems	

Source: http://www.wastecap.org/wastecap/commodities/mercury/mercury.htm

The use of electronic devices has proliferated in recent decades both in DC and LDC, and proportionately, the quantity of electronic devices, such as PCs, mobile telephones and entertainment electronics that are disposed of is growing rapidly throughout the world. In 1994, it was estimated that approximately 20 million PCs (about 7 million tonnes) became obsolete. By 2004, this figure increased to over 100 million PCs. Cumulatively, about 500 million PCs reached the end of their service lives between 1994 and 2003. 500 million PCs contain approximately 287 tonnes of mercury (Puckett and Smith, 2002). This fast growing waste stream is accelerating because the global market for PCs is far from saturation leading to proportional increase of electronic waste (Culver, 2005).

To limit emissions of Hg several techniques may be used (as discussed above). Some of these techniques are presented in Table 9. However, where mercury containing products are used, promotion of separate collection and treatment of Hg-containing waste is likely to be most effective

in limiting releases of Hg. Whilst promotion may give results in the developed world, this strategy may be more challenging in the developing world where there is often no differentiation between municipal, hazardous and medical waste in terms of applied techniques or achievable emission limits.

Table 9: Some Hg management techniques

Sector	Best available technology (BAT)	Emerging techniques
Municipal, medical and hazardous waste incineration	-Separate collection and treatment of Hg containing wastes -Substitution of Hg products -Sorbent injection -FGD -Carbon filter beds -Wet scrubber with additives -Selenium filters -Activated carbon injection prior to the ESP or FF -Activated carbon or coke filters -Selective catalytic reduction (SCR) -Co-incineration of waste and recovered fuel in cement kilns -BAT for cement kilns -Co- incineration of waste and recovered fuel in combustion installations -Avoid Hg entering as an elevated component of the secondary fuel -Gasification of the secondary fuel -Injection of activated carbon -BAT for combustion installations	Heavy metal evaporation process Hydro-metallurgical treatment + vitrification <u>Municipal waste incineration</u> PECK combination process

Source: http://www.unece.org/env/lrtap/TaskForce/tfhm/third%20meetingdocs/Summary_BAT_060407.doc

Nevertheless, promotion of Hg management is warranted at levels including households, industries and the public sector. However, except technical measures that may be used to reduce emissions of Hg, other measures such as substitution would be more cost effective. Table 10 shows some examples of substitution measures related to public water system unit in the US, where the costs, depending on the measure, are quite low.

Table 10: Examples of strategies using mercury-free alternatives in public water system units in the US, where abatement costs, depending on the measure, may be quite low.

Switch and relay alternatives	
Mechanical switch (metallic ball, snap switch, microswitch)	Uses a solid such as metallic ball that moves back and forth completing or breaking the circuit. Price for float switch replacement runs from US$ 25 to US$ 250. Price for free-floating float with inverter microswitch ranges from US$ 93 to US$ 175. Price for tilt switch ranges from US$ 1 to US$ 25.
Magnetic dry reed/magnetic switch	Metal reeds are drawn together completing the circuit in the presence of a permanent magnet. Prices for magnetic reed float switch range from US$4 to US$ 600 depending on use and features.
Continuous level transmitters	Use relay switches in a series. Price ranges from US$ 450 to over US$ 1200 depending on length. Allows for continuous data transmission capability.
Sensor alternatives	
Submersible pressure transmitter or transducer	The sensor probe is suspended by cable from the top of the tank and continuously measures pressure based on the water level above the sensor. Suppliers and manufacturers contacted report that these are low maintenance, come in no corrosion (titanium) models, and are easy to install. Prices range from US$ 350 to US$ 800.
Electronic pressure transmitter (nonsubmersible)	The transmitter is connected to plumbing at the bottom of the tank and measures pressure based on the water level above the sensor. Suppliers and manufacturers report that these are no or low maintenance, weather proof, and easy to install. These sensors measure the exact water level as opposed to the presence or absence of water at a certain level. Costs range from US$ 560 to US$ 900.
Ultrasonic, sonic, radar	Sound waves or radar travel down the measurement tube and reflect against the surface of the tank contents before returning back to the receiver. Electronics measure the time and calculate water level. Prices range from US$ 200 to over US$ 1000 depending on features and accessibility.

http://www.mass.gov/dep/water/drinking/mercbmp.pdf

The costs of Hg management may be small to medium in the case of developed countries, for examples costs of collection, transportation and recycling of switches in the US ranges between US$ 0.004 and $1.0. Some lesser developed and developing countries import considerable quantities of electronic waste. The Figure 3 below depicts the main electronic waste traffic routes in Asia.

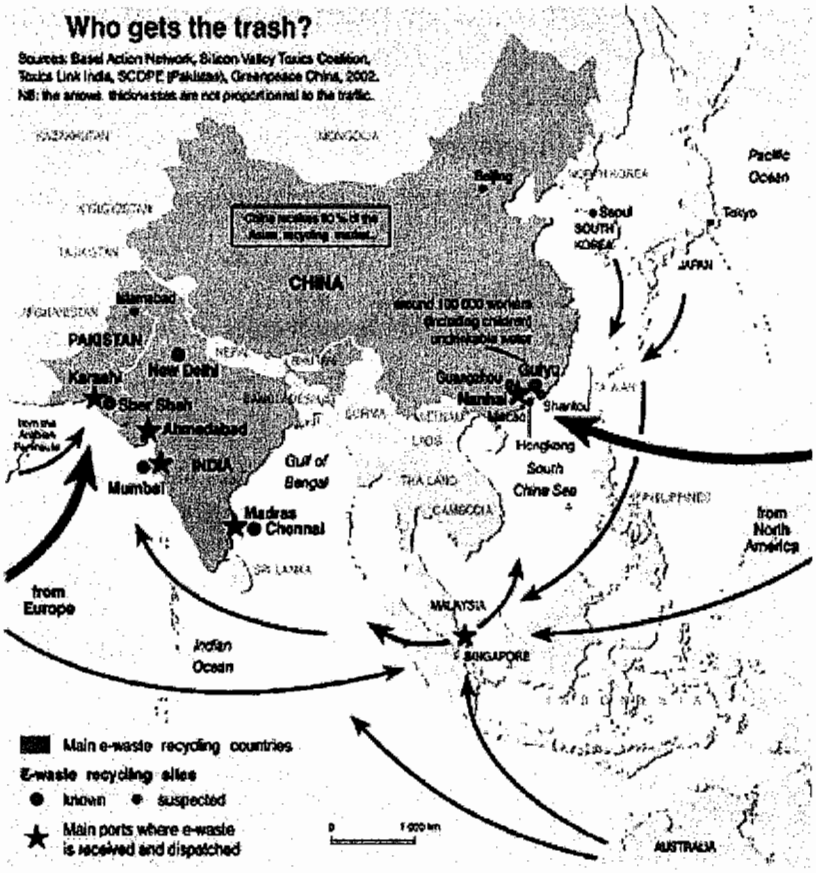


Figure 3: Main electronic waste traffic routes in Asia.

The benefits of separate collection and treatment of Hg containing waste are relatively large compared to the costs of abatement, including both technical and substitution measures.

7 Reduction of mercury emissions to air from medical, municipal, and hazardous waste incinerators and reduce migration and emission of mercury from landfills (all done)

7.1 Overall assessment of costs and benefits

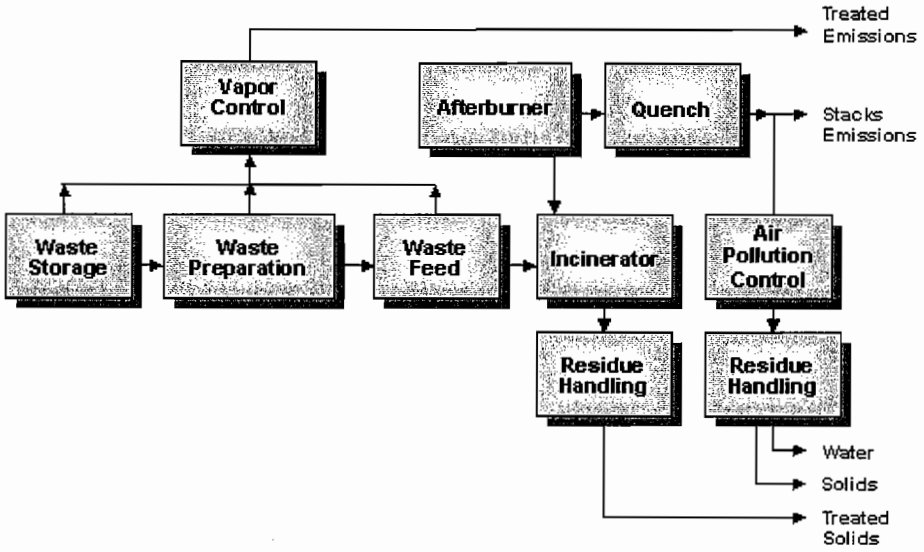
Qualitative Cost Assessment: Large to medium in the case of incineration and land filling, respectively

Qualitative Benefit Assessment: The benefits of incinerating or land filling (although they are high to medium, respectively), they are very large compared to the total costs of these management technologies.

7.2 Hg abatement efficiency and costs

Comparing of the external effects of incineration and land filling different studies revealed that the cancer risk from living near a landfill was about 100 times that of living near an incinerator. Furthermore, criticisms levelled against incineration arise from its history of releasing dioxins and furans. Consequently, for incinerators to provide an effective means of reducing the bulk of municipal waste in general, it is important that they do not emit harmful gases, compounds and particles. This is why the fulfilment of these requirements is correlated with high investment and maintenance costs.

For properly operated incinerators, the destruction and removal efficiency exceed the 99.99% requirement for hazardous waste and can be operated to meet the 99.99% requirement for PCBs and dioxins. Off gases and combustion residuals generally require treatment (http://www.frtr.gov/matrix2/section4/D01-4-23.html). Figure 4 below is a schematic cradle to grave illustration of how waste can be managed using an incinerator.



Source: http://www.frtr.gov/matrix2/section4/D01-4-23.html

Figure 4 : A schematic cradle to grave illustration of how waste can be managed using an incinerator.

When it comes to costs related to incinerator and waste treatment, Table 11 shows an example based on different scenarios and the type of waste in question. The Table represents estimated costs to apply incineration technology at sites of varying size and complexity where not only Hg is managed but other hazardous pollutants as well, e.g. dioxins.

Table 11: Cost of incinerator

Incinerator	Scenario A	Scenario B	Scenario C	Scenario D
	Small site		**Large site**	
	Easy	Difficult	Easy	Difficult
Cost per m^3	$1047	$1540	$914	$1399

Source: http://www.frtr.gov/matrix2/section4/4-23.html

As shown in the Table 11 the costs differ depending on whether the site is small or large. These costs range between $1047 in the case of a small site and $1399 for the difficult case when the site is large. However, for costs specific to mercury, Table 12 shows both investment and operating costs while investing in an incinerator.

Table 12: Investment and operating costs while investing in an incinerator.

Sector	Emission control technology	Hg reduction (%)	Annual costs (US$ 2008/ tonne waste)		
			Annual investment costs	Annual operating costs	Annual total costs
Waste incineration and cremation processes	wet scrubber (wSC) with alkaline addings – medium efficiency if emission control	20	0,12	0,08	0,20
	waste separation – medium	60	0,60	0,60	1,20
	dry ESP – optimized	70	1,84	6,99	8,83
	ESP+wet scrubber+activated carbon with lime+FF – optimized	99	2,31	2,48	4,79
	two-stage scrubber+wetESP – optimized	90	2,31	1,82	4,13
	virgin activated carbon injection (SIC)+FF – optimized	80	2,19	4,02	6,21
	virgin activated carbon injection (SIC)+venturi scrubber+ESP – optimized	95	5,25	6,15	11,40
	virgin activated carbon injection (SIC)+venturi scrubber with lime milk+caustic soda+FF– optimized	99	5,78	7,08	12,86

Investment and maintenance costs of appropriate landfills are relatively lower. Landfill controls can be implemented to limit mercury release and will also benefit management of many other hazardous wastes. As an example, the costs for the thermal treatment application at Lipari Landfill (Lipari site) in New Jersey included $430 000 in capital cost and $5, 019, 292 in operation and maintenance costs - The unit cost for this application was $67/tonne based on treating 80 000 tonnes of soil. The land fill Lipari was used for disposal of a variety of household, chemical, and other industrial wastes (http://costperformance.org/profile.cfm?ID=137&CaseID=137).

Since the costs related to appropriate incineration and land filling are high and medium respectively, in developed countries, these settings are economically hard to manage in least developed countries. Based on these high costs, opportunities to substitute mercury-free alternatives may be the most preferable option.

When it comes to the benefits of incinerating or land filling, these are very large. Using the abatement cost e.g., $67/tonne) for land fill and $1047 /tonne for incineration (assuming 1 m^3 = 1 tonne), these costs are much lower than the damage avoided or the benefits reached if these management technologies are in use. Hence, the benefits of incinerating or land filling are very large compared to the total costs of these management technologies.

8 Reduction of mercury consumption in vinyl chloride monomer (VCM) and chlor- alkali production

8.1 Overall assessment of costs and benefits

Cost Assessment: Small if achieved through best practices, possibly high per plant or for countries that have many plants, but small globally. If achieved through conversion, high capital cost. Small long-term cost for chlor-alkali, higher for individual facilities.

Benefit Assessment: Medium to Large for VCM, Large for chlor-alkali.

8.2 Hg in VCM production

The use of mercury as a catalyst in the production of VCM is a major use of and source of mercury emissions in a few countries, primarily in China, largely because it is a coal-based process compatible with the predominant fuel supply in those countries (Maxson, 2006). While alternative processes are available, significantly more information on this sector is necessary to better understand the current operating practices of existing facilities and the mercury catalyst management processes before cost estimates can be made. But given the number of facilities using this process, requiring or encouraging their conversion or upgrading them and enforcing consumption or release limits could be costly in the specific countries in question. Industry-to-industry technical exchange on best management practices for the mercury catalyst and the exploration of alternatives could be less expensive, but information on the cost and technical issues for conversion has not yet been fully analyzed. There is some evidence that points to potential economic incentives for upgrades that could offset some of the cost.

The Natural Resources Defence Council, in collaboration with China's Chemical Registration Center, estimates that in 2004 the VCM sector was the largest user of mercury in China, consuming 700 metric tonnes per year. Multimedia releases from this sector are not well characterized. Also, due to increased demand for PVC, one estimate suggests that mercury use in this sector is projected to reach 1,000 metric tonnes by the end of the decade. Addressing this sector is likely to reduce global mercury risks significantly if the projected demand estimates for PVC are correct.

8.3 Hg in chlor-alkali production

There are three different processes for chlor-alkali production. Two processes: the mercury method and the diaphragm techniques date from the end of the 19th century, while the third process: membrane technique was developed on an industrial scale in the 1970s. Membrane cells release less hazardous substances and are more energy-efficient than the older techniques (e.g. KEMI, 2004).

For chlor-alkali, the global trend for conversion to non-mercury cell technology or reductions in mercury use and emissions has been established. This industry is declining substantially in the world with chlorine and caustic soda now being produced using more efficient, environmentally friendly, non-mercury processes. As of 2004, there were approximately 150 chlor-alkali plants worldwide that still use mercury cell technology (UNEP, 2007).

There were about 14 U.S. facilities in the mid-1990s using the mercury-cell process (so-called mercury cell chlor-alkali plants: MCCAPs); this year only 5 such facilities will still be in operation. The existing U.S. facilities are subject to a technology based emissions standard (the MACT regulation), which requires controls and emissions limits for process vents and relatively stringent work practice standards or a cell room monitoring program to minimize fugitive emissions from the cell rooms. Mercury use by the U.S. chlor-alkali sector was reduced by 94 percent from 1995 to 2005, from about 160 tonnes in 1995 to 10 tonnes in 2005. Emissions were reduced about 50

percent from 1990 to 2002 (from about 10 tonnes to 5 tonnes), and are expected to decrease to 2.5 tonnes by 2008. These numbers suggest that the benefit of reducing mercury consumption in chlor-alkali production can be quite high, with little opportunity cost given industry trends.

According to Euro Chlor information, there remained at the beginning of 2005 over 50 MCCAPs in Europe that continue to use the mercury process to produce chlorine (Concorde, 2006). Mercury consumption and releases have been greatly reduced from the 500-1,000 tonnes per year estimated in the 1970's. However, the average age of the EU plants is nearly 35 years, and further efforts to reduce mercury releases below present levels may challenge the technical limits of what is possible without converting to a mercury-free process. Unacceptably high Hg emissions before and into the 1980's pressed the member countries of OSPAR (the Oslo and Paris Convention for the protection of the North Sea and North-East Atlantic) to recommend in 1990 that the mercury cell chlor-alkali process should be phased-out by 2010. The European IPPC Bureau, in its 2001 BAT (best available techniques) reference Document on chlor-alkali industry, confirmed that the mercury cell process does not reflect BAT, and the IPPC Directive calls for non-BAT processes to be phased out by mid-2007. The implementation of the 1990 OSPAR Decision and the IPPC Directive as well, are ultimately the responsibility of each of the countries concerned. However, the countries uneven response to the OSPAR and flexible interpretation of the 2007 IPPC deadline reflect the diverse and shifting political and economic priorities of different countries within the EU (Concorde, 2006).

The Swedish Chemicals Inspectorate (KEMI) concludes that the use of mercury in the Swedish chlor-alkali industry should be covered by a general national ban (KEMI, 2004). KEMI also considered that mercury for chlor-alkali production should be granted a time-limited exemption from the ban and be allowed to be marketed and used until 31 December, 2009. It is interesting to note that according to KEMI, a national ban on the use of mercury in the chlor-alkali industry after that date will produce no greater further impacts for the companies affected beyond those which follow from the IPPC Directive.

In other larger EU countries there is no general agreement that a phase-out of the mercury process is needed before 2020 (Concorde, 2006). The production costs of these old plants are low.

Chemical industry has self-imposed a target for 2007 of 1 g Hg/ tonne of chlorine capacity. A discussion is now being carried out that this limit can be lowered until 0.75 g Hg/ tonne of chlorine capacity by 2012. It should be added that the best performing EU MCCAPs report emissions in the range from 0.2 to 0.5 g Hg/ tonne of chlorine capacity, and this lower range of emission is reflected in the BAT reference Document on chlor-alkali production. The phase-out of mercury in the chlor-alkali industry is expected to be fairly straight-line phase-out of remaining mercury cell capacity by 2020 (EC, 2006). The industry has, through a voluntary agreement, committed to phase out the use of mercury until 2020.

Hg emissions from MCCAPs in regions other than North America and Europe seem to be higher. Srivastava (2008) report that the mercury consumption in Indian companies are at least 50 times higher than in the world best companies. This high consumption of mercury results in emission of about 47 g Hg/ tonne caustic soda produced, one of the highest emission factors ever noted for this industry. Srivastava (2008) calls for a serious effort by the Indian chlor-alkali industry in moving towards membrane cell technology.

8.4 Cost and benefits of Hg emission reductions

Recent studies on the costs and benefits of reducing Hg emissions from US coal combustion facilities were used to derive conservatively estimated annual EU health benefit of some $39-47 per 1 gram of MCCAP atmospheric mercury emissions eliminated (Concorde, 2006).

The Concorde (2006) analyses also the costs and benefits (especially energy savings, reduced costs of mercury monitoring and waste disposal, etc) to industry of converting a typical MCCAP to the membrane process. There are various cases of actual conversions that have generated an attractive two- to three-year return on investment. However, it was pointed out that an EU industry investment on average in conversion of the MCCAP process to membrane process may not show an attractive bottom-line return until close to 10 years. The Concorde (2006) study concludes that combining the considerable "bottom-line" benefits of MCCAP conversion with even a conservative estimate of the public health benefits, it can be expected that the overall benefits, even when accumulated over only 5 years, are nearly twice the costs associated with the technology transition. Therefore, the conversion of MCCAPs should be regarded with a high priority when discussing the whole range of public health and other benefits associated with industrial development of chemical industry.

More information on combined benefits and costs of converting European MCCAPs to membrane process is presented in Table 13 below.

The existing MCCAPs use various control techniques to reduce Hg emissions, including: 1) gas stream cooling, 2) mist eliminators, 3) scrubbers, and 4) adsorption on activated carbon or molecular sieves (e.g. US EPA, 1995). Gas stream cooling is often used as the primary mercury control technique or as a preliminary removal step to be followed by a more efficient control device. Mist eliminators can be used to remove mercury droplets, water droplets, or particulate matter from the cooled gas streams. Scrubbers are used to absorb the mercury chemically from both the hydrogen stream and the end box ventilation streams. Sulfur- and iodine-impregnated carbon adsorption systems are commonly used to reduce the mercury levels in the hydrogen gas stream if high removal efficiencies are desired. This method requires pre-treatment of the gas stream by primary or secondary cooling followed by mist eliminators to remove about 90 % of mercury content of the gas stream.

Table 13: Combined benefits and costs of converting European MCCAPs to membrane

Combined benefits and costs (billion euro of 2004)	***Estimated annual benefits & costs***	***During 5 yrs.***		***During 10 yrs.***	
		Discount rate 5%	Discount rate 10%	Discount rate 5%	Discount rate 10%
Present value – total conversion costs, including: Investment cost, cleanup, etc.	2.6 one-time	**2.6**	**2.6**	**2.6**	**2.6**
Present value total benefits, including:		**4.9**	**4.4**	**8.4**	**6.9**
Industry benefits		1.7	1.5	2.8	2.3
Health benefits*		3.2	2.9	5.6	4.6
Environmental benefits	various 0 annual significant	not included	not included	not included	not included
Ratio of total benefits/costs		**1.9**	**1.7**	**3.2**	**2.7**

Assumptions for conversion of European MCCAPs to the membrane process:
-annual chlorine production capacity ≈ 6 million tonnes
-10-15% of capacity will close rather than convert
-annual atmospheric mercury emissions ≈ 4-5 g Hg per tonne chlorine capacity ≈25-30 tonnes mercury total
-annual health benefits >25 euro per gram of mercury emissions eliminated
-annual environmental benefits may be similar to health benefits, but are not quantified here

Note:
* Health benefits are based only on estimates of neuro-developmental impacts – specifically loss of intelligence – of methyl-mercury exposure in the US due to fish consumption, although there is evidence of other health effects as well. The figure of 25 euro per gram of mercury emissions eliminated (multiplied by 25-30 tonnes of mercury emissions eliminated upon full conversion) is a conservative estimate based on two key sources: one assuming human methyl-mercury exposure from consumption of both marine and freshwater fish, and the other assuming exposure from consumption of freshwater fish only.

Major review of information on the costs of abatement for existing MCCAPs was carried out within the EU ESPREME (http://espreme.ier.uni-stuttgart.de) and DROPS (http://drops.nilu.no) projects. The results for chlorine production are summarized in Table 14 below.

Table 14: Annual investment and operating costs for chlor-alkali industry.

Sector	Emission control measures	Hg reduction (%)	Annual costs (US$ 2008/ tonne chlorine)		
			Annual investment costs	Annual operating costs	Annual total costs
Chlorine production (mercury cell plants)	good practices during maintenance and repair – optimized	20	0,02	0,02	0,04
	improvements of the mercury cells – state-of-the-art	15	0,06	0,02	0,08
	wet scrubber (WSC) with chlorinated brine or hypochloride addings- state-of-the-art	60	1,65	1,35	3,00
	virgin activated carbon injection (SIC)+FF - optimized	98		4,28	
	technology switching to diaphragm or membrane cells - BAT	100	36,96	0,00	36,96

9 Reduction of mercury use in products, including packaging

9.1 Overall assessment of costs and benefits

Qualitative Cost Assessment: Variable, ranging from small to large

In the European literature on the reduction of mercury used studied for this report, the costs related to a reduction of mercury in household measuring products are estimated as small since there are many available substitutes at similar prices. For other products, the availability of substitutes is smaller. For many other regions, the economic and technical situation is less favourable for reduction of mercury use in products. The qualitative cost assessment is therefore ranging between small to large.

Qualitative Benefit Assessment: small

For the European region, for which there available estimates, the total amount of mercury in household measuring products that are feasible to substitute are relatively small. For other products and regions, the potential is lower. Therefore, the qualitative benefit assessment remains small.

9.2 Mercury in products (incl. packaging) as a source of Hg emissions

Mercury in products is relatively scarce in Europe (except for products for dental practices) Therefore, measures aimed at reducing the amount of mercury will have relatively small effects on the use of mercury in society. The environmental impact of reducing the amount of mercury in products and mercury must be treated as relatively large since a removal of mercury in products is an 'up-stream' measure that indirectly affects 'down-stream' emissions such as emissions from incineration of waste, emissions from landfills and leakage to water and soil. Globally, the potential for reducing mercury in products will differ from the European situation. The differences relates to the level of economic and technical development, which in turn affects the local or regional availability of substitutes to mercury (Table 15).

An inventory of the amount of mercury demanded by relevant sectors shows that for EU-25, the amount of mercury demanded for use in products equals 155 tonnes (batteries, measuring & control, lighting, electrical & electronic, other). The other uses of mercury are covered in other chapters of this report.

Table 15: EU-25 and global mercury demand by sector (2005)

Mercury demand	Global demand [tonnes]	EU 25 market demand [tonnes]
Small-scale	1000	5
Chlor-alkali	619	190
Batteries	**400**	**20**
Dental	270	90
Measuring & control	**150**	**35**
Lighting	**120**	**35**
Electrical & electronic	**140**	**35**
VCM	700	Unknown
Other, laboratory, pharmaceutical etc	**40**	**30**
Total	3439	440

Source: EC 2006a

Also of importance for the emissions of mercury from products is the amount of mercury being recycled from these product categories. An estimate on the recovery of mercury specified in product categories is shown in Table 16 below. However, these estimates are uncertain on an EU level, and even more uncertain on a global scale.

Table 16: EU-25 and global product/process mercury recycling – 2005

EU25 and global product and process mercury recycling - 2005	**Hg in EU-25 waste stream (t)**	**EU-25 Hg recycled or recovered (%)**	**EU-25 Hg recycled or recovered (t)**	**Hg in global waste stream (t)**	**Global Hg recycled or recovered (%)**	**Global Hg recycled or recovered(t)**
SS gold mining	Not applicable	not applicable	Not applicable	Not applicable	not applicable	not applicable
Chlor-alkali	Not applicable	not applicable	32	Not applicable	not applicable	84
Batteries	**40**	**25%**	**10**	**500**	**15%**	**75**
Dental	72	25%	18	200	15%	30
Measuring & control	**42**	**25%**	**11**	**160**	**15%**	**24**
Lighting	**46**	**25%**	**11**	**150**	**15%**	**23**
Electrical & electronic	**42**	**25%**	**11**	**150**	**15%**	**23**
VCM	Unknown	unknown	unknown	700	43%	301
Other, laboratory, pharmaceutical, etc.	**36**	**25%**	**9**	**50**	**15%**	**8**
Total for these categories	278		101	1910		566

Source: EC DG-ENV (2006)

What can be seem is that the recycling rate is somewhere around 25 % in the EU and lower globally. For the products covered in this chapter it is estimated that some 254 tonnes of mercury in the EU-25, and 857 tonnes globally reach the waste stream without being recycled. This cause high potential for emissions from products once they reach the waste stream, which is covered in other chapters of this report.

9.3 Hg abatement efficiency and costs

The European ban of household measuring devices containing mercury, due to be applied by member states from 3 April 2009 will mainly cause costs related to restructuring of firms. In Europe, there are substitutes available at similar prices for all household applications, so the ban would be easy to implement. The availability of substitutes is only one of the factors determining the costs of reducing mercury in products. However, other costs relating to administrative efforts such as legislation and efforts related to phasing out of mercury are very difficult to estimate and also very dependent on the availability of substitutes for mercury in products. The ban relates only to households since it is estimated that mercury in measuring devices for professional use is not possible to substitute given the technologies currently available and the extensive control of these professional devices (EC 2006b). If a ban only covers a certain region, and only production (not use) there is a risk of re-allocation of markets and production, which would decrease the impact of the abatement measure.

The impact assessment for the proposed amendment to the European Council Directive 76/769/EEC (EC 2006b) covers the potential impact from a European product ban on household measuring devices such as thermometers. The general conclusion here is that the use of mercury in measuring and control equipment for households can be reduced from ~55 tonnes to ~28 tonnes per year in EU 15 corresponding to a 50 % reduction of mercury use in this product category. The costs of this ban would come mostly as restructuring costs since there are already substitutes available at similar prices. The costs would mostly affect manufacturers of Hg thermometers, but these costs would be offset by the increased benefits for the manufacturers of non-hg thermometers.

To reduce the use of mercury in batteries is already an ongoing process globally (EC DG-ENV 2006), and costs for continued reduction of mercury use in batteries should therefore be small.

The situation seems to be more difficult for electrical and electronic devices. Efforts are being made to promote mercury-free substitutes, but mercury use remains significant (EC DG-ENV 2006). This indicates that the reduction of mercury use in this product category would be associated with medium or high costs.

For lighting products, the availability of substitutes is smaller than for electrical and electronic devices (EC DG-ENV 2006). This indicates that the reduction of mercury use in lighting equipment is associated with high costs.

When studying the literature it is clear that the feasibility of any ban or restriction on products and packaging containing mercury will depend on what substitutes for mercury are available. Mercury has specific characteristics and it does not seem to be easily substituted in some products, for example some measuring equipments in hospitals.
The question of costs of reducing mercury in products and packaging is directly translatable to the question of whether there are compatible substitutes available at similar prices.

9.4 Benefits of Hg emission abatement

The benefit related to reduced mercury in household measuring products in the example above relates to relatively small amounts of mercury, ~28 tonnes. This reduces the total qualitative benefit assessment of such a measure. Also, the potential for re-allocation of markets and production further reduces the potential of such a measure. What increases the possible benefit however is that it would have measure both in the use part as well as in the waste part of the products' life cycle. In EC (2006b) it is estimated that the consumption of 33 tonnes of mercury for measuring devices would implicate some 8 tonnes of mercury emitted to air via landfills and incineration. A quick estimate would then indicate that reduced use of mercury in household measuring devices in EU-15 could reduce emissions by 6 tonnes annually. If extrapolating this estimate, the global reduction in emissions would be some 16 tonnes if the 150 tonnes of mercury used globally in measuring devices was reduced to 76 tonnes.

Given that the recycle rate for batteries, electrical & electronic devices as well as lighting equipment is estimated as equal to the recycling rate for measuring devices it is estimated that the emissions to air should be equal as well. However, due to the relative lack of substitutes, the potential emission reduction should be small for these product categories. Globally, it is indicated that the situation is less positive given that the recycling rate is lower and that the technical and economic availability of substitutes is low in many parts of the world. The benefit is therefore estimated as small.

10 Reduction of mercury use in dental practice

10.1 Overall assessment of costs and benefits

Qualitative Cost Assessment: low to large for amalgam separator installation for the developed world. These costs would be much higher in the developing countries.

Qualitative Benefit Assessment: If the benefits are mainly related to the ingestion of fish these would in most cases not be greater than the costs.

10.2 Hg abatement costs and benefits

Dental amalgam is a mixture of mercury with an alloy consisting of silver, tin, copper, and zinc particles. This practice has been used in dentistry to restore carious lesions in teeth for about 150 years in the US and worldwide, although there are records of its use as a dental filling material in China as early as the 7th Century (Phillips, 1991). Although dental amalgam is a source of exposure to elemental mercury and may be the source of health hazard, for example migraines, erethism, and multiple sclerosis, it is still the most commonly used material, comprising approximately 60% of all restorations (http://english.pravda.ru/news/science/06-06-2008/105448-dental-0).

As of 2008, the use of dental amalgam has been restricted in Sweden, Norway and Finland mainly for environmental reasons.

The question of direct impacts of the use of dental amalgam is controversial. Examples of studies showing negative impacts of dental amalgam have been presented e.g. Wojcik et al (2006). On the other hand, the American Dental Association Council on Scientific Affairs has concluded that both amalgam and composite materials are considered safe and effective for tooth restoration and the National Institutes of Health (NIH) has stated that amalgam fillings pose no personal health risk, and that replacement by non-amalgam fillings is not indicated. The US Food and Drug Administration is considering new labelling requirements for dental amalgams, and is also reviewing evidence about safe use, particularly in sensitive subpopulations. (http://www.fda.gov/cdrh/consumer/amalgams.html)

Hence, in the developed world there is no consensus to whether dental amalgam is a source of direct health hazard or not. Given the effects of mercury exposure through the environment, restrictions on the use and safe handling in dentistry to prevent releases of mercury to air and waste water have been imposed in several countries.

The amount of mercury used in dentistry in Europe in year 2000 was 70 metric tonnes, the US was 51 tonnes, while worldwide (include Europe and US) was 272 metric tonnes,. The worldwide demand for mercury in dentistry is predicted to be 250 metric tonnes by the year 2020 as more people worldwide get access to dentistry (Jacobsson-Hunt, 2007).

Table 17 shows that only 15% i.e. 30 tonnes of dental Hg are recycled or recovered while 200 tonnes Hg are accumulated in waste streams at the global level in year 2005 (http://ec.europa.eu/environment/chemicals/mercury/pdf/hg_flows_safe_storage.pdf).

Table 17: Recycling of product/process mercury in the EU and globally in 2005.

EU-25 and global product/process mercury recycling – 2005

EU25 and global product and process mercury recycling - 2005	Hg in EU-25 waste stream (t)	EU-25 Hg recycled or recovered (%)	EU-25 Hg recycled or recovered (t)	Hg in global waste stream (t)	Global Hg recycled or recovered (%)	Global Hg recycled or recovered (t)
SS gold mining	not applicable	not applicable	not applicable	not applicable	not applicable	not applicable
Chlor-alkali	not applicable	not applicable	32	not applicable	not applicable	84
Batteries	40	25%	10	500	15%	75
Dental	72	25%	18	200	15%	30
Measuring & control	42	25%	11	160	15%	24
Lighting	46	25%	11	150	15%	23
Electrical & electronic	42	25%	11	150	15%	23
VCM	unknown	unknown	unknown	700	43%	301
Other, laboratory, pharmaceutical, etc.	36	25%	9	50	15%	8
Total for these categories	278		101	1910		566

Note: If the Chinese industry estimate of VCM mercury catalyst recycling turns out to be optimistic (for example, if it is closer to 100 tonnes than 300 tonnes/yr), that single correction could make a very large difference in the global total for recycled mercury.

Sources: Author calculations based on responses to the Stakeholder questions posed by DG ENV to the different Member States in September 2005. See Czech Republic (2005), France (2005), Germany (2005), Netherlands (2005), Slovakia (2005), UK (2005). Also Brooks (2005), Maxson (2004, 2005), Euro Chlor reports to OSPAR.

In order to reduce the externalities of dental amalgam and depending on whether it is a source of health hazard or not there are two ways of concern:

1. Replace the amalgam filling.

As shown in Table 18 the abatement costs related to replace dental amalgam fillings with mercury free fillings at dentists and to dispose of the Hg safely are in the range of $129000 / kg Hg where the reduction potential is large.

Table 18: Costs for strategies avoiding Hg pollution and their potential to reduce Hg pollution

Activity	Costs $/kg Hg	Reduction potential	Place and year
Increase recycling of chair-side traps in dentistry	240	Medium	Minnesota 1999
Install amalgam separator	33000 - 1300000	Medium/ large	Minnesota 1999
Replace dental amalgam at dentists	129000	Large	Sweden 2004
Remove dental amalgam fillings at death	400	Large	Sweden 2004

Adapted from Hylander et al (2006).

2. Install dental amalgam separator or increase recycling of chair-side traps in dentistry.

As shown in Table 18 increasing recycling of chair-side traps in dentistry is a low cost strategies but the potential of reduction is medium. When it comes to installing amalgam separator where the potentials for reduction vary between medium and large depending on the kind of separator installed, the costs of the strategies range between $33, 000/kg Hg and $1300 000 /kg Hg.

Furthermore, results of cost effectiveness analysis conducted by US EPA gave rise to the following results (http://www.epa.gov/ARD-R5/mercury/meetings/Vandeven.pdf):

- Installation and purchase of separators at an estimated 110 000 to 133 000 clinics will require $111 million to $266 million, industry-wide;
- The operation and maintenance of these amalgam separators will require $78 million to $133 million per year;
- Conservatively assuming a separator has a useful life of 10 years, the combined annual cost is $ 89 million to $160 million per year;
- The annual cost of reducing one tonne of potentially bio-available Hg is $91 million to $282 million per tonne. That is $90625 /kg Hg and $281250/kg Hg , respectively.

Comparing the US EPA results to those presented in the Table 18, the first ones are in the lower range.

Since the benefits or the damage costs are mainly related to ingestion being $12,500/ kg Hg, most of the abatement costs presented here for capturing mercury used in dentistry are higher than the benefits. The use of non-mercury alternatives to dental amalgam for new fillings have a higher costs to consumers (2004 dental fees in the US indicated a $30 extra fee for composite fillings, based mainly on the increased time required). The incremental cost of composite fillings would be decreased if pollution effects were adequately factored in (http://www.mercurypolicy.org/new/documents/FINALReportfromMPPTestimony070708.pdf)

11 Reduction of supply from mining and extraction of virgin mercury and other ores (relates to trade and hierarchy)

11.1 Overall assessment of costs and benefits

Qualitative Cost Assessment: small, medium

The reduction of primary Hg mining is estimated as a relatively inexpensive way of reducing Hg emissions, but the cost distribution should affect the less developed countries the most.

Qualitative Benefit Assessment: large

Since the reduction in Hg supply is characterised as an up-stream abatement option, the qualitative benefit assessment is estimated as large. Although there will be feedback mechanisms reducing the initial effect.

11.2 Hg mining as a source of Hg emissions

The current main Hg mines are in Khaydarkan in Kyrgyzstan (550 tonnes) and China (ca. 200 - 650 tonnes and growing). Previously, the Almadén mine in Spain supplied some 240 tonnes and Algeria supplied an equal amount. Since 2004 however, the Almadén mine is closed since 2004, and the state owned corporation is currently involved mainly in trading of Hg. The mine in Algeria is closed since 2003 when unfavourable conditions made Hg mining too expensive at the site (MBM 2005). While the Almadén mine was still in use, some 10 – 30 tonnes of Hg was directly emitted from the mining of Hg. Primary Hg mining is off course still a large source of potential Hg emissions and adverse environmental effects.

11.3 Hg abatement efficiency and costs

The costs for abatement of Hg emissions via reduction in Hg mining will vary according to local conditions. As an example, the Hg mine in Algeria was put out of use in 2003 due to unprofitability, not environmental reasons (MBM 2005). But mercury is an important metal for some purposes, and easy access to this metal might be considered important for economic growth in some regions, for example China. From the production side, foregone profits if terminating a Hg mine, might be offset by other investment opportunities, but the major part of the costs will be born by Hg buyers who are short of substitutes for mercury.

11.4 Benefits of Hg emission abatement by reduction in Hg mining

The reduction in Hg mining has a number of environmental benefits. The obvious reduction in Hg related effects will be combined by the environmental effects related to reduced mining activities and the following turnover of soil. However, one should be aware that the benefits related to mercury emissions will be offset to some extent by the feedback mechanisms following the price increase induced by the reduction in Hg mining. The extent of these feedback mechanisms is currently unknown. Examples of feedback mechanisms are; increased mining activities in other mines; re-opening of previously closed mines; increased recycling activities etc. It should be noted that increased efforts to recycle mercury will decrease the mercury being discarded as waste.

12 Reduction of mercury supply and management of mercury from decommissioned chlor-alkali cells and existing stockpiles

12.1 Overall assessment of costs and benefits

Qualitative Cost Assessment: Variable, depending on whether a storage infrastructure needs to be developed.

Qualitative Benefit Assessment: Large for chlor-alkali, large for products and processes.

Large stocks of Hg exist on the global level. These include government stocks, surplus mercury in chlor alkali industries and stocks at mercury mining facilities (Maxson 2006).

The generation of Hg from recycling and the recovery of Hg from decommissioned chlor-alkali plants have become increasingly significant contributors (10-20% in recent years) to global supplies because recycling has increased and the production of mined Hg has declined. However, in the interest of eliminating surplus Hg supplies from the global market, the European Union (EU) draft regulation for a Hg export ban, presently under discussion in accordance with Actions 5 and 9 of the EU Hg strategy. This ban targets all Hg from decommissioned EU chlor-alkali plants for retirement as of 2011 (EC, 2005). The supporting analysis suggests that recycled and by-product Hg (along with reduced Hg mine production, as necessary) will be more than adequate to meet global Hg demand (Maxson, 2006). It is estimated that the switch to mercury-free technology in the chlor-alkali industry will release around 12,000 tonnes of metallic mercury (EC, 2006a).

The US government, through the Defense National Stockpile Center (DNSC), owns one of the world's larger stocks of Hg, and in the early 1990s began selling it on the international market after declaring it unneeded for future defense needs. A moratorium on sales was declared in 1994 as a result of concerns that marketing Hg may contribute to global environmental contamination. The relative merit of selling versus retiring the Hg was studied (DNSC, 2004), and in February 2006 the US government announced that the stockpile of some 4400 t of Hg would be stored indefinitely in a warehouse.

Global demand of mercury has decreased from around 7 000 tonnes per year in the late eighties to 3 000 - 4000 tonnes in 2005 (Maxson, 2006). The supply to meet this demand is described in Table 19 and indicates that mining and by-product mercury is the main source of mercury to the global trade.

Table 19: Sources of Hg supply (2005)

Sources of Hg supply	Range of Hg supply (Mt)
Mining and by-product Recycled Hg from chlor-alkali wastes	1800-2200 90-140
Recycled Hg-other Hg from (decommissioned) chlor-alkali cells	450-520 600-800
Stocks	0-200
Total	3000 - 3800

Source: http://www.chem.unep.ch/mercury/PM-HgSupplyTradeDemand-Final-Nov2006-PMformat19Jan07.pdf

Another example of decreasing demand is the USA where production exceeded the demand of less than 500 tonnes per year in the late nineties as presented in Figure 5 .

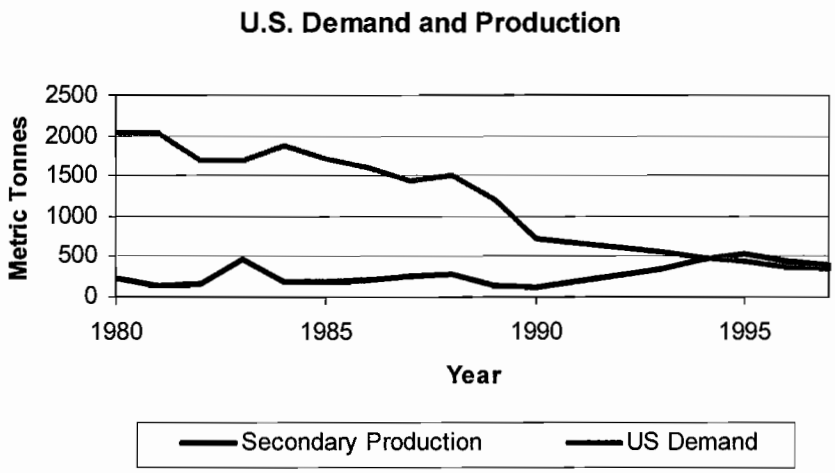


Figure 5: U.S. demand and Production

Source:(http://www.newmoa.org/prevention/mercury/breakingcycle/compendium/Weiler.ppt#256,1,Can the U.S. act alone on mercury?)

The reasons for the decreasing demand have been several including regulations and international agreements. The continued rate of decline in mercury demand will depend primarily upon reductions of use in the product manufacturing sectors (battery, electrical product, and measuring device) as well as in the industrial sectors chlor-alkali and vinyl chloride production. To reduce the consumption in the main consumption sector, small-scale gold mining, represents a major challenge.

A continued reduction of mercury demand driven by either environmental concern or economic realities will require the development of technological and economical instrument for the safe storage and management of surplus mercury.

For all excess mercury stocks, the cost of reducing the supply would be the opportunity cost to the forgone sale plus the cost of long term management of the excess stocks. The projected cost of storing federal mercury stockpiles (US$42 million over the next 40 years) in the United States

could be used to project the costs associated with storing U.S. private stockpiles, but the numbers would vary based on the costs in an individual country. One issue to be mindful of in terms of supplies from decommissioned sources and stocks is the timing of making these supplies available on the market: there could be economic, social and environmental costs in introducing large supplies of mercury into the market at one time.

The main risks associated with stocks of mercury are associated with the fate of the mercury if sold and distributed on the global market. The risks as well as the potential management options will depend on the ultimate use of mercury and ultimately the amounts of mercury released to the environment in that application. However, to avoid any risks and to prevent potential future contamination, several countries in the developed world are promoting efficient management of existing stockpiles and Hg containing waste to prevent environmental contamination.

In Sweden for instance, the strategy is that Hg should not be recycled but should be finally disposed of in a safe and environmentally sound way. Using this as a starting-point, the Government has commissioned two enquiries into how such final disposal can be effected. In 2001, the Committee on the terminal storage of mercury proposed that a legal requirement for waste containing mercury to be stored permanently deep in bedrock. Waste owners should cooperate and bear the responsibility for the construction, location, building and management of a deep storage facility. An estimated total of 1 100 – 1 400 tonnes of waste containing mercury is waiting to be put into terminal deep storage (http://www.regeringen.se/). The Swedish EPA has estimated the costs of deep storage of a facility of 1000-2000 tonnes Hg should be in the range of 200-300 million SEK (around 20-30 millions US$) (2001 prices). Hence in average the cost for 1500 tonnes would be 250 millions SEK (around 25 millions US$; 2001 prices). The cost per tonne would be around 170 000 SEK/tonne (or 17000 US$) (http://www.regeringen.se/content/1/c4/26/09/a4b611c4.pdf).

In order to manage, or retire excess mercury several potential alternatives have been identified. Through a contract with the U.S. Environmental Protection Agency's Office of Research and Development, SAIC (Science Applications International Corporation) has been developed a methodology to be used to evaluate, prioritize, and select alternatives in a systematic manner (Vierow 2002). This methodology identifies criteria for such an evaluation, such as environmental performance, catastrophic risks, need for regulatory changes, implementation considerations, and cost. A system to ascribe weightings, or the importance of one criterion over another, is proposed (with the assistance of a commercial software package). Finally, a total of 11 alternatives for the storage and treatment/ disposal of elemental mercury are evaluated according to these criteria. Preliminary results are presented in Table 20 to show how the alternatives compare to one another when evaluated using the methodology (Randall 2002): Assuming that only benefits (non-costs) or only costs are important. The second column ("overall") shows that the landfill options are preferred independent of the treatment technology. The storage options rank next, followed by the treatment technologies combined with mono-fills, bunkers, or mined cavities. The reasons why the landfill options are preferred become apparent when costs are considered. The third column of results shows the rankings if only cost is taken into account. The landfill options are cheapest and this clearly outweighs the relatively unfavorable rankings that result from a focus on the benefits. However, if the costs are not an important factor, then the three storage options occupy the first three places in the "non-costs only" ranking. The last column of shows unfavorable rankings for the operating costs of the storage options. This arises for two reasons: a) if storage continues for a long period, even relatively small per annum costs will add up; and b) storage is not a means for permanent retirement of bulk elemental mercury and the analysts assumed that, sooner or later, a treatment and disposal technology will be adopted, which adds to the cost. This is enough to drive the storage options out of first place in the base-case rankings. However, the analysis would

support continued storage for a short period (up to a few decades) followed by a permanent retirement option. This would allow time for the treatment technologies to mature.

Table 20: Summary of results for 11 evaluated alternatives

Alternative	Ranking (as fraction of 1 000)					
	Overall		Non-Costs Only		Costs Only	
	Score	Rank	Score	Rank	Score	Rank
Stabilization/amalgamation followed by disposal in a RCRA- permitted landfill	137	1	99	5	217	1
Selenide treatment followed by disposal in a RCRA- permitted landfill	123	2	66	9	217	1
Storage of elemental mercury in a standard RCRA-permitted storage building	110	3	152	2	126	5
Stabilization/amalgamation followed by disposal in a RCRA- permitted mono-fill	103	4	92	7	135	3
Storage of elemental mercury in a hardened RCRA-permitted storage structure	95	5	173	1	44	6
Selenide treatment followed by disposal in a RCRA- permitted mono-fill	94	6	74	8	135	3
Storage in a mine	81	7	140	3	44	6
Stabilization/amalgamation followed by disposal in an earth-mounded concrete bunker	70	8	108	4	42	8
Stabilization/amalgamation followed by disposal in a mined cavity	63	9	97	6	42	8
Selenide treatment followed by disposal in an earth-mounded concrete bunker	62	10	a*	a	A	a
Selenide treatment followed by disposal in a mined cavity	61	11	A	a	A	a
Number of alternatives evaluated	11	—	9	—	9	—
Total	1 000	—	1 000	—	1 000	—
Average score (total divided by number of alternatives, either 9 or 11)	91	—	111	—	111	—

Note: Shading indicates the highest ranking alternative. *) These options were evaluated for the overall goal but were not evaluated at the lower levels of cost and non-cost items separately, due to the low score from the overall evaluation. RCRA = Resource Conservation and Recovery Act

Hence, the methodology gives some ideas on the possible alternatives as well as the cost effectiveness of each of the alternatives. Furthermore, the methodology is designed to be flexible in order to allow for differences in criteria importance, the addition of other alternatives, and the substitution of better information (both qualitative and quantitative) as it is developed in the future.

