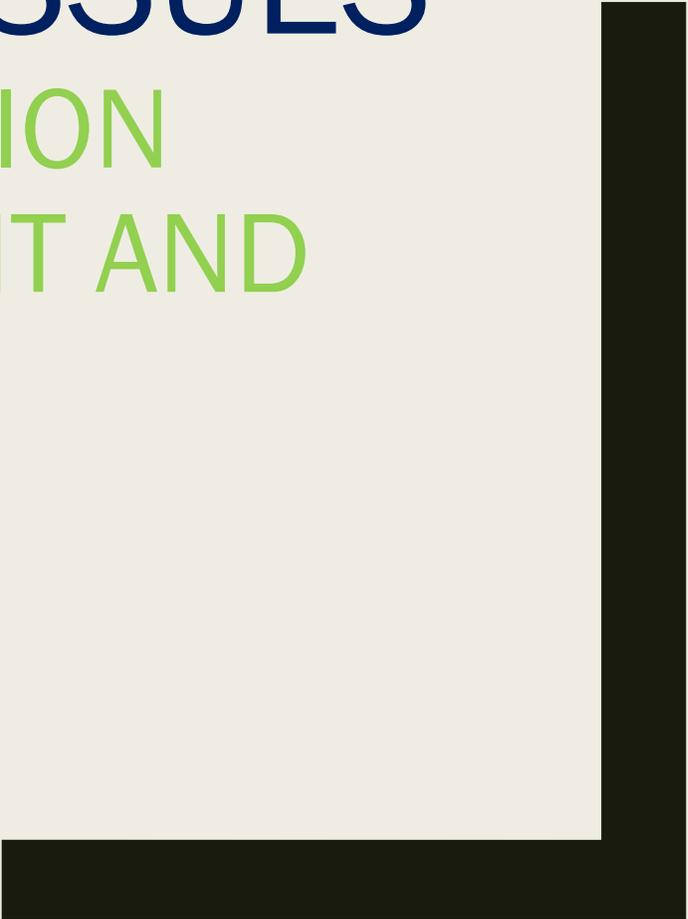




# ENVIRONMENTAL ISSUES

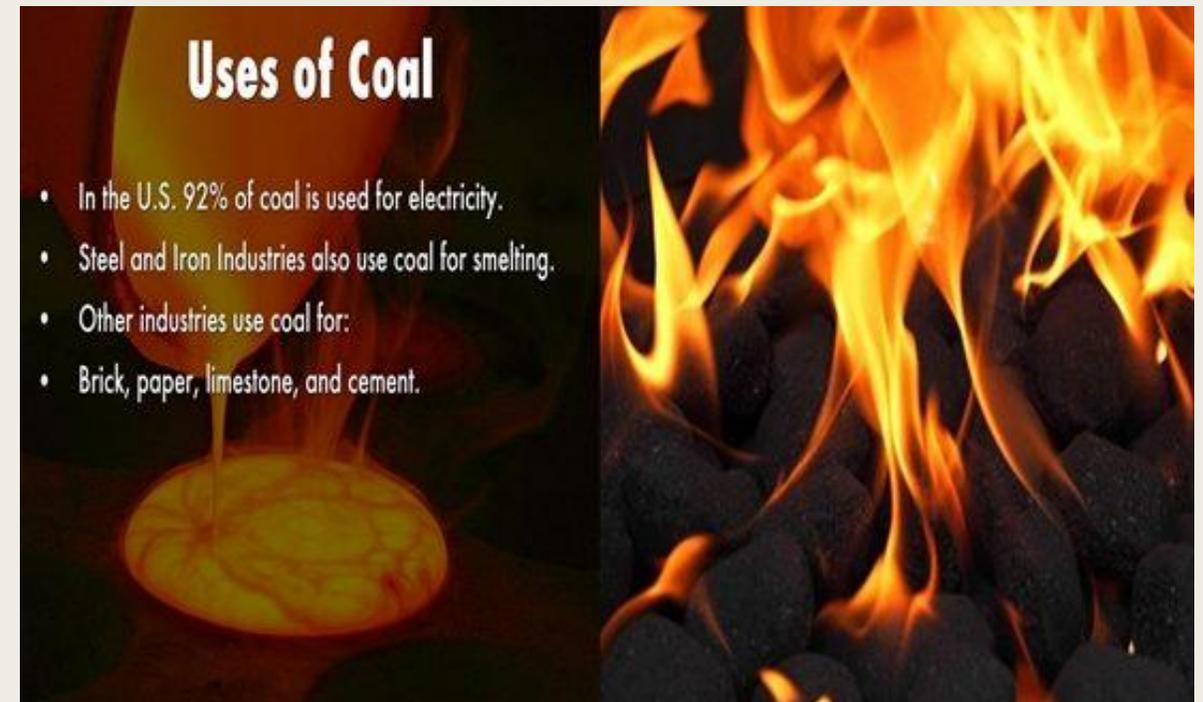
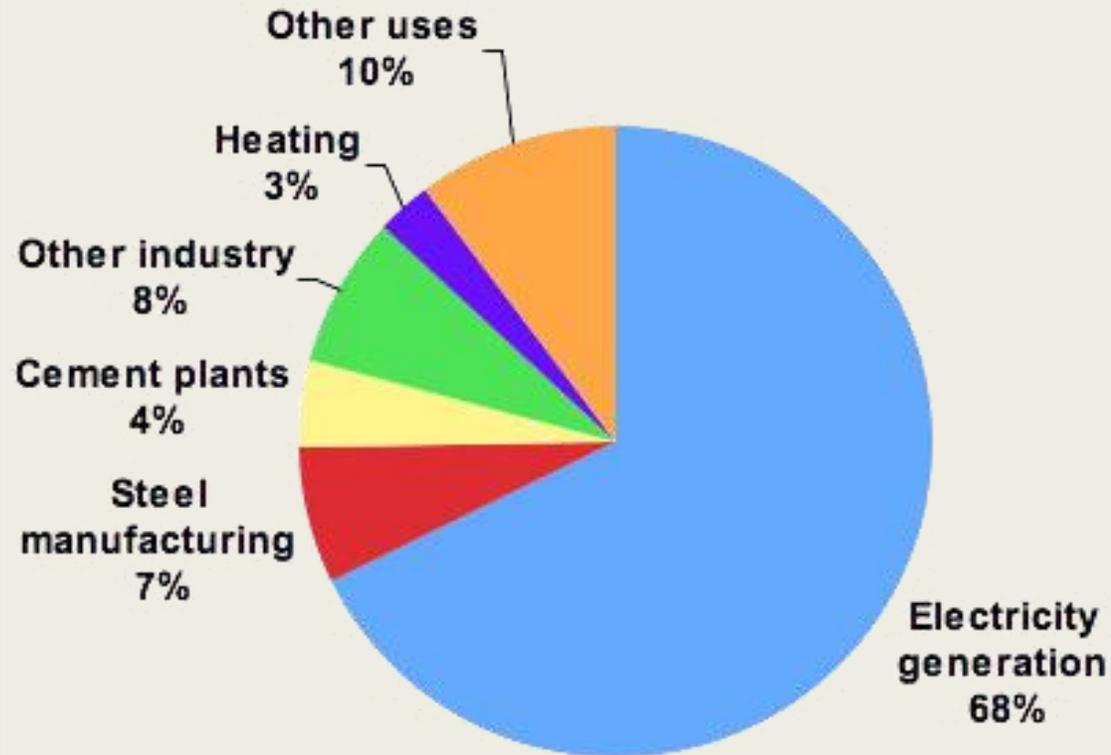
EMISSIONS, POLLUTION  
CONTROL, ASSESSMENT AND  
MANAGEMENT