13 Prevention of mercury contamination from spreading

13.1 Overall assessment of costs and benefits

- Small spills:

Qualitative Cost Assessment: High costs compared to substitution costs of the used product

-Large spills:

Qualitative Cost Assessment: Very high costs
Qualitative Benefit Assessment: The damage is quite difficult to estimate depending on whether the spill takes place in a developed or a developing country.

13.2 Hg abatement efficiency and costs

When the quantities of Hg spills are large measures are taken both in the developed world and the developing countries although the implementation of the measures is relative. In Europe and at the EU level the Commission Directive 93/112/EC of 10 December 1993 enable professional users to take the necessary measures relating to protection of health and safety at the workplace, and to protect the environment (http://www.reach.sgs.com/cts_directive_93_112_eec.pdf).

In the US, the Solid Waste Disposal Act of 1965, as amended, also known as the Resource Conservation and Recovery Act is the Federal Act that controls the management and disposal of solid and hazardous waste (http://www.epa.gov/osw/laws-reg.htm).

-Small spills

If the spilled quantities are small, in developed countries abatement measures are applied where the spill can be cleaned up by residents or workers following a set of relatively simple procedures. In the USA, for instance, many laboratories follow strict regulations on the use of mercury. There are well-documented procedures, especially in those accidents with broken glass and other cases when mercury is spilled. In all cases special removal kits are prescribed preventing any loss of mercury, which will evaporate afterwards. Moreover, special regulations and services exist to remove and store mercury at save places (http://www.knmi.nl/samenw/geoss/wmo/mercury/). In Canada, material from cleanup of mercury spills must be disposed of according to the provisions of the province's Environmental Management Act and the Hazardous Waste Regulation (http://www2.worksafebc.com/i/posters/2007/WS%2007_01.htm).

In developing countries in general, when small spilled quantities occur no clean up takes place and Hg is still used in many instances such as small scale mining and disinfection, such as following piercings. In Morocco for example, elemental Hg can be bought in a spice shop with left over Hg stored in the house with a high risk of spill.

In the US the cost of mercury spills is a topic of interest because some hospitals gain support for mercury reduction programs by using spill cost avoidance as a justification for change (http://www.epa.gov/osw/laws-reg.htm). In general, the true costs of mercury spills are not well documented and tend to be anecdotal. However, the cost of substitution to products with no Hg may be lower. For example the clean- up costs of 1 broken sphygmomanometer is equivalent to $5000. For that cost, one could buy 30 or 40 non-mercury ones (http://www.epa.gov/osw/laws-reg.htm). Table 21 shows some examples giving insight on the potential cost of cleaning up Hg spill.

Table 21: Small spill of Hg and its clean-up cost

Cost Estimate for Clean-up	Reference & Description
Small spill – over $1000 Large spill – around tens of thousands of dollars	http://www.middlecities.org/PDF/mercury_bulletin.pdf "Mercury Contamination Risk Control", Middle Cities Risk Management Trust, Okemos, MI "A typical thermometer contains ½ to 3 grams (.018 to .11 ounces) of mercury. A typical household mercury fever thermometer contains approximately 1 gram of mercury. A typical barometer contains 1 pound (454 grams) of mercury and poses a significant spill risk. The cost of cleaning up a spill will vary by the size of the spill and the degree of exposure to property and people. Small spill clean-ups usually cost over $1000 and large spills can go into the tens of thousands of US$. "
$10 000 for one broken barometer	http://www.pprc.org/pprc/pubs/topics/healthcare.html#mercury Northwest Guide to Pollution Prevention by the Healthcare Sector "A large barometer fell and broke in a 60 square foot office in a Medical Center located in the Puget Sound Region. The barometer was used to calibrate instruments used in treatment of patients. No one knew when the barometer fell and broke in the office. "The following are costs associated with the mitigation of the spilled mercury in this 60 square foot office area: Outside Vendor Cleanup Company – Time, Materials and Labor: $4000 Replacement of Mercury Spill Vacuum: $3200 Medical Follow up (Blood Testing) For Hospital Staff: $260 Mercury Disposal Costs: (Will Vary Per Vendor Used): $1600 Labor Hours Cost for Hospital Personnel Involved Est.: $1000 Total Costs for Spill Mitigation: $10060

Source: Adapted from http://www.sustainablehospitals.org/PDF/IP_spills_cost.pdf

-Large spills

Larger spills or spills in which the contamination has spread are often more expensive and difficult, as these spills involve more sophisticated methods of collection, decontamination, and disposal (http://www.epa.gov/osw/laws-reg.htm). For instance, in June 2000, a Newmont contractor carrying containers of mercury spilled 330 pounds of the chemical over 25 miles of roads and towns in Peru. The mercury was picked up by locals who thought it was valuable. Some of them boiled it on kitchen stoves looking for gold. The spill affected 1 100 people and required a massive, multimillion-dollar cleanup effort by Newmont that included digging up streets and the floors of homes. A later World Bank investigation found that Newmont had stopped using an Environmental Protection Agency-approved container for the mercury; that the mercury had been loaded incorrectly on an open truck; and that company officials initially misrepresented the size and seriousness of the spill, hampering emergency response efforts (http://www.theminingnews.org/news.cfm?newsID=191).

Hence, the developing countries may have regulations when it comes to large spill but they are often not respected and the case in Peru has been a wake-up call.

When it comes to large spilled quantities, the damage costs are difficult to estimate. In the case of Newmont, the mining firm offered up to around $5900 to more than 700 local residents, but over 1 100 others are still engaged in a legal battle (http://en.wikinews.org/wiki/Peruvians_sue_Newmont_Mining_Company_over_mercury_poisoning

14 Control and remediation of contaminated sites

14.1 Overall assessment of costs and benefits

Qualitative Cost Assessment: many techniques can be used for cleaning up contaminated sites and the costs dependent on the used method.

Qualitative Benefit Assessment: Compared to cleaning up costs, the benefits may be very large

14.2 Hg abatement efficiency and costs

Given the unique behaviour of Hg, several techniques exist or are currently being developed for remediation of contaminated sites. Since, the Hg species present in a given environment depend on the initial released form, the thermodynamic stability of this compound and the transformation rate of the released form to a more stable one (Baeyens et al, 1979). These issues must be well understood to effectively design and evaluate appropriate remedial solutions in Hg impacted areas (Hinton et al 2001). However, any measure employed must consider the risk to ecological or human health and have the acceptance of regulators.

Below are some examples of techniques where their costs are qualitatively described (adapted from: Minamata).

-Excavation and ex-situ (i.e. off-site or aboveground) treatment of Hg-contaminated soils is the most frequently employed practice for Hg recovery. Although excavation can be complicated if it extends below the water table or costly if the contamination is distributed over a large area, it is essentially a well-understood practice.

-Thermal Treatment: As the volatility of Hg and its compounds increase with temperature, thermal heating of excavated soil is a potentially effective means for Hg recovery from contaminated soils.

-Hydrometallurgical Treatments: Chemical extraction of Hg from excavated soils can be induced through four primaries mechanisms: desorption of adsorbed species; oxidation of metallic Hg; use of strong complexing agents; and through dissolution of precipitated Hg. Efficiency of any mechanism employed may decrease over time due to re-complexation and re-adsorption and removal of the most soluble compounds at early time.

-In-Situ recovery: Methods for in-situ recovery of Hg are far less established than ex-situ techniques. As well, due to subsurface heterogeneity, more uncertainly generally exists concerning the effectiveness of in-situ processes, and clean-up times tend to be longer than ex-situ treatments. Despite these factors, many in-situ technologies are very promising and – mainly due to the fact that contaminated soil and groundwater remain in the subsurface – may become more cost-effective and practical than excavation and treatment methods for many Hg-contaminated sites.

-Soil Vapour Extraction coupled with Soil Heating: Soil Vapour Extraction uses a vacuum to force air through the unsaturated zone. Currently, soil heating can be costly over expansive areas and difficult to homogeneously heat a soil volume.

- In-situ Leaching and Extraction: Used in conjunction with Pump-and-Treat systems, In-situ leaching and extraction involves the injection of chemicals to enhance Hg solubility in groundwater, thereby reducing clean-up time and improving recovery rates from groundwater.

Pump-and-treat is a frequently practiced, cost-effective remedial alternative employed either for removal contaminants from the subsurface and/or hydraulic containment of a contaminant plume.

-Electro-Kinetic Separation: This process involves the generation of an electric field through application of a low-voltage direct current in a soil matrix. Heavy metals, such as Hg, migrate towards electrodes placed in the soil where they accumulate and can subsequently be removed at a lower cost than excavating the entire impacted area.

-Interceptor Systems: Interceptor Systems, such as trenches and drains, are extremely simple and effective at recovering Hg as "free product" (essentially as metallic Hg); however, this treatment is limited by topography and stratigraphy and does not address Hg held in residual saturation.

- Phyto-remediation: Phyto-remediation is a promising albeit unproven technology, wherein plants assimilate and concentrate metals from soils. This technique holds much promise for the cost effect remediation of shallow soils over a fairly widespread area, but issues such as limited access to vegetation by wildlife and time required for clean-up must be addressed.

For the sake of illustrating clean up costs, an example from Sweden may give some insight on the magnitude of these costs. EKA was a chlor-alkali firm which closed in 1928. The total costs to decontaminate the area where the industry was located are estimated to $28 million in 2008. About 90% of the estimated existing 16 tonnes of hg will be removed leading to a cost of around $1 944 /kg Hg. An extra benefit of this measure is a removal of around 850 g dioxin (http://www.nwt.se/ArticlePages/200707/09/20070709211004_437/20070709211004_437.dbp.asp) .

Comparing the clean-up cost estimated in the Swedish case with Hg damage related to ingestion of fish i.e. $12 500/kg Hg, the benefits are much higher than the costs.

15 Increase of knowledge and capacity on mercury among states

15.1 Overall assessment of costs and benefits

Qualitative Cost Assessment: Small to large
Cost Categories: Research, information sharing

Qualitative Benefit Assessment: Large.

15.2 Increased knowledge on environmental assessment and options to reduce Hg pollution on global scale

Mercury pollution has been widely recognized as a global problem. Therefore there is a need for global action to protect human health and the environment against mercury pollution. The UNEP Governing Council in 2001 commissioned the Global Mercury Assessment, which was completed in 2002. This assessment concluded that policy action on global scale could have significant effect on mercury levels in the environment. Furthermore, the UNEP Governing Council concluded in 2003 that there is enough evidence on significant global adverse impacts from mercury to warrant further international action to reduce the risks to humans and wildlife from the release of mercury. In 2005, ministers and other government representatives from several countries met at the UNEP meeting and addressed the question of establishing of a possible international convention aiming at the reduction of emissions of and exposure to mercury on a global scale. Interesting report on the global assessment process and its history is described by Eckley Selin (2005).

One of the important issues related to establishing of global mercury convention is the understanding of the global mercury problem and its potential solutions by policy makers in individual countries and their political will to agree on reduction of Hg emissions and exposures. Increased knowledge on various options for such reduction is of primary importance towards obtaining such agreement. Therefore, there is considerable benefit to further increase knowledge of mercury contamination, specifically in the areas of inventories, human and environmental exposure, environmental monitoring, and socio-economic impacts.

International programs and conventions play a very important role in building capacity among various countries with regard to their knowledge on sources, environmental transport, effects and emission reduction options for mercury. The UNEP has developed a Toolkit as a guidebook on how to estimate emissions from various emission sources in countries which do not have their own methodologies for emission estimates. Accurate and complete data on emissions is a prerequisite for any further assessment of fate and effects of contaminants, as well as for assessing their future changes. A number of countries used this Toolkit when calculating their national emissions for submission to UNEP (UNEP, 2008 – in preparation).

The most comprehensive international agreement regulating mercury to date is the 1998 Aarhus Protocol on Heavy Metals to the UN ECE Convention on Long-range Transboundary Air Pollution (LRTAP) (www.unece.org), This convention covers the European countries, the United States and Canada. The member countries report their emissions to the European Monitoring and Evaluation Programme (EMEP) (www.emep.int). The Aarhus Protocol establishes the emission reduction limits for Hg and other heavy metals and suggests best available techniques for limiting emissions from various sources. An important tool for improving the capacity on development of emission inventories and their future scenarios for the LRTAP countries, as well as other countries is the Joint EMEP/ CORINAIR Atmospheric Emission Inventory Guidebook (http://reports.eea.eu.int/EMEPCORINAIR3/en/) (UN ECE, 2000).

The Arctic Council with its 8 member countries and 6 permanent participants representing Arctic indigenous groups is another setting providing the opportunity for capacity building and our knowledge on sources and impacts of mercury as a global pollutant. The Arctic Monitoring and Assessment Programme (AMAP) has been involved in development of global emission inventories for mercury (e.g. UNEP, 2008 – in preparation), monitoring the Hg levels in various environmental ecosystems in the Arctic and assessing environmental and human health impacts of this contaminant (e.g. AMAP, 2002)

15.3 Increased knowledge on environmental assessment and options to reduce Hg pollution on regional and national scale

Policy makers in Europe have taken the advantage of improved information on emissions. Following the preparation of a Position Paper on Ambient Air Pollution by Mercury (http://europa.eu.int/comm/environment/air/background.htm#mercury see also EU 2001), the EU adopted the European Mercury Strategy (http://europa.eu.int/comm/environment/chemicals/mercury), the EU Community Strategy Concerning Mercury. The development of this strategy has been accompanied by a number of research projects supported by the European Commission to obtain more knowledge on mercury and to develop tools that can be used by the EU member states and other countries to assess emissions, fate, and impacts of mercury pollution and to propose policies on how to reduce these emissions and impacts. These projects include: MAMCS (Mediterranean Atmospheric Mercury Cycle System: www.eloisegroup.org), MOE (Mercury Over Europe: www.eloisegroup.org), MERCYMS (An Integrated Approach to Assess the Mercury Cycle into the Mediterranean Basin: www.iia-cnr.unical.it/MERCYMS/project.htm), and ESPREME (Estimation of Willingness-to-pay to Reduce Risks of Exposure to Heavy Metals and Cost-benefit Analysis for Reducing Heavy Metals Occurrence in Europe: http://espreme.ier.uni-stuttgart.de). A large data base has been developed and used in various countries on emission control technologies that can be used to reduce emissions from various sources with information on the efficiency of these technologies and their investment and operational costs.

The overall objective of the EU DROPS project (http://drops.nilu.no) was to provide a full-chain analysis related to impact of health protection measures related to priority pollutants, including mercury in order to support the development of cost effective policy measures against pollution related diseases and their wider impacts (Pacyna, 2008). The main achievement of the project is the development and application of methodology for the assessment of costs and benefits from the implementation of measures for the reduction of human exposure to selected contaminants. This methodology consists of models, analytical procedures, and databases. The models and databases developed within the EU projects can be used in countries worldwide after certain adjustments to specific conditions that may be in place when using the European data outside the region.

The body of mercury information developed by the United States is described or referenced in the U.S. EPA's Roadmap for Mercury of July 2006 (www.epa.gov/mercury). International cooperation and capacity building was fond in the Roadmap as an important tool to help further mercury reduction efforts. For example, the United States participated in a capacity building program to help the government of Burkina Faso develop a more accurate and comprehensive mercury inventory. This work helped to inform local authorities on environmental concerns, setting the stage for the development of and regulations for mercury control.

The South African Mercury Assessment (SAMA) program has been organized in South Africa to improve the knowledge on sources, behaviour and impacts of mercury in the country (Leaner et al., 2008). Another initiative to improve our knowledge on these issues is the South African – Norwegian project on mercury in South Africa (MERSA). Both initiatives can provide a possibility for capacity building on mercury pollution in the whole continent of Africa with benefits to other African countries.

15.4 Increased knowledge as a factor to the development of policy options

Major benefits of an increased knowledge for the development of policy options to reduce pollution were reviewed by Swain et al. (2007). This review is available in the Appendix 1. The following policy options were reviewed: 1) policy options to reduce releases of Hg to the environment and 2) policies to limit exposures to Hg through risk communication. Releases of Hg to the environment can be reduced by policies related to the supply or demand of Hg, implementation of technological controls for reduction of industrial emissions or discharges from waste disposal, or the reduction of quantities of produced goods that result in such releases. In general, policy options used routinely to reduce pollutant emissions from industrial processes include technology requirements, emission performance standards, emission taxes, and cap-and-trade (CAP) approaches. Other policy options such as subsidies and restrictions on the sale and disposal of Hg (and Hg-containing items) could influence Hg releases from small-scale practices such as artisanal gold mining. Application of any of these alternative policies to Hg reduction will have benefits and costs. An economic approach to evaluating different policy options is to balance, at the margin, the benefits and costs of any policy option. Such policies are deemed economically efficient. The knowledge of policy options, their efficiency in Hg reduction and cost of implementation, as well as environmental, and human health benefits is needed for policy making at a national and regional level in order to introduce ecosystem based management of environmental resources in a given country.

In the case of Hg, economic analysis is complicated by the need to track benefits and costs at various geographic scales, from local to global. While the costs associated with the implementation of new processes or control technologies can be estimated in a relatively straightforward manner, the assessment of benefits is complicated by the scientific uncertainties reported in the environmental literature [i.e., the linkages between reducing environmental Hg releases and lower levels of Hg in the atmosphere and in fish (Lindberg et al., 2007; Munthe et al., 2007)] and health science literature [i.e., linkages between reduced levels in the environment, reduced exposures, and health improvement (Munthe et al., 2007). Ideally, economic analyses highlight these uncertainties as well as those introduced in the benefit–cost component of the analysis, and researchers will conduct additional analyses to assess the sensitivity of the results to the assumptions associated with the uncertainties (US EPA, 2000).

In addition to reducing Hg releases, human Hg exposures can also be reduced through risk communication policies, including fish consumption advisories, improved communication of the occupational risks associated with Hg releases during artisanal gold mining, and product labelling. Consumption advisories and the risk communication challenges associated with small-scale gold mining are often in focus. However, the practical implications of advisories on fish consumption have seldom been documented, and most likely vary a great deal depending on the nature of the advice, how it is communicated, and the alternatives available to the community.

Information digests for policy making with regard to the costs and benefits of reducing Hg emissions and exposure can be the way for communication of scientific knowledge to the policy makers at state, regional, and local levels. The development of information digests can be

coordinated by the UNEP Chemicals Global Mercury Partnership. The digests should include the guidance on how to prepare economic analysis (such as the U.S. EPA, 2000) and databases with information on efficiency and costs of possible environmental protection measures (such as the EU ESPREME project database http://espreme.ier.uni-stuttgart.de) the EU DROPS project database (http://drops.nilu.no).

Mercury Information Clearinghouse is another example of how the latest information on mercury policy, measurement, baseline levels and emissions, and control can be communicated to policy makers, as well as general public with mercury users and consumers. An example of such information channel can be mercury Information Clearinghouse on Advanced and Developmental Mercury Control Technologies available from the national technical Information Service at the U.S. department of Commerce (U.S. DoC, 2004).

Training workshops can be organized in different parts of the world with regard to the use of existing methods and databases on the assessment of benefits and costs related to the reduction of Hg pollution worldwide. Such workshops can be organized under auspicious of the UNEP Chemicals Global mercury partnership.

16 Increase of knowledge and capacity among individual mercury users and consumers

16.1 Overall assessment of costs and benefits

Qualitative Cost Assessment: Small.
Cost Category: Consumer education.

Qualitative Benefit Assessment: Large.

16.2 Capacity building as an instrument for pollution mitigation

Increased information knowledge and capacity building among individual Hg users and consumers may be seen as a policy instrument to reduce the emissions of Hg and thereby the environmental and health impacts of this pollutant. Except regulations and market based instruments, capacity building information and co-operation are a cost effective instruments to mitigate pollution.

Capacity building can be defined as "*People helping people to build skills to change their own future. Skills can be built a number of levels, including at the level of the individual, organization, community or system*". Furthermore, a World Bank summary of participatory processes refers to capacity building as the improved ability to make decisions about a project and transfer information between groups. The focus is on building people's capacity to participate in decision-making about a certain subject, as opposed to identifying capacities in a community and strengthening these elements.

- The information instruments: When it comes to informational instruments a distinction is usually made between information strategies for production and information strategies for consumption. Examples of information based strategies that may be introduced by government towards a cleaner production include (UNEP (2001)):
    - *promoting the adoption of targeted, high-profile demonstration projects, to demonstrate the techniques and cost-saving opportunities associated with cleaner production.*
    - *encouraging educational institutions to incorporate preventive environmental management within their curricula, particularly within engineering and business courses*
    - *issuing high profile awards for enterprises that have effectively implemented cleaner production.*
- Since it is often difficult or in some cases impossible for consumers to trace the original causes of environmental problems, it is vital that the authorities also use information instruments to improve consumers' understanding and awareness of these issues. Extensive research and monitoring work must be supported and published and public awareness of environmental issues should be increased through education and special training. Other informative measures such as environmental labelling schemes attempt to control consumption patterns by encouraging consumers to use products and services that are less harmful to the environment (Finland Env. Ad. 2006).
- Voluntary and co-operative regulatory instruments that do not involve the public directly include energy auditing schemes, promotion of energy savings, promotion of technologies, golden carrot

programmes (e.g. subsidising development and implementation of energy saving products and technologies) and other 'soft' policy instruments. These programmes can be understood as subsidising development or supply of preferred technologies and subsidies for provision of certain types of costly information to firms.

The benefits of capacity building may be summarized in the following:

-increase recycling
-increased use of substitutes
-clean up of spills e.g., remediation of contaminated sites
-increase of storage of excess Hg

16.3 Communication of risk of Hg pollution to mercury users and consumers

Proper communication of risk of Hg pollution to mercury users and consumers is of vital importance with regard to reducing environmental and human health impacts. The issue of risk communication is related to the non-technological measures to limit emissions and exposure to mercury.

The most known non-technological methods of mercury emission reduction include: energy conservation and pollution prevention solutions. Energy conservation means using less energy to achieve the same level of energy service. Energy services include heat, light, sound, shaft power, and mobility. Decreasing energy production and use will result in the decrease of mercury emissions and provide additional benefits of reducing emissions of sulfur dioxide and other pollutants. A system of credits or vouchers could be developed and presented to the utilities for mercury reduction goals. Demand-side management (DSM) programs should be identified. The DSM refers to actions undertaken by, for example, electric utility to modify customer demand patterns. The DSM programs consist of information dissemination, technologies, or financial incentives.

A few solutions of pollution prevention can be presented for mercury, including:

- materials separation,
- product content bans,
- input taxes on the use of mercury in products, and
- labeling of products.

Material separation deals mostly with the separation of mercury containing materials from the waste streams of MWCs and MWIs. A very small portion of wastes (perhaps less than 1 %) containing very high content of mercury from batteries, fluorescent lights, thermostats and other electrical items needs to be separated from the rest of the wastes, such as paper, plastic, dirt, containing very low concentrations of the element. Several communities in many countries all-over the globe have already implemented household battery separation programs in an effort to reduce mercury in wastes to be incinerated.

Labelling the mercury-containing products would help consumers to select the ones which are mercury-free. This is particularly important for switches and devices that most consumers would not expect to contain mercury.

Consumer education and awareness is also an important aspect of dealing with the public health threats posed by mercury. Considerable benefit has been found in Europe and the United States in

consumer awareness programs as awareness provides a critical tool for preventing exposures. Experiences with responding to and cleaning up local mercury spills and other unusual mercury hazards demonstrates that quick communication and effective response can make all the difference between mercury poisoning and a quick, easy clean-up effort. Experience also shows that making sure that contaminated areas are quickly identified and that local residents are aware of how to recognize and report environmental hazards can greatly help to prevent avoidable exposure. Well-established notification procedures go hand in hand with effective clean-up and rehabilitation policies and processes in helping to safeguard the public.

Elemental mercury is put to magico-religious uses, most problematically the sprinkling of mercury on floors of homes in Caribbean and Latino communities. Indoor mercury spills are persistent and release toxic levels of mercury vapour over long periods of time (e.g. Wendroff, 2005). It is claimed that ritualistic mercury contamination should be taken seriously by both the public health and the environmental health communities. Risk communication is an important issue in the matter.

Consumer advisory with regard to the risk to Hg pollution is also very important element of capacity building of users and consumers. Fish consumption advisory was mentioned in the previous chapter. Various reference doses with regard to safe level of methyl-mercury content in fish were proposed by various organizations, such as Food and Agriculture Organization (FAO), the European Commission, Health Canada, the U.S. Food and Drug Administration (FDA), the US EPA, ranging from 0.1 to 0.4 of MeHg per kg of body weight per day. It is very important that consumers are properly advised on the safe level of methyl-mercury in fish. However, one should be aware that this advice is based on solid scientific evidence. It should be remembered that eating fish provides high nutritional value such as vitamins A, F, and C, protein, omega-3 fatty acids, mono-lipids, iron and zinc.

Another example of a risk communication can be the advisory to small scale gold miners and their families (Swain et al., 2007). In the case of small-scale gold mining using Hg amalgamation, the primary toxicological issue is the inhalation of Hg converted to the gas phase during the heating of the amalgam. Heating often takes place inside or near the home. Artisanal workers and their families can be exposed to harmful levels of Hg vapor. Risk communication in the form of advice to avoid the Hg amalgamation technique or to reduce exposure during its use must take into account the limited options available to the gold miners and the widespread poverty and hardship associated with this occupation. Field researchers (e.g., Vega and Hinton, 2002; Spiegel et al., 2006) emphasize that effective risk communication strategies need to be intertwined with strategies targeting improved profitability through better gold recovery methods or reduced losses of Hg, thus reducing the artisanal miner's production costs. Within each country, the industry is geographically scattered, so the logistical aspects of risk communication are a major challenge. Thus, to be effective, in each region, risk communication strategies may involve training a cadre of small-scale gold miners who can demonstrate and discuss the advantages of improved practices to their fellow miners (Spiegel et al., 2006).

Industries using mercury have also responsibility to take for informing the public on human risk related to their products. For example, the Computer TakeBack Campaign aims to protect the health and well-being of electronics users, workers, and the communities where electronics are produced and discarded by requiring consumer electronics manufacturers and brand owner to take full responsibility for the life cycle of their products (www.computertakeback.com)

17 Concluding remarks

During the recent decade major progress has been made in the assessment of anthropogenic sources of mercury and development of emission inventories on national, continental and even global scale, including development of scenarios addressing mercury emissions until 2020 (UNEP,2008 – in preparation). Key relevant to the consideration of costs and benefits are:

1) what are the abatement costs for Hg emission reductions using various measures in different emission source categories?, and
2) what are the environmental and societal benefits of Hg emission reductions?

In an attempt to deal with these questions, a quantitative assessment of the potential costs and benefits associated with Hg reductions within major emission source categories has been attempted in this report. This assessment started with the information on socio-economic consequences of mercury use and pollution, integrated and synthesized within the paper published by a group of authors including Swain (the lead author), Jakus, Rice, Lupi, Maxson, Pacyna, Penn, Spiegel and Veiga in the Ambio journal in 2007 (Swain et al., 2007). The paper is included in Appendix 1 with the permission from Ambio and the lead author.

A number of technical and non-technical measures are available for reducing the Hg emissions from: anthropogenic sources where Hg is a by-product (e.g. power plants, smelters, cement kilns, other industrial plants), waste disposal and other various uses. Measures differ with regard to emission control efficiency, costs, and environmental benefits obtained through their implementation. Very often Hg emissions are substantially reduced by equipment employed to reduce emissions of other pollutants. The best example is the reduction of Hg emissions by the desulfurization installations. The same applies to de-NOx installations, and control devices reducing emissions of fine particles. It can be concluded that technical measures for mercury emission reduction are available within the major emission sources categories, such as combustion of coal to produce electricity and heat, manufacturing of non-ferrous metals, iron and steel production, cement industry and waste incineration. These measures vary with respect to the emission control efficiency and cost. Most measures could reduce Hg emissions from the above mentioned sources by up to 90 % without employing any "add on" equipment, such as adding absorbents specific for Hg.

Since the sources of waste containing Hg differ and the emissions from these sources are local and/or region specific, the costs to reduce the generation of wastes differ depending on whether the source is in a developed country or in a less developed one. Preliminary Qualitative Cost Assessment reveals that these costs are variable depending on the management technique, such as incineration and land filling. Whilst the introduction of various emission control measures may give results in the developed world, the outcome of this strategy may not be very positive in the developing world where there is often no differentiation between municipal, hazardous and medical waste in terms of applied techniques or achievable emission limits. Therefore, emphasis in the developing countries should be put on developing adequate policy instruments to mitigate Hg releases.

Efficient, non-technological measures and pre-treatment methods are also available for the reduction of Hg releases from various uses of products containing mercury. These measures include ban on use and substitution of products containing mercury, and cleaning of raw materials before their use (e.g. coal cleaning). These measures also include energy conservation options, such as energy taxes, consumer information, energy management and improvement of efficiency of energy production through a co-generation of electricity and heat in coal-fired power plants. These

measures also include prevention options, such as Hg containing wastes and material separation, labelling of Hg containing products, and input taxes on the use of mercury in products.

Capacity building through improvement of knowledge on Hg pollution impacts, emission reduction options, and their costs among authorities responsible for environmental protection in various countries and among individual mercury users and consumers is also a very important issue at present, as explained in the reported work.

The costs of mercury spills are not well documented and tend to be anecdotal. In the developed world costs to clean up small spills are very high compared to both the benefits of cleaning up as well as the costs of substituting the products with potential spill. For large spill the damage costs as well as the abatement costs are quite difficult to estimate depending on whether the spill takes place in a developed or a developing country.

Information is becoming available from the literature on benefits to the environment and society from implementation of various emission control measures for mercury. Environmental and human health consequences associated with Hg pollution have been studied for several decades, starting immediately after the Minamata disease was reported in 1956. The Swedish Medical Board issued bans for sale of fish from certain rivers and lakes due to high concentrations of methyl-mercury in 1967. The US Sport Fishing Institute suggested in 1969 that Hg may be a larger threat than DDT (cited in Eckley Selin, 2005). It became clear that ingestion of methyl-mercury with contaminated food is more dangerous than inhalation of inorganic mercury. Contaminated fish became the main factor in this context. However, there have been several reservations on how to relate the emission of inorganic Hg from various anthropogenic sources to the concentrations of methyl-mercury in fish and then ingestion of methyl-mercury. These reservations have not helped in the development of dose-response functions for Hg, which have only recently been developed.

The development of dose-response functions is a very important step in estimating environmental and human health benefits from reducing the Hg exposure and emissions in the first place. The societal cost-benefit analysis has not been a subject of the reported work. The results of the reported work are meant to contribute to such analysis to describe the environmental and socio-economic impacts of hg emission reductions at local, regional (e.g. continental) and global scale. However, the data reported here were used in another study to a preliminary estimate of societal costs and benefits of Hg reduction on global in the case that there will be a status-quo with Hg pollution in the future (Pacyna et al., 2008 – in preparation). This study concluded that the societal benefits in monetary terms are comparable with the abatement costs. However, the overall environmental and human health benefits from the reduction of mercury emissions from anthropogenic sources would be higher, probably much higher than the cost of abatement measures, because the estimates presented in the study by Pacyna et al (2008 – in preparation) include avoiding damage cost due to a loss of IQ and neurotoxic impacts only. The final conclusion of this study was that there are good reasons to invest in reducing Hg emissions and exposure in the future primarily for the sake of improvement of human health and more generally human welfare, also from economic point of view. The study reported here adds that there are measures for Hg emission reduction for which this investment can be done.

The development of dose-response functions has been also a very important factor in the assessment to what extend the emissions of Hg should be reduced. Shall they be phase-out or only reduce? If phase out, do we have substitution for Hg if necessary for the production process? If it is enough to reduce Hg emissions, do we have efficient enough measures? And the final question is, can we afford from economical point of view to implement measures, necessary for Hg emission reductions? The reported work has been challenged to provide at least some contribution to attempt

answering these questions. However, more research is needed to provide the policy making with more detailed answers to the above questions. The matter is further complicated by the fact that mercury is a global contaminant with emissions in one region to be deposited in another region. It has been recognized that the current efforts to reduce risks from mercury are not sufficient to address the global challenges posed by mercury (governing Council Decision 24/3). Decisions on the most effective way to address these global challenges will need to be taken, and the consideration of the costs and benefits of taking (or not taking) actions will provide input into that discussion.

Information on costs and benefits of mercury reductions within the strategic objectives discussed in this report is available in Table 22.

Table 22: Costs and benefits of Hg emission reduction for various reduction options

Reduction option		Costs	Benefits
1	Reduction from coal usage	Medium →Large	Large
2	Artisanal and small – scale gold mining	Small → Large	Small → Large
3	Reduction of Hg trade emissions	Small → Large	Small → Large
4	Reduction from industrial processes	Medium → Large	Medium → Large
5	Reduction of waste generation	Small → Large	Large
6	Promotion of Hg waste collection and treatment	Small → Medium	Large
7	Reduction from waste disposal	Medium → Large	Large
8	Reduction of Hg consumption in VCM and chlor-alkali production	Small → Large	Medium → Large
9	Reduction of Hg use in products	Small → Large	Small
10	Reduction from dental practice	Small → Large	Medium
11	Reduction of supply from mining and extraction	Small → Medium	Large
12	Reduction of supply from decommissioned cells and stockpiles	Small → Large	Large
13	Prevention of contamination from spreading	Large	Medium → Large
14	Control and remediation of contaminated sites	Small → Medium	Large
15	Increase of knowledge among states	Small → Large	Large
16	Increase of knowledge among users and consumers	Small	Large

It can be seen from Table 22 that costs and benefits vary significantly within various Hg reduction options defined within the strategic objectives set out in Annex 1 of the report of the first meeting of the Open Ended Working Group. Measures with the application of technology, such as implementation of installations to remove Hg from the flue gases in electric power plants, waste incinerators, and smelters are rather expensive (medium to large costs) compared to non-technological measures, such as prevention activity, capacity building, and promotion of Hg-containing waste separation (small to medium costs). Both groups of measures would result in large benefits. This indicates that the technological and non-technological solutions for mercury emission and exposure reductions can be carried out in parallel. More emphasis on technological measures can be put in the developed countries, while the process of emission and exposure reduction in the developing countries may start with non-technological solutions. Technological solutions may be introduced in these countries gradually as a follow-up process after non-technological solutions are in place.

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Products containing waste: http://www.wastecap.org/wastecap/commodities/mercury/mercury.htm

Cost of incinator: http://www.frtr.gov/matrix2/section4/4-23.html

Land fill Lipari: http://costperformance.org/profile.cfm?ID=137&CaseID=137

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Appendix 1

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Socioeconomic Consequences of Mercury Use and Pollution

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Socioeconomic Consequences of Mercury Use and Pollution

Corresponding author:

Edward B. Swain, Minnesota Pollution Control Agency, 520 Lafayette Rd, Saint Paul, Minnesota, USA.
Office: telephone 1-651-296-7800. Fax: 1-651-297-3864.
E-mail: edward.swain@state.mn.us

Paul M. Jakus, Department of Economics, UMC 3530, Utah State University, Logan, UT 84322-3530, USA.

Glenn Rice, 16 Princeton Ave., Ft. Mitchell, KY 41017, USA.

Frank Lupi, Department of Agricultural Economics, Michigan State University, East Lansing, MI 48824-1039, USA.

Peter A. Maxson, Concorde East/West Sprl, 10 Ave. René Gobert, 1180 Brussels, Belgium.

Jozef M. Pacyna, Center for Ecological Economics, NILU, P.O. Box 100, 2027 Kjeller, Norway and Faculty of Chemistry, Gdansk University of Technology, 11/12 G. Narutowicza Str., Gdansk, Poland

Alan Penn, Cree Regional Authority, 277 Duke S., Suite 100, Montreal, PQ H3C 2M2, Canada.

Samuel J. Spiegel, University of British Columbia, 6350 Stores Rd., Vancouver, BC V6T 1Z4, Canada

Marcello M. Veiga, University of British Columbia, 6350 Stores Rd., Vancouver, BC V6T 1Z4, Canada.

Edward Swain is a research scientist with the Minnesota Pollution Control Agency and an adjunct assistant professor at the University of Minnesota. His research on mercury ranges from the history of atmospheric deposition to factors that control methylation. His address is MPCA, 520 Lafayette Road, St. Paul, MN 55155, USA.
edward.swain@state.mn.us

Paul Jakus is a Professor in the Department of Economics at Utah State University. His specialty is non-market valuation, especially with respect to behavioral changes induced by fish consumption advisories. His address is: Department of Economics, UMC 3530, Utah State University, Logan, UT, 84322-3530, USA.
paul.jakus@usu.edu

Glenn Rice is a doctoral candidate at the Harvard School of Public Health. His research interest is human health risk assessment methods, a field in which he has worked for 15 years. His address is 16 Princeton Avenue, Ft. Mitchell, KY 41017, USA.
grice@hsph.harvard.edu

Frank Lupi has a joint appointment as an Associate Professor in the Agricultural Economics and the Fisheries and Wildlife Departments at Michigan State University. His recent research focuses on modeling Michigan fish and wildlife resource demand and value. His address is: Department of Agricultural Economics, Michigan State university, East Lansing, MI 48824-1039 USA.
lupi@msu.edu

Peter Maxson is an engineer and economist who, after many years' work in developing countries, has focused for nearly 20 years on all aspects of commercial mercury flows, national policies and other environmental issues. In the early 1990s he founded the small consultancy, Concorde East/West Sprl, 10 ave. René Gobert, 1180 Brussels, Belgium.
concorde.ew@tele2allin.be

Jozef Pacyna is Director of the Center for Ecological Economics at the Norwegian Institute for Air Research and Professor of Chemistry at the Gdansk University of Technology in Poland. His research on mercury includes assessment of Hg fluxes from anthropogenic sources, application of technological and non-technological measures to reduce Hg emissions, and socioeconomic aspects of such reductions. His addresses are: Center for Ecological Economics, NILU, P.O. Box 100, 2027 Kjeller, Norway and Chemistry Faculty, Gdansk University of Technology, 11/12 Narutowicza Str., 80-952 Gdansk, Poland
jp@nilu.no

Alan Penn works as an advisor for a group of aboriginal communities (Cree) in Northwestern Québec, Canada, who have had a long history of exposure to mercury and who have been the subject of several major epidemiological studies. The Cree experience encompasses Hg losses from chlor-alkali cells, forestry, mining, and - for the last twenty-five years, large-scale hydro-electric development - as well as exposure to MeHg from Hg in northern forest soils and peatlands. His address is: Cree Regional Authority, 277 Duke Street, Suite 100, Montreal (QC) H3C 2M2, Canada
apenn@gcc.ca

Samuel Spiegel is a policy analyst and researcher specializing in poverty and environment issues in Africa. He has worked with the United Nations Industrial Development Organization in Latin America, Africa, and Asia on legal and economic strategies concerning artisanal gold mining and mercury pollution. He is presently pursuing a Ph.D. as an interdisciplinary Trudeau Scholar at the University of British Columbia. His address is: University of British Columbia, 6350 Stores Rd., Vancouver, BC, V6T 1Z4 Canada

samspiegel@gmail.com

Marcello Veiga is the Chief Technical Advisor of the GEF/UNDP/UNIDO Global Mercury Project and an Associate Professor in the Department of Mining Engineering at the University of British Columbia. His address is: University of British Columbia, 6350 Stores Rd., Vancouver, BC, V6T 1Z4, Canada. veiga@mining.ubc.ca

Abstract

In the past, human activities often resulted in mercury releases to the biosphere with little consideration of undesirable consequences for the health of humans and wildlife. This paper outlines the pathways through which humans and wildlife are exposed to mercury. Fish consumption is the major route of exposure to methylmercury. Humans can also receive toxic doses of mercury through inhalation of elevated concentrations of gaseous elemental mercury. We propose that any effective strategy for reducing mercury exposures requires an examination of the complete life cycle of mercury. This paper examines the life cycle of mercury from a global perspective and then identifies several approaches to measuring the benefits of reducing mercury exposure, policy options for reducing Hg emissions, possible exposure reduction mechanisms, and issues associated with mercury risk assessment and communication for different populations.

INTRODUCTION

Mercury (Hg) has historically been used in a wide variety of activities, both in compounds and as a liquid metal, resulting in widespread dispersion and the creation of some heavily contaminated sites. Geological materials that contain high concentrations of Hg are usually found only in areas known as mercuriferous belts, such as along the west coast of the Americas. Even though most natural materials (including coal, oil, and minerals) contain very low levels of Hg, the use of large quantities of these materials releases significant amounts of Hg into the biosphere each year. Because Hg can vaporize at ambient temperatures, the earth's atmosphere plays a major role in the dispersion of Hg. Human activities, including Hg mining, use, and waste disposal, combined with releases from the refining of other metals and the combustion of fossil fuels, have significantly increased Hg emissions to the atmosphere. Compared to preindustrial times, atmospheric deposition has increased uniformly in remote regions by a factor of about three ($\pm$ 1x) (1). Deposition increases above three-fold have been documented near emission sources; these depend on stack height, the quantity and chemistry of the emitted Hg, and local atmospheric chemistry (1). Bacteria in aquatic systems convert a small proportion of the deposited Hg to methylmercury (MeHg), which bioaccumulates in fish (inorganic Hg does not bioaccumulate). Aquatic systems vary in the efficiency with which atmospherically deposited Hg is bioaccumulated in fish. For example, the Hg concentration of fish in neighboring lakes can vary by as much as ten-fold, even when atmospheric Hg is similar (2). Nevertheless, in a given aquatic system the production of MeHg is believed to be approximately proportional to atmospheric Hg deposition, so it is likely that historical increases in Hg emissions have increased MeHg concentrations in fish (3).

Hg use and releases are of concern because of two exposure pathways: consumption of MeHg-contaminated fish and inhalation of elevated concentrations of Hg vapor. The most common route of MeHg exposure for humans and wildlife is the consumption of fish from marine and freshwater sources. While low levels of Hg vapor are normally measured in the atmosphere, elevated concentrations can result from a variety of intentional Hg uses and accidents involving Hg, especially indoors where dilution is constrained.

In industrialized societies, although Hg was once a component in many products, it is now viewed as a material for which the risks of use generally outweigh the benefits. Hg-free substitutes are now viable for nearly all uses (energy-efficient lighting remains a notable exception), although their adoption varies greatly across jurisdictions and industrial sectors. The link between Hg emissions to the atmosphere and fish contamination has influenced policy development in industrialized countries since the mid-1990s, variously resulting in mandatory control of Hg emissions from waste incineration and other sources, restrictions on the labeling, sale, and disposal of Hg-containing products, and control of Hg emissions from coal-fired power plants as recently mandated by federal and state regulations in the United States (4, 5) and Canada (6).

Hg is also a commodity, with net flow from industrialized countries to developing countries, where its uses are less constrained. Annual global Hg consumption peaked at about 10 000 tonnes (t) in the 1960s; at that time large amounts were used in electrolytic and chemical processes, pesticides, paints, and batteries. Use gradually decreased to an estimated 3500 t in 2005 (Fig. 1a). In 2000, however, global trade statistics reveal that at least 9000 t of metallic Hg were bought and sold across national borders, confirming that Hg is an actively traded commodity. However, the Hg market is opaque, with considerable uncertainties associated with many of the estimates presented here.

Significant and growing coal combustion, particularly in developing countries, and industrial-scale refining and smelting of metals also are responsible, in part, for the continued elevation of atmospheric Hg levels (10). Although global Hg pollution of the biosphere is likely a major contributor to the widespread MeHg contamination of fish, effective international agreements that address Hg pollution have yet to be developed.

This paper describes how certain human activities mobilize Hg from geological stores into the biosphere and outlines the resulting social and economic consequences. We present possible policies to reduce exposure to Hg and MeHg, and explore issues associated with risk assessment and communication for different populations. We utilize substance flow analysis, which reveals not only the source and fate of a material, but also potential control points. We discuss policy options for addressing control points in the flows of Hg that could ultimately reduce fish contamination while simultaneously reducing the potential of harmful exposure to Hg vapor.

Concern about MeHg in fish

Exposure to MeHg through consumption of contaminated fish by humans has the potential to interfere with normal neurological development and function and may increase the risk of myocardial infarction (heart attack) (11). Negative neurological and reproductive effects of MeHg on fish-eating wildlife—birds (*e.g.*, loons), mammals (*e.g.*, river otter and mink), and fish that eat other fish—are also a concern (12).

Concern about inhalation of Hg vapor

Absorption of liquid Hg through the skin or digestive system is quite limited, but the body retains 80% of inhaled Hg vapor (13). An indoor spill of metallic Hg, even in quantities as small as a gram, can give rise to Hg concentrations in ambient air that approach WHO recommended limits for occupational exposure. Heating metallic Hg and Hg compounds, such as cinnabar and scrap dental amalgam, has generated fatal inhalation doses (14). Although heating Hg is a rare activity in most societies, an estimated 10 to 15 million people earn their living in small-scale gold-mining operations by amalgamating gold with Hg, and then concentrating the gold by heating the amalgam, thereby releasing the Hg in vapor form. This process directly exposes the miners and can expose their families and neighbors, (estimated to total about 50 million people), to elevated Hg levels (15). In 2005, small-scale or artisanal gold mining was estimated to contribute more than 10 percent of annual global anthropogenic Hg loading to the atmosphere (about 300 out of a total 2400 tonnes, Fig. 2).

Concern about Hg vapor extends beyond small-scale mining to include Hg in products. One such application, dental amalgam, is the most common way that people are exposed to elevated Hg vapor, although the levels are not as high as those frequently encountered in artisanal gold mining. Even though Hg levels in autopsy brain samples correlate positively with the number of amalgam fillings, vapor concentrations from amalgam are usually well below those associated with even subtle neurobehavioral effects (13). Otherwise, Hg is usually encapsulated in consumer and commercial products, such as fluorescent lamps and thermometers. However, these devices can break during use or disposal, releasing Hg into indoor air and the environment. Historical uses of Hg left a legacy of many small bottles of liquid Hg. In the United States, Hg spills have caused

expensive and disruptive clean-up efforts (16). Although adverse health effects have rarely been documented from Hg spills, we do not consider this as evidence of a low potential for harm. For example, three children were hospitalized in Michigan (USA) as a result of Hg poisoning, including one child who was no longer able to walk. Investigation revealed that exposure occurred after a small vial of Hg was spilled in the children's bedroom approximately two to three months prior to detection of the gross symptoms (17).

GLOBAL COMMERCIAL AND ENVIRONMENTAL PATHWAYS

Although somewhat simplistic, conceptually, it is useful to divide the earth's Hg between two repositories: Hg in the biosphere and Hg stored in geological formations. The biosphere encompasses the portion of Earth and its atmosphere that supports life; geological formations include deep sediment deposits, and buried minerals and fossil fuels. The most significant human impact on Hg is its mobilization from long-term geological storage into the biosphere, where Hg cycles between air, soil, and water.

Assuming only two repositories is simplistic because mobilized Hg can enter sub-compartments that appear to be stable, such as Hg encapsulated in a device such as a thermometer, Hg that has settled into deep ocean waters, and Hg sequestered in deep soils, such as the vast peatlands of Canada and Siberia (18, 19) or the ancient soil of the Amazon Basin (20). However, use of only two repositories is useful from a policy perspective because human activity can mobilize the Hg from apparently stable compartments of the biosphere. Thermometers inevitably break, and the Hg in soils can be mobilized through fire (19), forestry practices (21, 22), agriculture (20), climate change (18, 19, 23), and the creation of reservoirs (24). Additional research is needed to understand the fate of Hg that enters both coastal and deep-water marine systems (1).

The movement of Hg into and out of the biosphere is shown in Fig. 2, based on the global model of Mason and Sheu (25), a model that is representative of the current scientific understanding of global Hg cycling (see review of four models by Seigneur et al. (26)). Although there is a considerable range of estimates in the models for specific components of the global Hg cycle and there is uncertainty regarding the scale of natural emissions and reemission of deposited Hg (1), the four models converge on a relatively tight range for total global emissions (natural and anthropogenic); that is, from 6060 to 6600 t yr^{-1}, and for current anthropogenic emissions alone, from 2000 to 2400 t yr^{-1}. Reemission of previously deposited anthropogenic emissions roughly equals current anthropogenic emissions (1). In general, the global models can be considered uncertain, but useful, frameworks.

Although current anthropogenic emissions in Fig. 2 are constrained to 2400 t yr^{-1} to conform to the Mason and Sheu model, it would be reasonable to assign an uncertainty of $\pm$30% to total anthropogenic emissions (1), with some sectors embodying less uncertainty than average and some sectors more. It has been suggested that Hg emitted from global coal combustion has a $\pm$25% uncertainty; nonferrous metal production $\pm$30%; waste disposal and incineration has uncertainty up to 500%; and that Hg use in artisanal and small-scale gold production is too poorly understood to allow a quantitative uncertainty factor to be assigned (1). A protocol, or "toolkit," has been developed to assist countries that wish to identify and quantify sources of Hg emissions (27). The toolkit, including extensive text and a spreadsheet template, explains how to develop detailed quantification of Hg pathways that are only broadly defined in Fig. 2.

Given the uncertainties in the current understanding of global Hg pathways, Fig. 2 can reasonably be used as background information for discussions of policy options that might be adopted to reduce Hg emissions and, ultimately, exposure from fish consumption and small-scale gold mining.

Each letter in Fig. 2 codes for a compartment in which Hg is stored or from which it is released (see Tables 1 and 2). A two-letter code indicates a path from one compartment, indicated

by the first letter, to another compartment represented by the second letter. For instance, VL denotes the pathway of atmospheric Hg to the Earth's surface whereas LV is the path of Hg volatilization from land to the atmosphere, with the annual flux in tonnes next to each arrow. Note that Hg is relatively mobile in the biosphere; in this model, over 80% of the Hg deposited to the oceans is reemitted to the atmosphere. In contrast, only about half of the Hg deposited to land is reemitted within a few years, because Hg can associate strongly with soil.

Pathways with an asterisk (*) are amenable to manipulation to minimize Hg release or exposure at the time this manuscript was written. Therefore, we refer to these pathways as control points. For example, FH* denotes that the exposure of humans (H) to MeHg from contaminated fish (F) may be reduced through selection of fish to consume; it should be noted, however, that in some societies or regions there may be little choice of fish species to consume. The lack of an asterisk indicates that it is unlikely that present social or economic policies can affect that pathway. MP* indicates that the creation of products by manufacturers does not have to include Hg. PV indicates that once Hg is a product component, it is inevitable that some of that Hg will be released to the atmosphere as a result of breakage, no matter what policies, such as recycling, are adopted.

FOSSIL FUEL COMBUSTION: Compartment C

Fossil fuels (coal, oil, and natural gas) contain a wide range of Hg concentrations in their natural state. Some natural gas supplies are high in Hg vapor, but the Hg is routinely removed during refinement before distribution to avoid degradation of aluminum heat exchange surfaces via amalgamation in gas-processing plants (30). Few analyses have been performed on the Hg content of petroleum or oil sands, or on the fate of Hg throughout the oil exploitation and refinery process. While there is a lack of general data on Hg concentrations in oil and oil sands in their natural state, once refined, the Hg emissions from the combustion of these appear to be much lower than from coal (30).

Coal combustion is responsible for about 60% of anthropogenic Hg emissions (pathway CV*, 1500 t yr^{-1}; Fig. 2). A continuous decrease in Hg emissions in Europe and North America since 1980 has resulted from the installation of emission-control equipment, particularly electrostatic precipitators (ESPs), fabric filters, and flue gas desulphurization (FGD) technologies. These existing technologies incidentally capture Hg largely to the extent that coal combustion produces divalent Hg. Metallic Hg vapor (Hg^0) is usually poorly controlled by equipment designed to capture particulates or sulfur. The emitted form of Hg (and its removal) is highly dependent on the coal type and the installed emission control equipment (31).

There are two major types of FGD systems: wet and dry. In general, removal efficiency for Hg in FGD systems ranges from 30 to 85% depending on the proportion of divalent Hg, which is related to the halogen content of the coal. The greatest removal efficiencies with existing technology can be expected when a wet FGD system is installed downstream of a fabric filter (31).

Most utility power plants in developed countries are equipped with either ESPs or fabric filters for particulate control. Removal of Hg by these devices is highly dependent on halogen content and unburned carbon in the flue gases. Generally speaking, fabric filters remove approximately twice as much Hg as ESPs under similar flue gas conditions (5, 31). As part of efforts to control Hg emissions from coal-fired power generation, significant new information is emerging on flue gas chemistry (Hg, chlorine, sulfur, and the effect of nitrous oxide, or NOx, control) that will help to improve Hg control. A wide variety of technologies are being developed (5, 32, 33) and applied (34) to reduce Hg emissions. As with other emission control technologies (e.g., SO_2, NOx, etc.), it is possible that innovations will yield commercially available options that are significantly less costly than initially estimated (35).

ORE REFINING: Compartment O

Ores of metals, especially nonferrous metals such as gold, silver, copper, lead, zinc, and nickel, often contain Hg because the geological processes that concentrate these metals typically also concentrate Hg. In particular, sulfide ores often contain significant concentrations of Hg, because of a high chemical affinity between Hg and sulfur. Cinnabar—mercuric sulfide—has been the main source of Hg as a commodity for thousands of years. Despite recent mine closures in Spain and Algeria, cinnabar mining of 1300-1400 tonnes annually remains the largest source of elemental Hg (Fig. 2; 9) and is increasing in China to meet internal demand. The processing of cinnabar is associated with elevated atmospheric Hg emissions. As global Hg demand declines, however, less expensive sources of Hg—recycling, Hg from closed chlor-alkali plants, and as a byproduct from large-scale gold, zinc, and copper mining—may be expected to supply a greater proportion of Hg demand. The availability of Hg as a byproduct may increase significantly if new regulations restrict Hg emissions from ore refining.

Hg IN MANUFACTURING AND PRODUCTS: Compartments M and P

Sources of Hg to industries include new Hg from current mining (pathway OM) as well as recycled Hg (pathway RM). Hg has been intentionally used in many products and processes, although consumption decreased by ~ 50% from 1990 to 1998 (Fig 1). Annual use of Hg in products in 2004 (Fig. 3) was comprised mostly of dental amalgams (270 t), electrical switches and relays (150 t), measuring/control equipment (160 t), energy-efficient lighting (110 t), and disposable batteries (estimated at 600 t). Smaller quantities also continue to be used in an array of other products. For example, some Hg is used in cosmetics; in the USA, up to 65 ppm is allowed. Hg continues to be used in chlor-alkali (chlorine and caustic soda) production (possibly 700 t in 2004, but declining every year) and as a catalyst for the production of vinyl chloride monomer. The latter remains a significant use in China, India, and Russia (estimated at 250 t yr^{-1} in this paper, although recent information from China puts this number as high as 600 t (37)).

Before 1990, large quantities of Hg were used in ways that dispersed Hg widely in the biosphere; these uses included fungicides used in seed coatings, the paper industry, and latex paints (38). Today, most Hg added to products is not released during normal use, with the exception of Hg-containing skin-lightening soaps and creams; vaccines containing thimerosal (a Hg-containing preservative that is injected into the body during vaccination); dental amalgams; and volatilization from Hg-catalyzed polyurethane products. The largest remaining dissipative use of Hg is in dental amalgams, which can result in direct human exposure during inhalation, occupational exposure in the dental office, releases to wastewater both from dental offices and homes, emissions during incineration of dental wastes, and flue-gas emissions during cremation (pathways PH, PV, PD*, DA*, and DV*).

Electrical switches and relays, measuring/control equipment, energy-efficient lighting, and batteries do not release Hg until disposal, except due to misuse or accidents (pathways PH and PV). It is possible to manufacture these products in such a way as to limit air or water emissions of Hg (pathways MV* and MH*). Therefore, the extent of Hg emissions from Hg-added products is likely a function of the method of disposal (pathways MD* and PD*). Chlor-alkali factories reportedly have greatly decreased their Hg releases in many nations (39, 40). However, considerable uncertainty remains regarding the environmental fate of hundreds of tons of Hg unaccounted for annually by the global chlor-alkali industry, much of it released within developing countries.

Polyvinyl chloride (PVC) is typically manufactured from petrochemical feedstocks. There is, however, a Hg-catalyzed method to make a PVC feedstock, vinyl chloride monomer (VCM), from coal; this method typically results in large Hg consumption. Such PVC production is a substantial contributor to Hg releases (pathways MV*, MH*, but mostly MD*), conservatively estimated at

150 t yr^{-1} (9, 41), but possibly twice that amount (37). However, there remains considerable uncertainty as to what part of those releases go the atmosphere in contrast to other waste streams.

The substantial reduction of global Hg use (Fig. 1a) is due to two factors: (1) substitution of non-Hg products (*e.g.*, paints, batteries, thermometers, and pesticides) and production processes (mainly chlor-alkali) and (2) more efficient use of Hg in production, except, typically, in cases where production has been shifted to developing countries.

SMALL-SCALE GOLD MINING: Compartment S

A combination of high gold prices and persistent poverty contributes to a proliferation of small-scale gold mining that uses Hg amalgamation to concentrate gold (42, 43). While the scale of gold production by artisanal miners is not well defined, it may constitute 20 to 30% of global gold production, ranging from 500 to 800 t of gold each year (44, 45) and occurs in over 50 developing countries (15). Because gold is easy to sell and transport, and its value remains relatively stable in countries with unstable currencies, it constitutes one of the more important extraction economies (42).

Hg is widely used in small-scale gold mining, despite laws prohibiting its use. Hg is combined with gold-containing silt or crushed ore to form a gold-Hg amalgam, simplifying recovery of the gold. Generally the amalgam is then heated with a blowtorch or over an open fire, vaporizing the Hg and leaving the gold behind (pathways SV*, SH*). Miners are estimated to lose, on average, 1 to 2 grams of Hg per gram of gold produced; thus, this process annually releases approximately 1000 t of Hg to the biosphere, of which an estimated 300 t is emitted directly to the atmosphere (Fig. 2, 3). Virtually all of the Hg consumed by this activity is released somehow to the environment. The leading consumer of Hg through this activity is thought to be China (200 to 250 t yr^{-1}), followed by Indonesia (100 to 150 t yr^{-1}), while Brazil, Colombia, Peru, the Philippines, Venezuela, and Zimbabwe each consume an estimated 10 to 30 t yr^{-1} (46-48). The unregulated trading of Hg in developing countries makes it readily available at the mine sites (pathways OS*, RS*).

Hg use in small-scale mining has left a legacy of thousands of polluted sites with impacts extending far beyond localized ecological degradation, often presenting long-term health risks to persons living in mining regions (49). Inhalation of Hg vapor is the primary exposure pathway for miners, gold shop workers, and people living near areas where the gold-mercury amalgam is produced and processed. Miners and community members often breathe air with Hg concentrations above 50 micrograms per cubic meter—50 times the World Health Organization maximum public exposure guideline. Consequently, many miners and others—particularly amalgam burners, who are often women—demonstrate tremors and other symptoms of Hg poisoning (50). Two mining practices may be increasing local Hg exposure due to inadequate information: improper use of retorts to recover Hg may increase exposure to vapor (51) and cyanide leaching after Hg amalgamation may increase Hg bioavailability and fish contamination (15).

UNIDO efforts to reduce Hg releases have yielded new retorting techniques using readily available pipes and kitchen bowls, which allow miners to contain Hg emissions and recycle as much as 95% of the Hg from the vaporization process (52, 53). Such approaches are garnering increased attention, in particular as Hg prices increased four-fold and more between 2002 and 2005 (Fig. 1b). While the international price for one kg of Hg increased from less than $5 to more than $20 (all prices in constant 2005 U.S. dollars), the price for a kg reached more than $100 in the small-scale gold mining sites in Mozambique, Zimbabwe, and Indonesia.

Hg-free alternatives to dissolve gold (cyanide) or to concentrate gold (e.g., gravity separation, magnetic sluices, and coal-oil gold agglomeration methods) are relatively costly and currently inaccessible to most miners in developing countries (54). Other promising Hg-free techniques to extract gold from concentrates include electro-oxidation and alternative methods of leaching, such

as the iGoli Process. Widespread adoption of Hg-free gold-mining methods would require substantial time and investment in both technology and social-change efforts (55).

RECYCLING AND RETIREMENT (Compartments R, D, and X_T)

All products eventually enter the waste stream. Hg contained in waste products may be recycled (DR*), incinerated (DV*), left in place, dumped on land, dumped into wastewater (DA*), released through breakage during use or disposal (PV) or "retired" through placement in a warehouse, engineered landfill, or deep bedrock repository (DX_T). Every time Hg moves from one compartment to another, there is some loss to the atmosphere and potential for human exposure via inhalation and eventually via deposition, aquatic methylation, and fish consumption (56-58). In some societies, regulations may protect workers from exposure, incinerators may have Hg-control devices, and diversion of Hg-containing products from the waste stream may be mandated. But in much of the world, Hg exposure and disposal are unconstrained (44). The incentive for firms in industrialized countries to recycle is regulatory in nature rather than economic, because the market value of recovered Hg is usually much lower than the cost of recycling. On the other hand, recycled Hg may be considered a "cheap" Hg source because it is a product of the waste disposal process that has already been paid for.

Recycling

From a sustainability perspective, recycling of materials is generally preferred over landfill disposal because recycling obviates the need for (and costs associated with) landfills as well as the environmental costs associated with extraction of virgin material. However, unless it is integrated into a larger strategy of stable or decreasing Hg supply and demand, recycling Hg may not decrease global Hg pollution levels if the recycled Hg is merely returned to the marketplace. In the latter case, Hg recycling could have the effect of increasing the Hg supply and decreasing the price.

Under current regulations in most developed countries, it is cheaper to recycle waste containing a significant percentage of Hg and to sell the recovered Hg on the open market, than it is to dispose of Hg-bearing waste at a hazardous waste landfill (59). The generation of Hg from recycling and the recovery of Hg from decommissioned chlor-alkali plants have become increasingly significant contributors (10-20% in recent years) to global supplies as recycling has increased and the production of mined Hg has declined. However, in the interest of eliminating surplus Hg supplies from the global market, the European Union (EU) draft regulation for a Hg export ban—presently under discussion in accordance with Actions 5 and 9 of the EU Hg strategy. This ban targets all Hg from decommissioned EU chlor-alkali plants for retirement as of 2011 (60). The supporting analysis suggests that recycled and by-product Hg (along with reduced Hg mine production, as necessary) will be more than adequate to meet global Hg demand (36).

Retirement

The alternative to marketing surplus Hg is the intentional retirement of Hg; that is, permanent storage that removes Hg from commerce and the biosphere. Hg need not be recycled, or purified, before it is retired. Unprocessed wastes or pure Hg could be stored indefinitely in warehouses or engineered land disposal sites, such as lined and capped landfills. There have been few efforts to compare the benefits of recycling and retirement, although Sweden has decided to retire Hg wastes (61).

The U.S. government, through the Defense National Stockpile Center (DNSC), owns one of the world's larger stocks of Hg, and in the early 1990s began selling it on the international market after declaring it unneeded for future defense needs. A moratorium on sales was declared in 1994 as a result of concerns that marketing Hg may contribute to global environmental contamination. The relative merit of selling versus retiring the Hg was studied (62), and in February 2006 the U.S.

government announced that the stockpile of some 4400 t of Hg would be stored indefinitely in a warehouse.

Hg IN FISHERIES AND HUMAN COMMUNITIES: Compartments F & H

The consumption of fish is the primary route of exposure to Hg in the form of MeHg (pathway FH*). Patterns of human exposure to MeHg are largely determined by the global distribution of fisheries, the trade in fish, and fish consumption.

Concentrations of MeHg in fish tissues vary by over a factor of ten (63) because of variation in the environmental biogeochemical pathways of Hg and in aquatic foodwebs. Efforts effort to quantify the benefits of reducing anthropogenic Hg pollution are dependent on biogeochemical and foodweb models relating Hg releases to fish concentration. Much of the research on the biogeochemical pathways of MeHg has focused on freshwater ecosystems; in contrast, marine fish make up 92% of the global fish harvest (64). The quantification of reduction benefits would be enhanced if research efforts more closely matched the source of fish that people eat.

The global fish harvest has increased in recent decades and appears to have stabilized at around 130 million t, a figure that includes aquaculture (30 million t) and fish reduced and processed for use in meal employed in both agriculture and aquaculture (20 M t) (64, 65). Based on these estimates, per capita consumption is 24 and 14 kg live weight/year in developed and developing countries, respectively. In some countries (notably in the Western Pacific region), annual fish consumption is appreciably greater, ranging up to 75 kg/person-year. Freshwater fish account for about 5% of the total fish harvest in developed countries and 15% in developing countries.

Over one-third of the global marine harvest of approximately 85 million t enters international trade. Half of the production from developing nations, including tuna and other high-value piscivores, is exported to industrialized nations. The ability to assess patterns of exposure to MeHg is limited by data needed to link Hg concentrations to trade statistics. The quantity of fish produced via aquaculture is an increasing proportion of the global fish production (some 25%), but little is known about MeHg concentrations in these fish.

Fisheries are not easily classified. Commercial, recreational and subsistence fisheries are often closely inter-related. Subsistence fishers often sell part of their catch commercially, a practice that yields cash for goods that must be purchased, such as boats, motors, gasoline, and market foods. Small-scale production of fish appears to involve some 35 million producers and their families, of whom fewer than 5% are from developed nations (65). Subsistence fishing—fishing primarily for local distribution and consumption—remains a significant human exposure pathway in some populations, and can be associated with relatively high levels of chronic MeHg exposure (66, 67). Subsistence fisheries are often held as common property with rules of conduct tending to be informal, local, and unwritten. Quantitative data on production and distribution of fish are rarely available, thus complicating the evaluation of MeHg exposure. The Arctic and sub-Arctic regions present a challenge on several fronts, including the finding that Hg from lower latitudes may be deposited by so-called 'Hg-depletion events' (1), even though there are few anthropogenic emission sources. In some Arctic communities, marine mammals are also a significant dietary source of MeHg. In both Arctic and Sub-Arctic settings, alternatives to locally harvested fish and marine mammals may be culturally untenable, unavailable or not affordable (68).

ECONOMIC ANALYSES OF MERCURY USES AND POLLUTION

Economists often discuss a good's "opportunity cost"; that is, what must be sacrificed to obtain a good or service. For most goods, this is reflected in the price. But when the production of a good involves the release of a pollutant, such as Hg, the price may not include the associated environmental and social costs; these costs are called externalities. A negative production

externality implies that individuals are adversely impacted by production in ways that did not get factored into the product price; for anthropogenic Hg releases, this results when individuals are exposed to Hg or MeHg, as described in Fig. 2. Economists have developed a number of methods to measure the costs of these externalities. We briefly review those methods here, focusing on methods to quantify the benefits to human health associated with reduced Hg exposure. Relative to humans, the effects of Hg on wildlife are poorly understood, so with the exception of the effect of consumption advisories on recreational fisheries, the economic value of reducing Hg pollution has seldom been quantified for wildlife and ecosystem functioning. As our review of existing studies shows, the scientific uncertainties even for humans lead to differing assumptions about health outcomes, which are translated into substantial variation in benefit estimates.

An additional consideration is that economic valuation methods do not work well when the implied tradeoff exceeds a person's or community's ability to pay. Economic analysis becomes very challenging if such tradeoffs are not possible, as might be the case when valuing Hg contamination of subsistence fishing communities with no practical dietary substitutes for Hg-contaminated fish.

Few economic studies have been conducted to quantify the benefits of reducing Hg pollution, and all of those have been conducted in the U.S. (Table 3). Among those few studies, there is only one that included wildlife benefits (69). Including the effects of Hg on wildlife and ecosystems is a daunting task; those studies that exclude such benefits will underestimate the full benefits of Hg reduction (70).

Economists employ two general approaches in measuring the human health benefits associated with a policy (71). Benefit-cost analysis (BCA) evaluates changes in health using monetary values, such as the cost of illness (COI) and willingness to pay (WTP) or willingness to accept (WTA) approaches. Cost-effectiveness analysis (CEA) evaluates these changes using summary measures of population health (e.g., disability-adjusted life years (DALYs) and quality-adjusted life years (QALYs), more generally known as health-adjusted life-years (HALYs). BCA collapses all health-related benefits and costs into a single, monetary metric from which economic efficiency can be evaluated. Those policies in which the incremental benefits exceed the incremental costs are beneficial to society. In contrast, CEA does not monetize benefits, instead this approach evaluates potential policies by comparing the ratio of a policy's cost to its health outcome, in cost per HALY. Policies with low cost per HALY ratios are typically preferred to those with high ratios.

Health benefit assessment using benefit-cost analysis

COI methods are used frequently to monetize the health improvement associated with a change in morbidity (illness). These methods measure the direct costs (*e.g.*, treatment costs) and indirect costs (*e.g.*, foregone income) associated with illness and injury, but do not measure losses associated with pain and suffering. For MeHg, COI methods link changes in the exposure of pregnant women to modeled changes in the IQ of their offspring. IQ changes are subsequently linked to changes in future income (throughout adulthood) and supplemental educational costs. Similarly, MeHg exposures can be linked to non-fatal heart attacks, with COI used to estimate the benefits of Hg reduction policies.

WTP methods measure an individual's willingness to exchange wealth for health. Economists consider such methods to be superior to cost-of-illness methods because they include factors such as impairments to quality of life. For example, the value of a statistical life (VSL) measures an average individual's willingness to pay for a small change in the probability of dying sooner (72-75). Consider a Hg-reduction policy that could reduce the probability of death in a population from 2×10^{-5} to 1×10^{-5}, a reduction of one death per 100 000 people. If people are, on average, willing to trade \$60 in exchange for this policy, then the VSL is \$6 million (\$60 divided by 1×10^{-5}). Currently, the most common estimates for VSL used by researchers and policy makers in

industrialized countries are between $3 and $7 million; the range arises, in part, due to the different values people hold for different types of mortality risks. VSL is positively related to income: a VSL estimated in a high-income country is generally greater than that estimated in a low-income country.

Table 3 summarizes a number of studies that attempt to monetize the benefits (usually human health benefits) associated with reduced MeHg exposure. The BCA conducted by the USEPA (76) as a component of the Clean Air Mercury Rule (CAMR) examined the costs incurred by U.S. power plants to reduce Hg emissions and the monetized benefits associated with IQ increases in the children born to pregnant women whose MeHg exposures would be reduced as a result of the rule. Other groups also conducted benefit analyses of various Hg emissions reduction proposals under consideration during the development of this regulation (77-81). While the economic valuation models used are similar, assumptions regarding the impact of decreased Hg emissions on the changes in MeHg levels in different types of fish, and the health effects considered, differ markedly. All of the analyses emphasized the numerous uncertainties in evaluating specific policies for Hg reduction, including, (i) changes in Hg deposition rates, (ii) changes in fish MeHg levels, (iii) changes in MeHg intake by humans and the time it takes to observe this change, (iv) changes in IQ due to fetal exposure, and/or changes in all-cause mortality and fatal and non-fatal heart attacks in adults. Some analyses assumed that Hg emissions markedly decreased only U.S. freshwater fish MeHg levels; others assumed that marine fish levels, the primary source of MeHg exposure in the U.S., could also decline as a consequence of decreased emissions. All analyses considered the impact of reduced fetal MeHg exposures on changes in IQ and lifetime earnings, although the slope of the MeHg IQ loss dose-response functions and lifetime earnings estimates vary. Some of these analyses also examined the impact of a toxicity threshold for the fetal neurotoxicity of MeHg that would be consistent with the U.S. Environmental Protection Agency's reference dose. Other studies included the possible economic impacts of decreased myocardial infarctions and premature mortality in adults. (See 11, 76, 80, and 82 for descriptions of the uncertainties in the epidemiologic data regarding these health endpoints.) The U.S. EPA also simulated the time required for freshwater fish levels to change following an emissions reduction. These differences led to a large range of benefit estimates across the studies.

Much of the variability across the study results presented in Table 3 is a direct consequence of the differing assumptions that are made in response to uncertainties in the physical and health sciences of Hg and MeHg. For studies that have focused on nationwide programs, such as the emissions cap or the Clean Air Interstate Rule (CAIR) proposed in the U.S., we can see the impact of differing assumptions by comparing the results on a per capita basis. The EPRI study and that by Gayer and Hahn estimated costs of a 15 tonne cap and trade program at between $15 (Gayer and Hahn midpoint) and $21 (EPRI) per capita. Gayer and Hahn, focusing solely on IQ losses, estimate benefits of a Hg cap at less than $1 per capita. In contrast, the Rice and Hammitt study, examining a similar program but including IQ, heart attack and all-cause mortality effects and assuming that there will be changes in both freshwater and marine fish, estimate benefits at about $16 per capita. The authors noted that heart attack and all-cause mortality effects and marine fish MeHg reductions are much less certain than the other factors included in their analysis, but they did not discount the future benefits. Gayer and Hahn firmly conclude that the benefits of the Hg cap and trade program are less than its costs. Palmer et al., looking at Hg within the context of the CAIR, conclude that benefits (using Rice and Hammitt's estimate of $16) exceed the estimated costs of CAIR ($12 per capita). The primary factor driving the different conclusions is the decision on which health endpoints to include, a decision based on uncertainty in the physical and health sciences.

Economic benefits are based, fundamentally, on a person's WTP for reductions in Hg exposure. Whereas the studies in Table 3 represent a good start to a benefits literature, none of them address the theoretically correct, but difficult to estimate, WTP measures that incorporate

uncertainty, such as "option price" (87). For example, consider exposure over time to a given level of Hg in commercially caught seafood. As a result of that exposure, one raises the risk of developing Hg-related health problems, such as AMI, above the baseline risk. Different people receiving the same Hg exposure will react differently: some will have a heart attack and others will not. The option price (OP) measures a person's WTP without resolution of this uncertainty, that is, without finding out if he or she is one of the people whose sensitivity to MeHg increases the likelihood of heart attack. The basic OP model can be augmented to incorporate uncertainty in the health risk itself (e.g., is the best estimate of MeHg-associated increase in AMI risk zero or, is the dose-response slope 0.066 per ppm mercury in hair); it can reflect endogeneity in the risk (e.g., risk estimates can be adjusted based an individual's actions, such as eating more or less fish), and it can include ambiguity about risks (a person may not have a good point estimate of their risk and instead consider their risk to be within a given range). An approach to economic analysis that explicitly incorporates uncertainty seems well suited for the case of Hg, in which policy choices must be made despite the presence of scientific uncertainty in environmental fate, exposures and health effects.

The difficulty with such an approach is that different studies will produce different results. In most cases, a WTP measure such as OP would be elicited via stated preference methods, and WTP estimates will depend on the prior information that respondents have as well as that provided by the analyst. To the degree that researchers differ in the risks and uncertainties explained to respondents, study results will vary and must be evaluated within that context.

Health benefit assessment using cost-effectiveness analysis

The most commonly used HALY measures in CEAs are QALYs and DALYs. Different illnesses are associated with different degrees of severity; for these measures, severity is assessed by a utility weight (71, 73). The utility weights may be based on individuals' preferences for avoiding specific illnesses, or they may be based on expert opinions.

Both Ponce et al. (88) and Cohen et al. (89) examined neurocognitive deficiencies associated with fetal MeHg exposures, assuming that the deficiencies persist throughout the life of the affected individual. The benefit was assessed by multiplying the utility weight (*i.e.*, the decrease in the quality of life that results from cognitive deficits) by the duration of the effect (persisting over the individual's lifetime). For QALYs, this calculation results in the prediction of the quality adjusted life years an affected individual experiences; these are compared with the increased number of quality adjusted life years an individual would experience if a policy to reduce MeHg exposures were put into place. The benefits are expressed as net QALYs gained by the population. For DALYs, the product of the utility weight and duration of the effect results in a prediction of disability-adjusted life years incurred. Population benefits of a policy are then evaluated by the decrease in the number of disability-adjusted life years incurred.

Both QALYS and DALYs are used as the denominators in cost-effectiveness analyses, with the numerator being the cost of the policy. The cost effectiveness of different policies can be compared; those that exhibit the largest gain in QALYs (or decrease in DALYs) for the lowest cost are preferred to those that exhibit smaller gains in QALYs for larger costs.

Benefits assessment in different social contexts

All of the BCAs and CEAs of Hg policies that we found have been conducted in developed countries, with monetary measures and HALYs used to address different economic questions associated with MeHg exposures that result from eating fish. While some of these analyses have attempted to identify subpopulations that benefit from implementation of a policy, most could be improved from additional analyses of the distribution of benefits and costs across the population. Finally, some of these analyses have examined the time frame over which anticipated MeHg exposure decreases and health-consequent benefits might occur. For many, benefits accruing soon

after expenses are incurred are preferred to those same benefits accruing in the future (*i.e.*, time value of money). While beyond the scope of this manuscript, both the manner and rate by which future health benefits are discounted is central to many policy analyses and may be particularly important for Hg, given the uncertain environmental response times implied by current research on the biogeochemistry of Hg (3).

In contrast to the number of evaluations in developed countries, we are not aware of a benefits assessment that examines the costs or benefits of reduced Hg releases and MeHg exposures in developing countries, or benefit assessments focused on those engaged in subsistence fishing or small-scale gold mining (Table 4). Such assessments could differ substantially from those in developed regions. Moreover, caution is warranted when applying these economic techniques in situations in subsistence societies where some Hg policies may greatly disrupt the social structure in a society with few alternatives to subsistence fisheries (Table 4; 90, 91), or in regions where small-scale gold mining is prevalent and there is no realistic alternative to using Hg to make a living. Table 4 also demonstrates that economic analyses of the costs and benefits of reducing mercury reductions are lacking for many of the Hg exposure pathways.

Assessments for other effects, including recreational fishing and environmental degradation

Hg contamination may affect the quality of current recreational experiences, decrease future recreational use in this generation and use by future generations, and affect other values that one might hold irrespective of use. In a BCA, values for these impacts may be elicited directly by using stated preference techniques that rely upon choice in hypothetical situations (*e.g.*, choice experiments or contingent valuation) or they may elicit value indirectly by using revealed preference approaches based on the observed choices of people (e.g., the travel cost model). Champ et al. (92) provide an excellent introduction to these methods.

Jakus et al. (83) used observed human behavior to measure changes in commercial and recreational values due to fish and wildlife consumption advisories. For commercial fisheries, the cost of advisories was based on the market demand and supply for contaminated commercial species. Advice suggesting reduced consumption of striped bass means that at least some consumers will consume fewer bass at any given price. This "shift" in commercial demand is used to measure cost in terms of lost market value accruing to consumers and producers. A similar approach was used to measure impacts on recreational angling. Advice advocating restricted consumption of fish or wildlife altered the number of recreational trips or changed the species targeted. The travel cost method was used to calculate the change in the net value of fishing with and without consumption advisories. The method does not account for possible health impacts to those who do not change behavior in response to advisories.

Hagen et al. (69) used a stated preference method, contingent valuation, to value changes in human health as a result of Hg-reduction policies, as well as the effects on recreational anglers and on wildlife. In this study, people were asked to estimate their willingness to pay for a policy designed to reduce environmental Hg levels. Respondents were asked to consider benefits from changes in their health, their family's health and, possibly, the health of their neighbors and others. As such, this analysis included cultural values, as in the case of a parent who would like his or her children to enjoy eating fish that they have caught as a family, irrespective of the health implications. Values may have been expressed for future generations and broader ecosystem services (so-called "non-use" values), and thus WTP may or may not be tied to one's direct exposure to Hg.

While all of the above analyses have been conducted in developed countries, both revealed preference and stated preference methods have been used in the developing nations on issues other than Hg. In less-developed regions, the suite of Hg impacts may be similar to those encountered in more-developed countries, but the values that these societies (*e.g.*, subsistence fishing communities)

place on these impacts could be very different from the values of those in more-developed countries (Table 4) and should be examined in future studies.

POLICY OPTIONS TO REDUCE Hg POLLUTION

Environmental Hg releases can be reduced by policies that reduce the supply or demand of Hg, implement technological controls (or processes) that reduce mercury releases during the production of goods that result in Hg releases (e.g. gold and electricity), or reduce the quantities of produced goods that result in such releases. In general, policy options used routinely to reduce pollutant emissions from industrial processes include technology requirements, emission performance standards, emission taxes, and cap-and-trade (CAP) approaches. Other policy options such as subsidies and restrictions on the sale and disposal of Hg (and Hg-containing items) could influence Hg releases from small-scale practices such as artisanal gold mining. Application of any of these alternative policies to Hg reduction will have benefits and costs. An economic approach to evaluating different policy options is to balance, at the margin, the benefits and costs of any policy option. Such policies are deemed economically efficient.

In the case of Hg, economic analysis is complicated by the need to track benefits and costs at various geographic scales, from local to global. While the costs associated with the implementation of new processes or control technologies can be estimated in a relatively straightforward manner, the assessment of benefits is complicated by the scientific uncertainties reported in the environmental literature (i.e., the linkages between reducing environmental Hg releases and lower levels of Hg in the atmosphere and in fish; 1, 3) and health science literature (i.e., linkages between reduced levels in the environment, reduced exposures, and health improvement; 3, 11). Ideally, economic analyses highlight these uncertainties as well as those introduced in the benefit-cost component of the analysis and conduct additional analyses to assess the sensitivity of the results to the assumptions associated with the uncertainties (93). Resolution of uncertainty—regardless of the source—will increase the reliability of the economic analyses.

Each of the main policy options has particular strengths and weaknesses. Technology requirements mandate a particular production or control technology, and can have the advantage of offering well-understood pollution reduction. On the other hand, for any specific level of reduction in the release of a given pollutant, economic models suggest that, when compared to other policy options, technology mandates generally have a higher cost than more flexible approaches and may provide less incentive for technological innovation (94, 95). Performance standards offer some flexibility by which firms can reduce costs; for example, firms have an economic incentive to develop less costly control technologies. Ideally, performance standards provide regulators assurance about the level of a pollutant released at each regulated source, an important advantage for pollutants that can have significant local impacts.

Market-based reduction policies can take the form of emission taxes or CAP. Under an emission tax approach, a source may emit any quantity of a pollutant desired but is taxed for each unit released. In CAP, the regulatory authority sets an aggregate emissions level and issues permits (that sum to the target level) to polluters by an auction or simple distribution. Polluters are free to trade permits, with the prevailing price naturally reflecting the incremental cost of control. Economic models suggest that market-based policies spur innovation of new production technologies that are more efficient or less costly than extant technologies (35, 94, 95). If sources of emissions face differing abatement costs, the emissions tax and CAP approaches generally offer lower total costs of control (when summed over all facilities) relative to technology or performance standards. This is because choices about how much to control are made by facility management based on the prices they face rather than by the regulatory authority. A requirement of either the emissions tax or CAP approaches is that emissions be accurately monitored and enforced. For pollutants with local impacts, a key disadvantage of the emissions tax and CAP approaches is the potential for local impacts to persist or increase where facilities deem it uneconomical to reduce

pollution. Some have suggested that this problem can be addressed through differential trading rates in a CAP (96), differential taxes, or combining a CAP with a performance standard. Devising a policy to avoid local impacts under a CAP would require considerable knowledge about local factors that control exposure to such a pollutant.

With respect to large point sources of Hg emission to the air, reduction policies have generally relied on performance standards; for example, in the U.S., performance standards were finalized for municipal waste combustors in 1995, for medical waste incinerators in 1997, and for hazardous waste incinerators in 2002 (44). However, in the case of coal-fired electric power plants, in 2005 the U.S. federal government promulgated a CAP (5, 75). At the time of this writing, the regulation of Hg releases from both large and small sources, and strategies to address supply and demand of Hg, is rapidly evolving. This evolution is partly a function of the limits of economic analysis and uncertainties over the environmental fate, exposure, and health effects associated with Hg releases. While an economic approach may assess the relative economic efficiency of any set of potential policies, the choice of any one policy is subject to a variety of factors, only one of which is efficiency. For example, two different policies may be economically efficient, yet reduce very different amounts of pollutant, have different levels of benefits and costs, or have benefits and costs that are distributed quite differently across a population. Strictly speaking, benefit-cost analysis has little to say about a choice between these two policies. Thus, acceptable policies must also satisfy political, social, and cultural criteria.

POLICIES TO LIMIT EXPOSURES TO MERCURY THROUGH RISK COMMUNICATION

In addition to reducing Hg releases, human Hg exposures can also be reduced through risk communication policies, including fish consumption advisories, improved communication of the occupational risks associated with Hg releases during artisanal gold mining, and product labeling. In this section, we focus on consumption advisories and also provide a brief description of the risk communication challenges associated with small-scale gold mining. We note that the impacts of product labeling policies need additional study.

Fish consumption advisories are considered by many policy makers to be an unfortunate and, hopefully, interim public health necessity. In general, advisories are based on an assessment of the human health risks associated with pollutant exposures, including fetal exposures that result from consuming contaminated fish (e.g., 97). The primary policy goal of a fish consumption advisory is to reduce pollutant exposure by reducing the intake of a contaminant (MeHg, in this case), while maintaining recommended fish intake; this is accomplished by recommending consumption of different fish species, smaller fish, or fish from a different fishery (i.e., a different waterbody with less contaminated fish). The risk managers who develop fish consumption advisories consider multiple issues, including what level(s) of fish contamination should trigger the issuance of an advisory, the species of fish involved, and their availability to consumers. Consideration is given to identifying groups or individuals who should follow the advisory (e.g., fishers, women of reproductive age, or those responsible for food preparation). Techniques for communicating with different audiences need to be evaluated. Last, but certainly not least, the languages and concepts used by consumers to convey information should be studied, as well as aspects of local fishing economies, including distribution and sharing practices. The practical implications of advisories on fish consumption have seldom been documented, and most likely vary a great deal depending on the nature of the advice, how it is communicated, and the alternatives available to the community (e.g., 98, 99).

For public health officials, a fundamental tension exists in the development of fish consumption advisories: how to communicate to people that they should avoid eating highly contaminated fish, but, that they should continue to eat fish because of its nutritional value and the associated health benefits. Fish are high in protein and low in saturated fat. Frequent fish consumption has been shown to reduce the risk of heart disease (100). Policy-makers, thus, prefer to

consider such advisories as 'interim' in the expectation that other measures can be implemented which will effectively reduce the fish tissue MeHg concentrations (3). Knowledge of the impacts of fish consumption advisories on diet is quite limited, and this is an area that requires further research (89).

The contamination of fish by MeHg can be an elusive concept to convey because this toxicant cannot be detected visually in the fish and the fish do not appear to be diseased. Consumers can interpret consumption advisories in various ways; accurate communication of an advisory can be especially difficult when there are linguistic or cultural differences between the risk manager and the affected population (99). Since individuals who communicate advisories may differ in their views of the risks involved and their relation to the nutritional role of fish (e.g. 101), conflicting advice may be received by a fishing community. Those who develop advisories, therefore, require appropriate knowledge of the nature of the fishery itself, as well as fish sharing, preparation, and consumption rates and practices (97, 102, 103).

The use of fish consumption advisories presents additional challenges for remote and isolated communities dependent on subsistence fisheries, including some North American indigenous populations (99). In some subsistence societies, advisories have resulted in complete avoidance rather than reduced consumption of the most contaminated fish (104). The loss or substantial disruption of local fisheries can also have significant public health implications, as well as related cultural impacts (105). Alternative dietary choices available in larger population centers may simply not be available to subsistence populations, and the communities may already face significant diet-related public health problems (such as diabetes). In such settings, health service providers face the task of balancing the message of the consumption advisories against the public health consequences of significant changes in human nutrition (106).

In 2004, the US EPA and FDA released a joint statement (107) that described fish and shellfish as important components of a healthy diet. It noted that "a well-balanced diet that includes a variety of fish and shellfish can contribute to heart health and children's proper growth and development", although "nearly all fish and shellfish contain traces of Hg....". Finally, the statement advised women who may become pregnant, pregnant women, nursing mothers, and young children to avoid some types of fish (i.e., shark, swordfish and king mackerel) due to high MeHg levels and to eat up to 2 meals each week of fish or shellfish that are low in MeHg (e.g., shrimp, canned light tuna, salmon, pollock, and catfish). The joint statement also cautioned consumers to check local advisories about the safety of consuming fish caught in local waterbodies, noting that if no advice was available, to eat up to one fish meal of average size per week, but not to consume any other fish during that week. Several investigators have compared the risks associated with MeHg exposures and the nutritional value and health benefits of fish consumption (11, 88, 89, 108). Their findings generally are consistent with the EPA and FDA statement.

In the case of small-scale gold mining using Hg amalgamation, the primary toxicological issue is the inhalation of Hg converted to the gas phase during the heating of the amalgam. Heating often takes place inside or near the home. Artisanal workers and their families can be exposed to harmful levels of Hg vapor. Risk communication in the form of advice to avoid the Hg amalgamation technique or to reduce exposure during its use, must take into account the limited options available to the gold miners and the widespread poverty and hardship associated with this occupation. Field researchers (e.g. 49, 53) emphasize that effective risk communication strategies need to be intertwined with strategies targeting improved profitability through better gold recovery methods or reduced losses of Hg, thus reducing the artisinal miner's production costs. Within each country, the industry is geographically scattered, so the logistical aspects of risk communication are a major challenge. Thus, to be effective, in each region, risk communication strategies may involve

training a cadre small scale gold miners who can demonstrate and discuss the advantages of improved practices to their fellow miners (53).

CONCLUSIONS

Mercury is a naturally occurring element that can affect the health of humans and wildlife. Humans have historically found Hg to be a useful liquid metal for a variety of social and economic purposes, and currently release some 2400 t yr^{-1} of Hg into the atmosphere. The best estimate is that almost 90% of anthropogenic emissions comes from the combustion of fossil fuels in electrical power generation and from the release of Hg in large- and small-scale mining operations, although emissions associated with intentional Hg use are difficult to quantify and may be substantially underestimated. Some Hg emissions to the atmosphere are deposited relatively near the source, but a large portion enters the global atmospheric reservoir.

The most important pathways of human exposure to Hg are through the consumption of MeHg-contaminated fish and inhalation of Hg vapor. Worldwide, the greatest source of inhalation exposure likely is from small-scale gold mining. The release of Hg used in restorative dentistry can be a source of exposure, but the associated risks are not well understood. Exposure to environmental Hg is believed to have a number of potential negative effects on human health, including these: (i) cognitive deficits (e.g., reduced IQ) in children due to fetal exposure and in adults exposed to high concentrations of Hg vapors; and possibly (ii) increases in fatal and non-fatal heart attacks; and (iii) increases in premature death (i.e., some studies link Hg exposures to increased risk of premature mortality regardless of cause).

While the general pathways outlined in this paper are accepted, a great deal of uncertainty remains in the linkages between emissions and human health. Resolution of these uncertainties is important for analysis of Hg reduction policies, but will be difficult to achieve. The key physical and health science questions include the magnitude of the environmental response, the environmental response time (*i.e.*, the length of time between decreased Hg emissions and consequent changes in human health risks), to what degree decreased exposures will reduce the risks of cognitive deficits, heart attack, or premature death and, if so, in which populations. While some exposure pathways are better understood than others, the full extent of health damages in many of these pathways is not known. For example, while fetal exposures are relatively well studied (although uncertainties remain), the dose-response functions for health effects resulting from chronic exposure in adults, such as cardiovascular disease, remain uncertain.

Uncertainty with respect to health effects has implications for choices among many policy alternatives. Both of the primary approaches to economic evaluation, BCA and CEA, require that one be able to link changes in Hg emissions to changes in various health outcomes; uncertainty with respect to policy benefits implies uncertainty in the benefit-cost or cost-effectiveness metrics coming out of the analysis. The few economic studies of Hg policies all express concern about the degree of uncertainties in the physical and health science of Hg exposure, suggesting that a valuation approach that explicitly deals with uncertainty and ambiguity is warranted. Three other aspects of the economic and social analysis are also important for future research. First, all of the economic studies have been conducted in the context of a developed economy, but key aspects of Hg reduction policies affect people living in developing countries or regions (e.g., small-scale mining operations or subsistence fisheries). Second, little research has been done to quantify non-health-related benefits, such as non-use values associated with benefits to future generations. Third, costs (both economic and social) associated with structural changes in local food production systems such as subsistence fishing are not well understood and, therefore, not well quantified in cost-benefit analyses. Given uncertainty with respect to benefits and costs, it is difficult to conclude *a priori* that any one Hg-reduction policy is "better" than any other from an economic point of view, or even if the benefits of such a policy exceed the costs.

Given the variety of sources and reduction options, multiple approaches that reduce Hg releases or exposures are being proposed and considered at multiple levels in governments around the world. Economic and comparative risk analyses need to be conducted to examine these approaches. Because Hg emissions in one part of the planet are transported globally, the efficiencies and risks associated with these approaches need to be evaluated in light of the local, regional, and global impacts. Likewise, international trade also moves elemental Hg globally and is linked to emissions and exposure; better data on country-to-country and in-country commercial flows of Hg (indeed, most countries have a poor understanding of their domestic use of Hg) will contribute to refining existing policies and developing new ones. Decision makers also need to analyze potential interrelationships between policies, so that one policy does not reduce the efficiency of another. To the extent possible, effective and acceptable policies must satisfy political, social, and cultural criteria, as well as economic criteria.

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Table 1. Important global compartments of mercury in commerce and the environment, as diagrammed in Fig. 2.

Code	Mnemonic	Definition
A	Aquatic system	Hg in wetlands, lakes, rivers, and oceans. Hg introduced to aquatic systems may become MeHg, which may be bioaccumulated by **F**ish.
C	Coal and other fossil fuel combustion	Hg mobilized by the processing and combustion of the fossil fuels coal, oil, and natural gas ($\mathbf{X_C}$).
D	Disposal	Hg in discarded **P**roducts or process wastes from chlor-alkali or VCM plants.
F	Fish	Hg in fish, virtually all of which is in the form of MeHg, which is produced by natural bacteria in **A**quatic systems.
H	Humans	Hg absorbed by humans following exposure, generally through **F**ish consumption or inhalation of **V**apor.
L	Land	Hg in soil, mostly derived from atmospheric deposition of **V**apor, but can be elevated from mine waste, Hg waste disposal, or geologically rare mineral deposits containing Hg.
M	Manufacturing	Hg used in the manufacture of Hg-containing **P**roducts, or in processes that use Hg to make Hg-free products (e.g., chlor-alkali and vinyl chloride monomer processes).
O	Ore refining	Hg mobilized by the processing and refining of nonfuel mineral resources $\mathbf{X_O}$.
P	Products	Hg contained in products, including thermometers, switches, fluorescent lamps, batteries, fungicides, preservatives, seed-coatings, pharmaceuticals, etc.
R	Recycling	Hg that is extracted from discarded products or wastes, purified, and put into commerce or retired.
S	Small-scale gold mining	Hg utilized by independent, artisanal, miners to concentrate geological gold through amalgamation.
V	Vapor	Hg vapor in indoor and outdoor air.
W	Wildlife	Hg absorbed by fish-eating wildlife, such as seal, whale, otter, mink, osprey, eagle, kingfisher, and loon.
X	Out of the biosphere	Hg in the "X" compartments are not part of the Hg cycling in the biosphere and therefore do not harm humans or wildlife. "X" Hg may be mobilized at some point in the future, but for practical purposes is permanently stored unless humans intervene.
$\mathbf{X_B}$	Buried	Hg, formerly in the biosphere, that has been buried in the sediments of oceans, lakes, and river deltas.
$\mathbf{X_C}$	Coal and other fossil fuel deposits	Hg in buried fossil fuel deposits such as coal, oil, and gas, that may be extracted and burned.
$\mathbf{X_G}$	Geological	Hg in geological materials that release Hg vapor to the atmosphere through natural processes.
$\mathbf{X_O}$	Ores	Hg in non-fuel geological resources that are subject to mining and refining, including minerals containing Hg, gold, zinc, nickel, tin, copper, silver, lead, and iron. All geological materials contain some Hg, even limestone that is heated to make lime.
$\mathbf{X_T}$	retiremenT	Hg permanently stored, or "retired" by humans in warehouses, engineered landfills, or deep bedrock repositories.

Table 2. Important global pathways of mercury in commerce and the environment (diagrammed in Fig. 2). An asterisk (*) on the pathway code indicates that the path is amenable to manipulation by society's policies. The estimates of annual anthropogenic flow are constrained by setting total anthropogenic emissions at 2400 t yr^{-1} (25).