# Introduction

## ■ Base

- Coal has a long and rich history of use in providing a source of light, transport, and electricity for industry



# Introduction

## ■ Issues

- *Utilization of coal in power production is increasingly under challenge due to real or potential environmental impacts, such as*
- *greenhouse warming,*
- *acid deposition, urban smog production,*
- *trace toxic emissions and leaching of heavy metals to surface and groundwater*



# Introduction

## ■ Fact and Future

- Environmental regulations and agreements, enacted at both the national and international level, present a significant challenge to the future viability and operations of the coal and utility industries



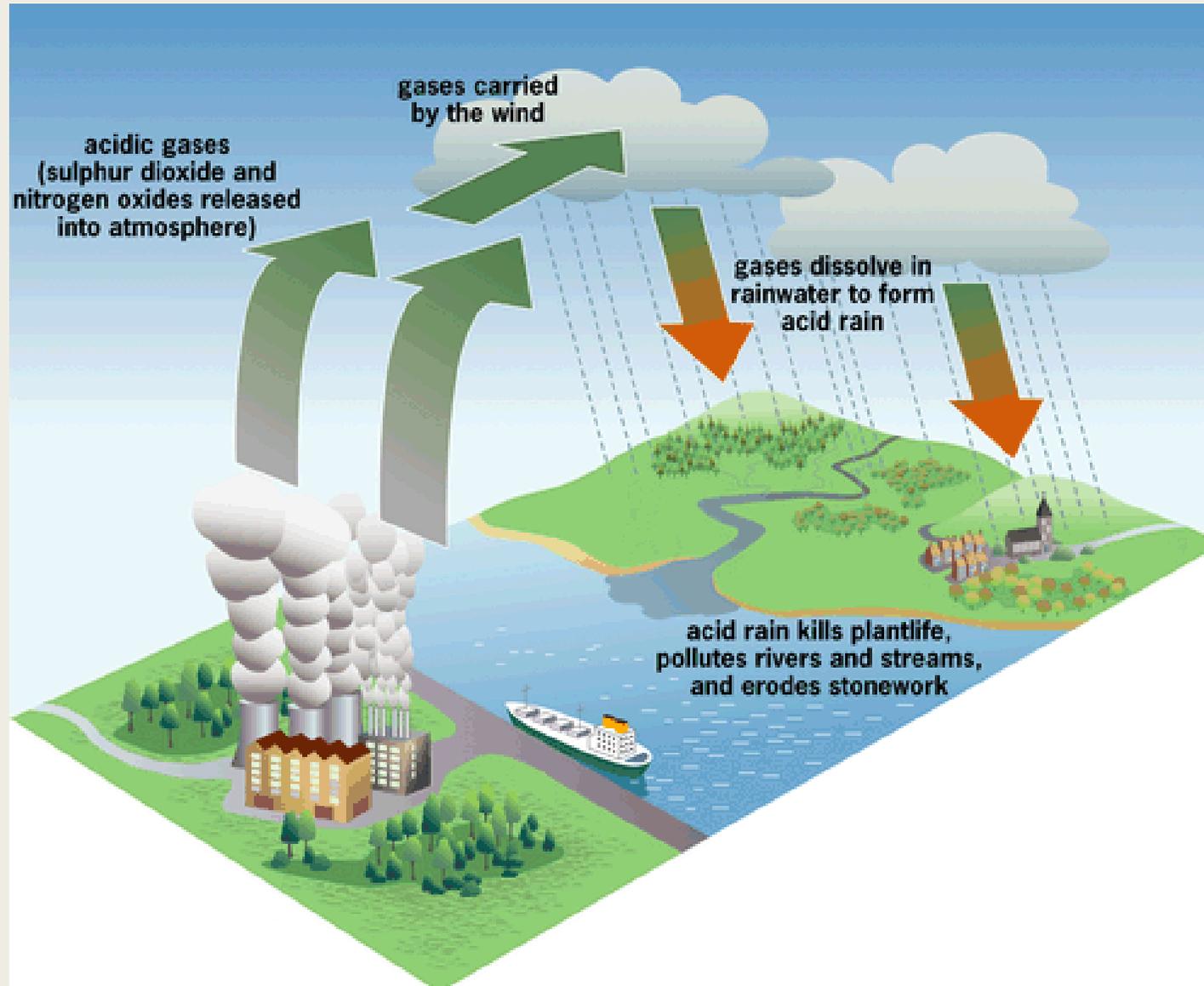
# Environmental Concerns

- Gaseous and particulate emissions produced in the combustion process, notably oxides of nitrogen (NO<sub>x</sub> ), sulfur dioxide (SO<sub>2</sub> ) and toxic trace elements which can result in atmospheric concentrations which exceed human health guidelines
- Conversion of NO<sub>x</sub> and SO<sub>2</sub> to acidic gases and particles which can contribute to atmospheric fine particle concentrations, and can be deposited to sensitive ecosystems through wet or dry deposition processes
- Impacts of NO<sub>x</sub> emissions on regional air quality through photochemical smog formation
- Emissions to air, water and land from operations associated with the mining of coal and the subsequent disposal of ash and spoil.

# Emissions of acid gases

- Sulfur oxides (largely sulfur dioxide ( $\text{SO}_2$ ))
- Oxides of nitrogen (largely  $\text{NO}$  but also some  $\text{NO}_2$ , which collectively are known as  $\text{NO}_x$ ),
- arise not only from S and N present in the coal but also from the combustion process itself.
- Both sulfur and nitrogen oxides contribute to acid deposition (colloquially known as 'acid rain') in which these gases, or the acids they are converted to, impinge on land, water or vegetation as a result of wet and dry deposition processes