Code	From	To	Comments	Annual Flow (tonnes)	Information Source
AF	Aquatic system	Fish	Only a portion of Hg entering an aquatic system bioaccumulates in fish, partly because only a portion is converted to MeHg.		
AV	Aquatic Systems	Vapor	The oceans are estimated to re-emit over 80% of atmospheric deposition; there is little binding capacity in ocean water, and photochemistry produces Hg^0, which has low solubility in water.	2600	25
AX_B	Aquatic system	Sediment burial	Some of the Hg entering an aquatic system associates with particles that settle to the bottom and is buried permanently by new sediment. Mason and Sheu conclude that Hg is building up in deep ocean water and only a small proportion is buried.	200	25
CV*	Fossil fuel combustion	Vapor	Emitted Hg vapor may be elemental or divalent, which greatly affects distance traveled before deposition to earth.	1500	28
CX_T*	Fossil fuel combustion	Retirement	Hg vaporized during combustion may associate with ash or can be caught separately. Coal ash is often used in construction, which may not retire the associated Hg as permanently as landfilling.	700	Estimate
DA*	Disposal	Aquatic system	Some Hg is discharged directly into surface water, or indirectly through treatment plants. In treatment plants, most Hg associates with solids, which if not discharged are incinerated or land-applied.		
DR*	Disposal	Recycling	This category includes Hg from closed chlor-alkali plants, which is saleable as is. The Hg in product waste can be purified at relatively large costs per kg Hg (100 to 1000 US$ per kg), which is then sold for less than $20 per kg. Retirement of recycled Hg may be a better economic choice for societies.	1200	Estimate
DV*	Disposal	Vapor	Disposal to the solid waste stream may include incineration, which vaporizes all Hg, of which some may be caught by pollution control equipment and landfilled.	110	28
DX_T*	Disposal	Retirement	Manufacturing waste Hg may be retired in landfills as sludge. Hg-products might be landfilled after breakage and spilling of Hg.		
FH*	Fish	Humans	Humans absorb most of the methylmercury (MeHg) consumed in a fish meal. The MeHg is in the protein, not the fat, of fish.	25 (as MeHg)	Estimate, assuming 0.2 ppm
FW	Fish	Wildlife	Fish-eating wildlife are particularly vulnerable to elevated Hg in fish.		

LA*	Land	Aquatic system	Of the Hg deposited from the atmosphere to land, a variable proportion (approximately 5 to 20%) is delivered to lakes and rivers draining the land. Human alteration of the landscape (e.g., agriculture and urban development) can affect the transport to aquatic systems.	200	25
LV*	Land	Vapor	The land re-emits about half of the Hg deposited from the atmosphere. Human alteration of the landscape (e.g. climate change, fire, agriculture) can change the rate of re-emission to the atmosphere.	1600	25
MD*	Manufacturing	Disposal	Any manufacturing process that employs Hg will have Hg waste.	830	Estimate
MH*	Manufacturing	Human vapor exposure	Any manufacturing process that employs Hg will produce Hg vapor that potentially exposes the workers.		
MP*	Manufacturing	Products	Products containing Hg are still manufactured even though cost-effective Hg-free substitutes exist for almost all uses, probably because of economic and technological inertia.	1070	Estimate
MV*	Manufacturing	Vapor	Manufacturing both makes Hg-containing products and uses Hg in processes that emit Hg (chlor-alkali and VCM).	120	Estimate
OA*	Ore refining	Aquatic systems	The processing of Hg-containing ores sometimes produce wastes or tailings that enrich aquatic systems with Hg.		
OM*	Ore refining	Manufacturing	Almost all Hg mines in the world are now closed, as the world's Hg demand is now met by by-product Hg from non-Hg ores, recycling, and the closure of chlor-alkali plants.	1600	Estimate
OS*	Ore refining	Small-scale gold mining	By-product Hg is one source for gold mining.	500	Estimate
OV*	Ore refining	Vapor	Heating ores will vaporize any Hg present, either emitting it to the atmosphere or incidentally catching it with air pollution control devices, unless special Hg control efforts are made.	330	28
PD*	Products	Disposal	Hg-containing products will eventually reach the end of their useful life and will either break or be disposed of.	1020	Estimate
PH	Products	Human vapor exposure	When Hg-containing products break and spill, they create the risk of human exposure and time-consuming clean ups.		
PV	Products	Vapor	Hg spills from broken products contribute to the atmospheric burden of Hg.	40	Estimate
RM	Recycling	Manufacturing	Recycled Hg can be used by many manufacturers.	700	Estimate
RS*	Recycling	Small-scale gold mining	Hg used in mining does not have to be of a high purity, so recycled Hg, especially from chlor-alkali plants, can be used.	500	Estimate
RX_T	Recycling	Retirement	Hg need not be purified to be retired, although there may be some advantages in handling and containment. 4400 t retired in 2006 (62)		

SA*	Small-scale gold mining	Aquatic systems	Hg may be used directly in flowing water to concentrate gold, contaminating water and its sediments.	700	Estimate
SH*	Small-scale gold mining	Human vapor exposure	The gold-Hg amalgam is heated to concentrate the gold, exposing miners and their families to Hg vapor.		
SV*	Small-scale gold mining	Vapor	Hg vaporized during heating of Hg-gold amalgam adds significantly to the global atmospheric burden of Hg.	300	29
VA*	Vapor	Aquatic Systems	All atmospheric Hg eventually deposits to earth, with oceans receiving almost half.	3100	25
VL*	Vapor	Land	Hg deposition rates to the continents has increased by about a factor of 3 over pre-industrial rates.	3500	25
X_CC*	Fossil Fuel Deposits	Combustion	Although the Hg concentration in fossil fuel is usually low, much is burned, and all Hg vaporizes during burning, but some binds to particles and is captured. Pre-treatment of fuel has the potential to remove Hg prior to combustion.	3000	Estimate
$X_C X_T$ *	Fossil Fuel Deposits	Retirement	Some of the Hg in fossil fuel is separated from fuel prior to combustion through coal cleaning or natural gas treatment. Oil refineries are poorly understood where the fate of Hg is concerned.	700	Estimate
X_GV	Geology	Vapor	Hg is naturally released from geological deposits, naturally enriched soils, and volcanoes. Lindberg et al. (1) point out that this path is poorly known and may be greater than 1500 t yr^{-1}.	100	25
X_OO	Ore resources	Ore refining	Hg is in relatively high concentrations in sulfide ores of gold, silver, copper, lead, and zinc, and in lower concentrations in non-sulfide ores. Heat and other processes release the Hg, which enters the biosphere unless efforts are made to capture it.	>2500	Estimate

Table 3. Summary of economic analyses that have been performed on the costs or benefits of reducing mercury emissions or just reducing exposure through fish consumption advisories (e.g., 83). All of the studies concern the United States.

Study	Scenario	Health Endpoints or Other Endpoints	Benefits Measurement Tools	Costs or Benefits in 2004 $US (Entire U.S. unless noted)
EPRI (77)	Utility sector cap of 15 tons by 2018 or MACT by 2008 (about 24 tons emitted).	IQ change in fraction of population above MeHg RfD.	Benefits not monetized.	Cost of cap: $6 thousand million. Cost of MACT: $19.3 thousand million.
Gayer and Hahn (78)	Utility sector cap of 15 tons by 2020 or MACT by 2008.	IQ	Parental willingness to pay for IQ increases through chelation therapy.	Cost of cap: $3.4 - $5.5 thousand million Benefits of cap: 60 – 150 million Cost of MACT: $15.4 – 20.7 thousand million Benefit of MACT: $82 - $142 million.
Hagen et al. (69)	50% reduction from all sources in Minnesota (U.S.).	Unspecified health effects, recreational fishing, effects on wildlife	CVM	Benefits to Minnesota residents: $255 million per year (1998 Minnesota population = 4.7 million).
Jakus et al. (83)	Issue mercury-related advisories on the Maryland portion of Chesapeake Bay (U.S.)	IQ, AMI, ACM Recreational fishing Commercial fishing	COI VSL TCM	Benefits: Avoided illness $15.4 million per year for consumers of Maryland-Chesapeake Bay fish. Lost Recreation/Commercial value: $9.1 million
Lutter et al. (84)	60%-90% reduction in power plant emissions (U.S.)	Neurological deficiency	Benefits not monetized.	Total cost: $1.2 - $1.9 thousand million $120 000 - $190 000 per case averted
Palmer et al. (79)	Hg cap under CAIR for power plant emissions (U.S.)	IQ, AMI, ACM	COI VSL	Cost: $3.4 thousand million Benefit: Same as Rice and Hammitt
Rae and Graham (85)	30%, 51%, and 100% reductions in power plant emissions (Southeastern U.S.)	IQ, Non-fatal AMI Hypertension ACM	COI VSL	Benefit: $619 – 2 102 million per year for four states in SE United States, only.
Rice & Hammitt (80)	Cap of 26 tons and 15 tons **later ?** on power plant emissions (U.S.)	IQ, alternatively assume with and without a threshold, non-fatal AMI, ACM	COI VSL	Benefit: $3.8 - $5.7 thousand million
Trasande et al. (81)	Evaluate costs of current emissions from all sources	IQ	COI	$9.5 thousand million per birth cohort $1.4 thousand million due to power plants
USEPA (76)	Cap of 38 tons in 2010, 15 tons in 2018.	IQ	COI	Benefits: $0.25 to $1.56 million
US EPA (86)	Hg cap under CAIR and CAMR for power plant emissions (U.S.)	IQ	COI	Costs: $750 million per year by 2020. Benefits: Less than $168 million per year.

Abbreviations: ACM=All Cause Mortality AMI=Acute Myocardial Infarction COI=Cost of Illness CVM=Contingent Valuation Method IQ=Intelligence Quotient change MACT=Maximum Achievable Control Technology TCM=Travel cost Method VSL=Value of a Statistical Life

Table 4. Mercury exposure pathways and the extent of knowledge pertinent to cost-benefit analysis of reduction options. Benefit and cost methods that have been applied are in bold (references in parentheses); other possible approaches are listed. In many cases a necessary prerequisite is to quantify any connection between Hg releases and any endpoint.

Exposure Pathway	**Measurement Tools (for Benefits of Reducing Exposure)**	**Source of Elevated Hg**	**Hg Exposure Reduction Options**	**Measurement Tools (for Costs of Reducing Exposure)**
FH—Commercial Fishing	**COI VSL** (76, 78, 80, 81, 83, 85, 86)	VA—atmospheric deposition	a. Reduce Hg emissions from coal, ore refining, & small scale gold mining via: i. Incentives to develop control technology. ii. Incentives to transfer control technology globally. b. Purchase and consume low-Hg fish c. Consume non-fish source of protein	a. **COT** (77) i. ii. b. **LMV (83)** c. COS
FH—Recreational Fishing	**COI VSL (83)**	VA—atmospheric deposition	a. Reduce Hg emissions b. Consume low-Hg fish, release high-Hg fish. c. Fish low-Hg waters (e.g. different lake)	a. **COT (78)** b. **LRV (83)** c. **LRV (83)**
FH—Subsistence Fishing	COI, VSL	VA—atmospheric deposition	a. Reduce Hg emissions b. Reduce fishing & find alternate source of protein. c. Disseminate culturally appropriate fish consumption advice. d. Consume low-Hg fish, sell high-Hg fish.	a. COT b. QOL c. QOL d. QOL
FH—Subsistence Fishing	COI VSL	DA—Disposal of Products and Wastes to Aquatic Systems	a. Reduce Hg discharge to fishery b. Reduce fishing & find alternate source of protein c. Create incentives for switching to Hg-free products & processes for chlor-alkali and vinyl chloride monomer plants. d. Disseminate culturally appropriate consumption advice. e. Consume low-Hg fish, sell high-Hg fish.	a. COT b. QOL c. COS d. QOL e. QOL
FH—Subsistence Fishing	COI VSL	OA—Ore Refining discharges	a. Reduce Hg discharge b. Reduce fishing & find alternate source of protein. d. Disseminate culturally appropriate fish consumption advice. e. Consume low-Hg fish, sell high-Hg fish.	a. COT b. QOL c. QOL d. QOL
FH—Subsistence Fishing and Recreational Fishing	COI VSL	Reservoir creation or operation	a. Evaluate impacts before reservoir creation. b. Create and operate to minimize Hg in fish. c. Reduce fishing & find alternate source of protein. d. Disseminate culturally appropriate fish consumption advice. e. Consume low-Hg fish, sell high-Hg fish. f. Consume low-Hg fish, release high-Hg fish.	a. COT b. COT COS c. QOL d. COT e. QOL f. **LRV (83)**
FH—Subsistence Fishing	COI VSL	SA—Small-Scale Gold Mining discharges	a. Provide incentives for efficient or reduced Hg use through: i. Reduce international supply of Hg through retirement, etc. ii. Transfer of culturally acceptable technology. iii. Build community capacity to reduce Hg-related problems. b. Economic development for opportunities other than gold mining. c. Reduce fishing & find alternate source of protein.	a. COS COT i. **COHR (62)** ii. COT iii. COT b. COED c. COS QOL

FW—Wildlife consumption of fish	**SPM (69)**	VA—atmospheric deposition	a. Reduce Hg emissions.	COT
FW—Wildlife consumption of fish	SPM	Reservoir creation or operation	a. Evaluate impacts before reservoir creation. b. Operate to minimize Hg in fish.	a. COT b. COT COS
FW—Wildlife consumption of fish	SPM	OA—Ore Refining	Reduce Hg discharge	COT
FW—Wildlife consumption of fish	SPM	DA—Disposal of Products, Wastes to Aquatic Systems	Reduce Hg discharge to fishery	COT
FW—Wildlife consumption of fish	SPM	SA—Small-Scale Gold Mining	a. Provide incentives for efficient or reduced Hg use through: i. Reduce international supply of Hg through retirement, etc. ii. Transfer of culturally acceptable technology. iii. Build community capacity to reduce Hg-related problems. b. Economic development for opportunities other than gold mining.	a. COS COT i. COHR ii. COT iii. COT b. COED
SH—Inhalation exposure	COI, VSL	SV—inhalation while concentrating gold	a. Provide incentives for efficient or reduced Hg use through: i. Reduce international supply of Hg through retirement, etc. ii. Transfer of culturally acceptable technology. iii. Build community capacity to reduce Hg-related problems. b. Economic development for opportunities other than gold mining.	a. COS COT i. COHR ii. COT iii. COT b. COED
MH—Inhalation exposure	COI, VSL COI, VSL	MV—inhalation while manufacturing with Hg	a. Provide incentives for Hg-free processes. b. Develop inexpensive Hg vapor monitoring.	COS COT
PH—Inhalation exposure	COI	PV—Hg vapor from Hg-containing product use and breakage.	a. Choose Hg-free products (e.g. dental fillings, thermometers, medical devices, pharmaceuticals, barometers, paints, thermostats, lamps, etc.) b. Create incentives for switching to Hg-free product production.	a. COS b. COS

Abbreviations:
COED=Cost of Economic Development. COI=Cost of Illness (including both MeHg and loss of protein and PUFA) COS=Cost of Substitute
COHR=Cost of Hg Retirement COT=Cost of Technology, including the costs of research, and development and dissemination of fish consumption advice.
LMV=Lost Market Value LRV=Lost Recreational Value PUFA=Polyunsaturated Fatty Acids QOL=Quality of Life SPM=Stated Preference Method
TCM=Travel Cost Method VSL=Value of a Statistical Life (including both MeHg and loss of protein and PUFA)

Figure Legends

Figure 1. a. Historical mercury production and consumption. Consumption has exceeded production since about 1990, with demand met by large supplies from government stockpiles and closed chlor-alkali plants, plus contributions from recycling (7). b. Mercury and gold prices in the U.S. from 1900 to 2005, adjusted to constant 2005 U.S. dollars. The correlation between gold and mercury prices begins after 1971 with the breakdown of a fixed exchange rate system (7, 8, 9).

Figure 2. Important global pathways of mercury in commerce and the environment. Width of pathway line is proportional to the flow per year. See Table 1 for explanation of abbreviations and the text for discussion of the compartments and Table 2 for discussion of the pathways.

Figure 3. Estimates of global mercury consumption for 2004 (9, 36)

Figure 1.

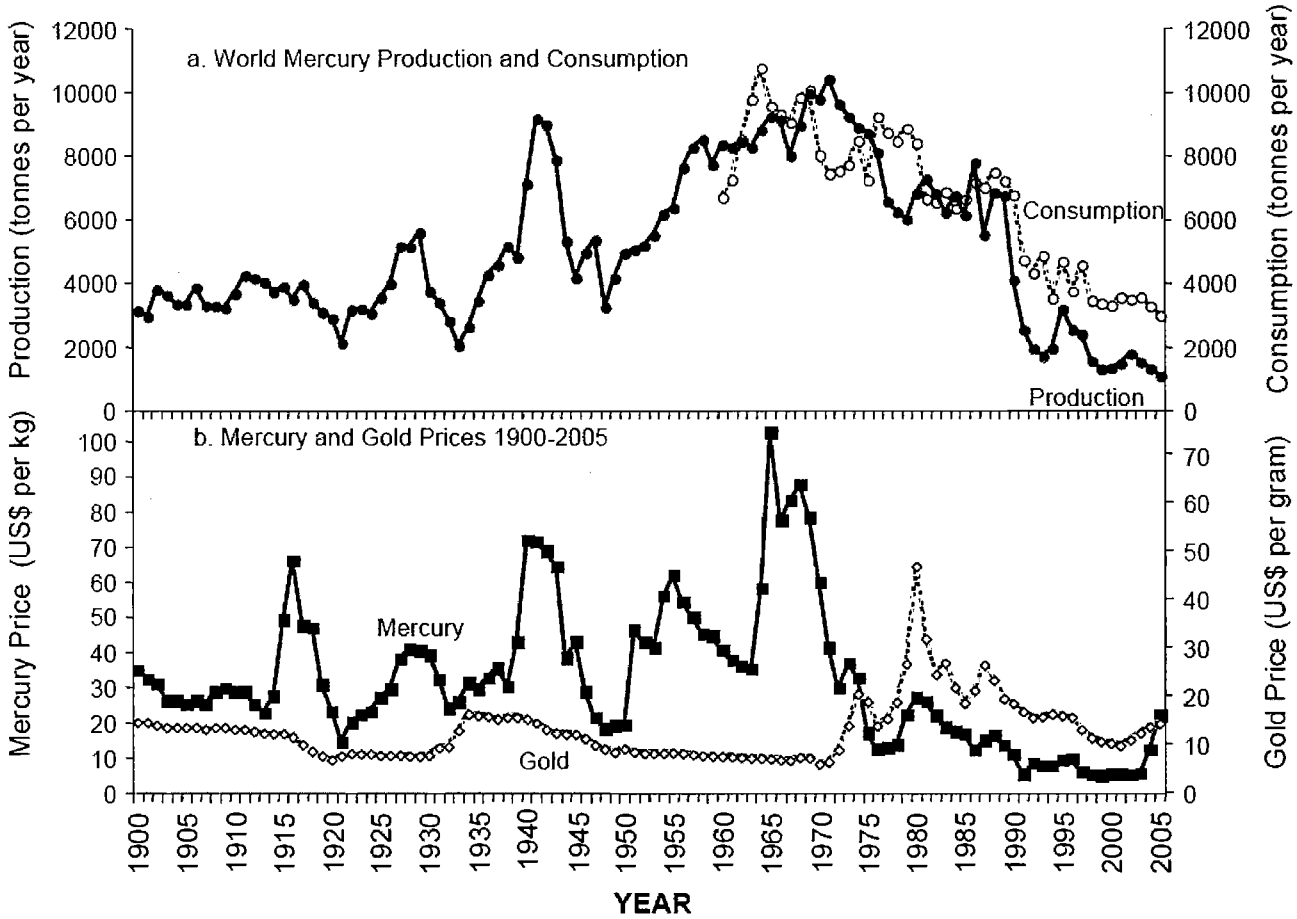

a. World Mercury Production and Consumption
Production (tonnes per year)
Consumption (tonnes per year)
Consumption
Production
b. Mercury and Gold Prices 1900-2005
Mercury Price (US$ per kg)
Gold Price (US$ per gram)
Mercury
Gold
YEAR

Figure 2.

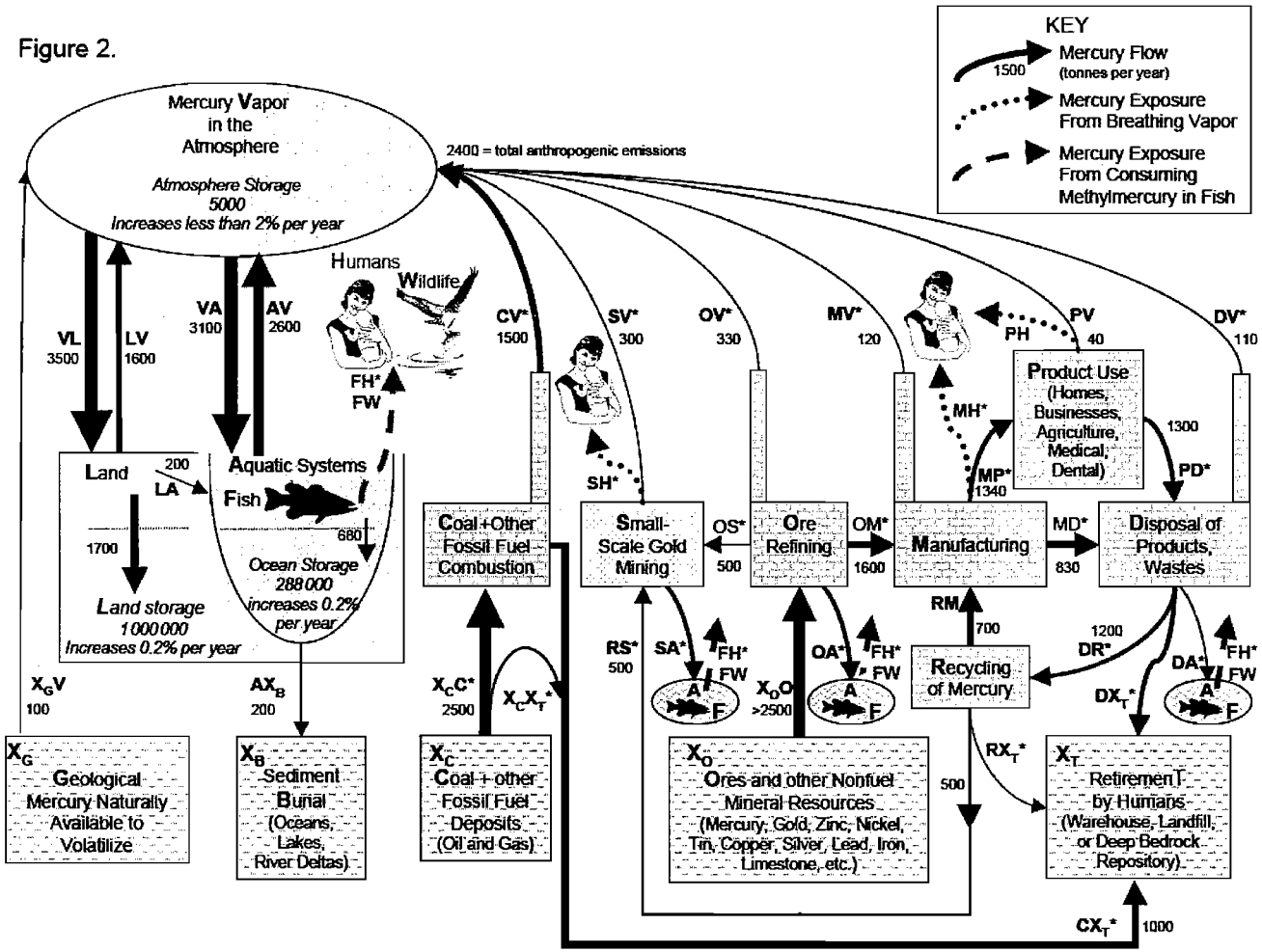
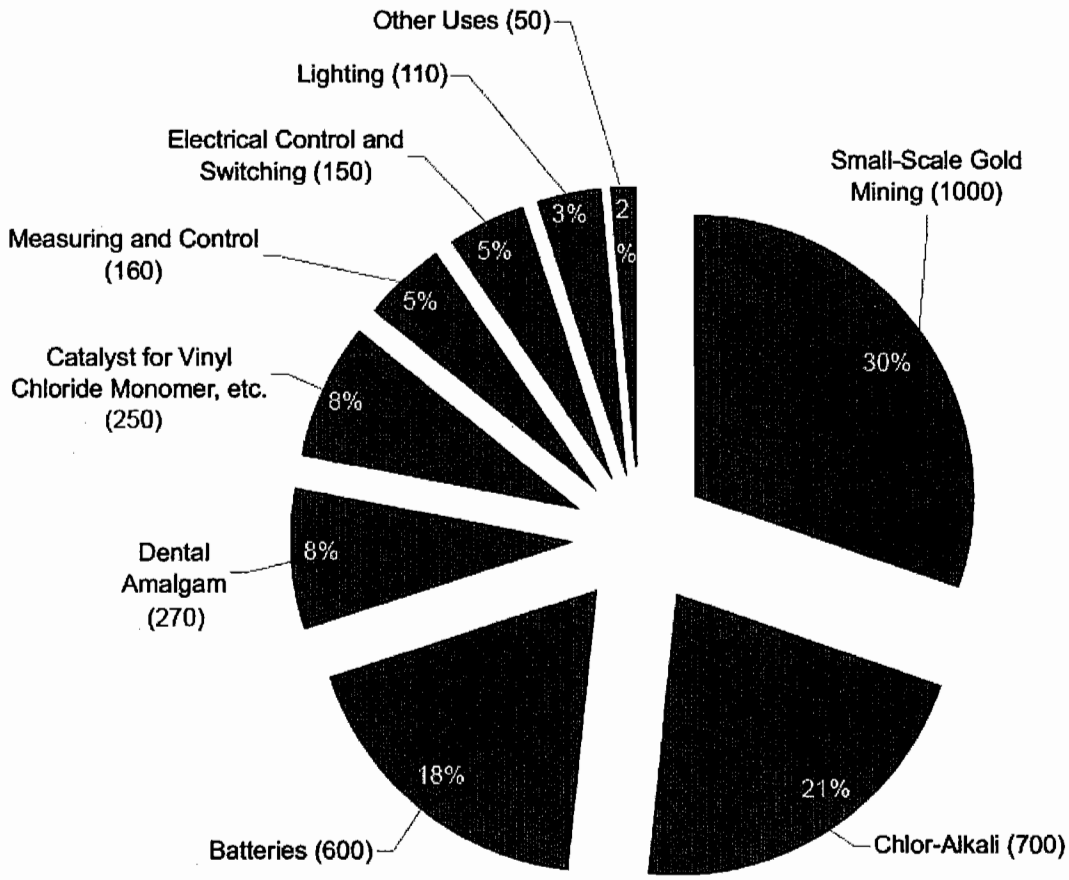

KEY
Mercury Flow (tonnes per year)
1500
Mercury Exposure From Breathing Vapor
Mercury Exposure From Consuming Methylmercury in Fish
Mercury Vapor in the Atmosphere
Atmosphere Storage 5000 Increases less than 2% per year
2400 = total anthropogenic emissions
Humans
Wildlife
VL 3500
LV 1600
VA 3100
AV 2600
FH* FW
Land
200 LA
Aquatic Systems
Fish
1700
680
Land storage 1000000 Increases 0.2% per year
Ocean Storage 288000 increases 0.2% per year
X_GV 100
AX_B 200
X_G Geological Mercury Naturally Available to Volatilize
X_B Sediment Burial (Oceans, Lakes, River Deltas)
CV* 1500
SV* 300
OV* 330
MV* 120
PV 40
PH
DV* 110
SH*
MH*
MP* 1340
Product Use (Homes, Businesses, Agriculture, Medical, Dental)
1300
PD*
Coal+Other Fossil Fuel Combustion
Small-Scale Gold Mining
OS* 500
Ore Refining
OM* 1600
Manufacturing
MD* 830
Disposal of Products, Waste
X_CC* 2500
X_CX_T*
RS* 500
SA*
FH* FW
A F
X_OO >2500
OA*
RM
700
Recycling of Mercury
1200 DR*
DA*
DX_T*
RX_T*
500
X_C Coal + other Fossil Fuel Deposits (Oil and Gas)
X_O Ores and other Nonfuel Mineral Resources (Mercury, Gold, Zinc, Nickel, Tin, Copper, Silver, Lead, Iron, Limestone, etc.)
X_T Retirement by Humans (Warehouse, Landfill, or Deep Bedrock Repository)
CX_T* 1000

Figure 3.


Other Uses (50)
Lighting (110)
Electrical Control and Switching (150)
Measuring and Control (160)
Catalyst for Vinyl Chloride Monomer, etc. (250)
Dental Amalgam (270)
Batteries (600)
Chlor-Alkali (700)
Small-Scale Gold Mining (1000)
3%
2%
5%
5%
8%
8%
18%
21%
30%

Opportunities to Improve Energy Efficiency of Industrial Boilers

Wojciech Jozewicz
ARCADIS
Research Triangle Park, NC 27713, USA

Stratos Tavoulareas and Rui Afonso
Energy Technologies Enterprises Corp.
McLean, VA 22101, USA

Nick Hutson
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711, USA

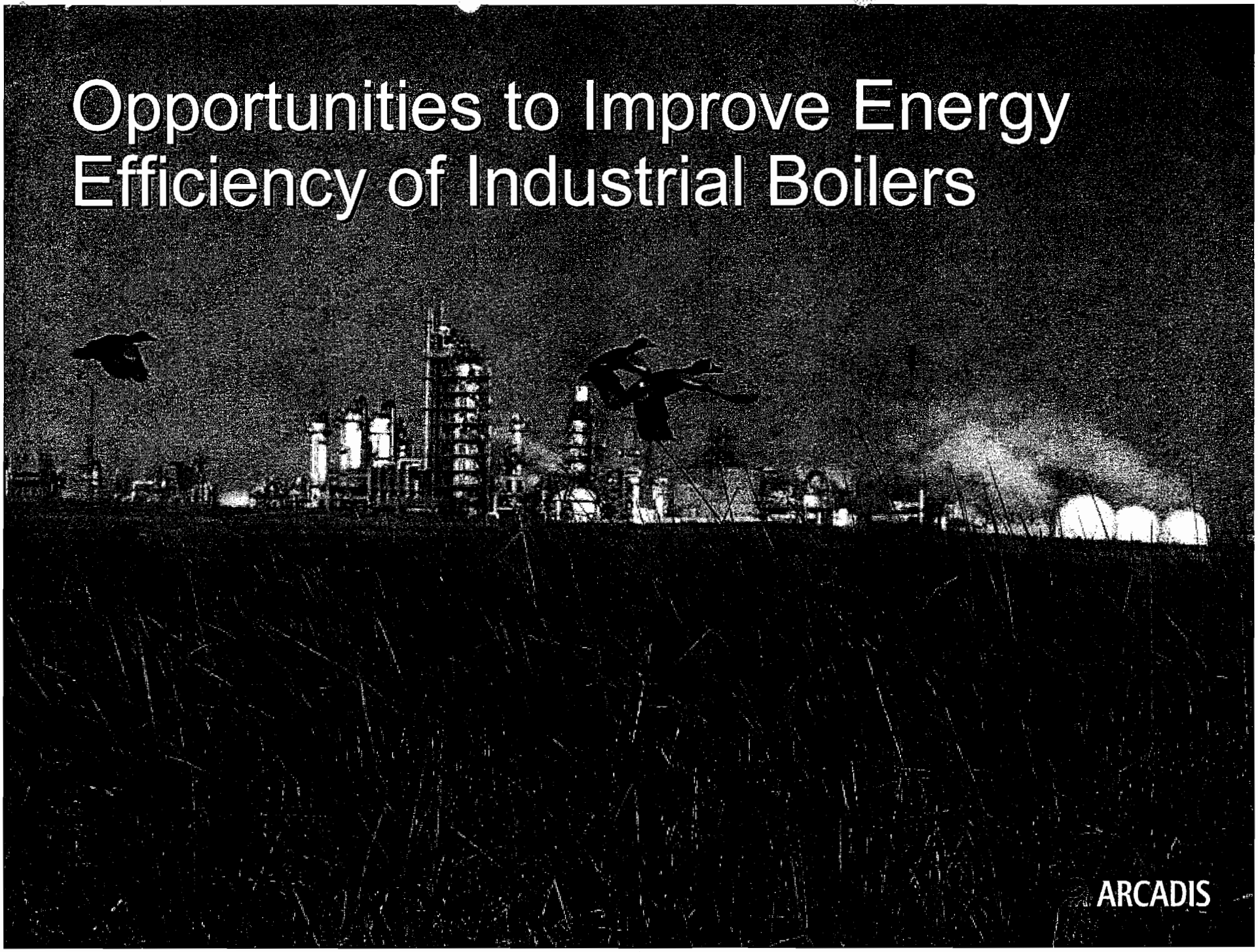
Presentation at the Energy Efficiency & Air Pollutant Control Conference
Wrocław, Poland
September 21-25, 2009

Background

- 160,000 industrial and commercial boiler units in the U.S. with an aggregate capacity of about 800 GW_{th}(fuel input)*
- In 2007, this group of boilers used $3x10^9$ GJ of energy and emitted 0.77, 0.37, 6.11, and 149 million metric tons of SO_2,NO_X, PM, CO_2, respectively.*
- Approximately 8.7 million metric tons of hard coal used for industrial boilers in Poland in 2002

*Source: EEA 2005 and 2007

Opportunities to Improve Energy Efficiency of Industrial Boilers



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Objectives

- Present an overview of boiler types and their contribution to GHG as well as SO_2, NO_X, PM, and Hg emissions
- Identify opportunities for improving energy efficiency of industrial boilers
- Describe potential CO_2 emissions saved as a result of energy efficiency measures implementation

Outline

- Industrial boiler types
- Boiler population and emissions
- Operating and maintenance practices
- Energy efficiency measures
- Structure of power generation in Poland
- Methodology and key assumptions
- Menu of measures
- Applicability of measures
- Key insights

Other Efficiency Measures

- Fuel adjustments
  - Co-firing
  - Fuel switching
- Combined heat and power
- Repowering
- Future options
  - Organic cycles (low temperature, waste heat, etc.)
  - Kalina cycle (water-ammonia)
  - Integrated Gasification Combined Cycle
  - Fuel cells

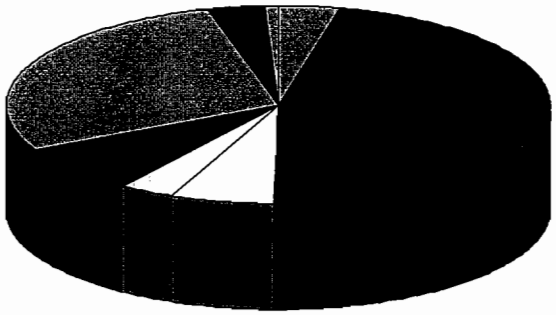
Industrial Boiler Types

- Pulverized coal (PC)
  - large industrial units
  - tangential, wall, cyclone and wet vs. dry bottom
- Fluidized bed (FBC)
  - fuel and inert material suspended by an upward flow of combustion air through bed
  - improved mixing, higher residence time, lower temperature than PC, lower emissions, fuel flexibility
- Stoker
  - around for the longest time
  - spreader and underfeed
- Firetube

Source: EPA

U.S. Boiler Population and Emissions

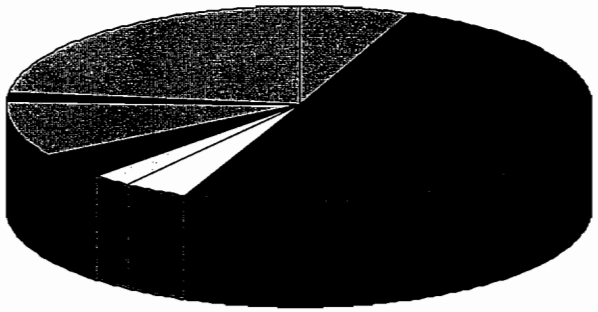
- 50% gas-fired
- 37% coal-fired



- OIL (4%)
- GAS (47%)
- COAL, UNSPECIFIED (6%)
- COAL, STOKER (3%)
- COAL, PULVER (8%)
- COAL, OTHER (28%)
- COAL, FLUID. BED (3%)
- OTHER (1%)

but

- Coal-fired account for 48% of CO_2 emissions

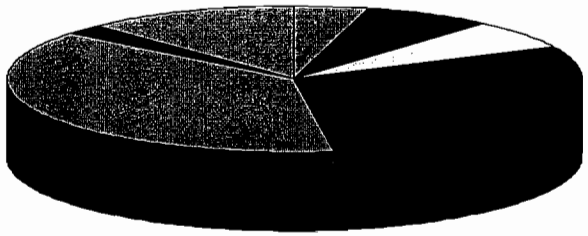


- OIL (6%)
- GAS (50%)
- COAL, UNSPECIFIED (4%)
- COAL, STOKER (2%)
- COAL, PULVER (4%)
- COAL, OTHER (9%)
- COAL, FLUID. BED (1%)
- OTHER (23%)

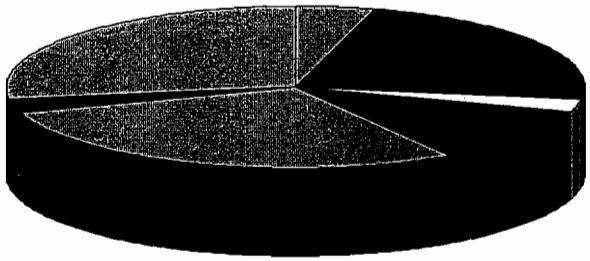
Source: EEA, 2007

U.S. Industrial Boiler Criteria Emissions (coal-fired %)

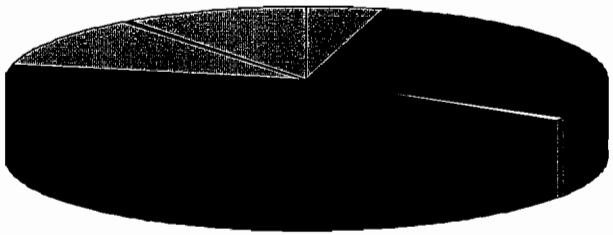
- SO_2 (77%)



- NO_X (46%)



- PM (57%)



OIL (4%)
GAS (7%)
COAL, UNSPECIFIED (0%)
COAL, STOKER (6%)
COAL, PULVER (30%)
COAL, OTHER (38%)
COAL, FLUID. BED (2%)
OTHER (12%)

OIL (4%)
GAS (23%)
COAL, UNSPECIFIED (0%)
COAL, STOKER (3%)
COAL, PULVER (11%)
COAL, OTHER (29%)
COAL, FLUID. BED (3%)
OTHER (27%)

OIL (4%)
GAS (29%)
COAL, UNSPECIFIED (0%)
COAL, STOKER (1%)
COAL, PULVER (44%)
COAL, OTHER (11%)
COAL, FLUID. BED (1%)
OTHER (10%)

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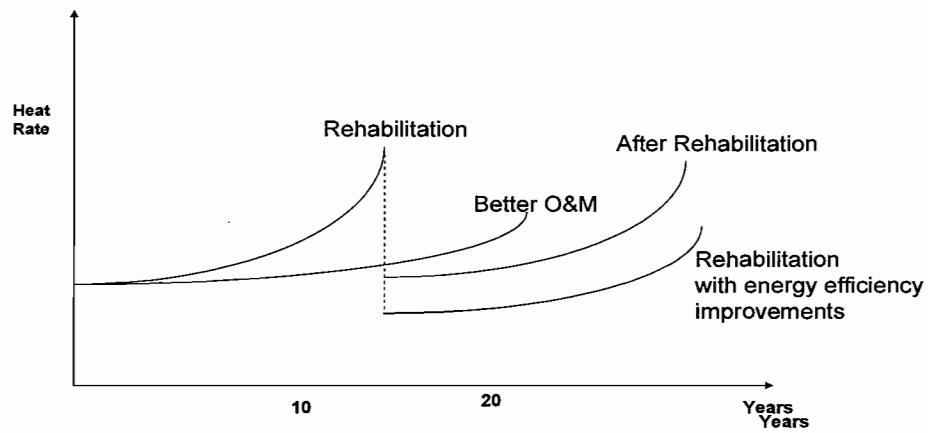
Operating & Maintenance Practices

- Significant impact on plant performance (including efficiency), reliability, and operating costs
- Deterioration rate greatly dependent on the O&M practices
- Rapid deterioration results in:
  - higher heat rate
  - higher CO_2 and NO_X emissions
  - higher operating costs
  - lower reliability



Available Efficiency Measures *

- New burners/burners upgrades
- Air preheat and economizer
- Improved combustion measures: tuning, optimization, instrumentation and control (I&C)
- Minimize boiler short cycling
- Minimize gas-side heat transfer surface deposits (slagging and fouling)
- Minimize air infiltration
- Condensate return system
- Boiler blowdown heat exchanger
- Steam line maintenance
- Water treatment
- Backpressure turbine/turbine-generator

Methodology

- Only commercially available energy efficiency improvement measures considered
- Industrial boiler data limited, only generic assessment possible
- Efficiency gains and CO_2 emissions potentially prevented given in percentage points rather than actual efficiency gain
- Applicability of measures described for different types of boilers
- Potential for annually prevented CO_2 emissions given for coal- and gas-fired boilers

Key Assumptions

- Baseline boiler efficiency assumed to be 78%
- O&M practices different from capital expenditures
- No site-specific conditions considered
- Cogeneration and repowering not considered

Menu of Measures

Efficiency Measure	Efficiency Improvement, %	CO_2 Prevented, %
Backpressure Turbine/Generator	10+	10+
Water Treatment	Up to 10	Up to 12
Boiler Blowdown Heat Exchanger	Up to ~ 7	Up to ~ 8
Minimize Short Cycling	Up to 4 - 6	Up to 5 - 7
New/Upgraded Burners	4 - 5	Up to ~ 6
Air Preheat and Economizer	~ 3	Up to ~ 4
Combustion Tuning	~ 3	Up to ~ 3
Minimization of Gas-side Heat Transfer Surface Deposits	1 - 3	Up to ~ 4
Minimization of Air Infiltration	1.5 - 3	Up to ~ 4
Condensate Return System	2	2
Steam Line Maintenance	1	1 [d]
Fuel Switching	Minimal	20-30

Applicability of Measures

Measure \ Boiler Type	Pulverized Coal	Fluidized Bed	Stoker	Large Watertube	Small Watertube	Firetube
New Burners or Upgrades						
Air Preheat and Economizer						
Improved Combustion Measures						
Short Cycling Minimization						
Minimization of Gas-side Heat Transfer Surface Deposits						
Minimization of Air Infiltration						
Condensate Return System						
Boiler Blowdown Heat Exchanger						
Steam Line Maintenance						
Water Treatment						
Backpressure Turbine or Turbine-Generator						
Co-firing				NG/ Oil firing	NG/ Oil firing	
Fuel Switching		Coal to Biomass	Coal to Biomass			

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CO_2 Emission Prevention Potential

Approach	Specific Measure	50 MW_{th} Coal –fired Efficiency Gain, %	50 MW_{th} Coal-fired Prevented CO_2 Emissions, metric tons/year [a]
Pressure Recovery	Backpressure Turbine/Generator	10+	10,400
Water Quality Improvement	Water Treatment	Up to 10	8,300
Steam Management	Boiler Blowdown Heat Exchanger	Up to ~ 7	7,300
	Condensate Return System	2	2,100
Boiler synchronization	Minimize Short Cycling	Up to 4 - 6	5,200
Combustion Improvement	New/Upgraded Burners	4 - 5	4,700
	Minimization of Air Infiltration	1.5 - 3	2,300
	Combustion Tuning	~ 3	3,100
Boiler maintenance	Minimization of Gas-side Heat Transfer Surface Deposits	1 - 3	3,100
Line maintenance	Steam Line Maintenance	1	1,000
Heat recovery	Air Preheat and Economizer	~ 3	2,600

a. assuming 6,000 m^3/h gas flow, 0.65 capacity factor, 15 vol % CO_2 in flue gas

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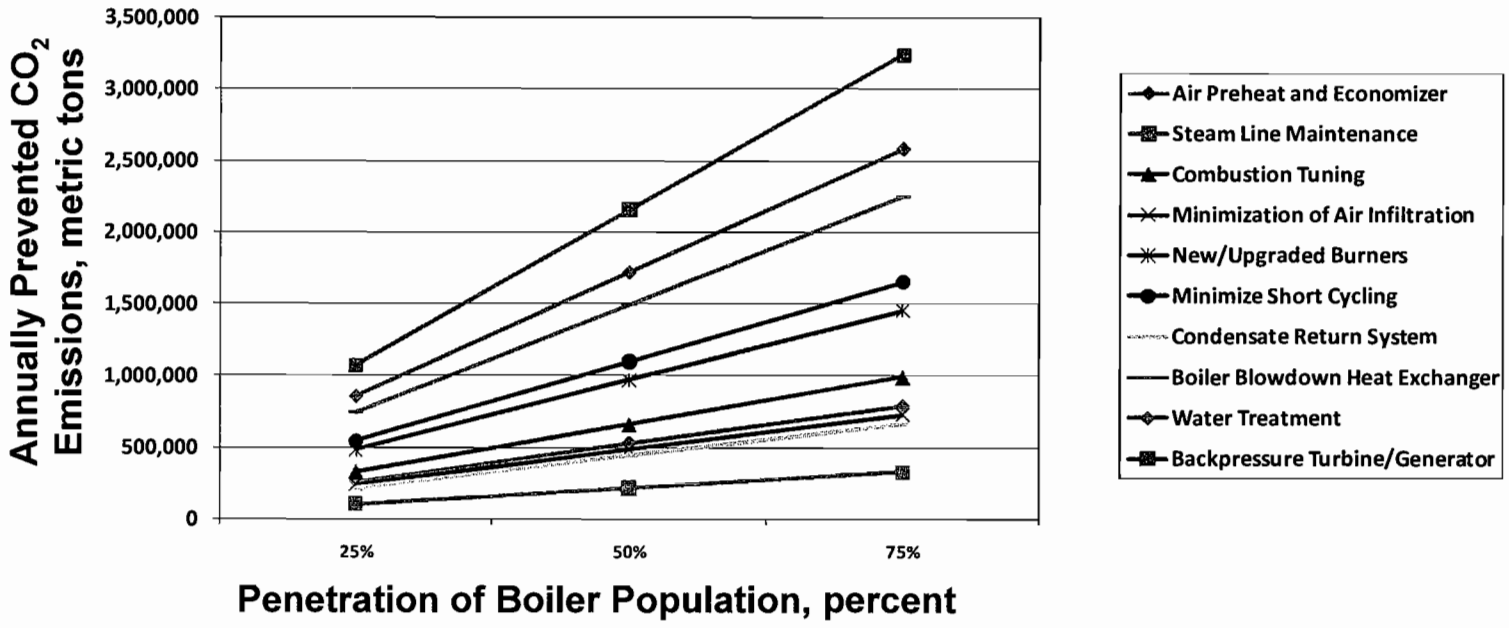
Potential for Annually Prevented CO_2 Emissions: Gas-fired Boilers

Capacity of boiler population considered: about 64 GW_{th}



Preliminary example results for illustration only. The draft slide does not reflect EPA policy.

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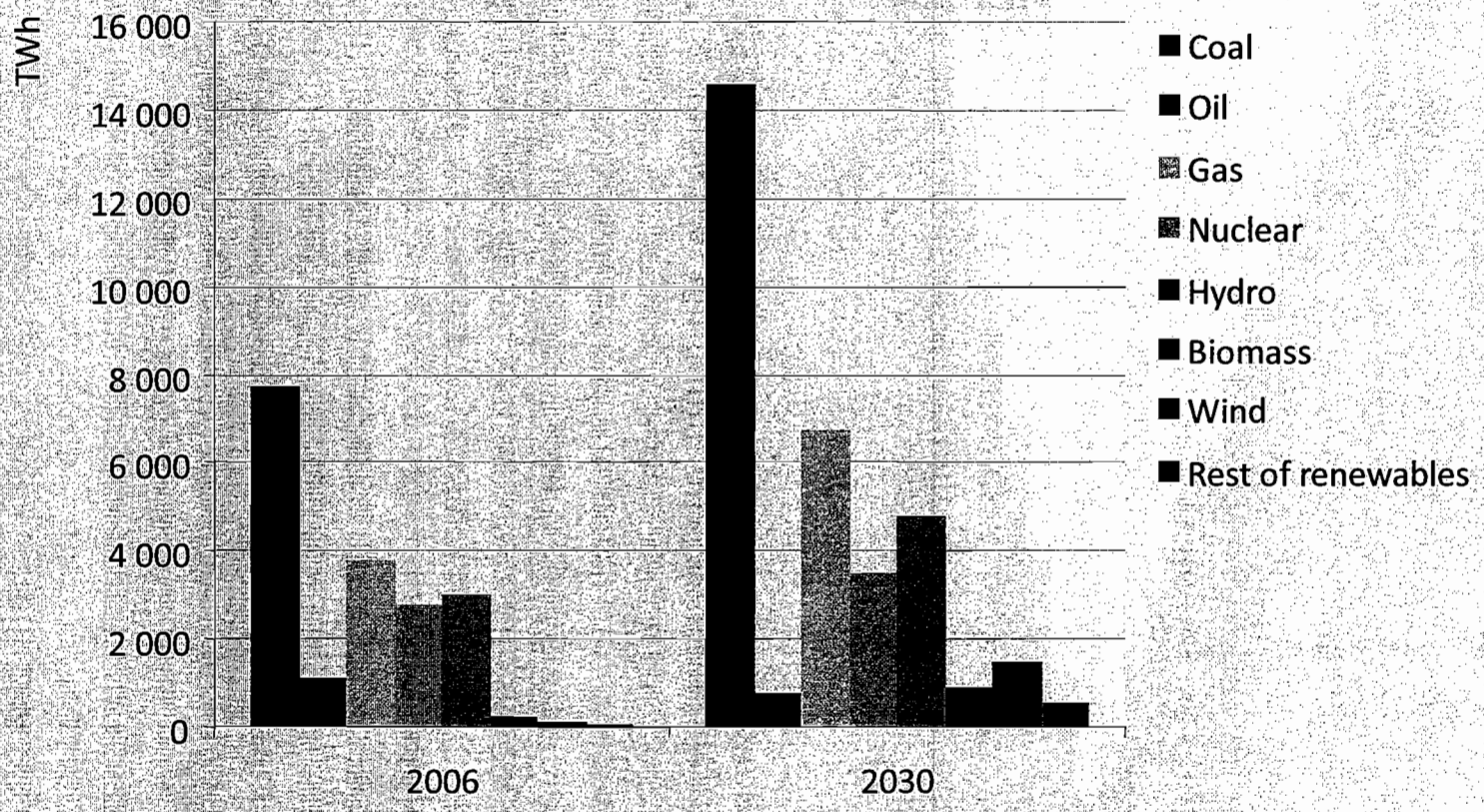
The Reference Scenario: World electricity generation

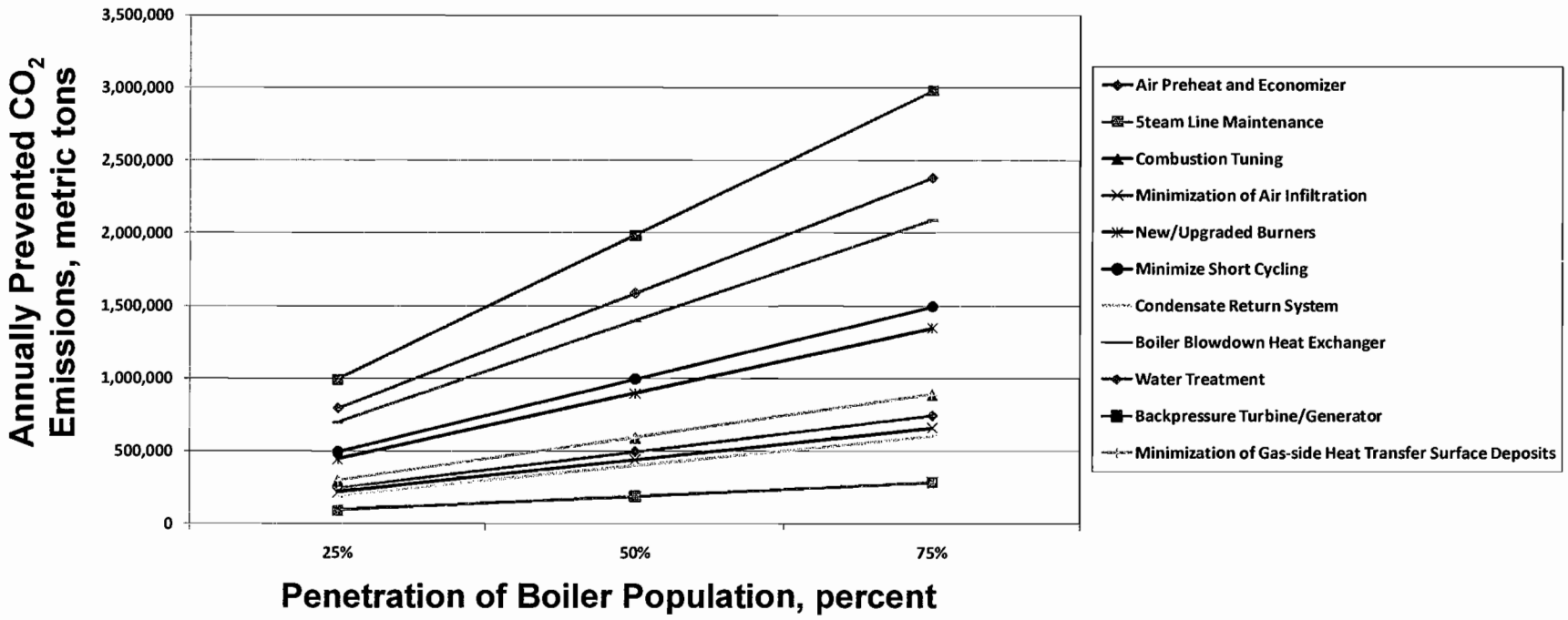
IEA WEO 2008



The shares of coal & renewables in the power-generation fuel mix increase to 2030 – mainly at the expense of natural gas & nuclear power

Potential for Annually Prevented CO_2 Emissions: Coal-fired Boilers

Capacity of boiler population considered: about 64 GW_{th}



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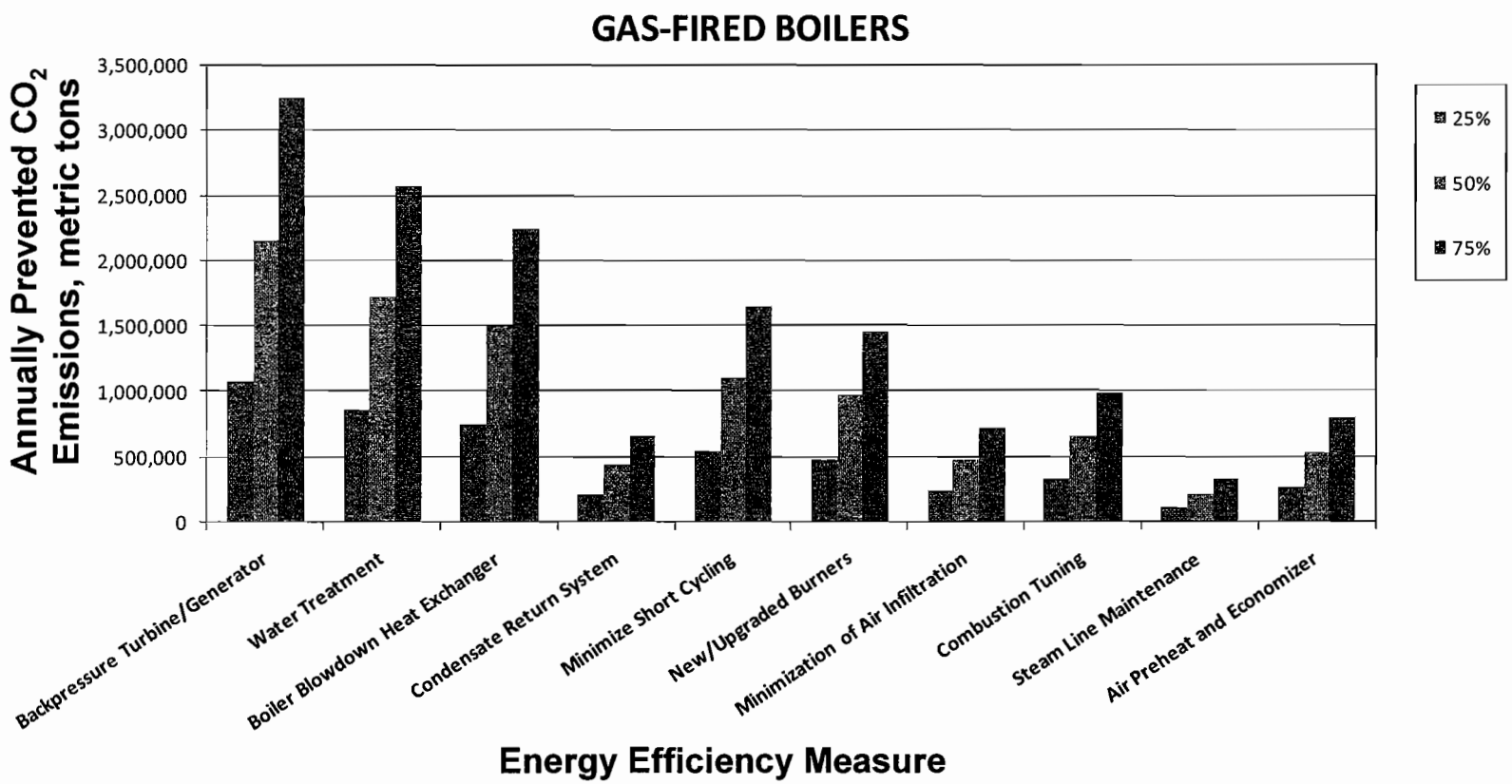
Matrix of Potentially Prevented CO_2 Emissions: Gas-fired Boilers



Preliminary example results for illustration only. The draft slide does not reflect EPA policy.

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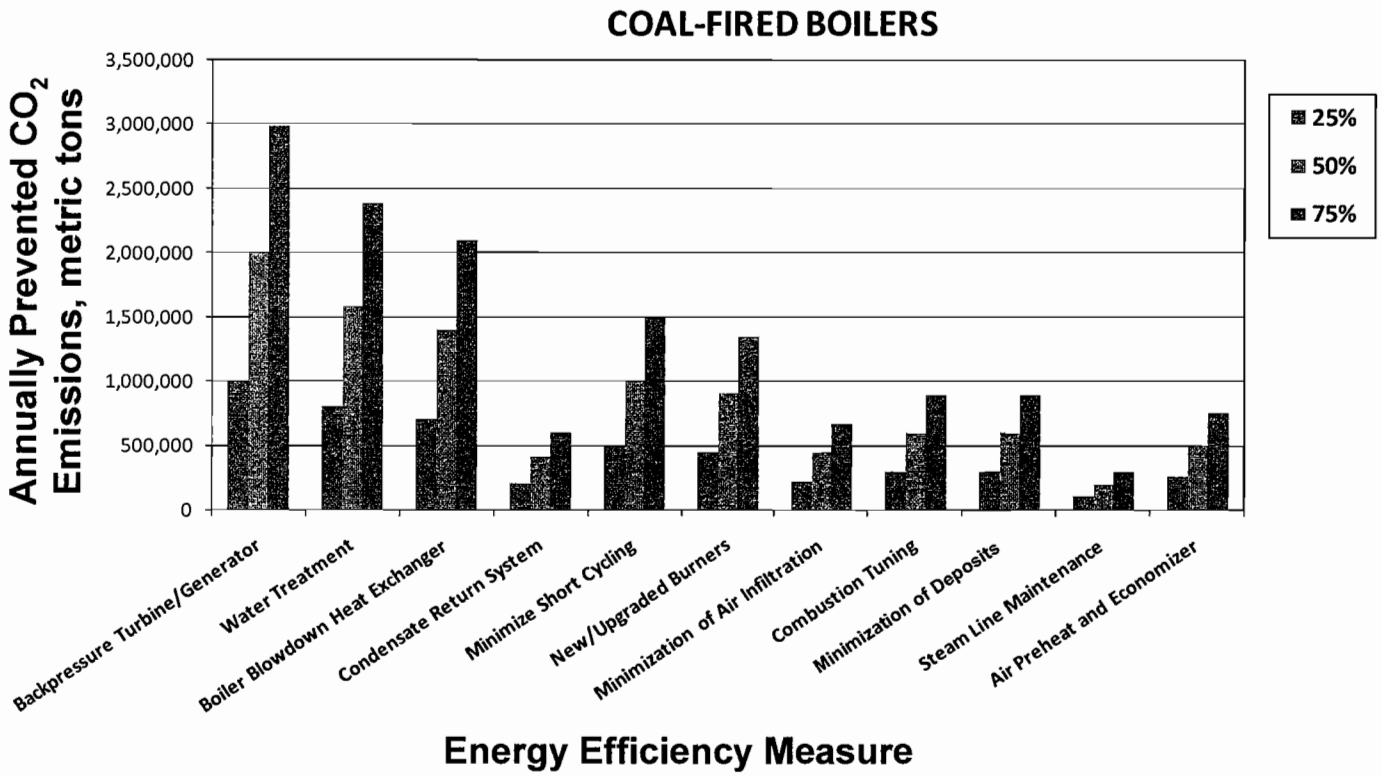
Matrix of Potentially Prevented CO_2 Emissions: Coal-fired Boilers



Preliminary example results for illustration only. The draft slide does not reflect EPA policy.

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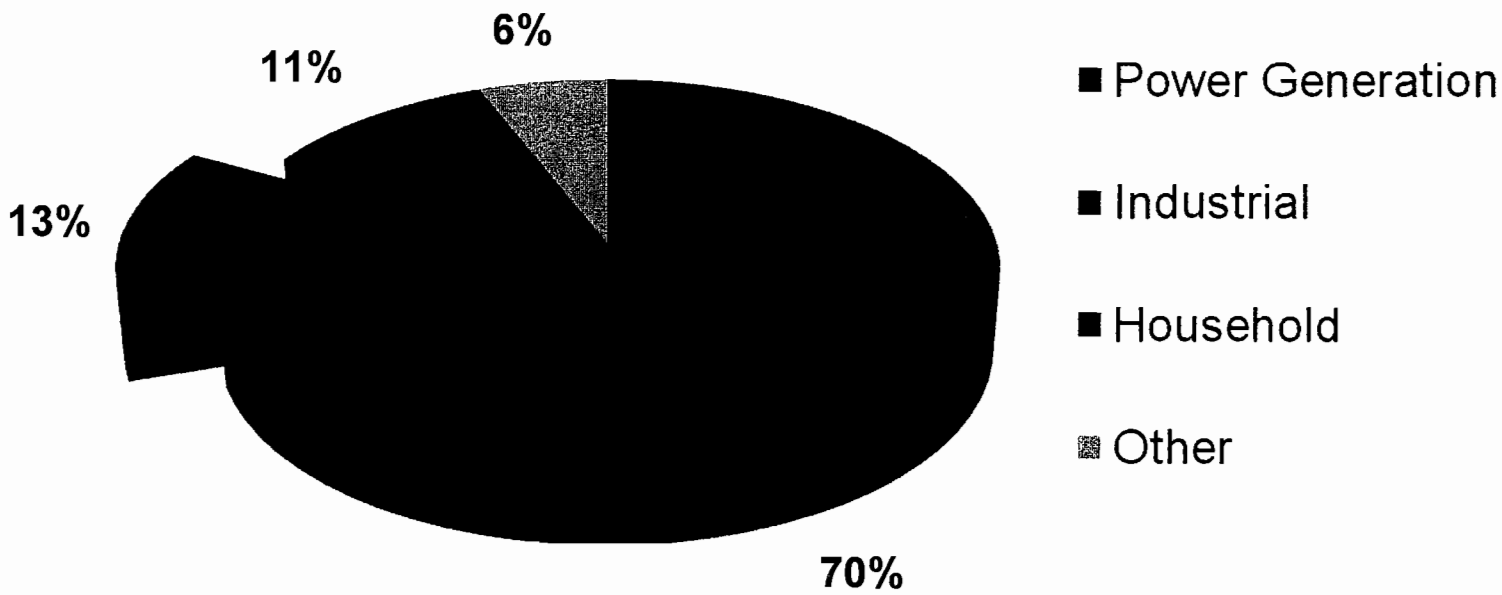
Profile of Coal Use in Poland

- 69.3 million metric ton of hard coal used in 2002 for energy production
- 12.5% (8.7 million metric ton) of the above by industrial boilers
- Assume 1 metric ton of coal producing 2.86 metric ton of CO_2
- Emissions (hard coal) approximately 25 million metric ton of CO_2 in 2002



Source of data: Blaschke et al., 2005

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Constraints of This Analysis

- Uncertainties due to limited database on industrial boilers
- Data sufficient to obtain a generic assessment regarding the CO_2 reduction potential, not sufficient to perform a site-specific assessment
- Great variety of boiler types and vintages
- Some of the efficiency options are not commercially available and may be presently considered to be technological risks

Insights

- Energy efficiency measures with potential of up to 10% improvement were identified. Combustion-related measures capable of up to 3% improvement.
- Annually preventable CO_2 emissions for varying penetration of boiler population were determined for each energy efficiency measure.
- Different scenarios could be identified to achieve a desired annual amount of prevented CO_2 emissions from industrial boilers.


For additional information please contact:
Wojciech Jozewicz
ARCADIS
4915 Prospectus Drive, Suite F
Durham, NC 27713, USA
wojciech.jozewicz@arcadis-us.com
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Best Practice in Coal Fired Power Stations and the move towards Carbon Capture

Energy Efficiency and Air Pollution Control Conference
Wroclaw, September 2009

Dr John Topper
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john.topper@iea-coal.org
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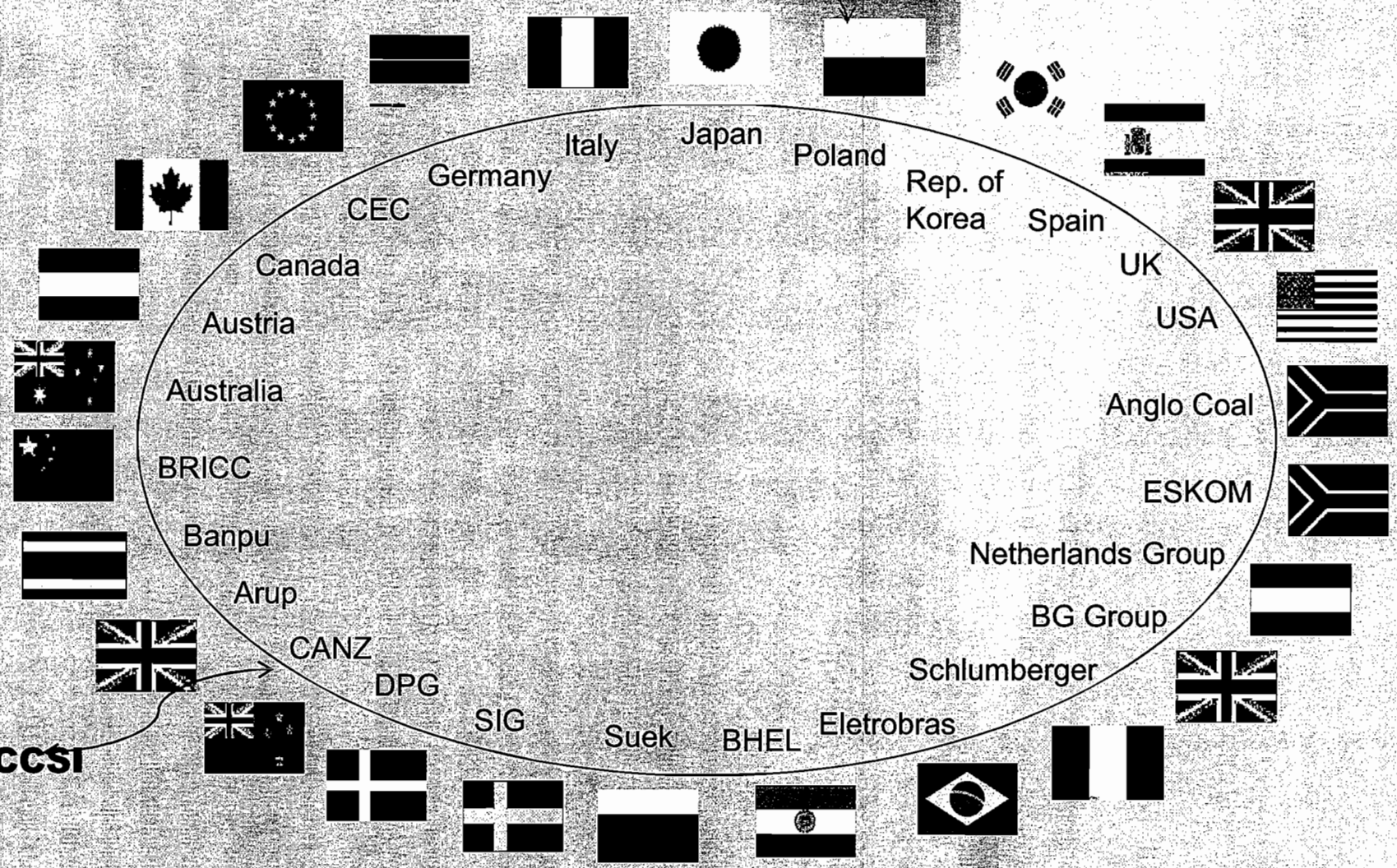

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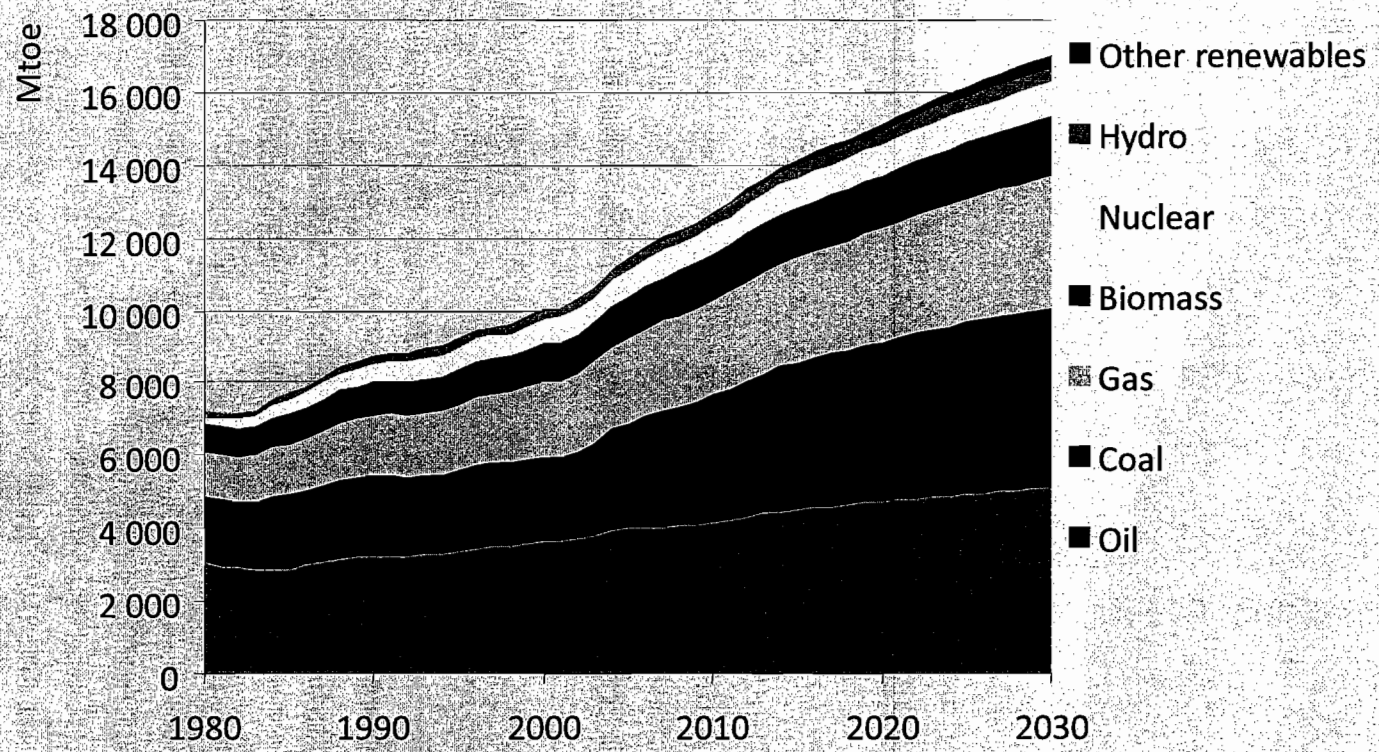
Coal Demand , Best Practice Today, and CCS

- IEA's Projections for Coal
- Best Practice in Power Plant use
- Carbon Capture and Coal

World primary energy demand in the Reference Scenario: this is unsustainable!

IEA WEO 2008



World energy demand expands by 45% between now and 2030 – an average rate of increase of 1.6% per year – with coal accounting for more than a third of the overall rise

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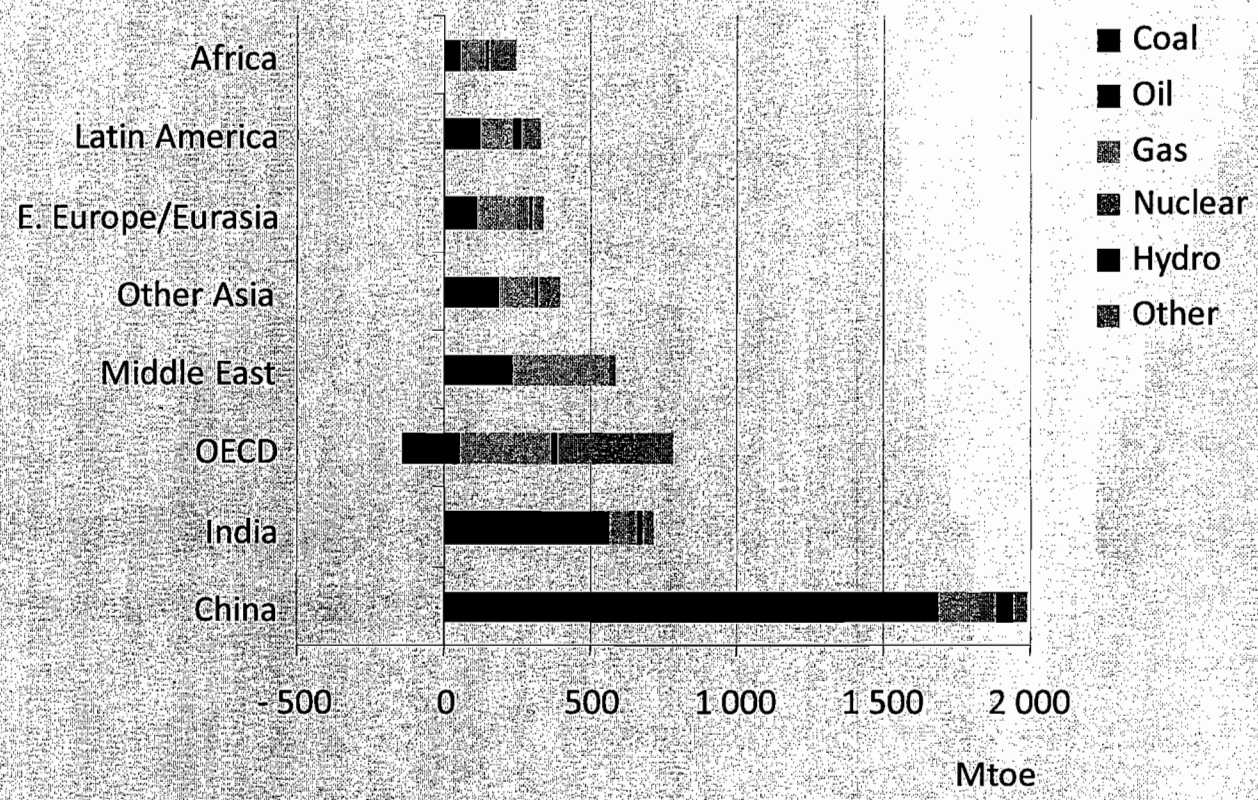
Incremental primary energy demand in the Reference Scenario, 2006-2030

IEA WEO 2008



The increase in China's energy demand to 2030 – the result of its sheer market size & stronger economic growth prospects – dwarfs that of all other countries & regions

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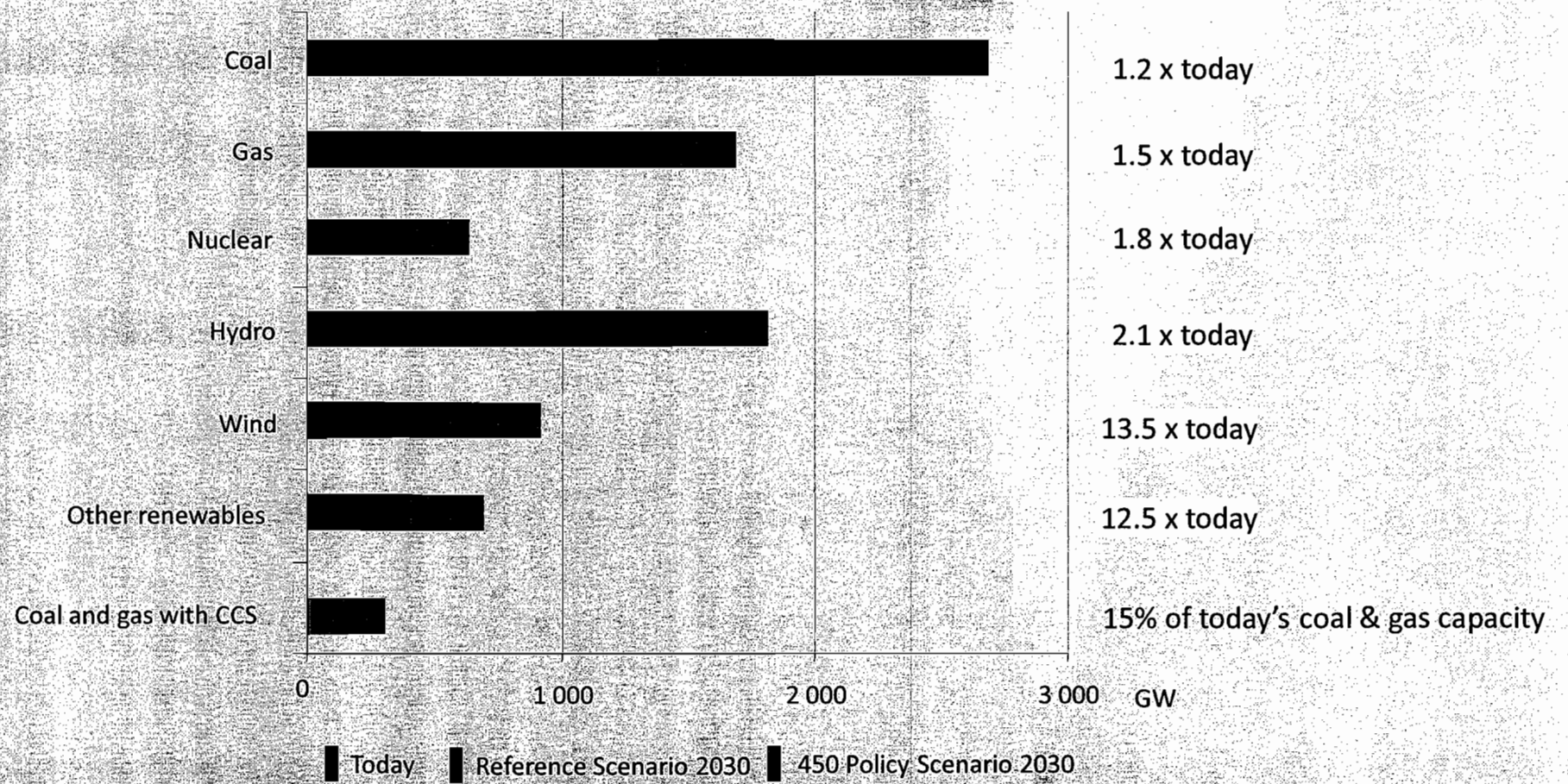
Total power generation capacity today and in 2030 by scenario



In the 450 Policy Scenario, the power sector undergoes a dramatic change – with CCS, renewables and nuclear each playing a crucial role

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Global view of Coal Use today

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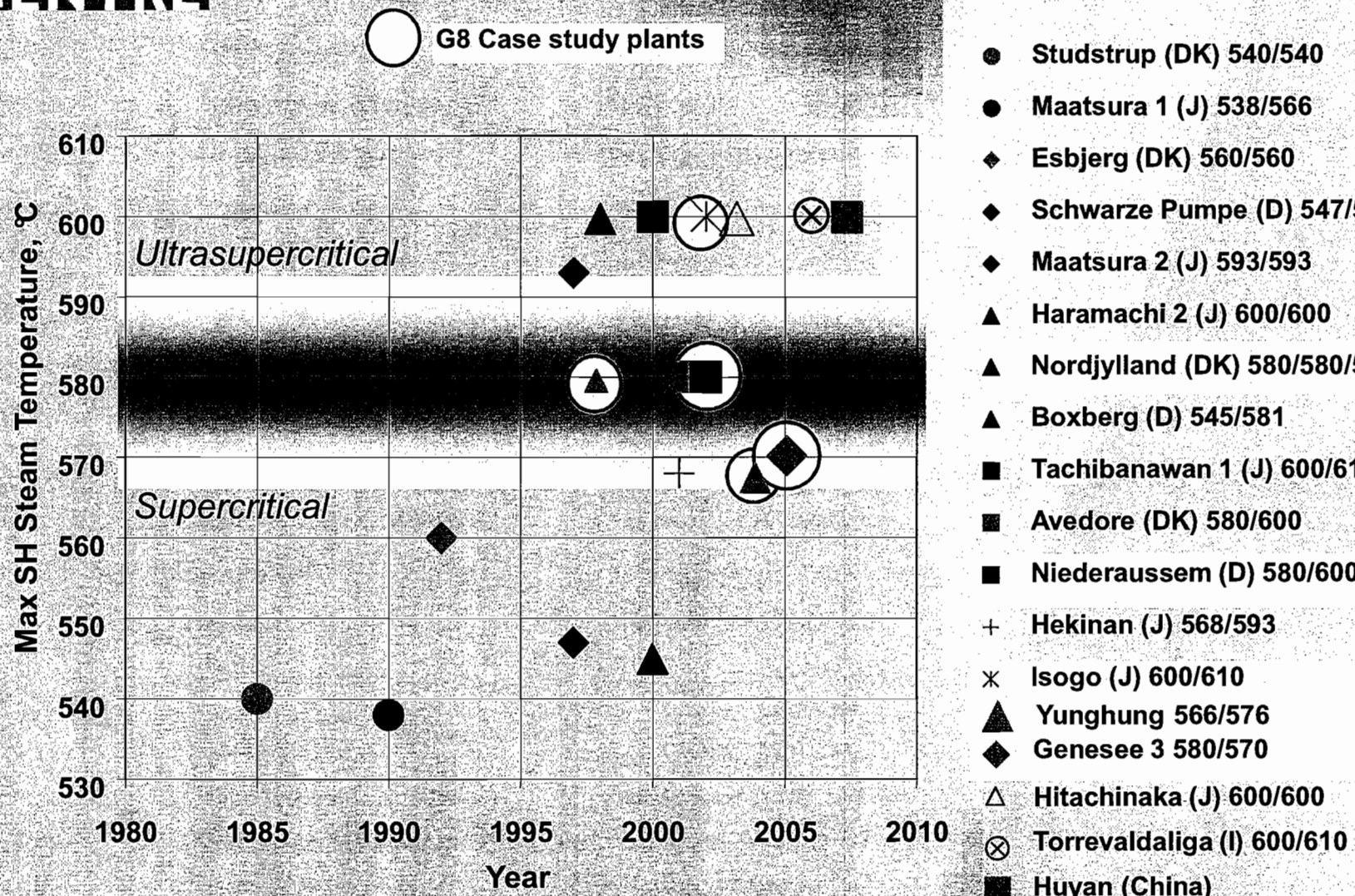
Recent Plant State-of-the-Art Conditions



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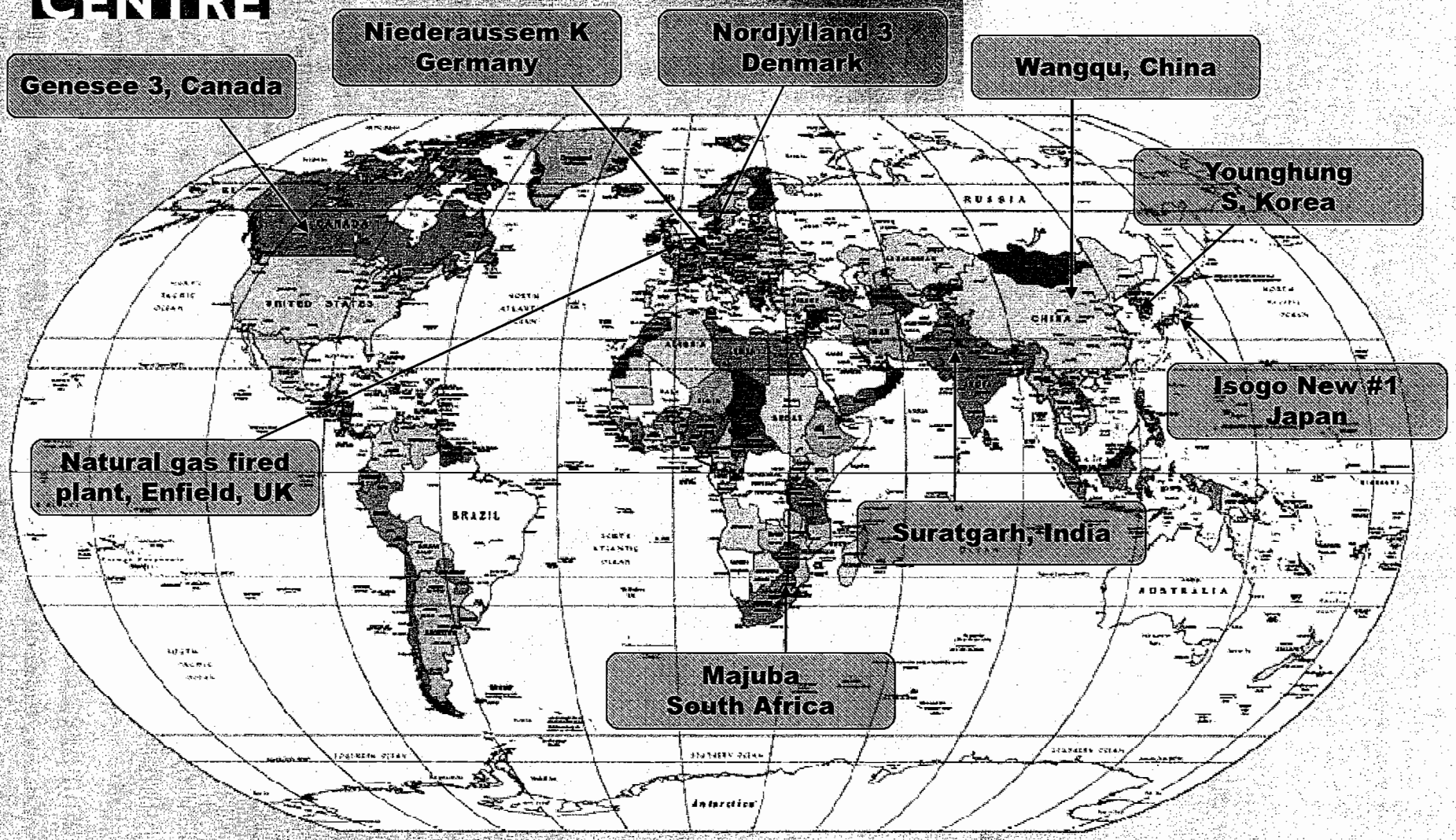
Locations for G8 case studies on Coal Plant



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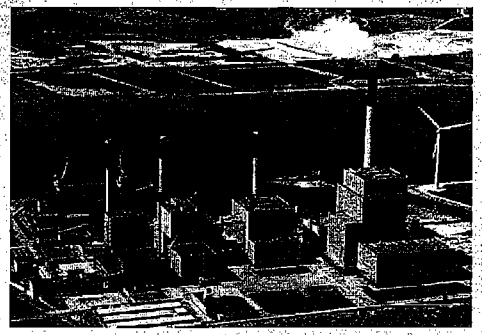
Nordjylland 3, Denmark – highlights



USC, tower boiler, tangential corner firing, int. bituminous coals, cold sea water

- **Most efficient coal-fired plant**
- **Operating net efficiency 47% LHV, power only mode/44.9% HHV (not annual)**
- **High steam conditions 29 MPa/582°C/580°C/580°C at boiler by early use of new materials (P91)**
- **Large number of feedwater heating stages**
- **Double reheat has prevented LP blade erosion**
- **Very low emissions and full waste utilisation**
- **NOx abatement** — **Combustion measures and SCR**
- **Particulates removal** — **ESP**
- **Desulphurisation** — **Wet FGD**

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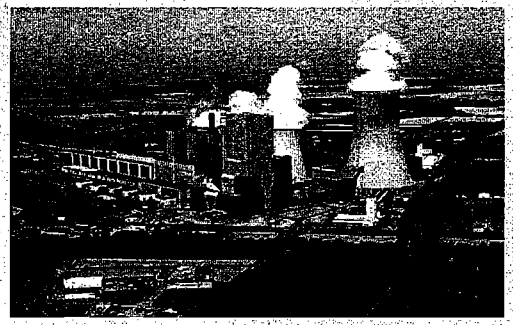
Niederaussem K, Germany – highlights



USC, tower boiler, tangential wall firing, lignite of 50-60% moisture, inland

- **Most efficient lignite-fired plant**
- **Operating net efficiency 43.2% LHV/37% HHV**
- **High steam conditions 27.5 MPa/580°C/600°C at turbine; initial difficulties solved using 27% Cr materials in critical areas**
- **Unique heat recovery arrangements with heat extraction to low temperatures – complex feedwater circuit**
- **Low backpressure: 200 m cooling tower, 14.7°C condenser inlet**
- **Lignite drying demonstration plant being installed to process 25% of fuel feed to enable even higher efficiency**
- **NOx abatement** — **Combustion measures**
- **Particulates removal** — **ESP**
- **Desulphurisation** — **Wet FGD**

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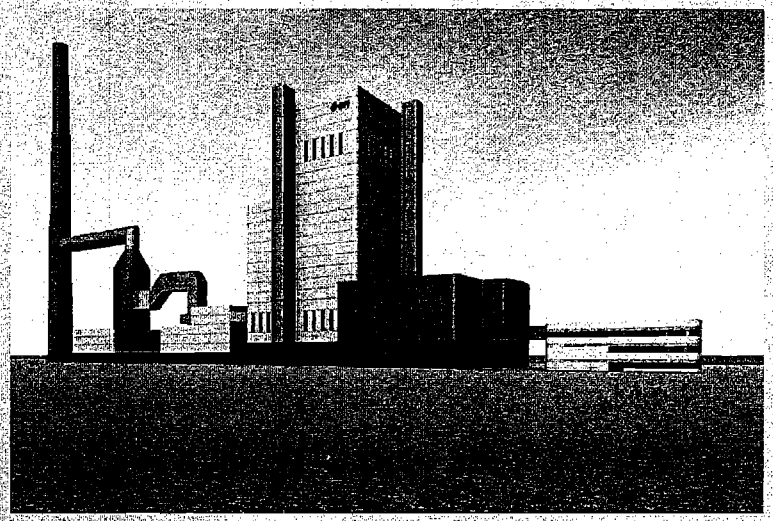
E On 50% efficient plant

... 50 plus by using new materials

Location	**Wilhelmshaven**
Efficiency	50 %
Capacity	500 MW_e
Investment	1 billion €
Start of operation	2014



2007 — **2010** — **2014**

Size of plant
Search for location

Material development
Request for proposal

Construction
Start of operation

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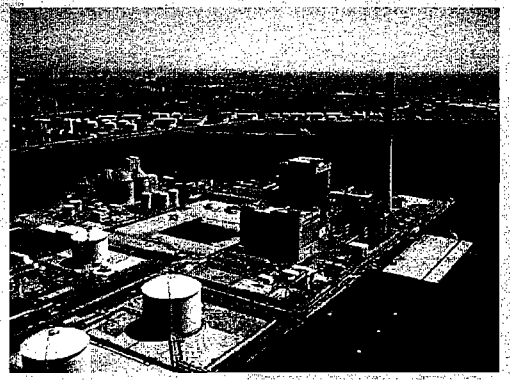
Isogo New Unit 1, Japan – highlights



USC, tower boiler, opposed wall firing, int bitum and Japanese coals, warm sea water

- **Near zero conventional emissions (NOx 20 mg/m^3, sulphur oxides 6 mg/m^3, particulates 1 mg/m^3, at 6% O_2, dry); full waste utilisation**
- **Highest steam conditions: 25.0 MPa/600°C/610°C at turbine: ASME CC 2328 steels in S/H; P122 for main steam pipework**
- **Operating net efficiency >42% LHV/40.6% HHV**
- **Efficiency tempered slightly by 21°C CW, fewer FW heating stages**
- **Dry regenerable activated coke FGD (ReACT)**
- **NOx abatement Combustion measures and SCR**
- **Particulates removal ESP**
- **Isogo New Unit 2 will use ReACT specifically for multi-pollutant control, including mercury**

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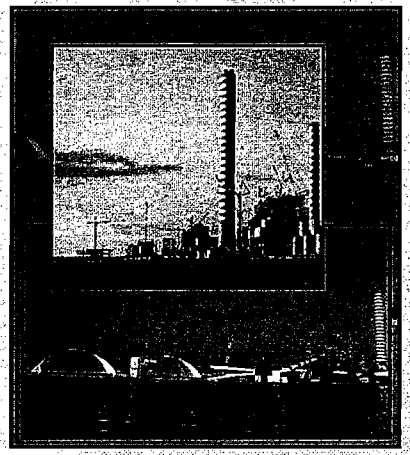
Torrevaldaliga Nord – highlights



USC, boilers supplied by Babcock Hitachi , using bituminous coal

- **3 units at 660MWe = 1980MWe station**
- **Very low conventional emissions (NOx <100 mg/m^3, sulphur oxides <100 mg/m^3, particulates 15 mg/m^3, at 6% O_2, dry); full waste utilisation**
- **Highest steam conditions: 604°C/612°C at turbine: 25 MPa**
- **Operating net efficiency >44.7% LHV**
- **Wet scrubber based limestone/gypsum FGD**
- **NOx abatement SCR**
- **Particulates removal Bag filters**
- **New sea port for coal delivery**
- **Solids handling all enclosed**

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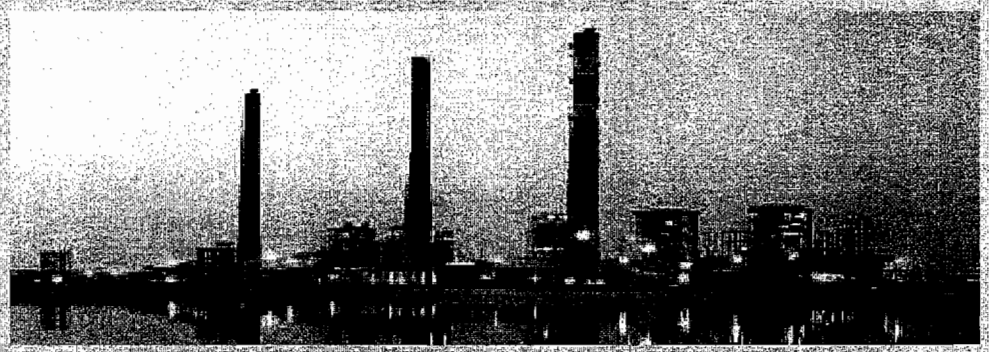
Coal use in China, India and South Africa

Power generation:

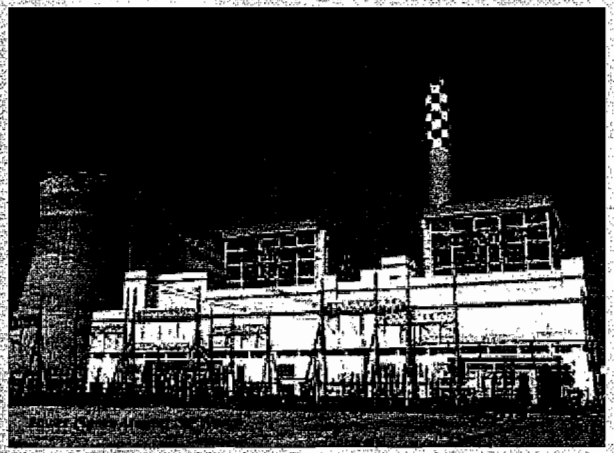
	Subcrit PCC	*SC/USC PCC*	*FBC*	*IGCC*
China	X	X	X	X
India	X	(X)	X	X
South Africa	X	(X)		