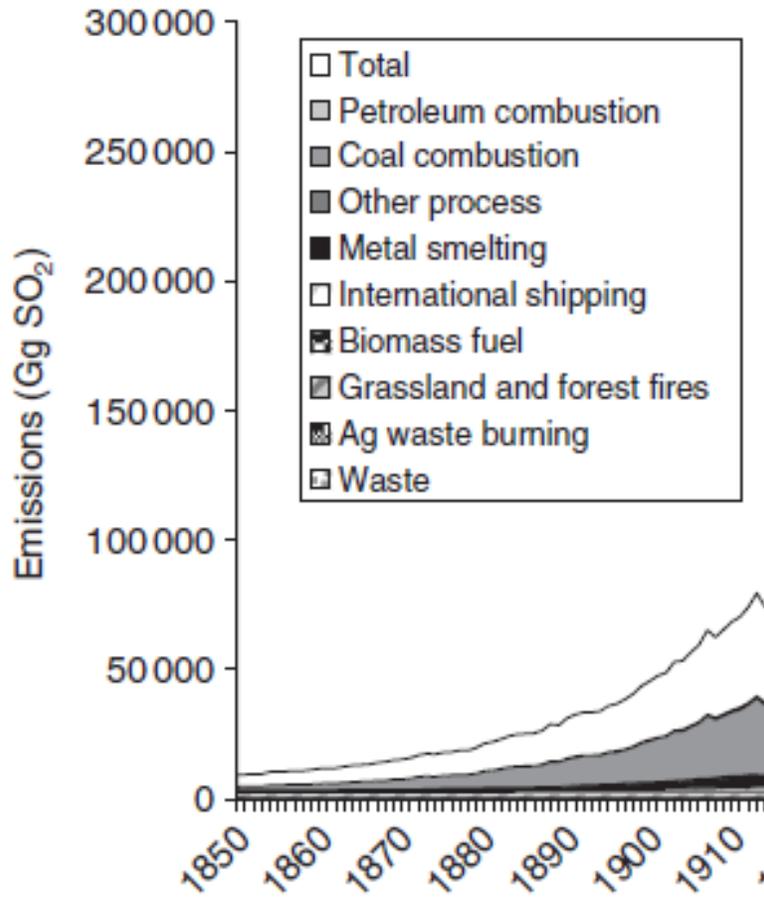
# Emissions of acid gases



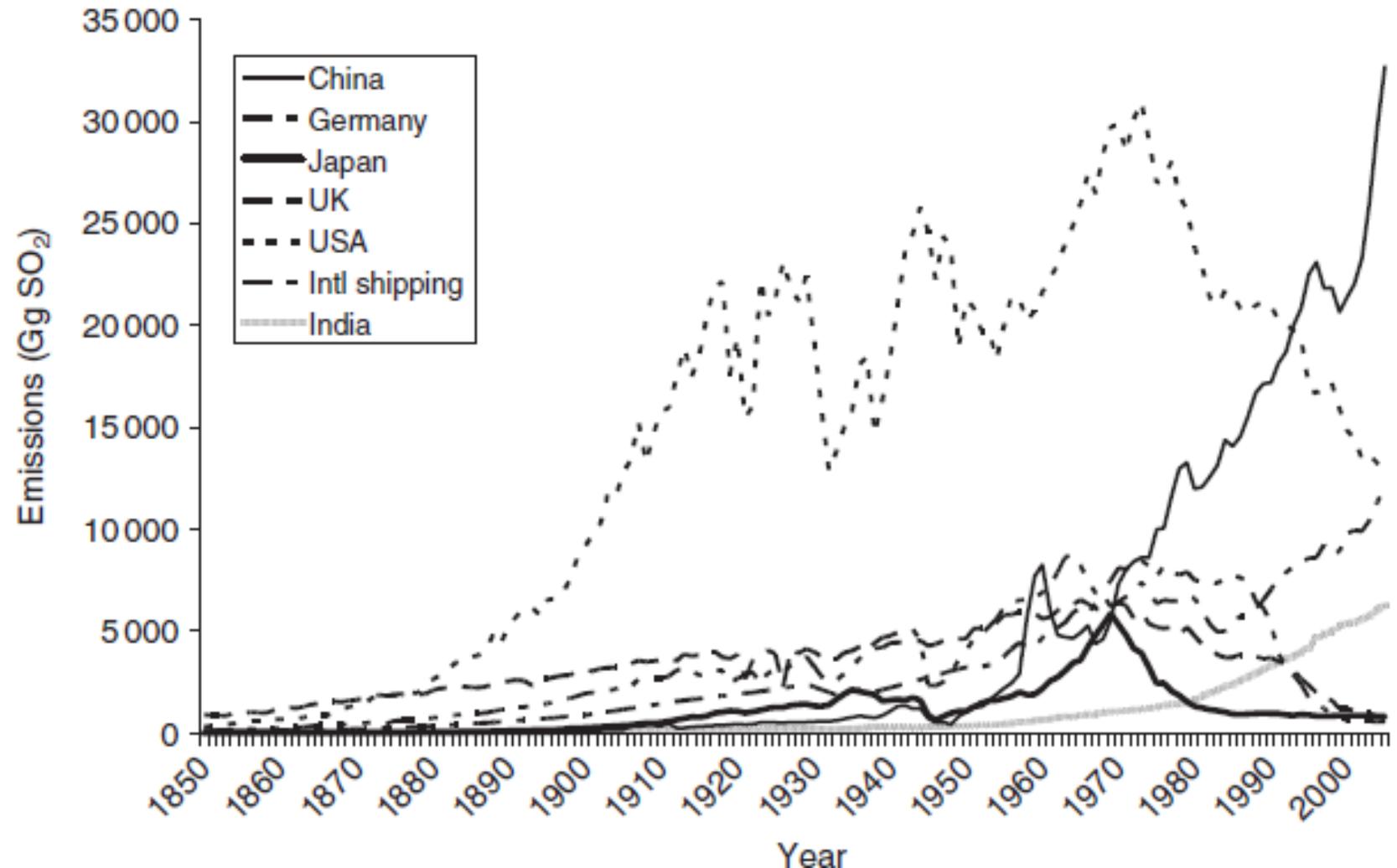
# Consequences of Acid Rain



# Sulfur oxides (Global sulfur dioxide emissions from 1850 to 2000)

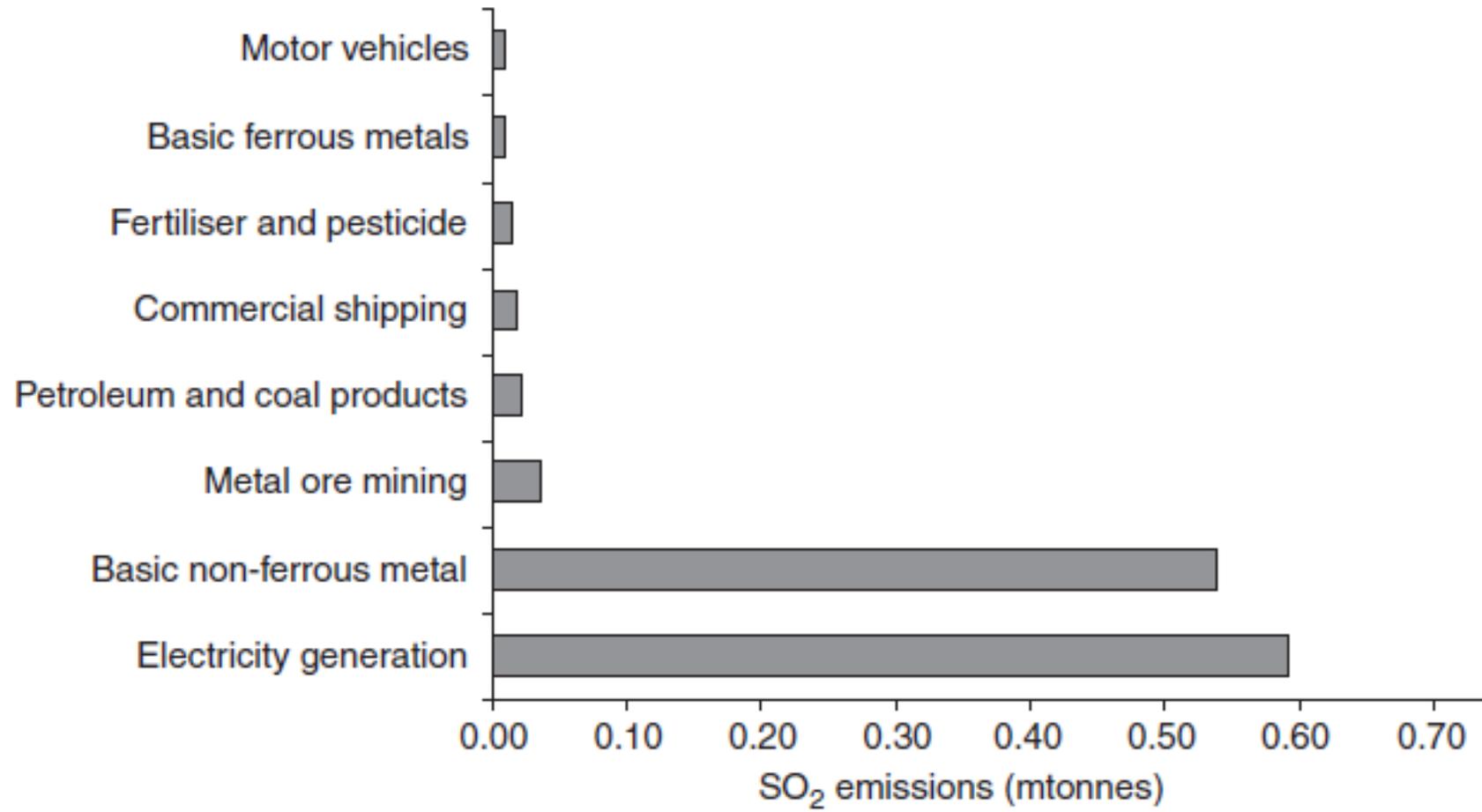
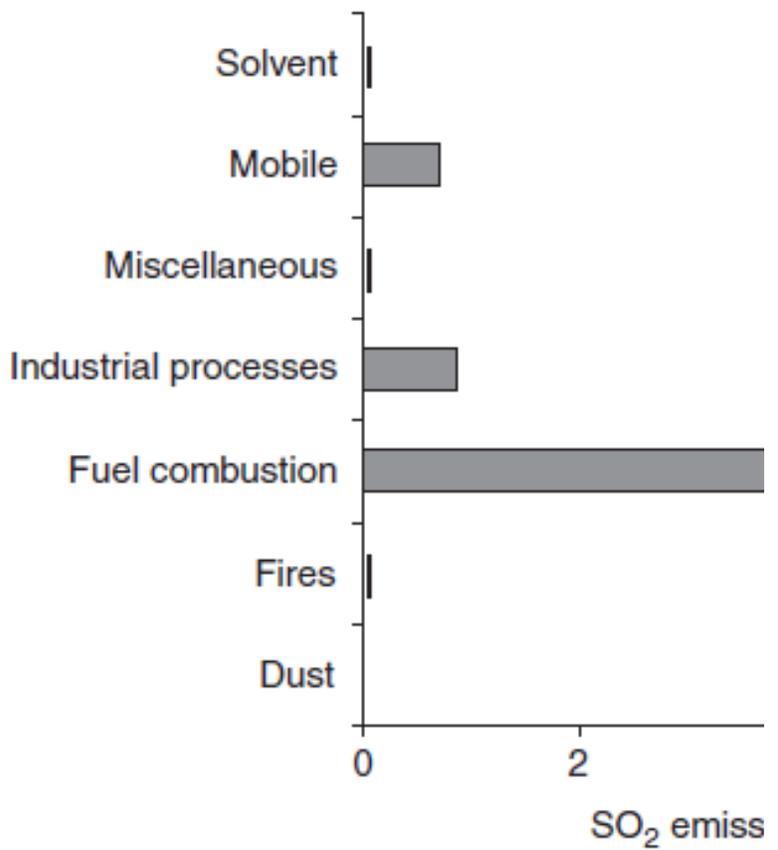


Emissions from select countries and international shipping.



Emissions by source sectors

# US sulfur dioxide emissions as a function of sector for 2008



# Australian sulfur dioxide emissions as a function of sector for 2009/2010

# SO<sub>2</sub> Emissions Reduction

- *fuel substitution* (i.e., choosing a coal of lower S content)
- *fuel treatment* to reduce the S content
- *flue gas desulfurisation* (FGD) in which scrubbing agents (usually based on Ca) react with SO<sub>2</sub> to produce a disposable waste product; in some cases the product can be recovered for use as a building material

# SO<sub>2</sub> Emissions Reduction

Accepted Manuscript

A technological review of developments in chemical-related desulfurization of coal in the past decade

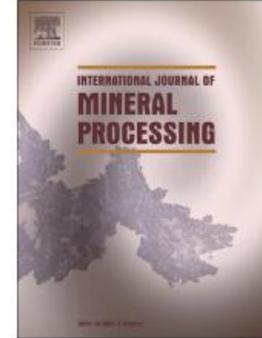
Wencheng Xia, Guangyuan Xie

PII: S0301-7516(17)30048-0

DOI: [doi: 10.1016/j.minpro.2017.02.013](https://doi.org/10.1016/j.minpro.2017.02.013)

Reference: MINPRO 3024

To appear in: *International Journal of Mineral Processing*



than organic sulfur by gravity separation after liberation pretreatments. The primary desulfurization methods include physical, physico-chemical, chemical, and microbial desulfurization. Among the above-mentioned desulfurization methods, chemical-related desulfurization is considered to be the most effective methods for both inorganic and organic sulfur, which is essential to be reviewed. This review is to