Sipat power plant, India

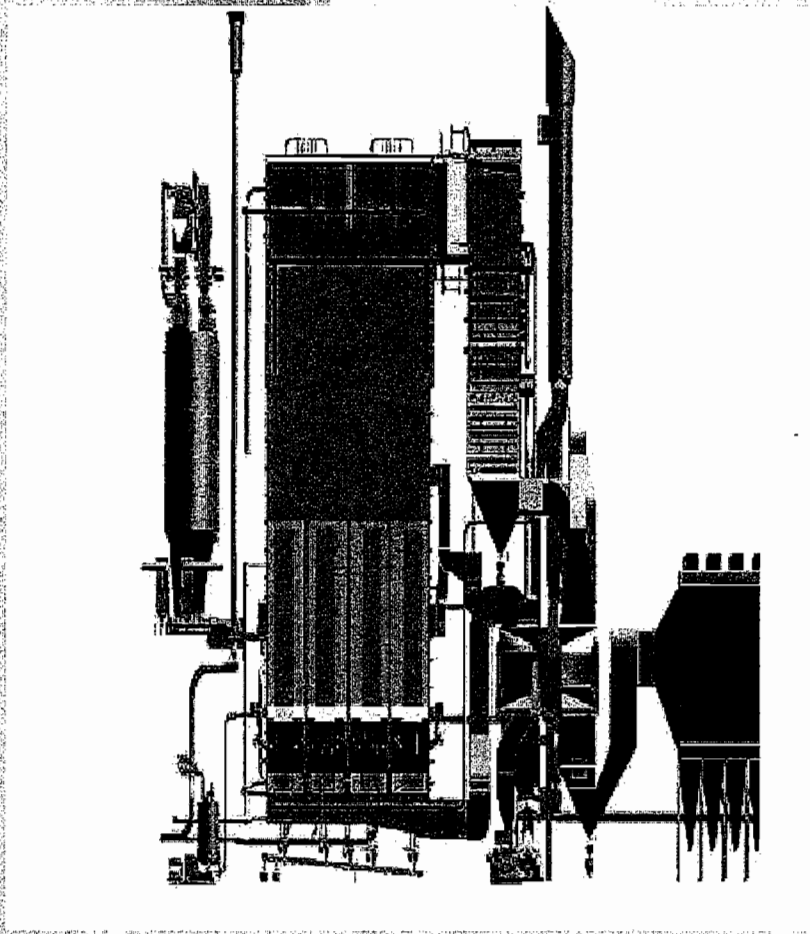
•Shanghai, 900 MW SC units

•Fuyang Huaren, 660 MW SC units



Lagisza Supercritical CFBC – new design

- The world's first CFBC unit with supercritical steam conditions
- Largest CFBC; 460 MWe
- Start-up in 2009
- Emissions of SOx, NOx and particulates lower than required by latest EU LCPD limits.
- Located to NE of Katowice, Poland



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The Reference Scenario: Efficiency improvements in coal-fired generation

IEA WEO 2008

The average efficiency of coal-fired generation rises from 34% in 2006 to 38% in 2030, as supercritical technology initially & then ultra-supercritical become widespread

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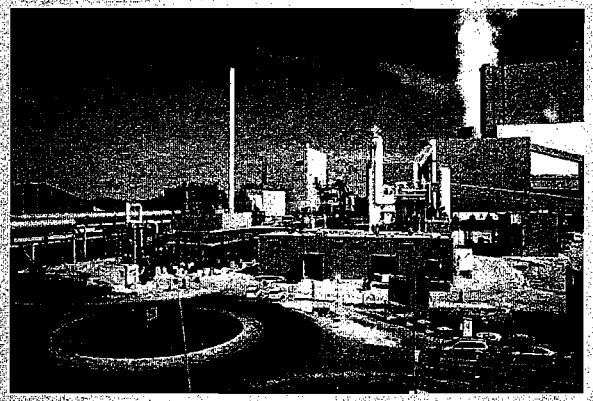
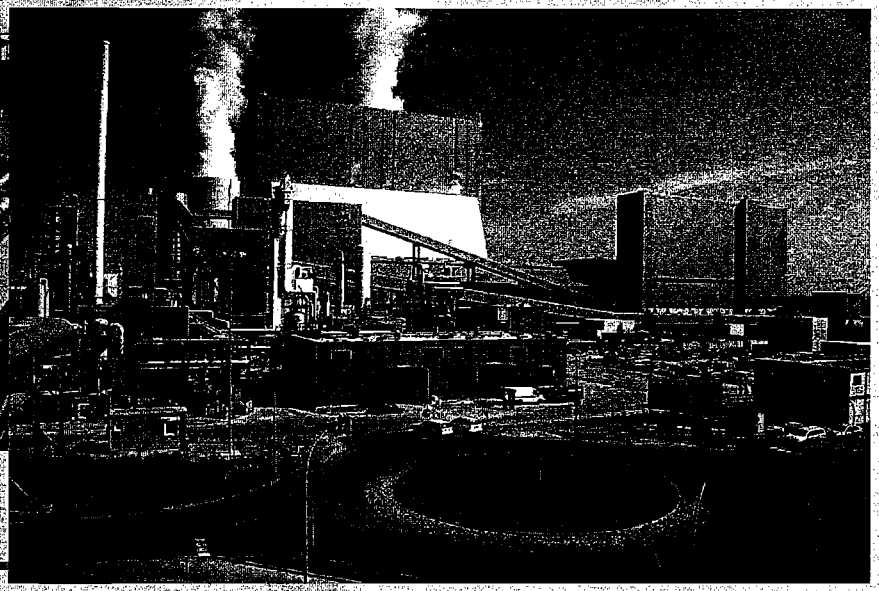
Vattenfall's 30 MWth oxy fuel carbon capture unit





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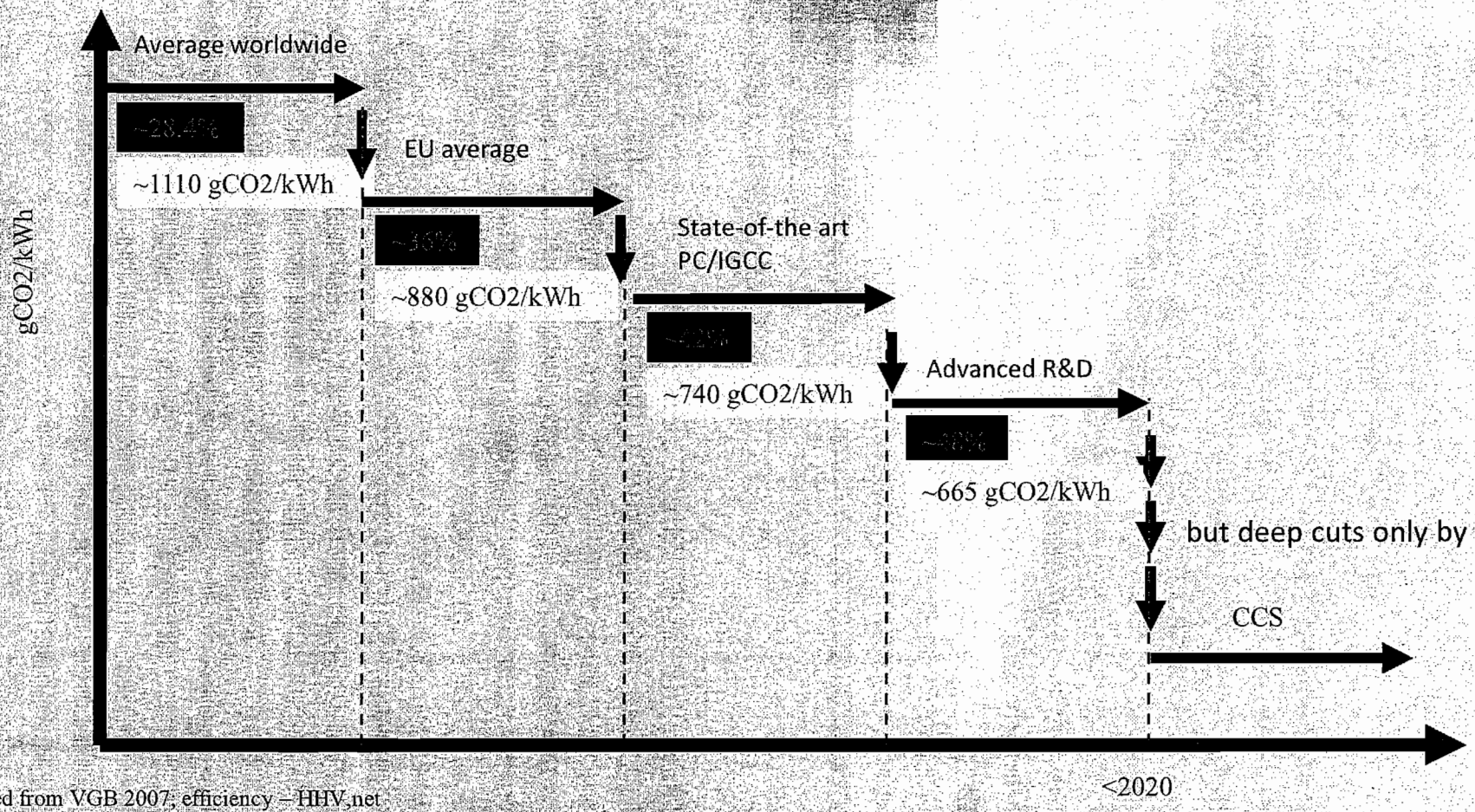
CO2 emission reduction by key technologies



adapted from VGB 2007, efficiency – HHV,net

Energy Efficiency makes big change but deep cuts of CO2 emission can be done only by Carbon Capture and Storage (CCS)

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Carbon Capture

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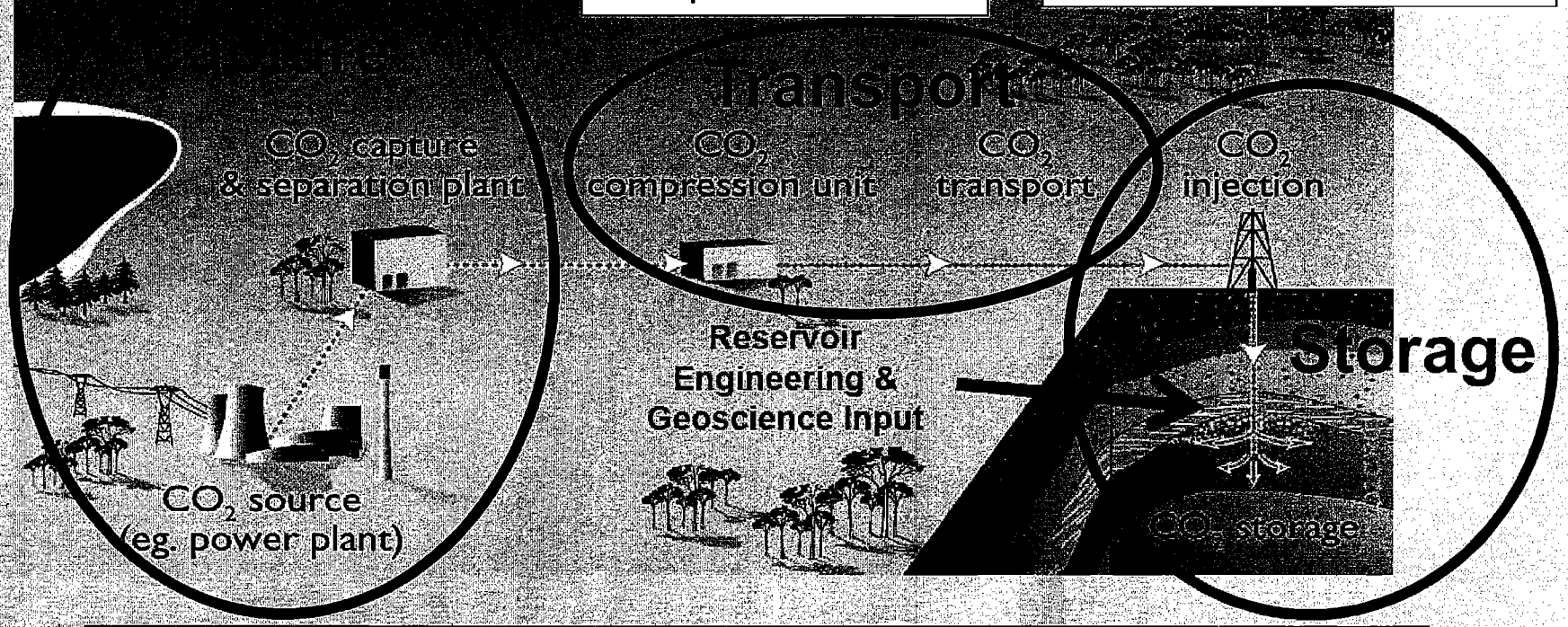
Carbon capture and storage

Three Options;
- Post-combustion
- Pre-combustion
- Oxyfuel

Two Options;
- Pipelines
- Ships

Three Options;
- Coal seams, 40 Gt CO_2
- Oil and gas fields, 1,000 Gt CO_2
- Deep saline aquifers – up to 10,000 Gt CO_2



Outline

- Climate change
- The importance of coal-fired power generation
- CO_2 mitigation technologies for coal-fired power plants
  - More efficient generation
  - CCS
    - Post-combustion CO_2 capture
    - Oxy-combustion CO_2 removal
    - IGCC with pre-combustion CO_2 removal

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Italian CCS activities – Oxy-fuel combustion – CCS2, Brindisi

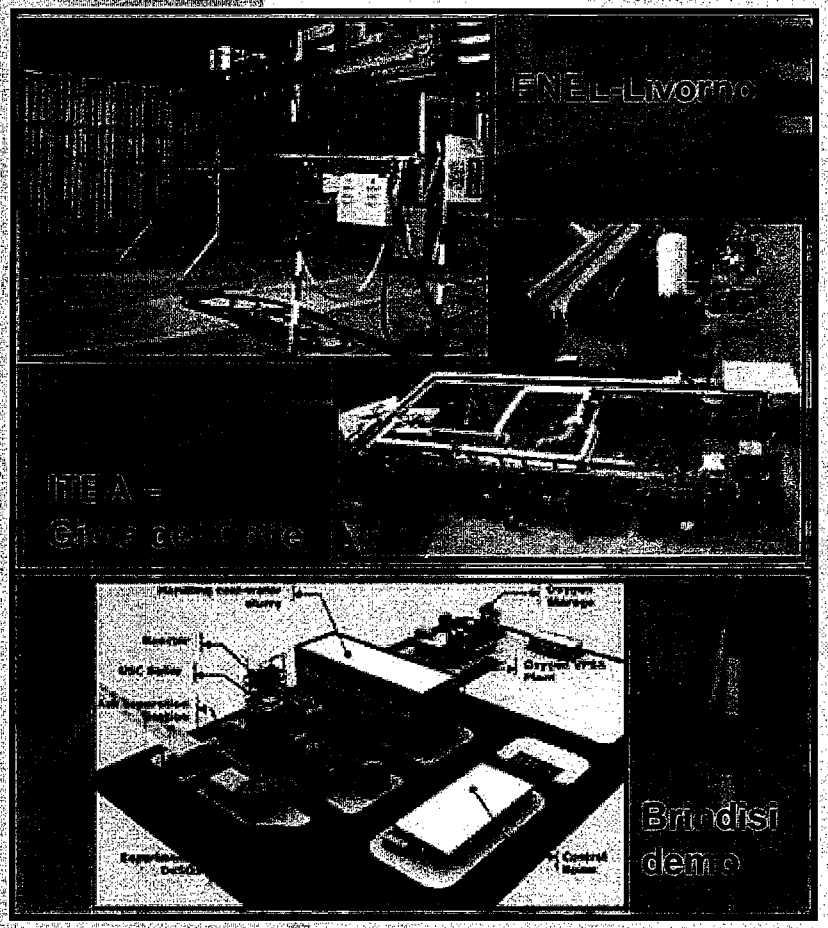
Pilot plant

- Pressurised oxy-fuel technology
- Test programme (3 and 5 MW_{th} test facilities)

Demonstration plant

- Full scale combustor (48 MW_{th}) combustion tests at Brindisi
- Commercial operations 2011

- Data used for 35-70 MWe PCC-based zero emissions oxy-coal power plant (2012)



Courtesy ENEL

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China's 1st Post Combustion CO2 Capture Pilot Plant

The design parameters are:

- **Flue gas flow to unit 2000-3000 Nm3/h**
- **Steam consumption 3GJ/tonne CO2**
- **Solvent consumption < 1.35 kg/tonne CO2**
- **Owners: Huaneng**
- **CSIRO assisted**

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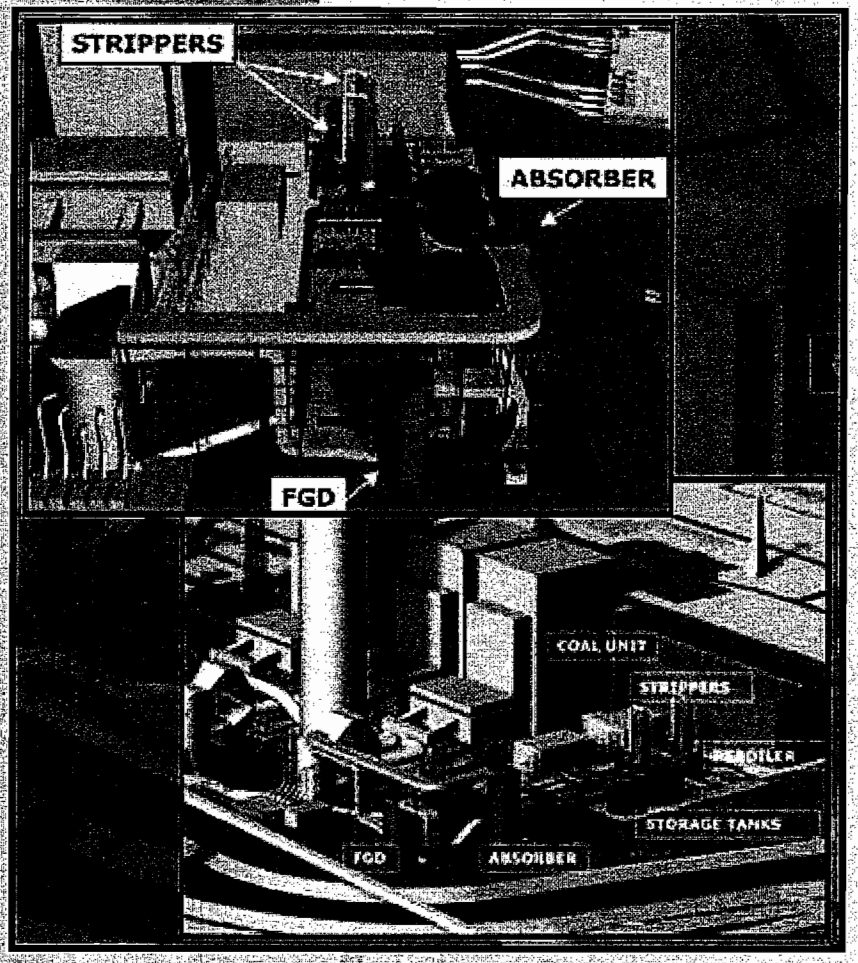
Italian CCS activities
Post-combustion CO_2 capture – CCS1, Brindisi

Pilot plant

- MEA scrubber
- 2.5 t/h CO_2 (5 kt/y) capture
- Completed December 2008
- Startup 2009
- 4 year programme
- ENI will inject CO_2 (24 kt total) into depleted Stogit gas field

Demo plant

- Retrofit of SC PCC unit at Porto Tolle
- CO_2 storage (up to 1 Mt/y) from 2015
- Deep saline aquifer beneath North Adriatic Sea
- Detailed feasibility underway



Courtesy ENEL

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OECD roadmapping – PCC

Current position (2009)	2009-2015	2015-2017	2017-2020	2020-2025	2025-2030	Post-2030
COMMERCIAL USC TO 25-30 MPa/600°C/620°C 46% NET, LHV, BITUM COALS, INLAND, EU, EVAP TOWER COOLING (44%, HHV). ON HIGH MOISTURE LIGNITE 43% NET, LHV, SIMILAR CONDITIONS (37%, HHV)	COMMERCIAL USC TO 25-30 MPa/600°C/620°C	COMMERCIAL USC TO 25-30 MPa/600°C/620°C	COMMERCIAL USC TO 650°C	COMMERCIAL CCS USC TO 35 MPa/700°C/720°C (scrubbing only for 700°C, oxy-coal to 600°C)	COMMERCIAL CCS USC TO 35 MPa/700°C/720°C RANGE OF CAPTURE SYSTEMS (oxy-coal to 650°C only)	COMMERCIAL CCS USC ROUTINELY BEYOND 35MPa/700°C/720°C ALL CAPTURE SYSTEMS ALL COALS, ALL FIRING CONFIGURATIONS. EFFICIENCIES 40-45%, NET, LHV, INCL. CO_2 CAPTURE, DEPENDING ON CONDITIONS AND SYSTEMS USED
	R&D, PILOT TESTS FOR HIGHER TEMPS. FIRST 700°C DEMO BEGINS OPS 2014	700°C DEMOS. R&D materials. Side-stream CCS	R&D Materials, Novel steam cycles, novel post-comb, oxy-coal materials 650-700°C	R&D Studies supporting commercial plants. OXY-COAL PILOT 650, 700°C	>700°C/720°C DEMOS, ALL WITH CCS, VARIOUS HYBRIDS. R&D materials	
	CCS R&D PILOTS AND DEMOS	FULL FLOW CCS DEMOS ON USC 600°C PLANTS	ADVANCED FULL FLOW CCS DEMOS (scrubbing only for 700°C technology)			
Emissions on bitum coals: Particulates 5-10 mg/m³, SO_2 <20 mg/m³, NOx 50-100 mg/m³, dry systems can give lower emissions		Full environmental controls at at least 2009 state-of-the-art emissions		Emissions on all coals: Particulates 1 mg/m³, SO_2 10 mg/m³, NOx 10 mg/m³, 90% mercury removal		Near-zero emissions all coals: Particulates <1 mg/m³, SO_2 <10 mg/m³, NOx <10 mg/m³, 99% mercury removal, 90% CO_2 capture

From 2014: 500 MWe 700°C PCC demo in Europe. Needs supplementing with other demos. Sidestream CO_2 capture needed

By 2020: 700°C plants should be offered commercially, supported by continuing materials dev/testing

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Development of IGCC by RWE Power

RWE Power will develop a zero-CO_2 lignite-fired IGCC in Germany

Plant will be commissioned with CO_2 transport and storage if market and regulatory conditions are appropriate

- Capacity: 450 MW_{gross}, 360 MW_{net}
- Net efficiency (target): 40%
- CO2 storage: 2.6 million tonnes per year in depleted Gas reservoir or saline aquifer
- Commissioning: 2014

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Green Gen – The first Chinese IGCC

Near Tiajin, southeast of Beijing. The first phase of GreenGen is expected on line in 2011, generating 250MWe, expanding to 650 megawatts in later phases.

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OECD roadmapping – IGCC

Current position (2009)	2009-2015	2015-2017	2017-2020	2020-2025	2025-2030	Post-2030
5 DEMOS/EX- DEMOS OPERATE, 250-300MWe VARIOUS ENTRAINED GASIFIERS ON VARIOUS COALS 600 MWe COMMERCIAL PLANTS UNDER CONSTRUCTION HIGHER CAP. COST THAN PCC BUT COST W. CAPTURE COMPETITIVE. 40-43% NET, LHV, 46% NEW PLANTS (LATEST F-TURBINES) ON BITUMINOUS COALS. AVAILABILITY ~80%	CONSTRUCT, OPERATE COMMERCIAL PLANTS WITH LATEST F AND W TURBINES	COMMERCIAL PLANTS WITH LATEST F- AND W-CLASS GTs. SOME WITH CAPTURE COMMERCIAL OP OF NEW WATER QUENCH GASIFIERS	COMMERCIAL PLANTS OPERATING WITH LATEST F- AND W-CLASS GTs VARIOUS GASIFIER TYPES	COMMERCIAL PLANTS OPERATING WITH H- OR J-GTs ABLE TO BURN HIGH HYDROGEN. FULL CO_2 CAPTURE AVAILABLE CAPITAL COST COMPARABLE WITH PCC FOR NON-CAPTURE SYSTEMS	COMMERCIAL IGCC WITH H- OR J-CLASS GTSs WITH ULTRA-LOW NOx ON HYDROGEN FUEL FULL CO_2 CAPTURE	ADVANCED IGCC WITH CO_2 CAPTURE AS STANDARD USING GAS SEPARATION MEMBRANES AND SHIFT MEMBRANE REACTORS CAPITAL COST LOWER THAN PCC WITH CCS EFFICIENCY 40-45%, LHV, INCL. CO_2 CAPTURE, DEPENDING ON TECHNOLOGY, COAL TYPE, CONDITIONS ITM OXYGEN AS OPTION WITH ITM-OPTIMISED H_2 GT DRY GAS CU INCL. MERCURY FUEL CELLS IN SOME PLANTS EVENTUALLY OTHER SYSTEMS WITH CO_2 GTs CO_2/H_2O GTs
	R&D Reduce capital cost, increase availability, extend range of coals Gas turbine developments Dry syngas cleaning Cryogenic air separation – ITM Modelling to optimise IGCC blocks	R&D Reduce cost, extend range of coals, increase availability GT developments Dry syngas cleaning Slipstream gas conditioning for fuel cells ITM PILOT (stand alone)	R&D Develop H-class IGCC GT Develop GT for ITM cycles Novel gasifiers new power cycles Pilot dry gas cleaning, fuel cells, ICSS DEMONSTRATE ITM (stand alone)	R&D Studies supporting commercial plants	R&D Studies supporting commercial plants Develop CO_2 GTs	
	PRE-COMB CCS R&D PILOTS AND DEMOS			PILOT OF FUEL CELL ON ULTRA-CLEAN SYNGAS SLIPSTREAM DEMONSTRATE ITM OXYGEN SUPPLY IN IGCC	COMMERCIAL SCALE DEMO OF DRY GAS CLEANUP DEMONSTRATE ITM O_2 IN IGCC WITH ITM-OPTIMISED GT AND CCS DEMONSTRATE ULTRA-DEEP SYNGAS CLEANING WITH FUEL CELLS	
Emissions: Particulates <1 mg/m³ SO_2 <20 mg/m³ NOx <50 mg/m³, SCR will allow lower levels Mercury capture demonstrated		FULL FLOW PRE-COMB CCS DEMOS USING SCRUBBING Supporting R&D Full emissions controls at at least 2009 state-of-the-art	ADVANCED CCS DEMOS	Emissions: Particulates 0.1 mg/m³ Emissions of SO_2 and NOx 10 mg/m³ 90% mercury removal		Near-zero emissions, all coals: Particulates 0.1 mg/m³ SO_2 <10 mg/m³ NOx <10 mg/m³ 99% mercury removal

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OECD roadmapping – CO_2 capture

Current position (2009)	2009-2015	2015-2017	2017-2020	2020-2025	2025-2030	Post-2030
4 LARGE SCALE CAPTURE DEMONSTRATIONS ON NON-POWER PLANTS CAPTURE EXPERIENCE IN CERTAIN INDUSTRIES AND FOR FOOD PROCESSING NUMBER OF PILOT CAPTURE PLANTS	POST-COMB CAPTURE: LARGE DEMOS 85% CAPTURE INCLUDING RETROFITS USING SCRUBBING R&D & PILOTS ON PCC AND CFBC: develop/improve chemical solvents; laboratory work on post comb capture using dry systems	POST-COMB CAPTURE: LARGE DEMOS 85% CAPTURE INCLUDING RETROFITS USING SCRUBBING R&D & PILOTS: test advanced solvents, dry systems Capture slipstream on 35MPa/700°C/720°C unit.	POST-COMB CAPTURE: ADVANCED DEMOS >85% CAPTURE INC RETROFITS: R&D: advanced solvents membrane contactors dry absorption, adsorption	FIRST COMMERCIAL SYSTEMS, >85% CAPTURE, ALL 3 MAIN METHODS OF CAPTURE, NEW PLANTS AND RETROFITS POST-COMB CAPTURE: Supporting R&D: new solvents, membrane contacting systems with novel solvents, solid absorbents or adsorbents	COMMERCIAL SYSTEMS 90%+ CAPTURE. POST-COMB CAPTURE: NEW SOLVENTS, MEMB CONTACTING, SOLID ABSORBENTS, ADSORBENTS OXY-COAL 650°C STEAM SYSTEMS PRE-COMB CAPTURE WITH H-CLASS GTs WITH ULTRA-LOW NOx ON H_2 GENERAL: REDUCED ENERGY USE OF CO_2 CAPTURE AND COMPRESSION	COMMERCIALLY AVAILABLE SYSTEMS, 90%+ CO_2 CAPTURE, EFFICIENCIES 40-45%, NET, LHV POST COMBUSTION CAPTURE: GREATLY REDUCED WATER CONSUMPTION FROM VARIOUS SYSTEMS. OXY-COAL: VARIOUS SYSTEMS UP TO 700°C STEAM, INTEGRATED ITM PRE-COMB CAPTURE: HIGH SPEC GTs WITH ULTRA-LOW NO_x ON H_2; MEMBRANES; SHIFT MEMBRANE REACTORS; ADVANCED IGCC CYCLES WITH ITM; IG FUEL CELLS CHEMICAL LOOPING SYSTEMS
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	PRE-COMB CAPTURE: LARGE DEMOS. R&D: new solvents, membranes, adsorption systems	PRE-COMB CAPTURE: LARGE DEMOS 85% CAPTURE PHYSICAL AND CHEMICAL SCRUBBING R&D: H_2 combusting GTs, slipstream tests on memb separation, lab test membranes and membrane reactors, advanced gasifiers	PRE-COMB CAPTURE: ADVANCED SOLVENTS >85% CAPTURE FULL FLOW DEMOS R&D: air-extracting GTS for hydrogen, shift with low steam requ't, pilot membranes, membrane reactors, gasification fuel cell cycles, advanced gasifiers, novel IGCC cycles	PRE-COMB CAPTURE R&D: H-class GTs for high H_2 fuels, pilot shift membrane reactors, novel IGCC cycles, pilot ITM IGCC	PRE-COMB CAPTURE: DEMO SHIFT MEMBRANE REACTORS; DEMO GASIFICATION FUEL CELL CYCLES FOR CCS; DEMO NOVEL GASIFICATION-BASED CYCLES; DEMO ITM IGCC CCS Supporting R&D	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

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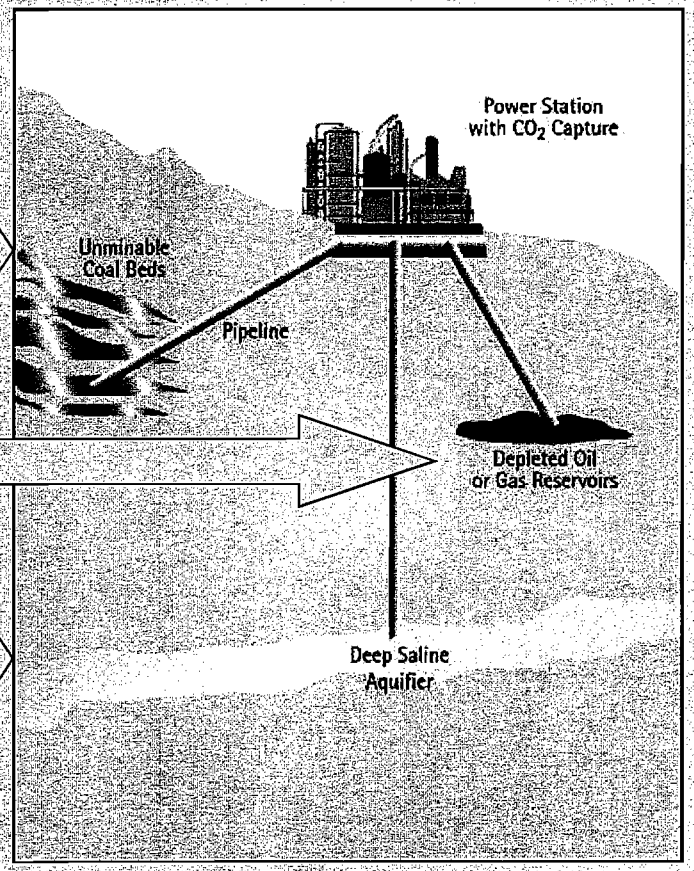
Geological Storage Options

Unminable Coal Seams
30 Gt CO_2
Able to store <2 Years of 2030 Emissions

Depleted Oil & Gas Fields
930 Gt CO_2
Able to Store 50 Years of 2030 Emissions

Deep Saline Aquifers
400-10 000 Gt CO_2
Able to store 20 - 530 Years of 2030 Emissions



Note: CO_2 Storage capacity at cost of 20 US $ per tonne of CO_2

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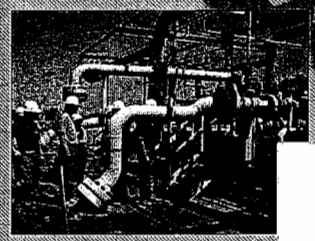
Largest CO_2 Storage Projects

Snohvit capturing and injecting 0.7 Mt/y CO_2 since 2008

Rangeley injecting 0.8 Mt/y CO_2 since 1980's

Sleipner capturing and injecting 1 Mt/y CO_2 since 1996



Weyburn capt and injecting Mt/y CO_2 since 2000

Total Anthropogenic CO2 captured and injected currently 5 Mt/y

In-Salah capturing and injecting 0.8 Mt/y CO_2 since 2004

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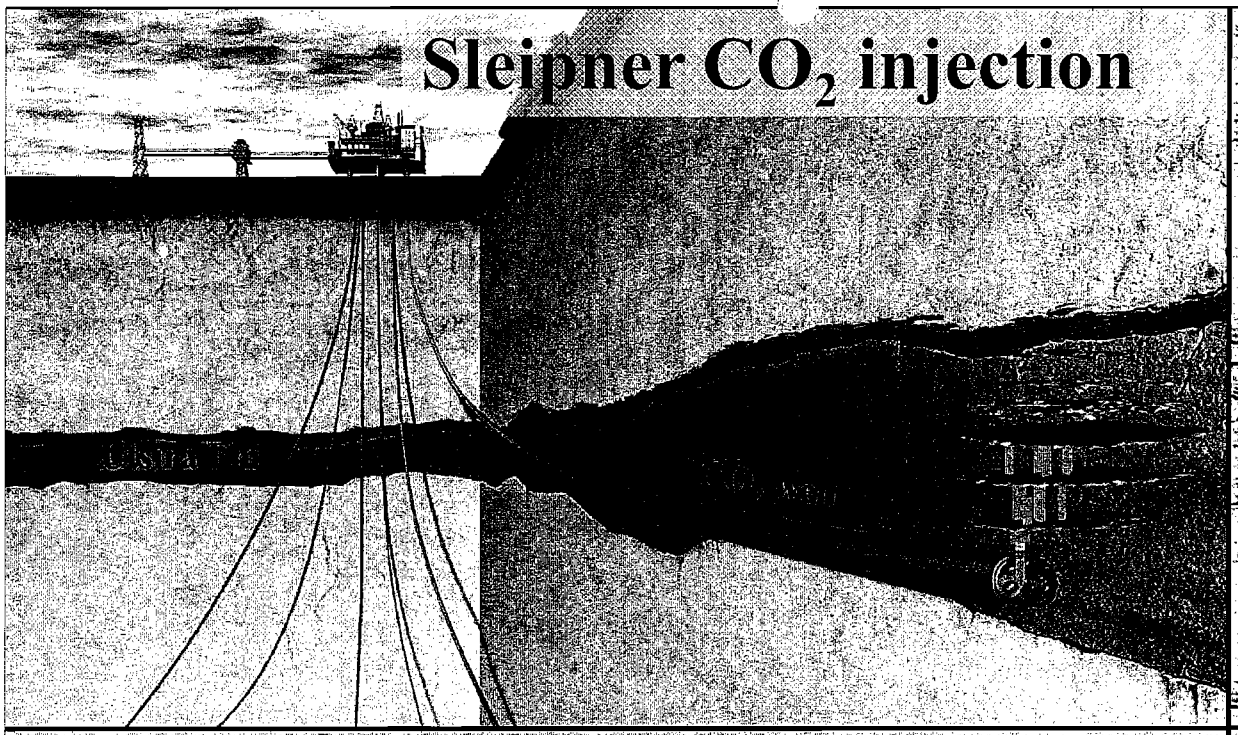
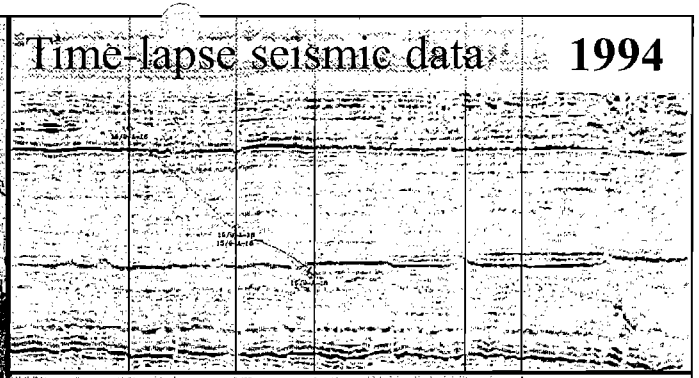
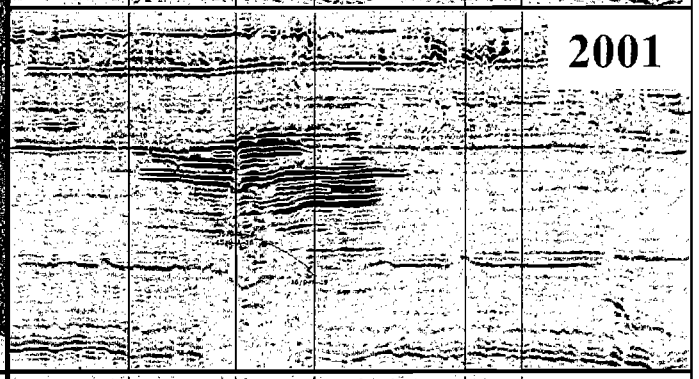
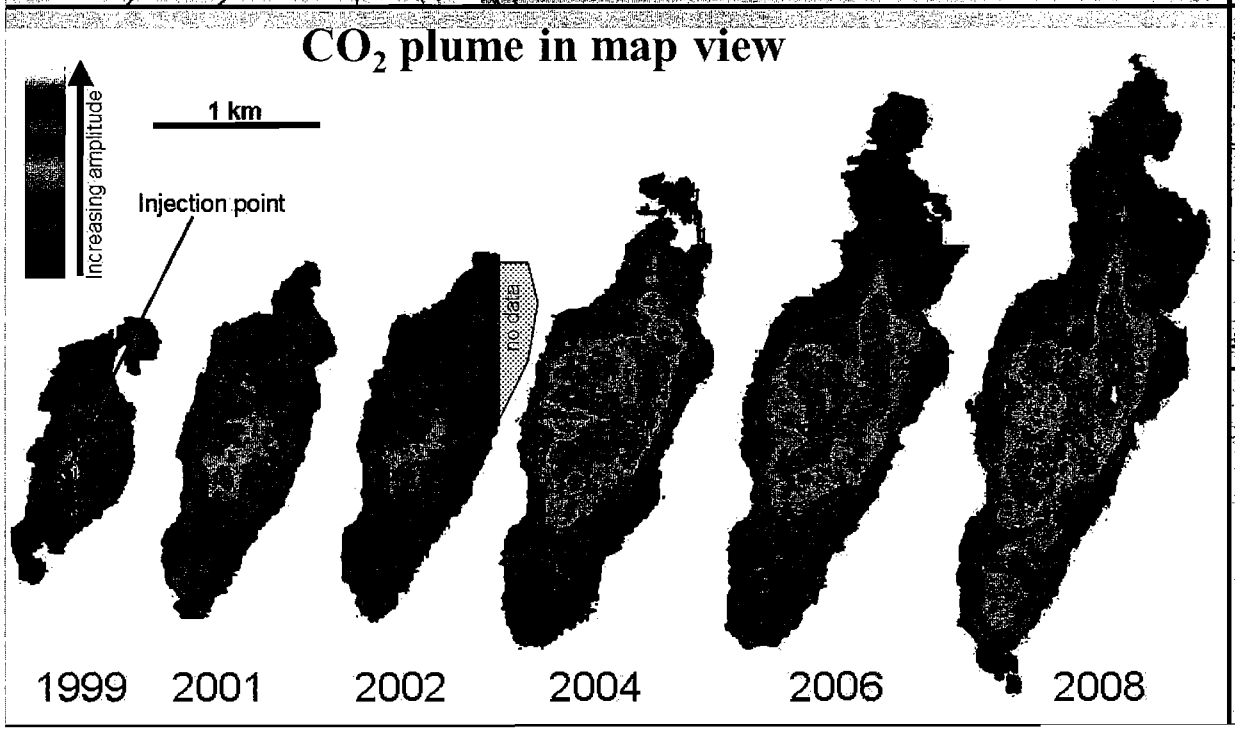
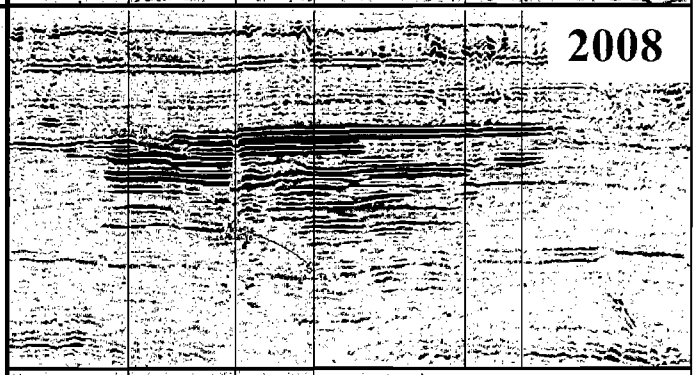
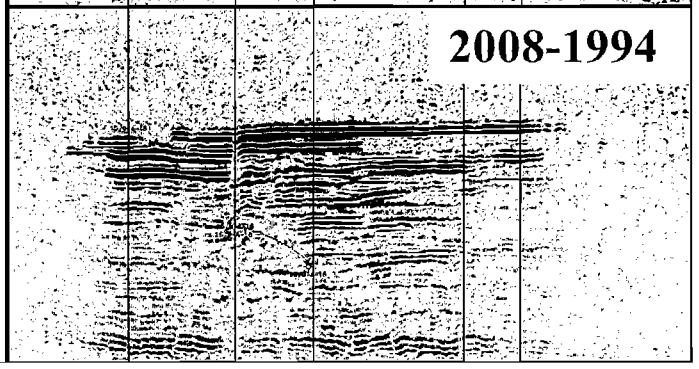

Sleipner CO_2 injection


Time-lapse seismic data
1994


2001


CO_2 plume in map view
1 km
Increasing amplitude
Injection point
no data
1999
2001
2002
2004
2006
2008


2008


2008-1994

001815

IEA CLEAN COAL CENTRE

How Does the CO_2 Stay Underground?

- **Structural Trapping**
  - CO_2 moves upwards and is physically trapped under the seals
- **Residual storage**
  - CO_2 becomes stuck between the pore spaces of the rock as it moves through the reservoir
- **Dissolution**
  - CO_2 dissolves in the formation water
- **Mineralisation**
  - The CO_2 can react with minerals in the rock forming new minerals

lution of CO_2

Residual trapping of CO_2

Mineral trapping of CO_2

G01816

Climate Change: Mitigation of Carbon Dioxide Emissions from Coal-fired Power Plants

United States Environmental Protection Agency

Ravi K. Srivastava

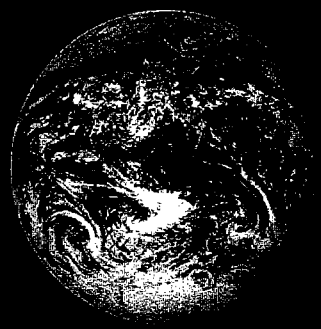
Chief, Air Pollution Technology Branch

Frank Princiotta

Director, Air Pollution Prevention and Control Division

Wroclaw 2009 – Energy Efficiency and Air Pollutant Control Conference
Wroclaw, Poland

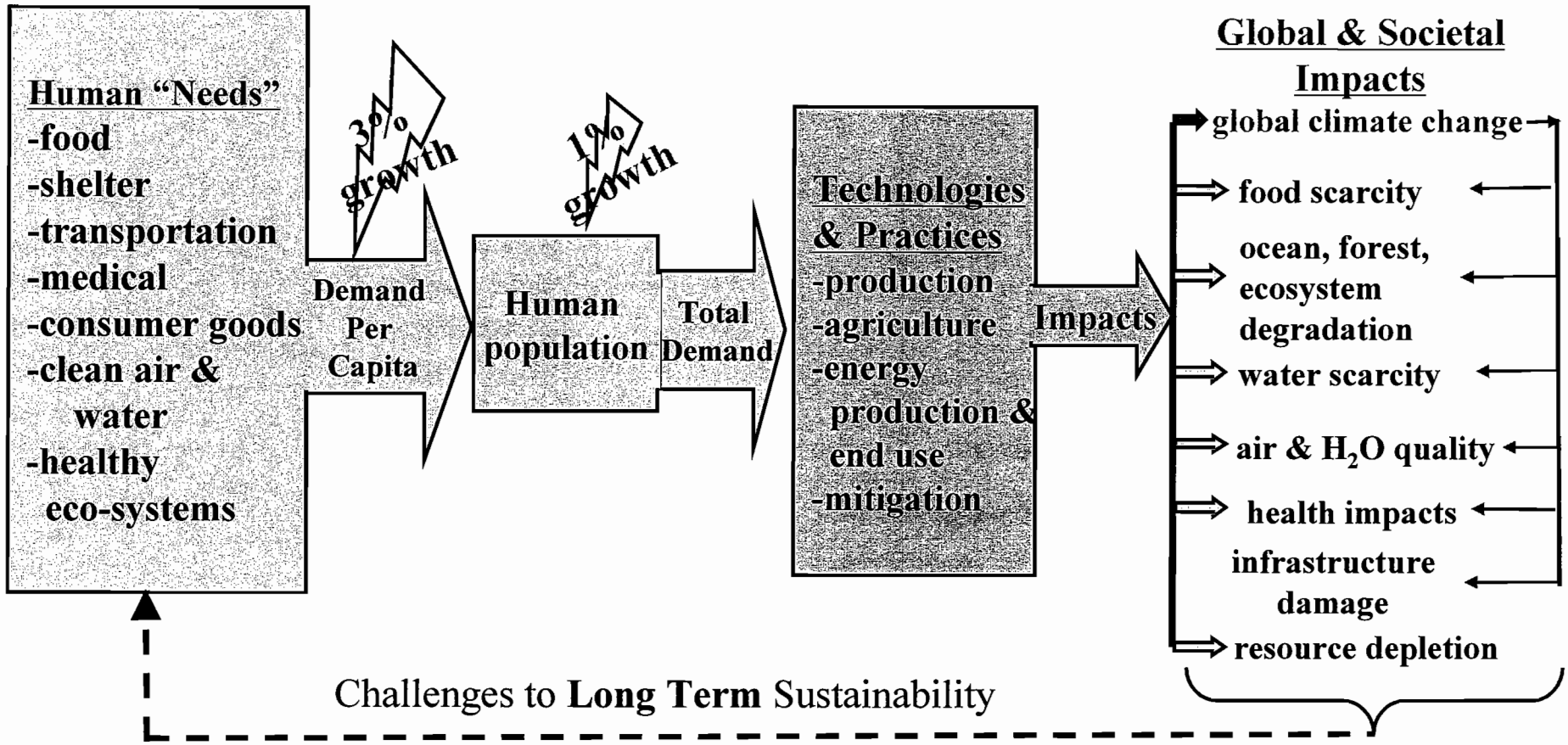
The views expressed in this presentation are those of the author and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency.