# SO<sub>2</sub> Emissions Reduction

ACCEPTED MANUSCRIPT

## **Biodesulfurization of organic sulfur in Tondongkura coal from Indonesia by multi-stage bioprocess treatments**

Ismi Handayani<sup>a</sup>, Yustin Paisal<sup>b</sup>, Syo

<sup>a</sup>Department of Metallurgical Engineering,

### Highlights

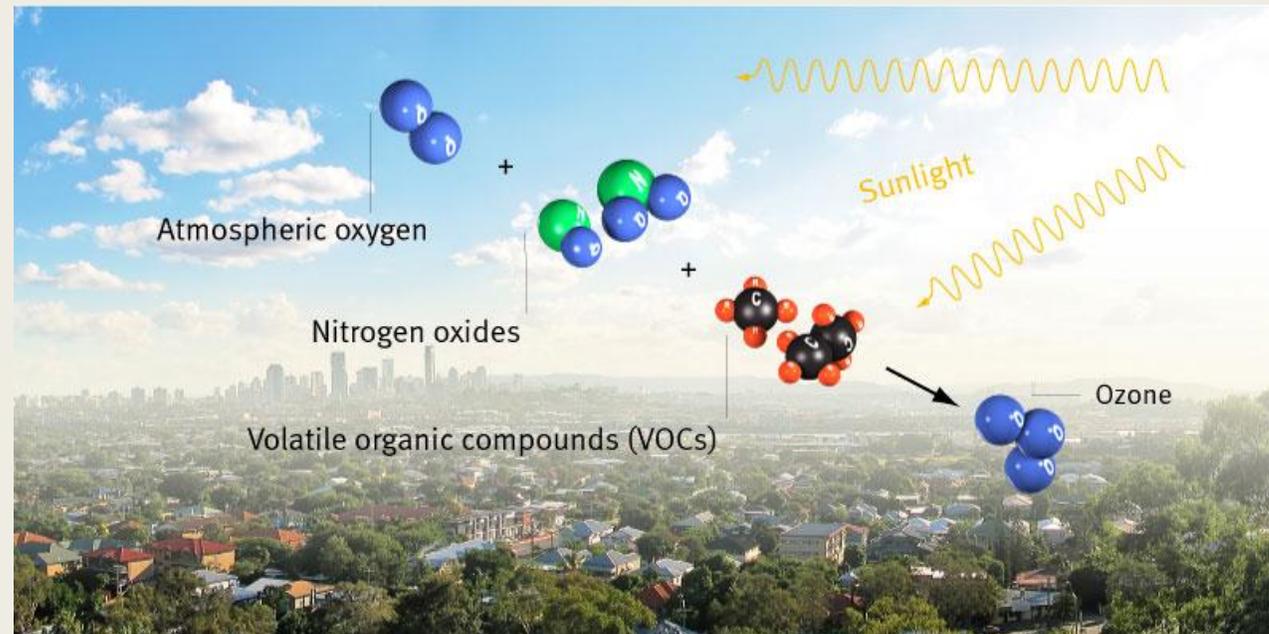
- ✓ Multi-stage bioprocess treatments (MBT) are successfully applied to coal biodesulfurization.
- ✓ Organic sulfur, pyritic sulfur and sulfate from Tondongkura coals were removable.
- ✓ *Pseudoclavibacter* sp. strain SKC/XLW-1 was efficient in coal biooxidation-bioflotation process.
- ✓ The biooxidation process is more responsible for organic sulfur removal from the studied coal.
- ✓ MBT is a cheaper and environmentally friendly alternative to conventional coal desulfurization.
- ✓ More interestingly, MBT did not reduce the hydrocarbon content of coal.

# Nitrogen oxides – Environmental Concerns

- Winter time urban pollution episodes;
- Acidic deposition and acidification of remote soil and freshwater ecosystems;
- Photochemical ozone formation;

# Nitrogen oxides – Environmental Concerns

- Winter time urban pollution episodes;
- Acidic deposition and acidification of remote soil and freshwater ecosystems
- Photochemical ozone formation



# Nitrogen oxides – Environmental Concerns

- Winter time urban pollution episodes;
- Acidic deposition and acidification of remote soil and freshwater ecosystems;
- Photochemical ozone formation;
- Fertilization of sensitive soil and plant ecosystems leading to changes and reductions in biodiversity;

# Nitrogen oxides – Environmental Concerns



# Nitrogen oxides – Environmental Concerns

- Winter time urban pollution episodes;
- Acidic deposition and acidification of remote soil and freshwater ecosystems;
- Photochemical ozone formation;
- Fertilization of sensitive soil and plant ecosystems leading to changes and reductions in biodiversity;
- Stimulation of plankton blooms in marine waters

## TINY KILLERS

A spurt in the growth of the *Karlodinium veneficum* plankton (right), associated with fish kills worldwide, is believed to be behind the latest mass fish deaths affecting farms along the Johor Strait



### Plankton blooms

- Plankton are micro-organisms as small as 0.01 nanometer, which can reproduce in a space of three hours.
- A "bloom" happens when they multiply very quickly.

### Triggers

Warmer temperatures, tidal conditions or higher concentrations of nutrients in seawater encourage plankton growth or kill the plankton-feeders.

### Impact

- Large amounts of plankton suck oxygen from the water, suffocating other life, and clog delicate fish gills. Some plankton release toxins.
- The bloom ends when the plankton no longer have enough nutrients to survive on.

Sources: AVA, ASSOCIATE PROFESSOR FEDER FROM THE ASIAN SCHOOL OF THE ENVIRONM NANYANG TECHNOLOGICAL UNIVERSITY, MR CHAN PROGRAMME CHAIR OF REPUBLIC POLY DIPLOMA IN MARINE SCIENCE AND AQU