Office of Research and Development
National Risk Management Research Laboratory

September 2009

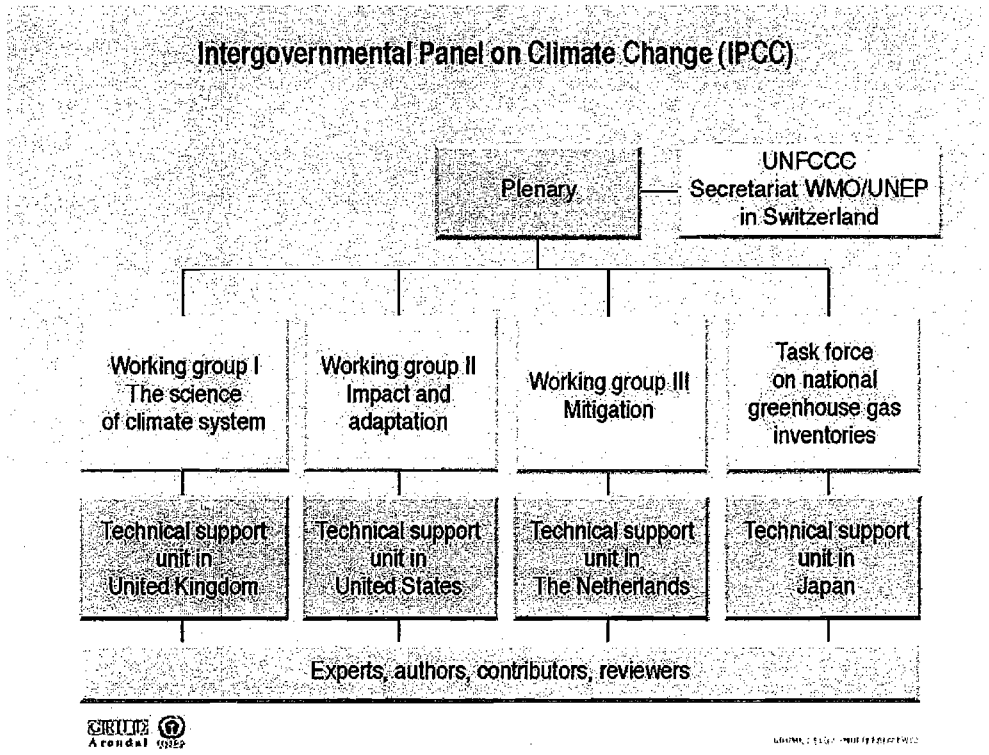
Relationship of Climate Change to Sustainability and the Role of Technology



001819

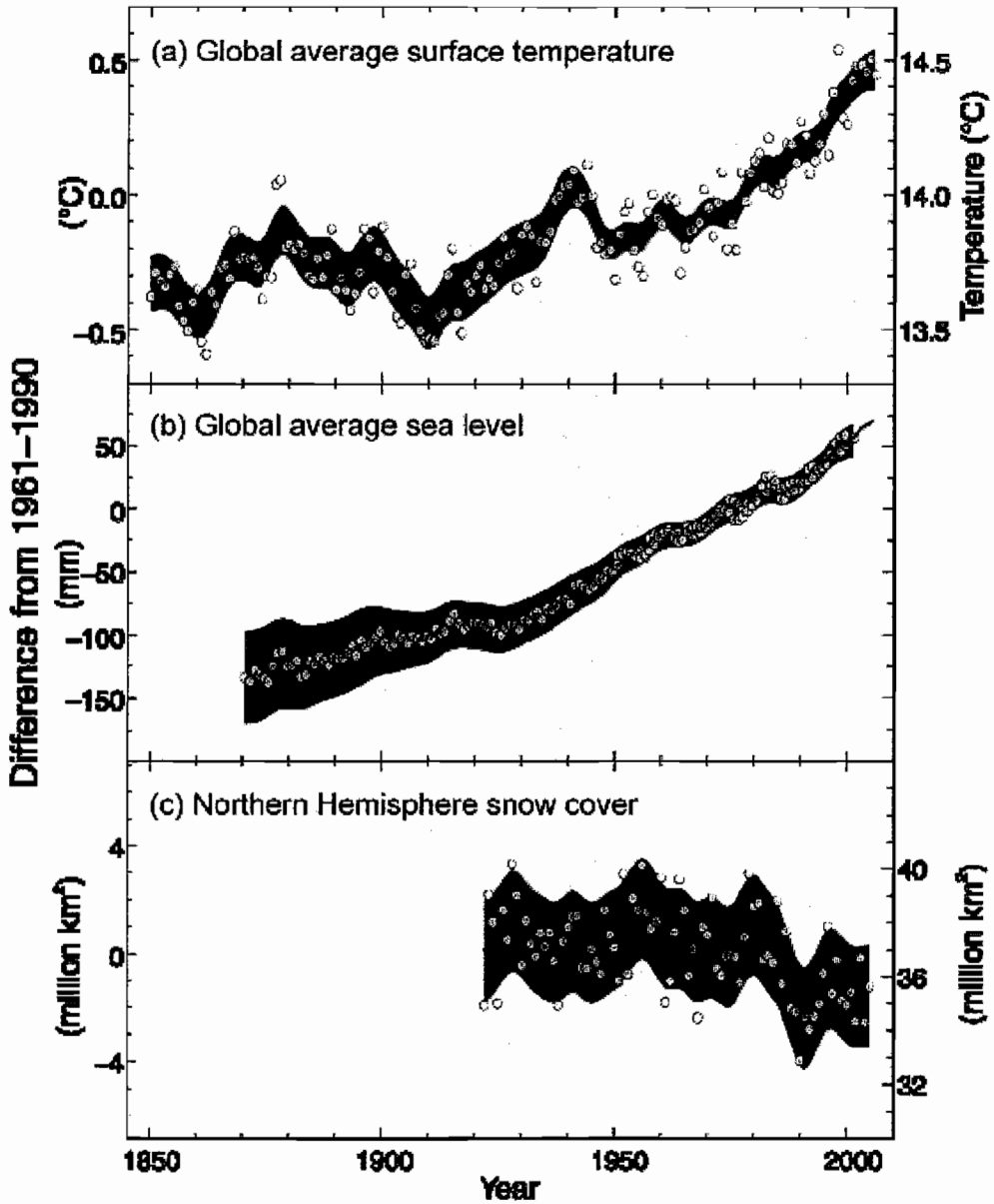
2007 IPCC Report

- Human activities (fossil-fuel use, land-use changes, and agriculture) are contributing to observed increase in atmospheric concentrations of greenhouse gases
- Warming of the climate system is ***unequivocal*** as evidenced by melting polar ice, rising sea level, changes in precipitation patterns, droughts, heat-waves, etc.
- The earth is warming and it is ***very likely*** due to the increased anthropogenic GHG concentrations
- Continued GHG emissions at or above current rates would cause further warming later in this century



Source: United Nations framework convention on climate change (UNFCCC)

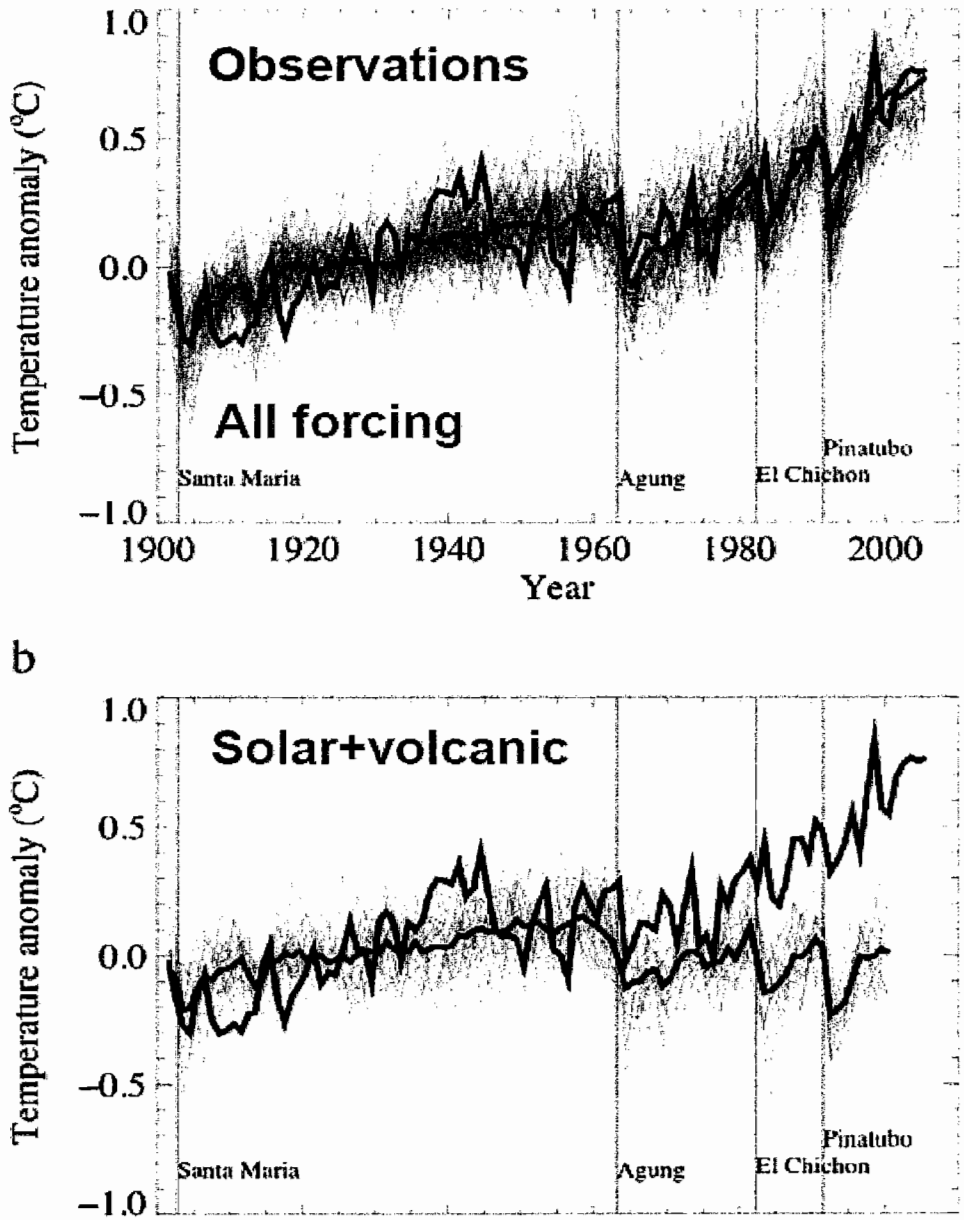
Changes in temperature, sea level and Northern Hemisphere snow cover
1850 to 2005



Source: IPCC Fourth Assessment Report, 2007

Attribution

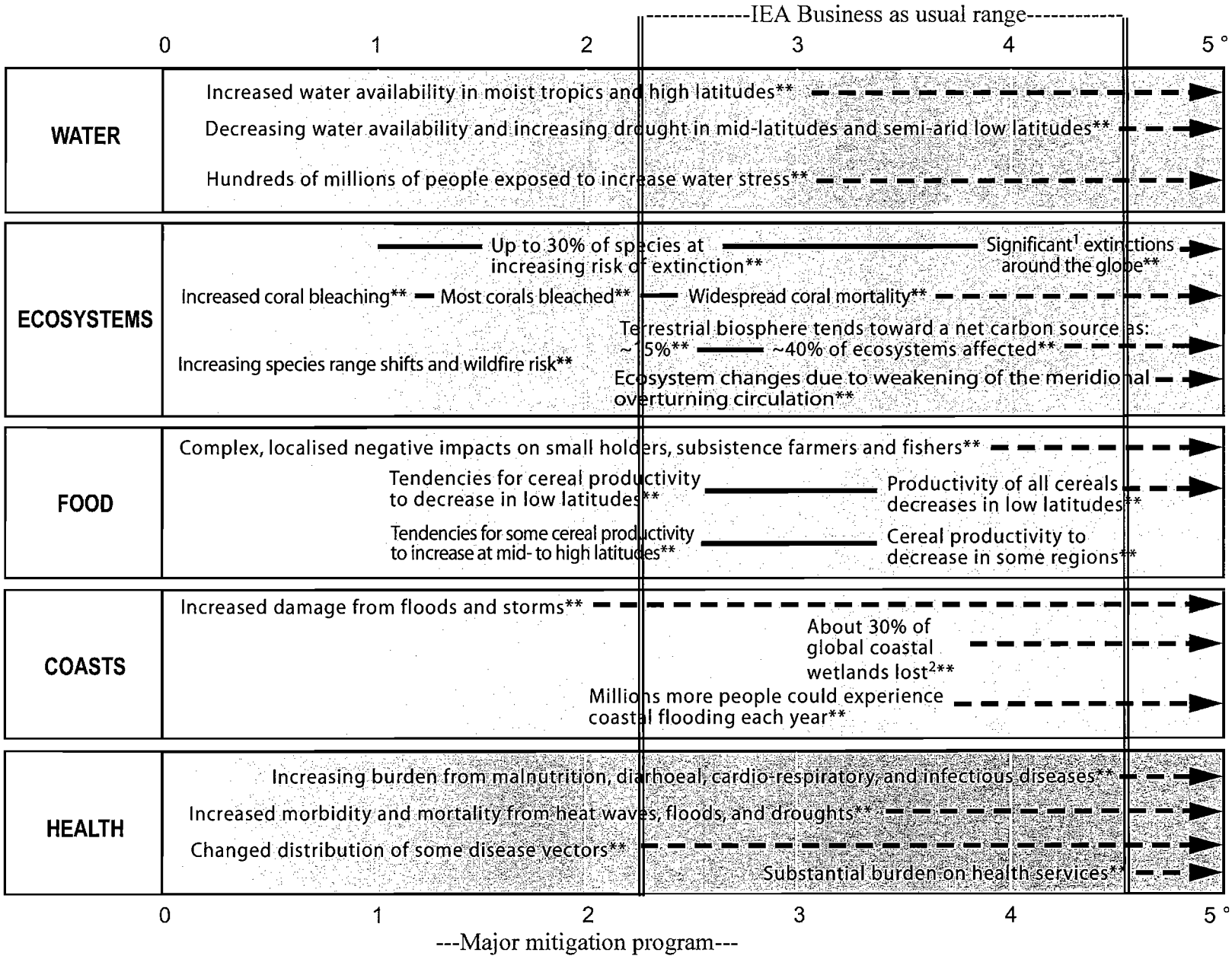
- are observed changes consistent with
- ☑ expected responses to forcings
- ☒ inconsistent with alternative explanations



Source: IPCC Fourth Assessment Report, 2007

001822

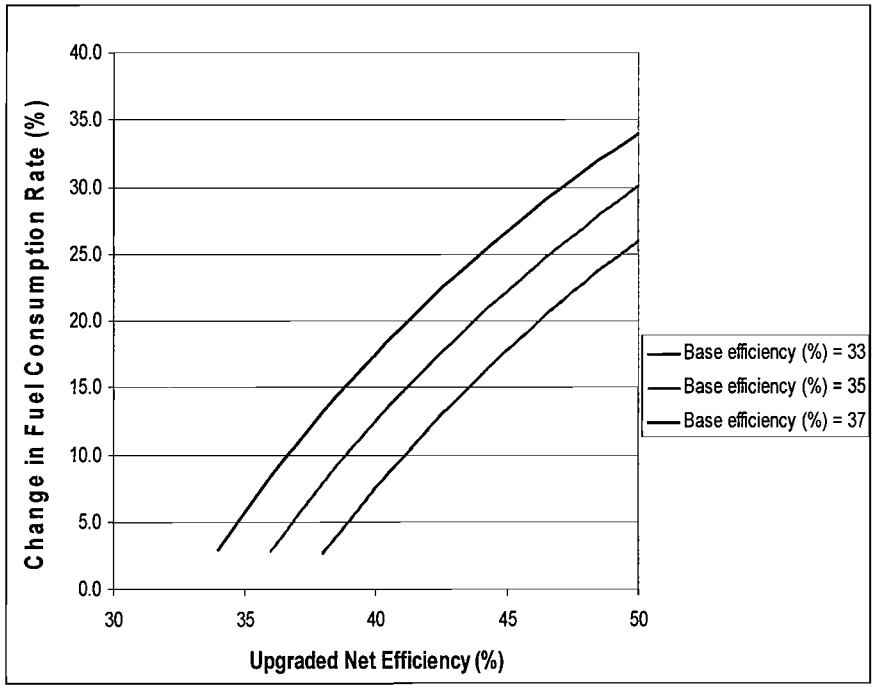
Global Impacts vs.1990 to 2100 Warming per IPCC, 2007



001823

Fuel Prices and Deployment of Advanced PC Technologies

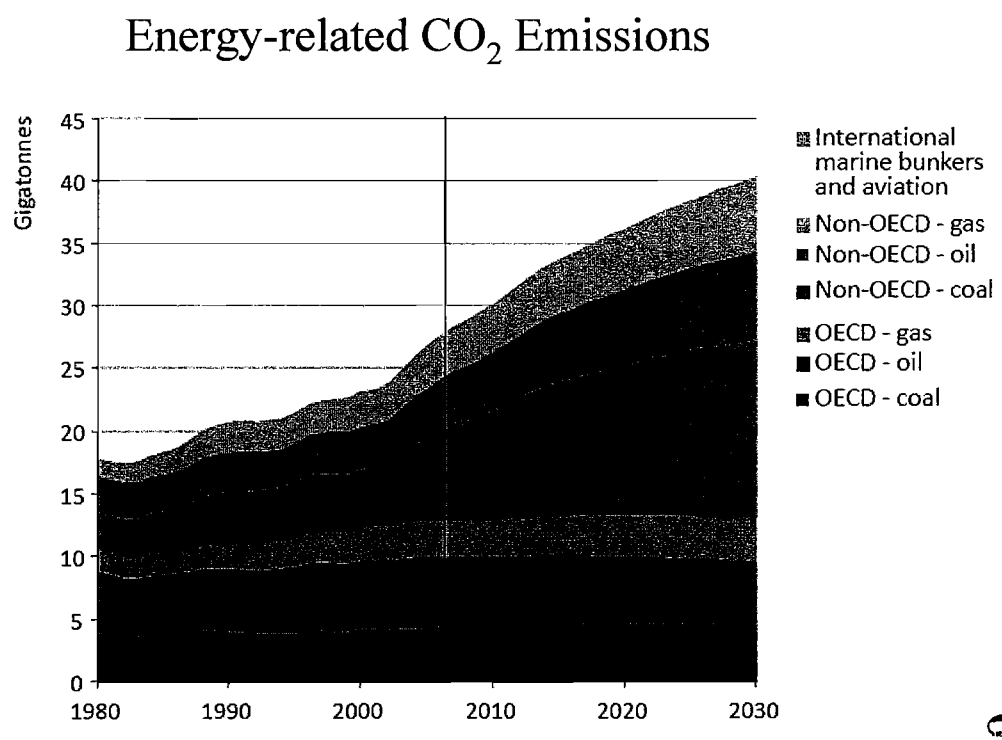
- Moving from subcritical generating conditions (e.g., 33% efficiency) to USC generating conditions (e.g., 40% efficiency) can reduce coal consumption per kWh of electricity generated by over 15 % - a substantial saving.



When fuel prices are driven upwards, more efficient generation technologies become more attractive.

Coal-fired Power Generation: A Key Area of Focus

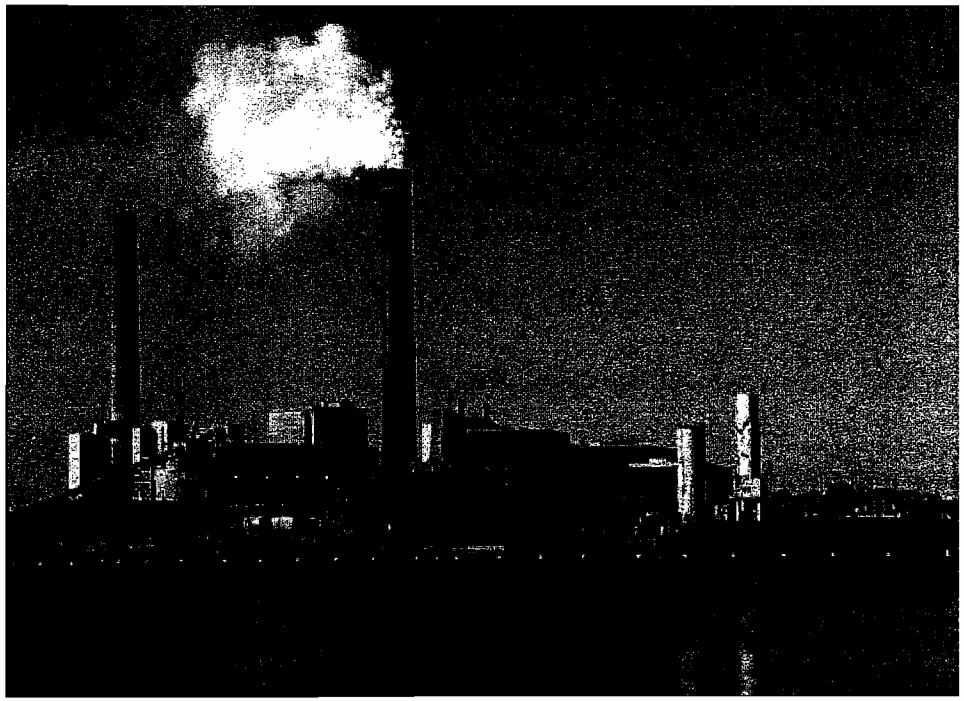
- Emissions from a total of about 1,000 coal-fired power plants globally were about 8 Gt CO_2 in 2007. This contributed to about 27% of total global CO_2 emissions. (IEA, 2008)
- Worldwide energy-related CO_2 emissions from coal use are expected to grow significantly through 2030.
- Since coal plants are large point sources, they potentially offer attractive opportunities for cost-effective reductions in CO_2.



World Energy Outlook 2008, IEA

CO_2 Mitigation Options for Coal-fired Power Plants

- More efficient generation
- Substitution of coal by gas or biomass
- Carbon capture and sequestration (CCS)



Efficiency Improvements Options

Power Plant Improvements	Efficiency Increase (percentage points)[14]
Air Preheaters (optimize)	0.16 to 1.5
Ash Removal System (replace)	0.1
Boiler (increase airheater surface)	2.1
Combustion System (optimize)	0.15 to 0.84
Condenser (optimize)	0.7 to 2.4
Cooling System Performance (upgrade)	0.2 to 1
Feedwater Heaters (optimize)	0.2 to 2
Flue Gas Moisture Recovery	0.3 to 0.65
Flue Gas Heat Recovery	0.3 to 1.5
Coal Drying (Installation)	0.1 to 1.7
Process Controls (installation/improvement)	0.2 to 2
Reduction of Slag and Furnace Fouling (magnesium hydroxide injection)	0.4
Sootblower Optimization	0.1 to 0.65
Steam Leaks (reduce)	1.1
Steam Turbine (refurbish)	0.84 to 2.6

Source: DOE/NETL, 2008

- Strong correlation between plant efficiency and types of fuel and power generation technology used
- Modest CO_2 reduction potential (1.0% efficiency gain equals approximately 2.5% CO_2 reduction)

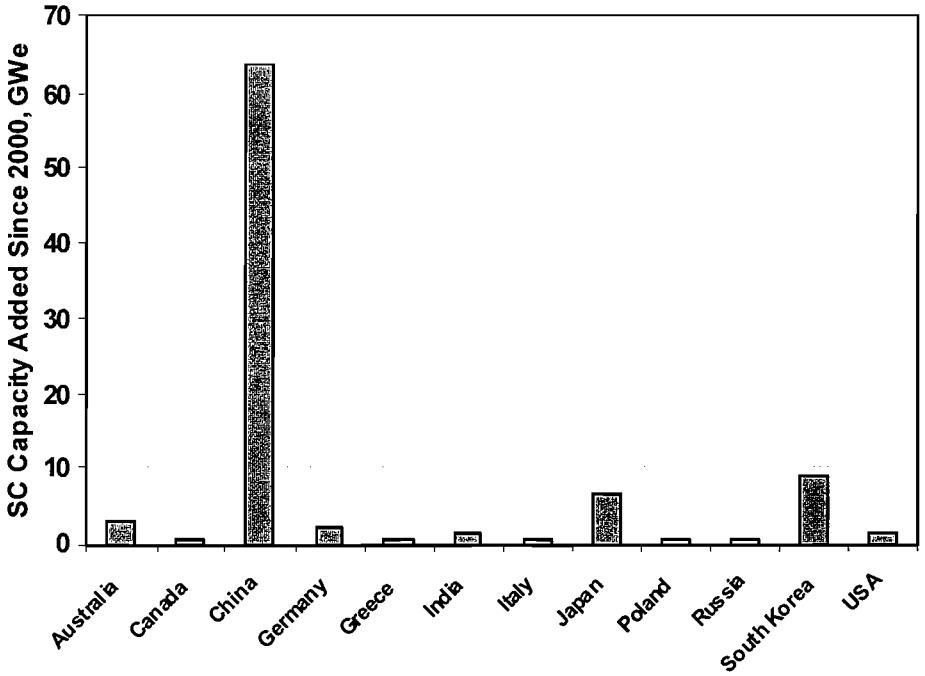
Beyond Subcritical: Supercritical, Ultra-supercritical, and Advanced Ultra-supercritical Pulverized Coal (PC) Plants

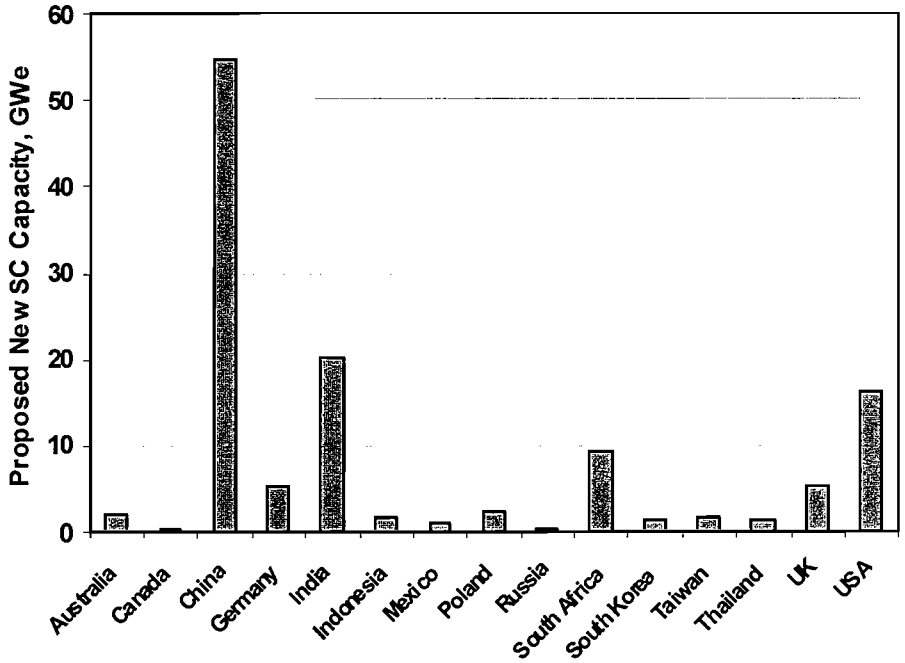
- **Supercritical plants:**
  - Typical steam outlet pressures of 3500 psi (24.1 MPa) with 1050/1050 °F (566/566 °C) double reheat
  - Typical plant efficiencies are in the 36 - 38 % range (HHV, net); newly constructed supercritical plants should have an efficiency of approximately 41 %

- **Ultra-supercritical (USC) plants:**
  - Typical steam outlet pressures of 3700 psi (25.5 MPa) with 1100/1100 °F (593/593 °C) double reheat
  - Plant efficiencies range from 38 to 43% (HHV, net)

- **Advanced USC (AUSC) plants:**
  - May have steam outlet pressures as high as 5080 psi (35 MPa) and steam outlet temperatures as high as 1300 °F (704 °C)
  - Plant efficiencies (HHV, net) are estimated to be up to 46 %

Supercritical PC Plants

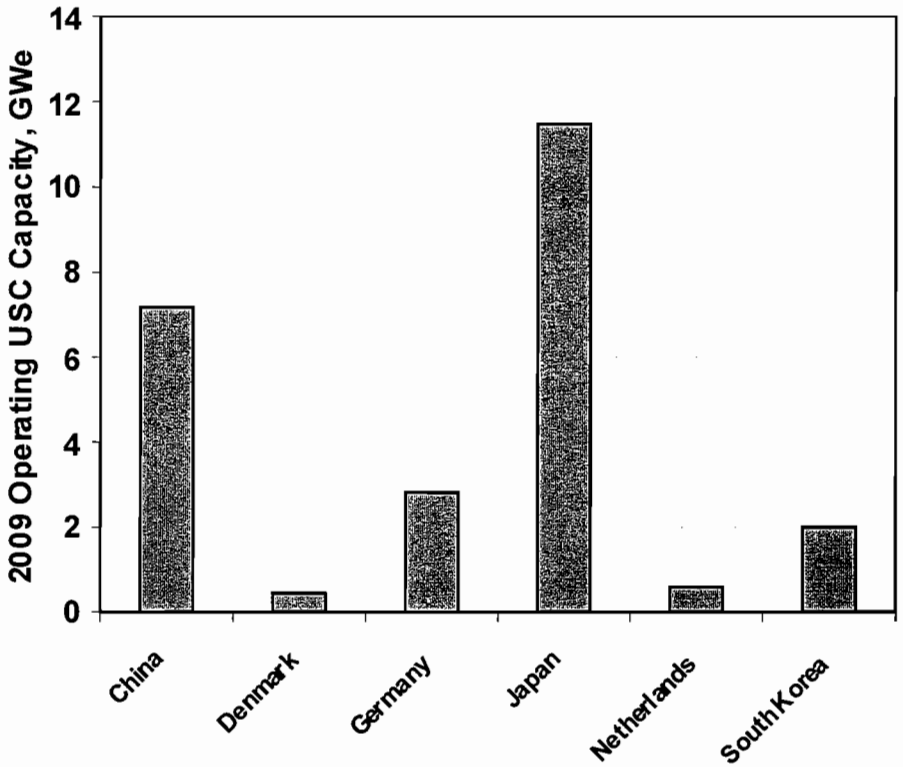


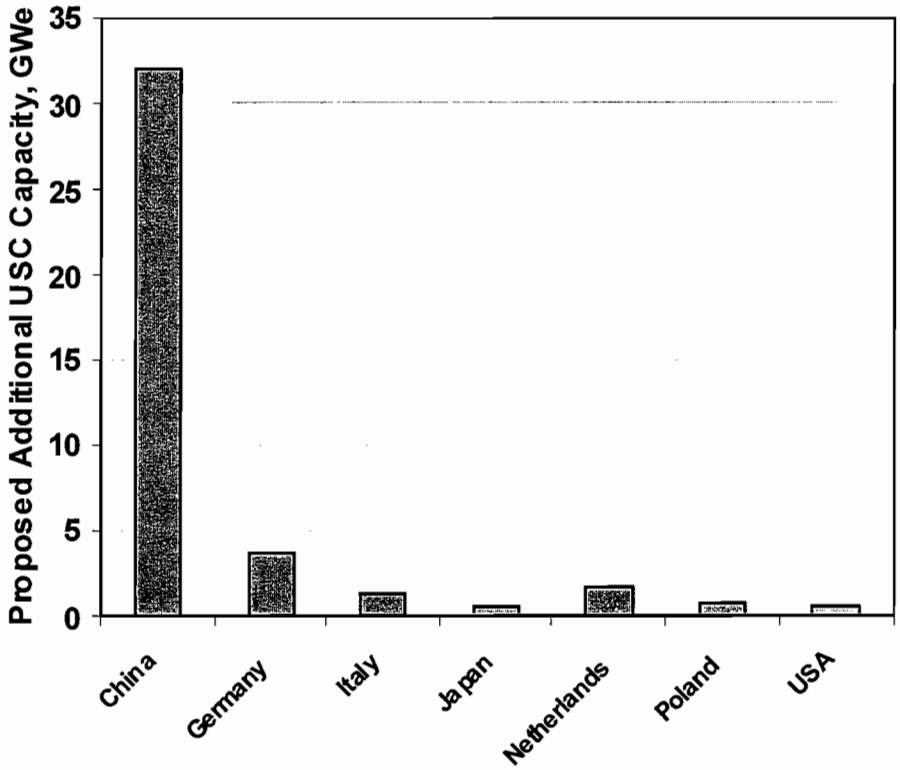


- Approximately 90 GWe of supercritical capacity has been added worldwide since 2000.
- Total proposed supercritical capacity is 122.6 GWe (includes projects that are proposed, planned, or under construction).

Source: IEA/CCC CoalPower 5 Database

USC PC Plants

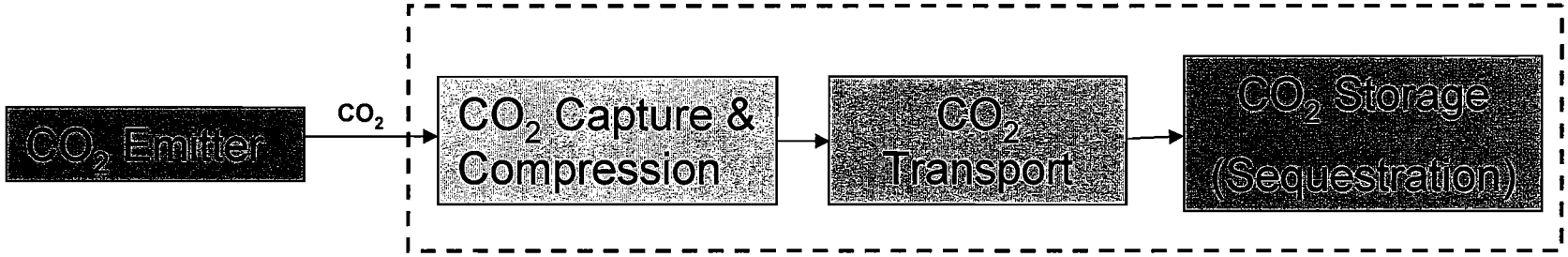




- Total worldwide USC capacity is approximately 24.6 GWe.
- Total proposed USC capacity is 40.7 GWe (includes projects that are proposed, planned, or under construction).

Source: IEA/CCC CoalPower 5 Database

What is CCS?



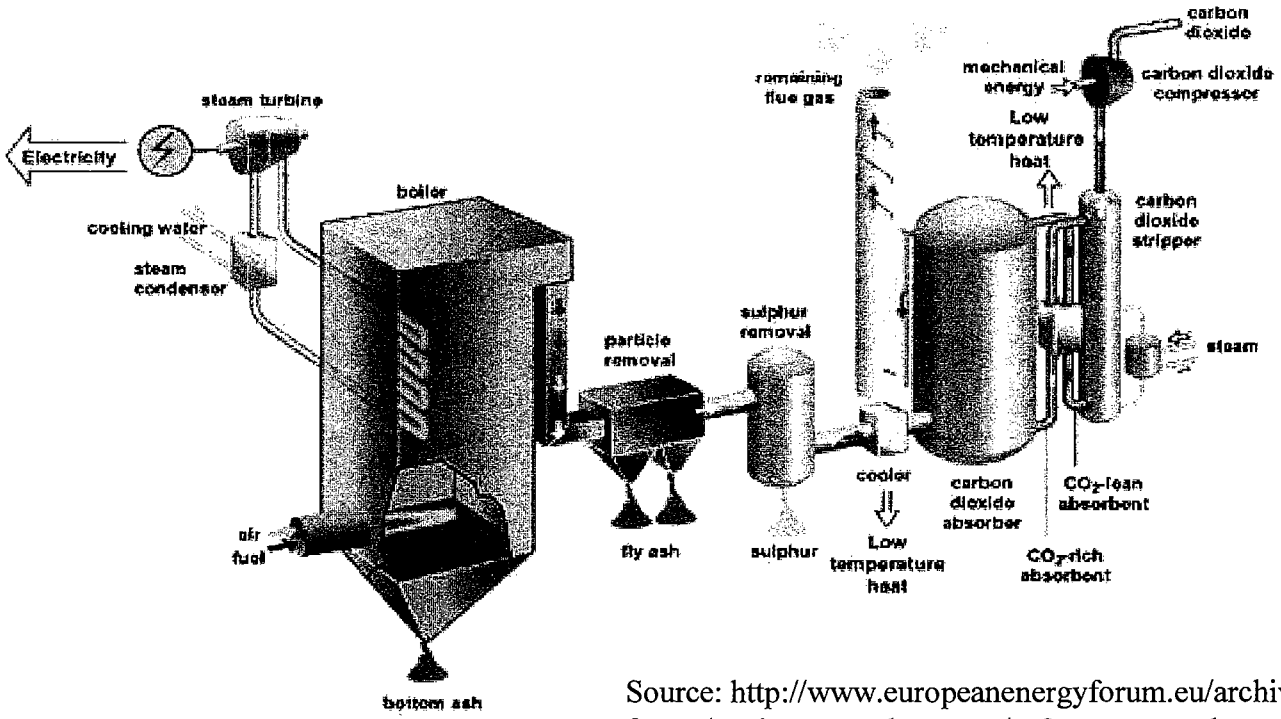
Combustion sources such as power plants

- Post-combustion
- Pre-combustion
- Oxy-fuel combustion

- Pipeline
- Tanker

- Depleted oil/gas fields
- Deep saline reservoirs
- CO_2 driven EOR
- Unmineable coal seams
- Ocean

PC Plants: Post-combustion Capture



Source: http://www.europeanenergyforum.eu/archives/european-energy-forum/environmental-matters/co2-capture-and-storage-2013-part-of-the-solution-to-the-climate-change-problem

Why post-combustion capture?

- Key retrofit solution for pc-fired units, also envisioned for new applications
- Considerable experience with flue gas scrubbing
- Flexibility in switching between capture and no-capture operation

Post-combustion Capture: Amine Chemistry

- Primary, secondary amines (MEA, DEA)

Primary: $CO_2 + 2RNH_2 \rightarrow RNH_3^+ + RNHCOO^-$
Secondary: $CO_2 + 2RNH \rightarrow RNH_2^+ + RNCOO^-$

  - A carbamate with varying degrees of stability is formed
  - Fast reaction kinetics
  - Max. loading: 0.5 mol/mol amine

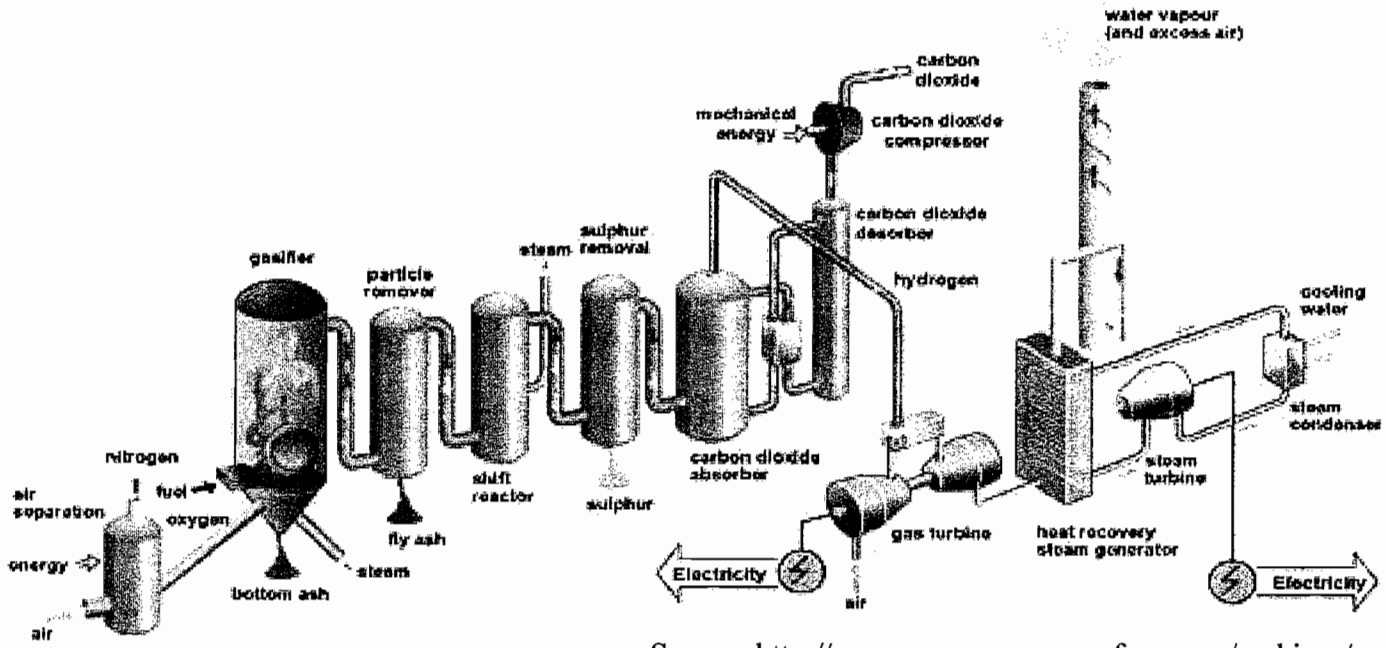
- Tertiary amines, sterically hindered amines (TEA, MDEA, AMP)

Tertiary: $CO_2 + RN + H_20 \rightarrow RNH^+ + HCO_3^-$
Primary/sterically hindered:
$CO_2 + RNH_2 + H_20 \rightarrow RNH_3^+ + HCO_3^-$

  - Formation of bicarbonate in presence of water
  - Slow reaction kinetics
  - Max. loading: 1.0 mol/mol amine

Source: Progress in post-combustion CO_2 Capture, Paul Feron, 2006

Integrated Gasification Combined Cycle (IGCC) with Pre-combustion CO_2 Capture



Source: http://www.europeanenergyforum.eu/archives/european-energy-forum/environmental-matters/co2-capture-and-storage-2013-part-of-the-solution-to-the-climate-change-problem

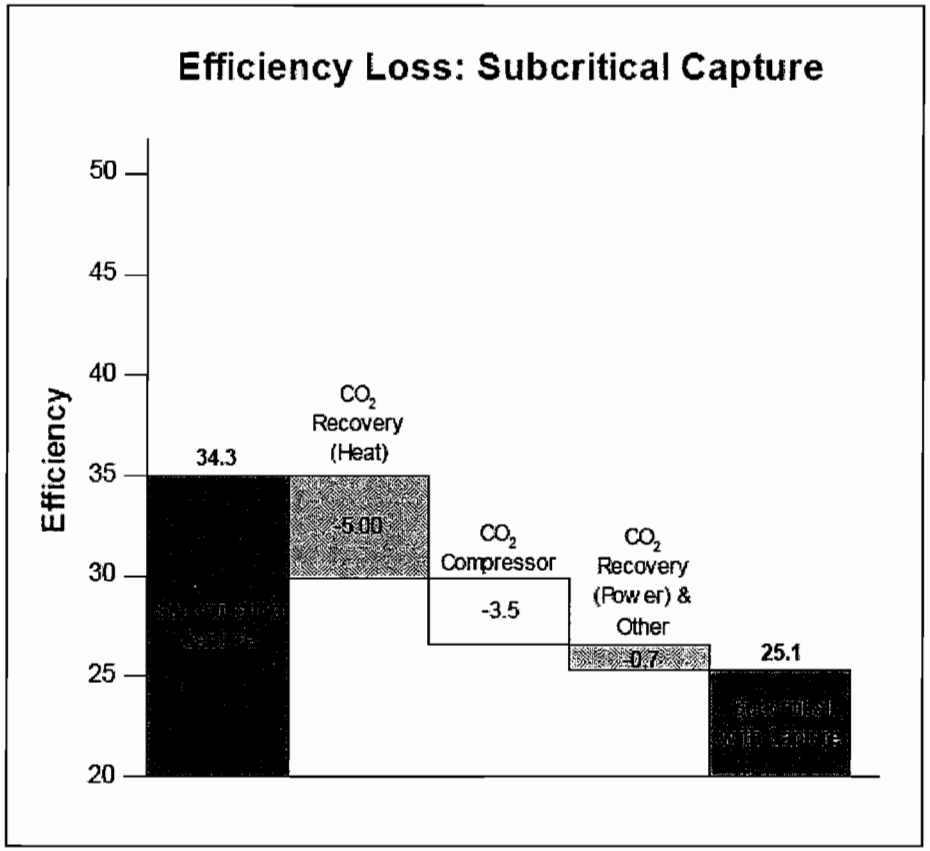
Why IGCC with pre-combustion CO_2 Capture?

- Potentially a cost-effective CCS approach, mainly for new applications
- Can be used to produce hydrogen, fuels and power

Amine-based Post-combustion Capture

- Capture approach with most experience
  - Amine technologies in commercial use for natural gas and syngas purification; capture efficiencies typically 85-90%
  - Three U.S. small plants in operation today; largest = 300 tons CO_2/day
- Carbon capture from flue gas is a more challenging application
  - Process needs: low (less than 10 ppm) SO_2, NO_2 levels; much energy for stripper – output penalty can be 30% or more today; large space requirements
- Projects
  - Several amine-based projects in the Europe
  - Advanced amine - Belchatow, Poland, 260 MW on new block 858 MW operational in 2013

Amine-based Post-combustion Capture: Example Efficiency Loss



Losses cause the efficiency to drop by 9.2 points from 34.3% to 25.1%. For supercritical and USC plants, the same losses would be experienced in terms of category and quantity, and the losses are simply subtracted from a higher original efficiency. For example, an USC plant with an efficiency of 43.3% would lose 9.2 efficiency points to have an efficiency of 34.1% with capture.

Source: The Future of Coal, MIT, 2007

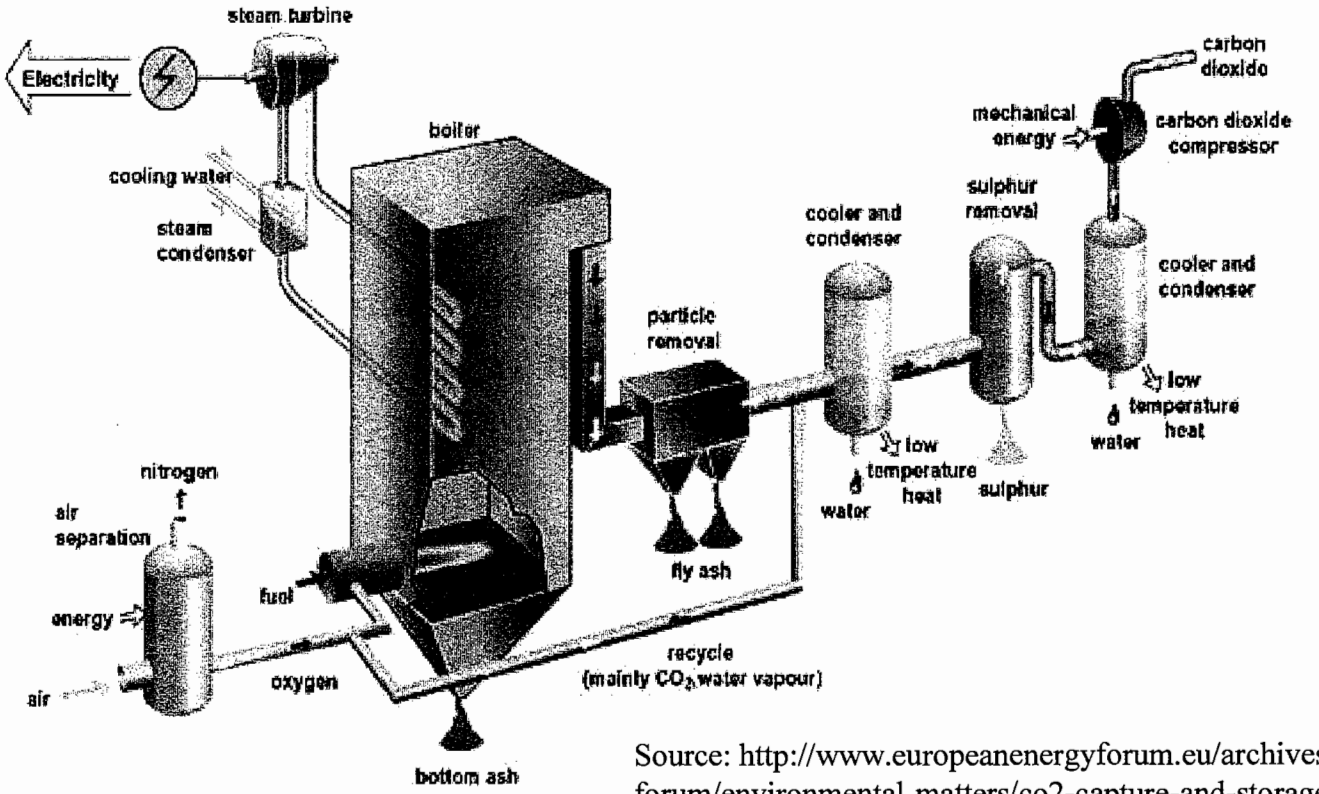
The Chilled Ammonia Process

- **Process**
  - Cooled flue gas treated with ammonium carbonate solution to form ammonium bicarbonate; moderately raising the temperature releases CO_2.
- **Potential Pros**
  - Lower heat of regeneration and higher net CO_2 transfer than MEA; stripping steam not required.
  - Low-cost, globally available, stable reagent.
- **Potential constraints**
  - Ammonium bicarbonate decomposes at 140 F, so temperatures in the absorber have to be lower than this limit.
  - Ammonia more volatile than MEA and can produce slip in the exhaust gas stream.
  - Ammonia is consumed through the irreversible formation of ammonium sulfates and nitrates as well as removal of HCl and HF.
- **Demonstration**
  - Integrated CCS demonstration project on a 30 MW stream just started at the AEP Mountaineer plant.
  - Transalta and AEP Northeastern,each at 1.5 million tons CO_2, are planned to be completed by 2015.