PHOTO: VINCE LOVKO GRAP

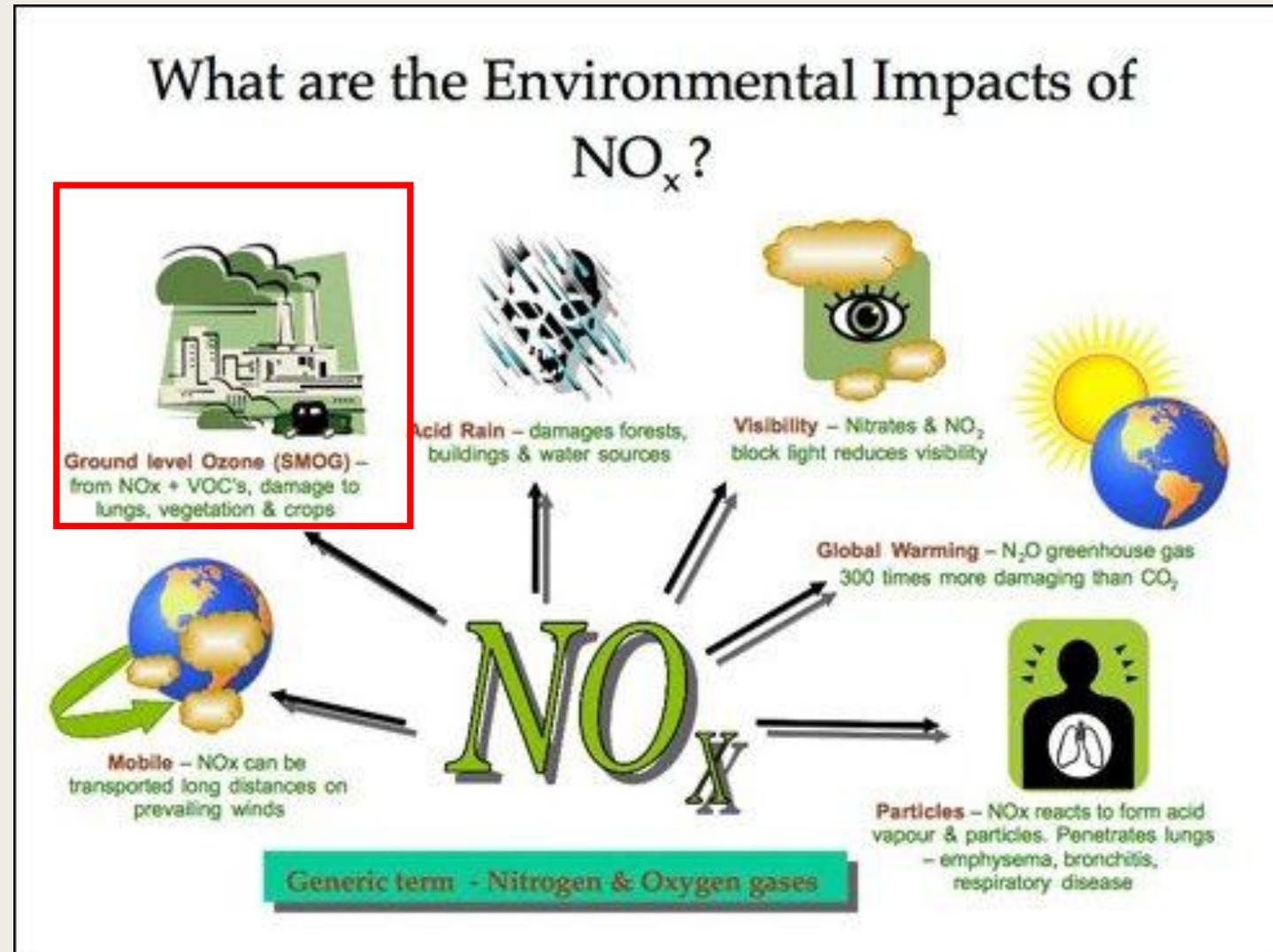
# al Concerns

note soil and

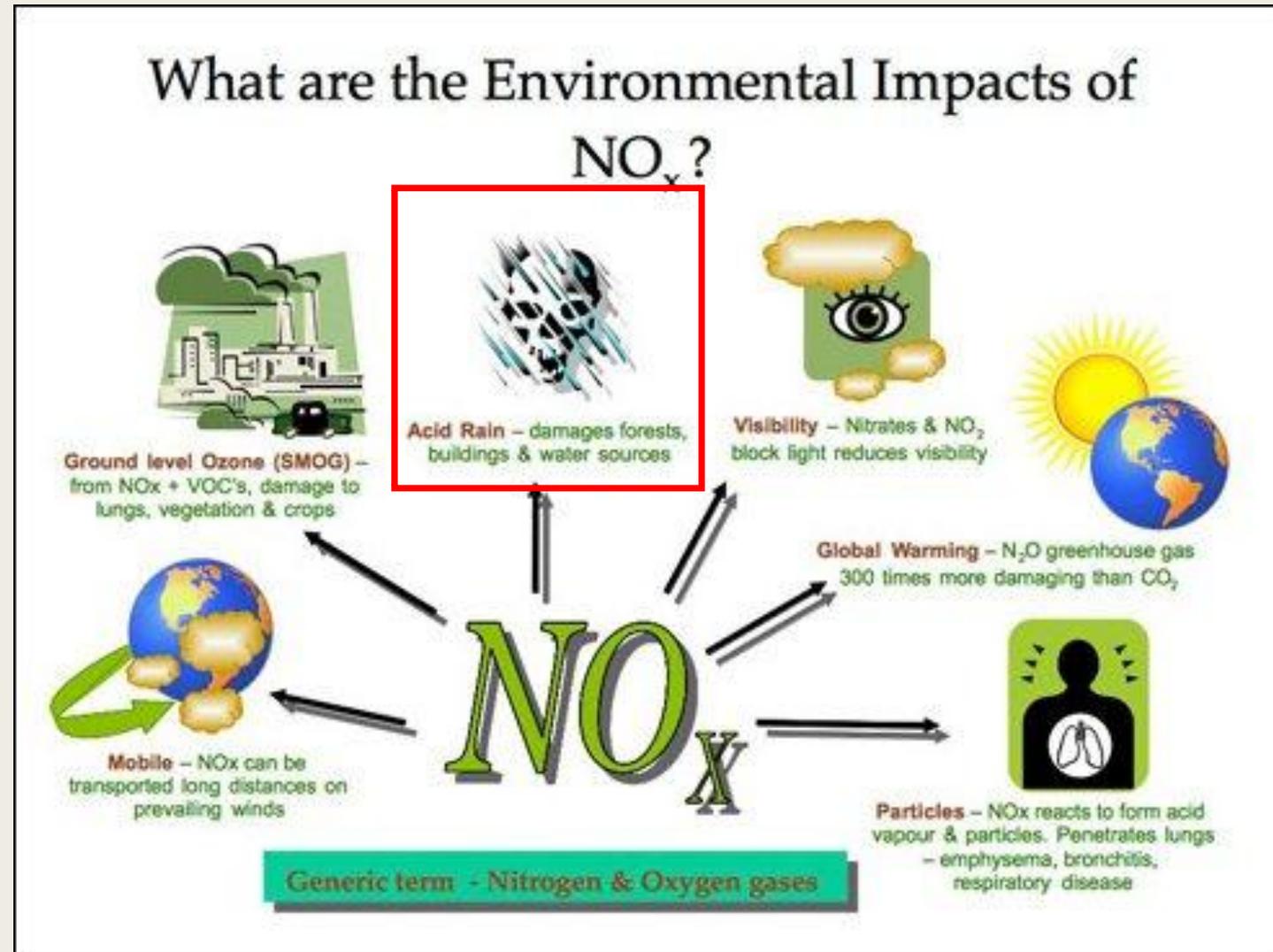
- Stimulation of plankton blooms in marine