Post-combustion Capture: Development Needs

- Process improvements
  - Improved reagents for more efficient capture, tolerance against corrosion from oxygen and trace contaminants, and lower degradation rates
- Integration with power plant
  - Maximizing MW, efficiency requires optimal thermal integration
  - Concepts for “capture readiness”
- Pilot and demonstration testing to build experience with power plant applications

Oxy-combustion

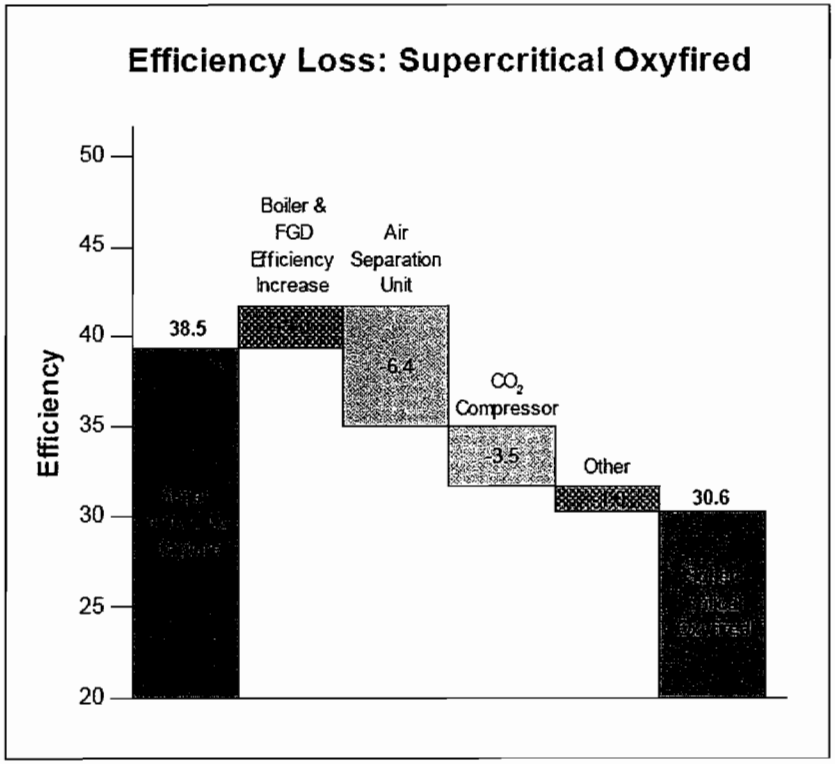


Source: http://www.europeanenergyforum.eu/archives/european-energy-forum/environmental-matters/co2-capture-and-storage-2013-part-of-the-solution-to-the-climate-change-problem

Why oxy-combustion?

- Potential for new and retrofit applications
- With flue gas recycle can be engineered to be similar to existing air-fired pc units - use existing boiler heat transfer surfaces and turbine

Oxy-combustion: Example Efficiency Loss



Losses amount to 10.9 percentage points with the air separation unit accounting for more than half of these losses. The efficiency of a for a supercritical plant drops from 38.5 to 30.6 with addition of oxy-combustion and CO_2 capture.

Source: The Future of Coal, MIT, 2007

Oxy-combustion: Overarching Considerations

- O_2 supply energy penalty
  - 15-20% of energy penalty with the current cryogenic technology
- Air in-leaks
  - Will dilute CO_2 stream and increase compression volume and costs
- Purity of CO_2 exhaust gas
  - Corrosion during transportation
  - Impacts on compression costs
- Not suitable for partial CCS

Contaminant Chemistry and CO_2 Purity

- Reactions involving contaminants

– $NO + NO + O_2$	=	$2NO_2$	Slow	(1)
– $2NO_2$	=	N_2O_4	Fast	(2)
– $2NO_2 + H_2O$	=	$HNO_2 + HNO_3$	Slow	(3)
– $3HNO_2$	=	$HNO_3 + 2NO + H_2O$	Fast	(4)
– $NO_2 + SO_2$	=	$NO + SO_3$	Fast	(5)
– $SO_2 + H_2O$	=	H_2SO_4	Fast	(6)

- Rate of reaction (1) increases with pressure to the 3rd power – only feasible at elevated pressures
- No nitric acid is formed until all the SO_2 is converted
- Hg, As, and other trace contaminants are dissolved in acid solution
- Pressure, reactor design, and residence times are important
- Is high NOx desirable for above reactions to take place?
- Can oxy-combustion operate without additional air pollution controls?

Source: Professor Jost Wendt, University of Utah, USA

Oxy-combustion: Projects

PROJECT	Location	MWth	Start up	Boiler Type	Main Fuel	CO2 Train
B & W	USA	30	2007	Pilot PC	Bit, Sub B., Lig.	
Jupiter	USA	20	2007	Industr. No FGR	NG, Coal	
Oxy-coal UK	UK	40	2008	Pilot PC		
Vattenfall	Germany	30	2008	Pilot PC	Lignite (Bit.)	**With CCS**
Total, Lacq	France	30	2009	Industrial	Nat gas	**With CCS**
Pearl Plant	USA	66	2009	22 MWe PC	Bit	Side stream
Callide	Australia	90	2010	30 MWe PC	Bit.	**With CCS**
Ciuden - PC	Spain	20	2010	Pilot PC	Anthra.(Pet ck)	?
Ciuden - CFB	Spain	30	2010	Pilot CFB	Anthra.(Pet ck)	?
Jamestown	USA	150	2013	50 MWe CFB	Bit.	**With CCS**
Endessa	Spain	~ 1500	2015	???	???	**With CCS**
Vattenfall (Janschwalde)	Germany	~1000	2015	~250 Mwe PC	Lignite (Bit.)	**With CCS**
Youngdong	Korea	~400	2016?	~100 MWe PC?	?	?

•IEA International Oxy-fuel Network established in 2005.

Oxy-combustion: Development Needs

- Oxygen supply
  - Currently cryogenic ASU has high capital and operating costs
  - New membrane technologies are under development
- Combustion behaviour with O_2/CO_2, impact on heat transfer and fouling
- Flue gas cleaning, water condensation and treatment
- Pilot and demo-plant testing to develop experience base

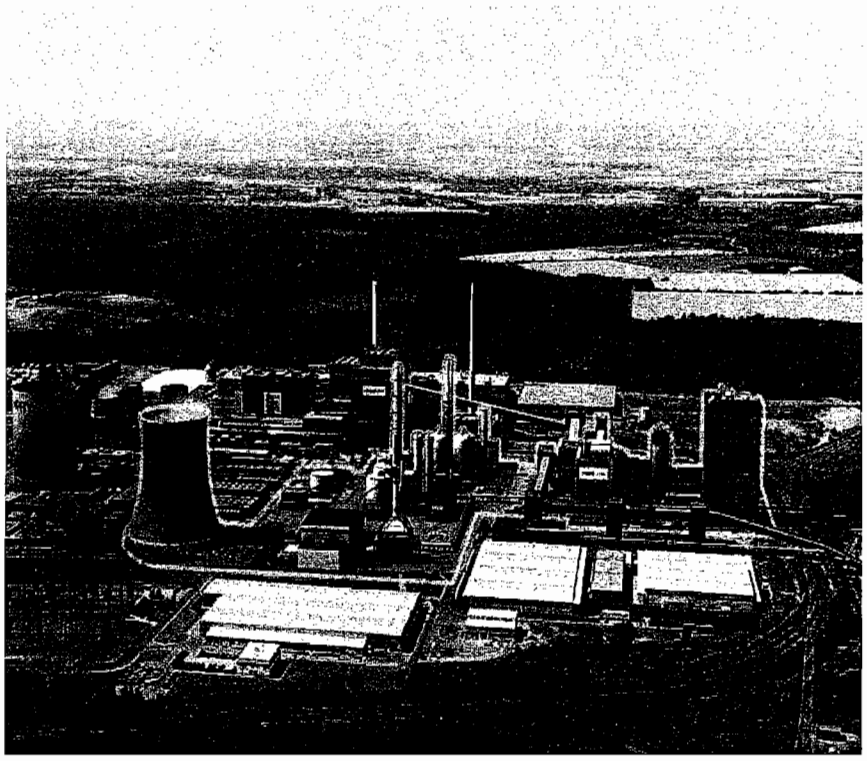
IGCC with Pre-combustion CO_2 Capture: Pros and Cons

Pros:

- Proven industrial scale technology in oil refineries, but needs scale-up for power plants.
- High level (90-95% of CO_2 emissions) of capture possible.
- Can produce H_2 and/or liquid fuels from coal.

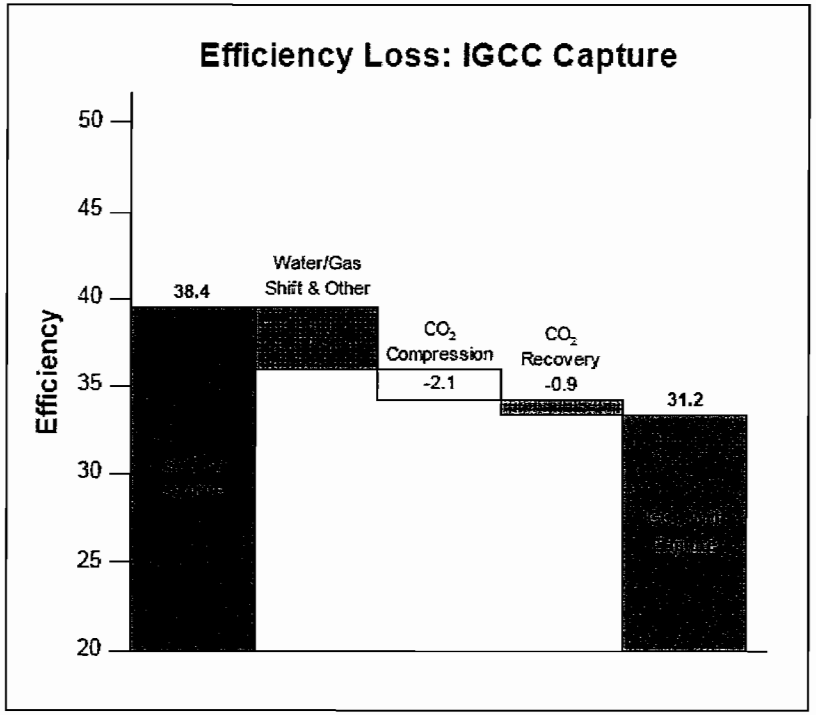
Cons:

- Requires a chemical plant in front of the gas turbine – impact on reliability/availability.
- High investment cost for dedicated new-build plants.
- Development of efficient H_2 burning turbines.
- Bypass of the capture process units is not practical because everything downstream of the shift reactor is designed for a process with CO_2 capture.



RWE, Huerth, Germany: 450 MWe, 2.6 MtCO2/yr. stored; construction- 2010, completion- 2016.

IGCC with Pre-combustion CO_2 Capture: Example Efficiency Loss



The parasitic energy requirements to capture the CO_2 in an IGCC plant are estimated to result in an efficiency loss of about 7 percentage points vs. about 9 to 10 percentage points for PC with CO_2 capture. The largest efficiency loss is due to the steam required for the water gas shift reaction. CO_2 compression is second largest, but is less than for PC because the compression begins at a higher pressure.

Source: The Future of Coal, MIT, 2007

IGCC with CO_2 Capture: Status

Pre-combustion Capture Technologies

Capture Technology	Technology Type	Chemistry	Technology Provider / Developer	Phase of Development	Remarks
Selexol	Absorption	Polyethyleneglycol, dimethyl ether blend	UOP LLC	53 plants existed in 1992 for industrial application	Must be operated at high pressure (typically 1000 psi, at least 300 psi) for practical solvent capacity.
Rectisol	Absorption	Methanol	Linde AG, Lurgi AG		Must be operated at high pressure (1000 psi to 400 psi) and low temperature (-40 F) for practical solvent capacity.
SEWGS	Adsorption	Combined WGS catalyst with hydrotalcite adsorbent	Air Products	Product development	Desorption kinetics must be improved; some loss in capacity with cycling.
Hydrotalcites	Adsorption	Anionic, layered clay materials	EPA/ORD, U of South Carolina and others	Academic, small-scale testing; sorbent development	Sorbent works best at elevated temperatures (200 – 400 C); slow desorption kinetics; some loss in capacity with cycling.

- IGCC and CO_2 removal offered commercially, but have not operated in an integrated manner at power plants.
- Several worldwide, physical solvent-based operating non-power installations (3 in U.S.) with largest plant ~340 MW equivalent in size.
  - Captured CO_2 from Great Plains gasification plant in North Dakota piped approximately 200 miles to Canada for enhanced oil recovery (EOR); 2.7 million tons CO_2 per year.
- Several projects appear to be under way.

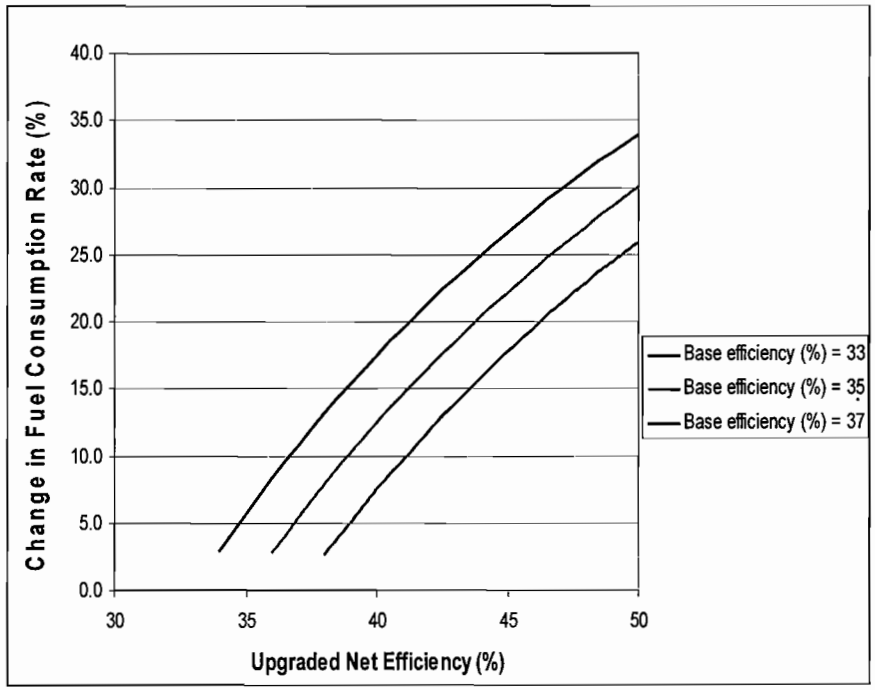
IGCC with CO_2 Capture: Projects

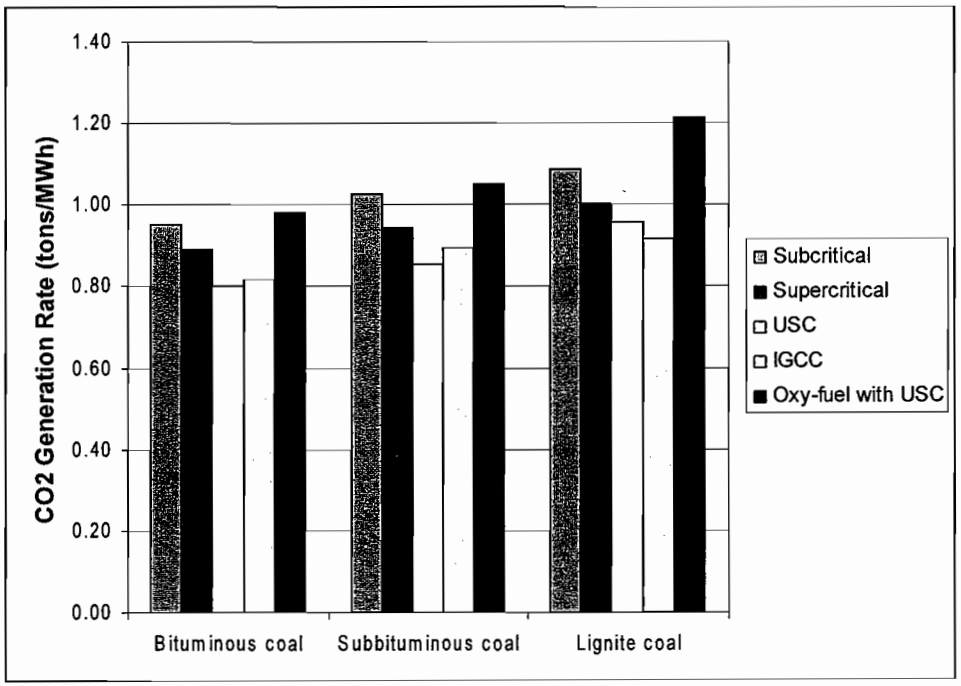
Project	Status
Centrica, Teesside, U.K.: EOR offshore, North Sea oilfields; 800 MWe, 5 Mt/yr CO_2 injected; construction- 2009, completion- 2012.	July 2008- pending decision on transportation and storage decisions, particularly pipeline versus rail transportation.
EPCOR, Alberta, Canada: EOR; 270 MWe, 1.2 Mt/yr CO_2 injected, Siemens SFG-500 (Selexol); completion- 2015.	August 2008- EPCOR announced a design partnership with Siemens for the Genesee IGCC plant, currently running as a SCPC plant.
GreenGen, Tianjin, China: EOR offshore; 650 MWe, CO_2 capture quantity undetermined; Phase 1 (250 MWe) online 2011, final phase (expansion to 650 MWe) by 2016.	September 2009- Phase 1 construction started in June 2009.
Powerfuel, Yorkshire, U.K.: EOR offshore, North Sea oilfields; 900 MWe, 4.7 $MtCO_2$/yr. stored, Shell SCGP WQ (Selexol); Phase 1: construction- 2009, completion- 2012; Phase 2 completion 2014..	February 2009- a phased development plan announced for proposed Hatfield Colliery IGCC plant. GE Energy CCGT turbines to power the plant through in Phase 1. Phase in IGCC with Shell's proprietary technology by 2014. The goal of this approach is to give the plant greater fuel flexibility while CCS technology matures.
ZeroGen, Brisbane, Australia: offshore storage, Northern Denison Trough; 530 MWe, 420 $KtCO_2$/yr. stored, Mitsubishi technology; construction- 2009, demonstration- 2015, completion- 2017.	June 2009- ZeroGen Pty Ltd, a subsidiary of the Queensland state-owned Stanwell Corporation, has announced the reconfiguration of the ZeroGen project into two stages. The project will now involve the development of a world-class demonstration plant by 2012, followed by an equally advanced full-scale plant labeled 'ZeroGen Mark II' by 2017.
RWE, Huerth, Germany: CO2 destination undetermined; 450 MWe, 2.6 $MtCO_2$/yr. stored; construction- 2010, completion- 2016.	August 2008- RWE made a final decision to move forward with plans to build a state of the art IGCC plant in Huerth, Germany. The plant will be fueled with local lignite and will be equipped with CCS technology. RWE said broad public acceptance was integral to their decision.
Monash Energy, Latrobe Valley, Australia: offshore storage, Gippsland Basin; CTL project, 30 kBPD/yr. (synthetic hydrocarbons), 10 $MtCO_2$/yr. stored; construction- 2009, completion- 2016.	May 2008- Monash Energy has invested $20 million on preliminary work related to the commercial and technical feasibility of an IGCC CTL CCS-equipped plant in Australia's Latrobe Valley. As of December 2008, the project has been put on hold.

IGCC with Pre-combustion CO_2 Capture : Development Needs

- Gas turbine for H_2-rich fuel gas
- Improvement of economics and reliability of IGCC-technology
- Pilot and demo-plant testing

Efficiency Improvement: Fuel Reduction and Pollution Prevention





CO_2 generation rate = f(coal carbon content, HHV, plant efficiency).

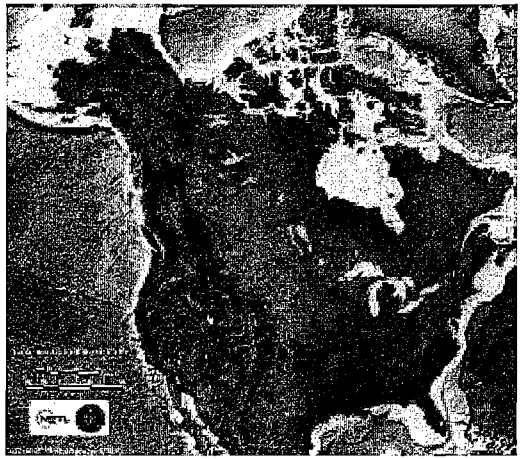
Clearly, coal properties can have a significant bearing on technology choice.

Collateral Impacts

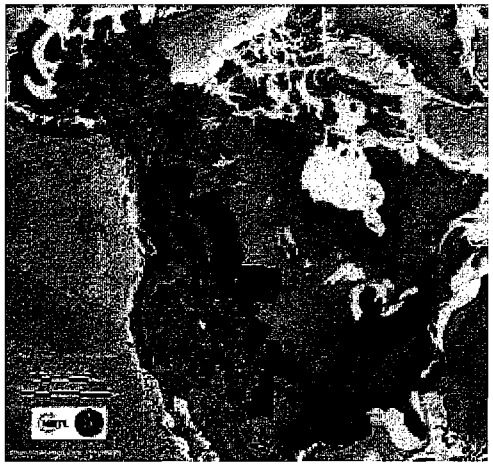
- Carbon capture and compression requires significant amount of energy
  - Post combustion: heat for regeneration; electricity for CO_2 compression
  - Gasification: electricity for O_2 production, solvent pumping and cooling, CO_2 compression; steam for water-gas shift
  - Oxy-fuel combustion: electricity for O_2 production, CO_2 compression, purification
  - potential for increase in emissions
- Carbon capture requires very clean flue gas – decrease in emissions of SO_2, NOx, and PM
- Use of controls for SO_2, NOx, and PM requires energy – potential for increase in emissions

Three key Terrestrial CO_2 Storage Options

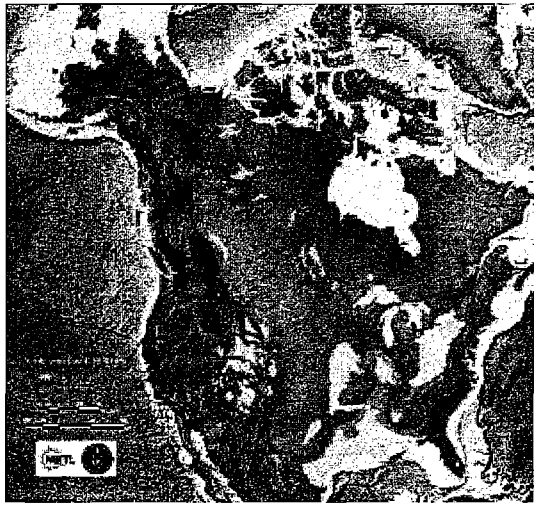
US Emissions ~ 3.8 GT CO_2/yr point sources



Oil and Gas Fields



Saline Formations



Unmineable Coal Seams

North American CO_2 Storage Potential (Giga Tons)

Conservative Resource Assessment

Sink Type	Low	High
Saline Formations	3300	12,600
Unmineable Coal Seams	160	180
Oil and Gas Fields	140	140

Hundreds of Years of Storage Potential

Source: NETL/DOE

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Sequestration Issues

- Availability and access to suitable underground storage area
- Permanence; centuries of containment needed
- Potential regulatory and liability issues
- Maximum allowable concentrations of potential CO_2 contaminants
- Potential groundwater pollution issues

Final Thoughts

- Anthropogenic activities are contributing to observed increase in atmospheric concentrations of greenhouse gases and these increases are causing a warming of our planet.
- Warming of the climate system is ***unequivocal*** as evidenced by melting polar ice, rising sea level, changes in precipitation patterns, droughts, heat-waves, etc.
- Worldwide energy-related CO_2 emissions from coal use are expected to grow significantly through 2030.
- Since coal plants are large point sources, they potentially offer attractive opportunities for cost-effective reductions in CO_2.
- Considering the large worldwide capacity of coal-fired generation and potential requirements of CCS, retrofitting will be a significant activity.
- Development and use of more efficient generation technologies will reduce CO_2 emissions and save fuel costs at coal-fired power plants.
- 3 major candidates for CO_2 capture: PC boilers/advanced CO_2 scrubbing, IGCC/carbon capture and oxygen-fed PC combustors – development is still needed.
- Considering the climate change challenge, rapid development of mitigation approaches is needed.

Our children and future generations are relying on us to be responsible in preserving their environment.

Appendix

Relative Performance and Costs

Table 3.1 Representative Performance And Economics For Air-Blown PC Generating Technologies

	SUBCRITICAL PC		SUPERCRITICAL PC		ULTRA-SUPERCRITICAL PC		SUBCRITICAL CFB[6]	
	W/O CAPTURE	W/ CAPTURE	W/O CAPTURE	W/ CAPTURE	W/O CAPTURE	W/ CAPTURE	W/O CAPTURE	W/ CAPTURE
PERFORMANCE								
Heat rate (1), Btu/kW_e-h	9,950	13,600	8,870	11,700	7,880	10,000	9,810	13,400
Generating efficiency (HHV)	34.3%	25.1%	38.5%	29.3%	43.3%	34.1%	34.8%	25.5%
Coal feed, kg/h	208,000	284,000	185,000	243,000	164,000	209,000	297,000	406,000
CO_2 emitted, kg/h	466,000	63,600	415,000	54,500	369,000	46,800	517,000	70,700
CO_2 captured at 90%, kg/h (2)	0	573,000	0	491,000	0	422,000	0	36,000
CO_2 emitted, g/kW_e-h	931	127	830	109	738	94	1030	141
COSTS								
Total Plant Cost, \$/kW_e (3)	1,280	2,230	1,330	2,140	1,360	2,090	1,330	2,270
Inv. Charge, ¢/kW_e-h @ 15.1% (4)	2.60	4.52	2.70	4.34	2.76	4.24	2.70	4.60
Fuel, ¢/kW_e-h @ \$1.50/MMBtu	1.49	2.04	1.33	1.75	1.18	1.50	0.98	1.34
O&M, ¢/kW_e-h	0.75	1.60	0.75	1.60	0.75	1.60	1.00	1.85
COE, ¢/kW_e-h	**4.84**	**8.16**	**4.78**	**7.69**	**4.69**	**7.34**	**4.68**	**7.79**
Cost of CO_2 avoided[5] vs. same technology w/o capture, \$/tonne	41.3		40.4		41.1		39.7	
Cost of CO_2 avoided[5] vs. supercritical w/o capture, \$/tonne	48.2		40.4		34.8		42.8	

Basis: 500 MW_e net output. Illinois # 6 coal (61.2% wt C, HHV = 25,350 kJ/kg), 85% capacity factor

(1) efficiency = 3414 Btu/kW_e-h/(heat rate);
(2) 90% removal used for all capture cases
(3) Based on design studies and estimates done between 2000 & 2004, a period of cost stability, updated to 2005\$ using CPI inflation rate. 2007 cost would be higher because of recent rapid increases in engineering and construction costs, up 25 to 30% since 2004.
(4) Annual carrying charge of 15.1% from EPRI-TAG methodology for a U.S. utility investing in U.S. capital markets; based on 55% debt @ 6.5%, 45% equity @ 11.5%, 38% tax rate, 2% inflation rate, 3 year construction period, 20 year book life, applied to total plant cost to calculate investment charge
(5) Does not include costs associated with transportation and injection/storage
(6) CFB burning lignite with HHV = 17,400 kJ/kg and costing \$1.00/million Btu

Source: The Future of Coal, MIT, 2007

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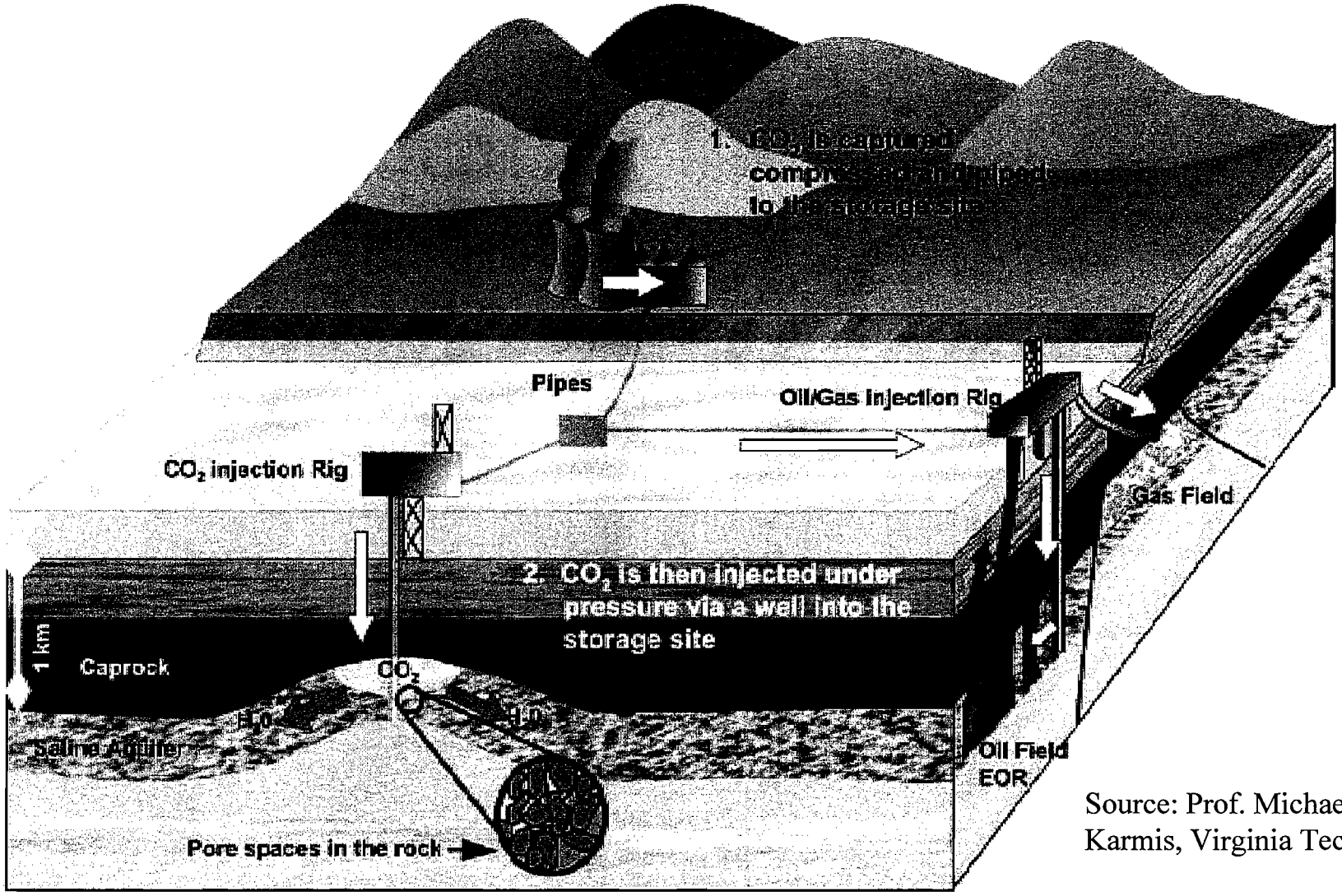
Storage of CO_2, Two Options:

EOR and Deep Saline Aquifers



Source: Prof. Michael Karmis, Virginia Tech

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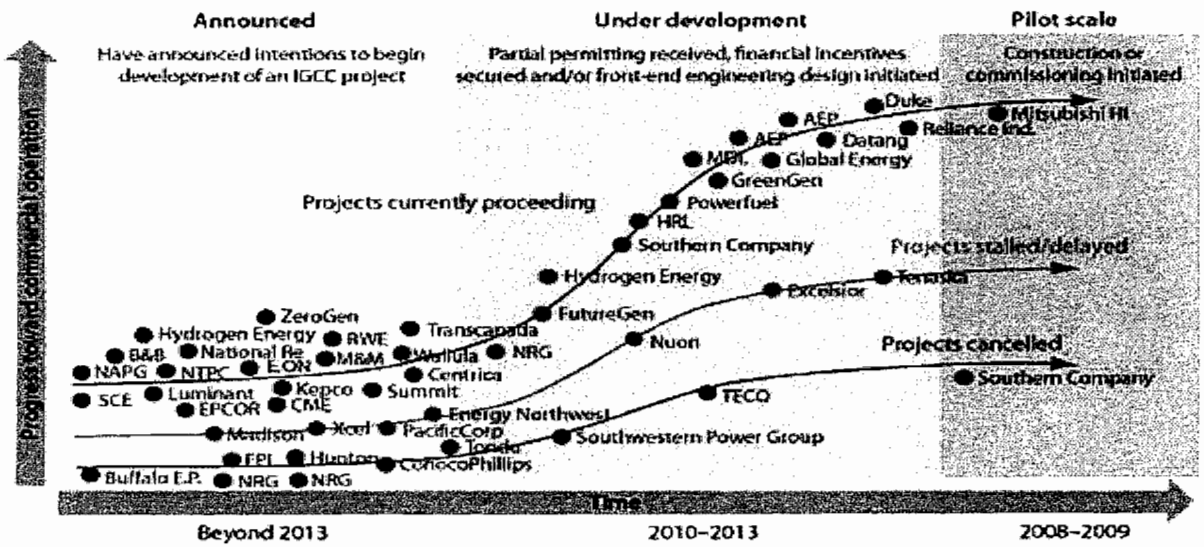
IGCC Use

IGCC Units Using Coal for Electricity Generation

Plant Name	Year	Location	Technology Name	Feed	Syngas Output (MWt)
Buggenum	1994	Netherlands	Shell Gasification Process	Coal	466
Polk County	1996	USA	GE Gasification Technology	Coal/Petcoke	451
Vresova	1996	Czech Rep.	Lurgi Dry Ash Gasification	Lignite	636
Puertollano	1997	Spain	Krupp Koppers PRENFLO	Coal/Petcoke	588
Sanghi	2002	India	GTI U-GAS Gasification Process	Lignite	109
Nakoso	2007	Japan	MHI Air-blown Gasifier	Coal	455
Sulcis	2009	Italy	Shell Gasification Process	Coal	957

Source: World Gasification Database; Gasification Technologies Council



Source: Emerging Energy Research

001860

cmpc
CELULOSA

Nacimiento, Septiembre 23, 2009
GO-027/2009

28 SET. 2009
RECIBIDO
CONAMA

H.W. 19794

Señor
Hans Willumsen A.
Jefe Dpto. Control de la Contaminación
Teatinos 258 – Piso 6°
SANTIAGO

Ref.: Anteproyecto de Norma de emisión para termoeléctricas

De nuestra consideración,

Deseamos referirnos al Anteproyecto de Norma de emisión para termoeléctricas, con el objeto de darle a conocer nuestra perspectiva acerca de la eventual inclusión de las calderas industriales de CMPC Celulosa S.A. en su alcance. Hemos optado por recabar su atención al respecto porque nuestra posición apunta a un tema de fondo que, pensamos, escapa del ámbito de los aportes que pueden formalizarse en el Comité Ampliado.

A continuación incluimos, a título de referencia rápida, una Tabla que resume las principales diferencias entre ambas actividades.

ITEM	INDUSTRIA FORESTAL	TERMOELÉCTRICA
Objeto	Abastecimiento de vapor y energía eléctrica al mismo proceso productivo	Suministro de energía eléctrica a la red pública
Combustible	Madera (renovable)	Petróleo, Carbón, Petcoke, Gas Natural y combinaciones (fósil)
Equipos	Ubicados en el interior de la planta industrial, es decir, insertos en un proceso muchísimo mayor. Mantención y operación deben sintonizarse con el proceso principal.	La Unidad generadora de vapor es el equipo principal de una termoeléctrica.
Emisiones	NOx y CO, MP ?	NOx, SO2, CO2, metales pesados (mercurio, níquel, vanadio) → MP ?

CMPC CELULOSA S.A.
Av. J. Hemmelmann 198, Casilla 1795, Nacimiento - Chile, Fono (56-43) 403930 Fax (56-43) 403914

cmpc
CELULOSA

Sobre la base de lo indicado, a lo que agregamos un breve documento con mayores detalles (adjunto), nuestra opinión es que las Calderas que operan en las plantas industriales del sector forestal no reúnen las características que ameriten ser incluidas en una futura Norma de Emisión para Termoeléctricas. En particular, CMPC Celulosa S.A. ha determinado priorizar el abastecimiento eléctrico de los procesos frente al suministro a la red pública, desarrollando e invirtiendo en proyectos que operativizan dicha decisión, como la "Línea de Transmisión Mininco – Nacimiento" que, con una inversión de US$ 6 millones, interconectó eléctricamente las 3 fábricas de celulosa y una de papel de diario.

El caso de otras instalaciones que generan exclusivamente energía eléctrica para suministrar a la red pública mediante combustión de biomasa es diferente.

Complementariamente a lo señalado debemos manifestarle que no es nuestro objetivo oponernos a la regulación de las emisiones atmosféricas de las calderas de la industria forestal sino que ésta debe quedar inscrita en eventuales regulaciones del sector industrial en general y no adscritas a una actividad específica como la generación termoeléctrica. Para ello, como en otras oportunidades, ofrecemos nuestra total disposición y colaboración técnica.

En caso de requerirse información adicional sobre lo señalado, mucho apreciaremos contactar directamente a Pedro Navarrete, correo electrónico pnavarrete@celulosa.cmpc.cl, teléfonos 98370564 ó 43-403930.

Sin otro particular, le saluda atentamente,

Mario Basualto L.
Gerente de Medio Ambiente & Asuntos Públicos
CMPC CELULOSA S.A.

INCL: Lo indicado

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CELULOSA

ABASTECIMIENTO DE ENERGÍA ELÉCTRICA DE LAS PLANTAS DE CMPC CELULOSA S.A

1. Antecedentes

El proceso kraft para la producción de celulosa permite la recuperación de los productos químicos. Esta recuperación implica la combustión de la lignina de la madera lo que permite la producción de vapor de alta presión y la consecuente generación de energía eléctrica y calefacción del proceso productivo. En general, las fábricas de celulosa son excedentarias en energía eléctrica.

El proceso utilizado para producir papel es altamente demandante de energía.

CMPC Celulosa S.A. posee 3 plantas de celulosa kraft, Laja, Pacífico y Santa Fe, en las localidades de Laja, Mininco y Nacimiento, respectivamente. Santa Fe (sólo celulosa de eucalipto) tiene 2 líneas de producción mientras que Pacífico (sólo celulosa de Pino) tiene 1 sola y Laja (celulosa de Pino y papel) detuvo el año pasado (2008) la línea de producción más antigua, quedándose con 1 sola y mantuvo la producción de papel de envolver y de fotocopia. Las 3 plantas están ubicadas bastante próximas.

- **Planta de Celulosa Laja:**
  La planta de celulosa Laja está generando 22,5 MW y consumiendo 35 MW por lo cual extrae 12,5 MW del sistema eléctrico. Esta fábrica produce, además, diversos tipos de papeles que implican un consumo eléctrico de 8 MW (23 % del total consumido).

- **Planta de Celulosa Pacifico:**
  La planta de celulosa Pacifico opera normalmente con dos generadores de 38 y 37 MW los cuales alimentan consumos por un total de 81 MW, incluyendo Plywood y ERCO. El balance se obtiene extrayendo desde el sistema eléctrico 20MW.

- **Planta de Celulosa Santa Fe:**
  La planta de celulosa Santa Fe opera normalmente con tres generadores de 21, 30 y 40 MW los cuales alimentan un consumo total de 83 MW. El balance se obtiene aportando al sistema eléctrico 8 MW.

Las principales características de estas instalaciones, desde el punto de vista de la energía eléctrica son las siguientes:

Item	Laja	Pacífico	Santa Fe
Celulosa, ton	180.000	500.000	L-1 = 340.000 L-2 = 780.000
Papeles, ton	75.000		
E. generada, GWh	174,8	587	760,7
E. consumida, GWh	272	422	687,6
Calderas	**Recuperadora** Kvaerner Pulping 1996 142 t/h – 44 bar	**Recuperadora** Ahlstrom 1990 300 t/h; 60 bar	**Recuperadoras** L1: CBC – L2: Andritz L1: 1989 – L2: 2006 L1: 185 t/h – L2: 540 L1: 75 bar – L2: 85
	Biomasa 1 Babcox&Wilcox 1963 105 t/h vapor	**Biomasa** Kvaerner 2006 150 ton/h; 61 bar	**Biomasa** Tampella - Kvaerner 2005 80 t/h; 65 bar
	Biomasa 2 JMW-Suecia; 1957 35 t/h vapor	**Poder 1 y 2** Briones Ltda; 1990 43.2 t/h vapor	**Poder** CBC; 1989 68 t/h; 65 bar
Turbogeneradores	Alstom – 22,5 MW	Siemens – 38 MW Siemens – 37 MW	Siemens – 21 MW 30 MW y 40 MW

Nota: un 23 % de la energía eléctrica consumida en Planta Laja corresponde a la demandada por la producción de papel.

- **INFORSA**
  La Planta papelera de INFORSA no presenta generación propia y su consumo de régimen es 89 MW. Durante 5 meses del año (Mayo, Junio, Julio, Agosto y Septiembre) INFORSA entra en un régimen de restricción durante las Horas de Punta (HP) bajando su consumo normal de 89 MW a 22MW. Esta reducción del consumo se ejecuta operativamente al detener las dos líneas productoras de fibra.

Además de Inforsa, Empresas CMPC posee en las inmediaciones de las plantas de celulosa otras instalaciones industriales para el aprovechamiento de la madera: 1 Aserradero, en Nacimiento y 1 fábrica de Paneles Plywood, en Mininco. Además, tanto en el interior de las plantas de celulosa como colindantes a ellas, existen otras instalaciones que les proveen parte de los insumos; es el caso de ERCO Worlwide, productora de Clorato de Sodio para las 3 plantas, ubicada en Mininco, y AGA, productora de Oxígeno, con plantas en Laja y en Santa Fe.

2. Interconexión eléctrica entre Plantas CMPC

La prioridad fijada por Empresas CMPC para la administración de los excedentes de energía eléctrica es el abastecimiento de sus propios procesos fabriles para lo cual en el año 2003, con una inversión de US$ 6 millones, construyó el proyecto "Línea de Transmisión Mininco – Nacimiento" consistente en una nueva red de distribución de energía eléctrica que conectó las plantas Pacífico, Santa Fe, Inforsa y Laja entre ellas y, además, al sistema SIC de la generadora Endesa. Así se construyeron, operado y mantenido: una línea de transmisión de un circuito de 220 kV, con 41,7 km de longitud, una subestación eléctrica en la Planta Santa Fe (Nacimiento) y la ampliación de la Subestación Pacífico (Mininco). El proyecto se desarrolló en las regiones del Bíobío y de la Araucanía, las Provincias de Malleco y Bíobío, y las comunas de Renaico, Collipulli, Nacimiento y Negrete. Con una vida útil de 30 años, se considera reinvertir para mantener esta línea de transmisión operativa.

El sistema implementado es operado y administrado por CMPC Celulosa S.A. y provee ventajas claves en términos de costos energéticos e intercambio de energía entre las plantas. El proyecto tuvo por objetivo interconectar eléctricamente las tres de plantas de CMPC Celulosa S.A., de manera de hacer posible:

a) la transmisión de excedentes eléctricos generados entre ellas,
b) la optimización de la contratación de la potencia de respaldo, y
c) la conexión directa de la planta Pacifico al nudo de Charrúa

Este proyecto permitió desconectar la Planta Pacífico del tramo Charrúa-Temuco del SIC, aliviando el nivel de saturación que se preveía para este tramo en los próximos años.

Además de abastecer con energía eléctrica a las Plantas CMPC INFORSA y Aserradero AMSA (Nacimiento) y Tableros Plywood (Mininco), el sistema diseñado provee, desde Pacífico, a la planta ERCO y a Plywood; desde Santa Fe y Laja a las respectivas plantas AGA (oxígeno) existentes en cada una de ellas.

3. Conclusiones

3.1. CMPC Celulosa S.A. consume esporádicamente cantidades menores de energía eléctrica desde la red pública. Los procesos productivos que se llevan a cabo en sus 3 plantas se autoabastecen en una importante proporción mediante generación propia.

3.2. Los excedentes de energía se suministran a otras instalaciones industriales, propiedad de Empresas CMPC y también de terceros que proveen insumos a los procesos, ubicadas en las inmediaciones de las plantas de celulosa y en su interior.

3.3. CMPC Celulosa S.A. construyó un proyecto para la interconexión eléctrica de sus 3 plantas y de una fábrica de papel de diario ratificando de este modo su definición estratégica para el abastecimiento prioritario de los procesos industriales propios frente al suministro de excedentes a la red pública.

60186C 19.794

GOBIERNO DE CHILE
COMISION NACIONAL
DEL MEDIO AMBIENTE

Carta D.E. N°: 093752 /

Ant.: Carta de CMPC Celulosa, de fecha 23 de septiembre del 2009.

Mat.: Regular o no co-generadoras en la futura norma de emisión para termoeléctricas.

Santiago, 29 OCT. 2009

Señor
Mario Basualto
Gerente de Medio Ambiente & Asuntos Públicos
Presente

De mi consideración,

En relación a su carta GO-027/2009, me permito señalar que ha sido integrada al Expediente Público de la Norma y que está siendo analizada junto a otros antecedentes, con los cuales se espera fundamentar la regulación o no de la co-generación y utilización de biomasa.

Desde ya se agradece su valiosa colaboración en el proceso de regulación.

Saluda atentamente a usted,

Lilian Veas Acuña
Jefa (s) Departamento Control de la Contaminación
Comisión Nacional de Medio Ambiente

CGCF/aat

Distribución:

-Archivo Departamento Control de la Contaminación
-Expediente Público

Acta reunión Comité Operativo Norma de Emisión para Termoeléctricas
14 de octubre 2009 Inicio: 9:30 hrs. - Término: 11:30 hrs.

Temas:

El consultor presenta un avance del estudio. Expositores: Carlos Barria- Pedro Sanhueza

Acuerdos:

- El Comité Operativo aprueba el avance y expresa que está conforme con los fundamentos que se han entregado. Se reconoce que el estudio responde a la fecha a sus objetivos, que ha sido muy clarificador en cuanto a la descripción del mercado eléctrico, su estructura de tarifa, y muy clara la metodología y criterios para diseñar y evaluar cada escenario.

Contacto en CONAMA D.E.:
Carmen Gloria Contreras Fierro
cgcontreras@conama.cl
fono: 240 5772

..//

GOBIERNO DE CHILE
CONAMA

"COMITÉ OPERATIVO DE NORMA DE EMISION PARA TERMOELECTRICAS"

FECHA : 14/10/2009
HORA INICIO : 09:30 hrs.
HORA TÉRMINO: _____
LUGAR : Sala de Reuniones del 4° piso

N°	NOMBRE	INSTITUCION	DIRECCION	FONO	E-MAIL
1.	Olga Espinoza M.	SAG	Paseo Bulnes 140-5°p	345-1535	olga.espinoza@sag.gob.cl
2.	Evelyn Salazar	GeoAire.		2093838	geoaire2@gmail.com
3.	PEDRO SANHUEZA	GEOAIRE		2093838	GEOAIRE@Gmail.com
4.	JAIME ORDENES G.	KAS INGENIERIA		2232346	jaime.ordenes@kasing.cl
5.	Priscilla Ulloa	CONAMA	Teatinos 258	2405787	pulloa@conama.cl.
6.	Ingrid Henríquez	CONAMA	"	2405698	ihenriquez@conama.cl.
7.	TEO SAAVEDRA	MINVU	ALAMEDA 924	3513633	tsaavedra@minvu.cl

398100

Nº	NOMBRE	INSTITUCION	DIRECCION	FONO	E-MAIL
	CARLOS BARRIA	KAS ING.	Brown Norte 684	2232346	carlos.barria@kasing.cl
8.	María Teresa Palma	KASING	"	"	teresa.palma@kasing.cl
9.	MARÍA PÍA BRAVO	KASING	✓	✓	PIA.BRAVO@KASING.cl
10.	Samuel Jerardino	KASING	✓	✓	samuel.jerardino@kasing.cl
11.	Alberto Gil Leyton	Conama			agil@conama.cl.
12.	Sandra Briceño	conama			sbriceno@conama.cl.
13.					
14.					
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REGULACIÓN Y MERCADOS ENERGÉTICOS - INGENIERÍA ELÉCTRICA E HIDRÁULICA - GESTIÓN AMBIENTAL
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KA-068-09

Santiago, 23 de Octubre de 2009

29684

OFICINA DE PARTES
23 OCT. 2009
RECIBIDO
CONAMA

Señores
COMISIÓN NACIONAL DEL MEDIO AMBIENTE
Atención Sr. Hans Willumsen
CC: Srta. Carmen Gloria Contreras
Teatinos 254/258
Oficina de Partes Santiago, Chile
Presente

Ref.: Remite Informe N°1
"ANÁLISIS DE IMPACTO ECONÓMICO Y SOCIAL
DE LA NORMA DE EMISION PARA TERMOELECTRICAS"

De nuestra consideración:

Por intermedio de la presente, adjunto remito Informe N°1, en su revisión 1, del estudio de la referencia en 4 ejemplares y 1 CD con la información respectiva.

Sin otro particular, le saluda atentamente,

Marcela Jerardino Etcheverry
Directora KAS Ambiental S. A.

c.c. Archivo
Carpeta Proyecto