# Nitrogen oxides – Environmental Concerns



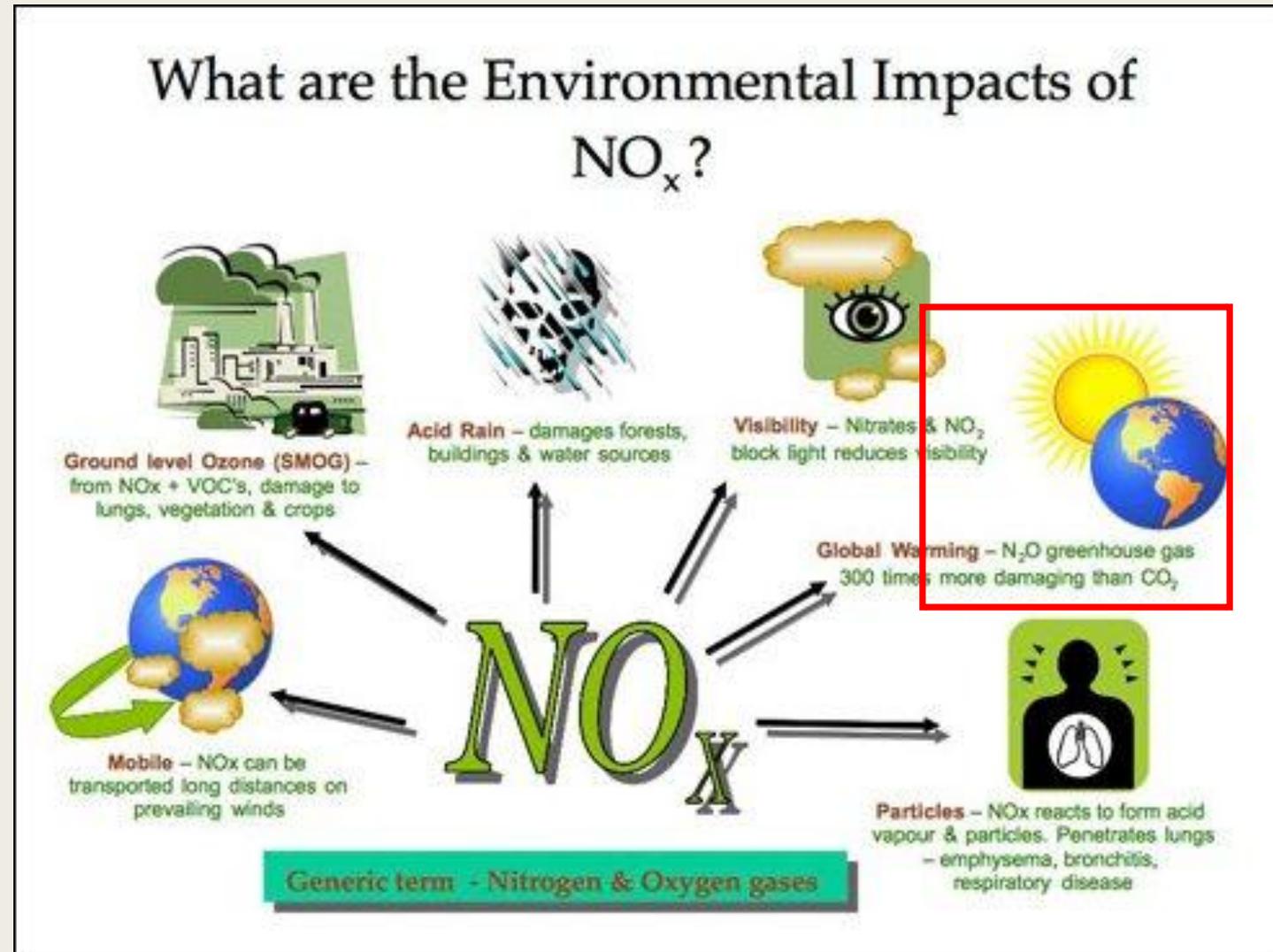
# Nitrogen oxides – Environmental Concerns



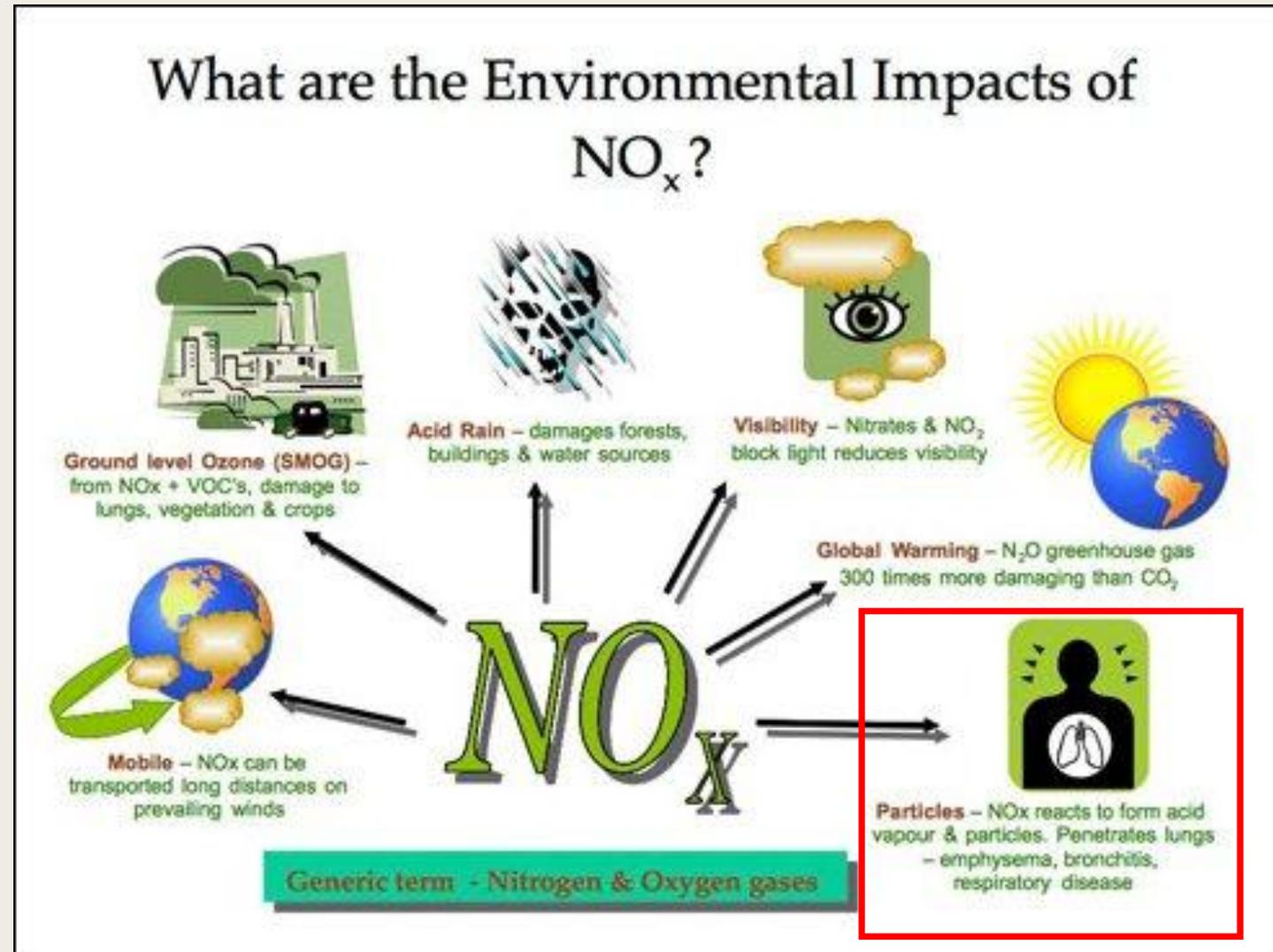
# Nitrogen oxides – Environmental Concerns



# Nitrogen oxides – Environmental Concerns



# Nitrogen oxides – Environmental Concerns



# Nitrogen oxides – Environmental Concerns



# Nitrogen oxides – Factors

## Boiler design factors

- firing mode (front wall, opposed wall, tangential)
- capacity or maximum continuous rating (steam flow rate)
- burner type (e.g., low-NO<sub>x</sub>)
- number and capacity of burners
- burner zone heat release rate (plan, volume and basket)

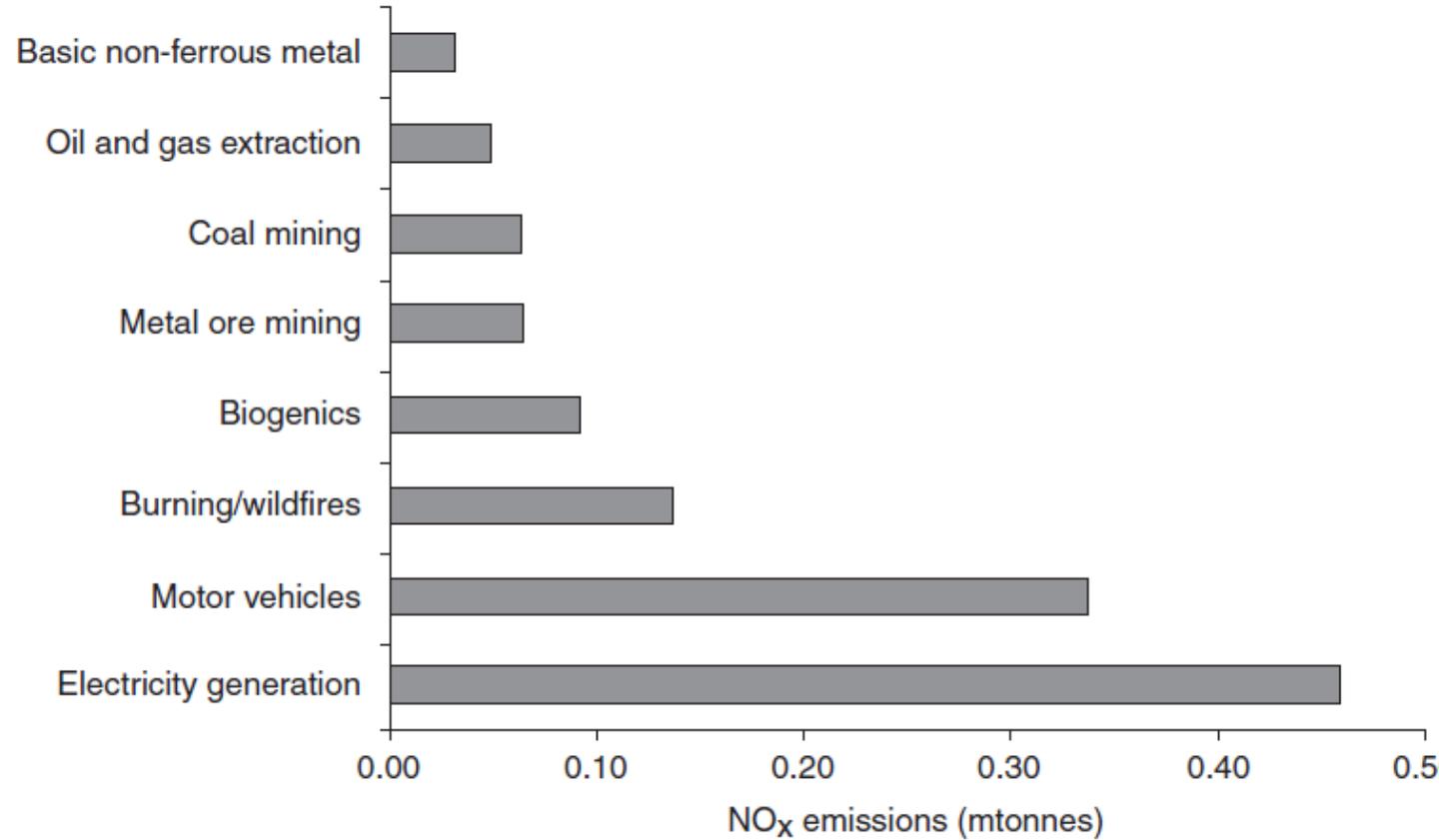
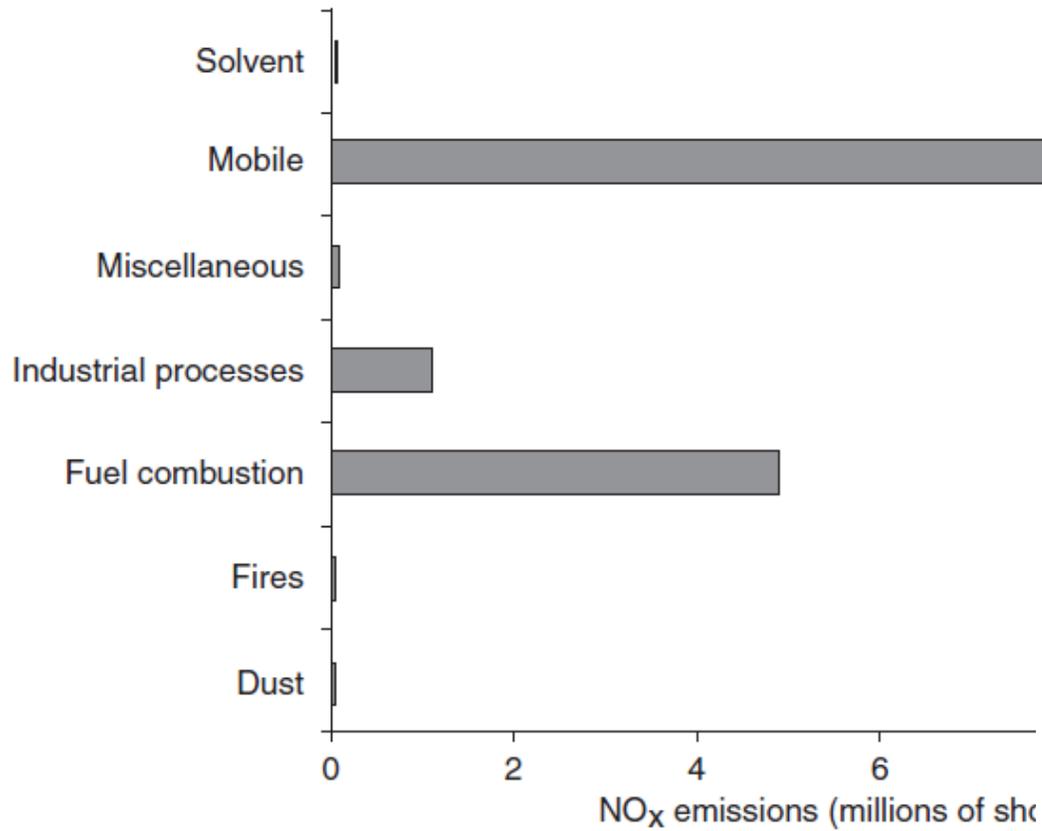
## Boiler operating factors

- load
- excess air or oxygen
- burner tilt
- burner swirl vane settings

## Coal property factors

- volatile matter content
- fuel ratio (FC/VM)
- coal carbon-to-hydrogen ratio (C/H)
- nitrogen content.

US nitrogen oxides emissions as a function of sector for 2008.



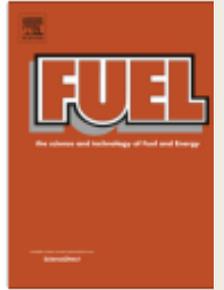
Australian nitrogen oxides emissions as a function of sector for 2009/2010



ELSEVIER

Contents lists available at ScienceDirect

Fuel

journal homepage: [www.elsevier.com/locate/fuel](http://www.elsevier.com/locate/fuel)

## Pretreatment of coal by ionic liquids towards coal electrolysis liquefaction



Shuai Liu, Wei Zhou<sup>\*</sup>, Fang Tang, Bingfeng Guo, Yuti

*Department of Chemistry, Shanghai University, 99 Shangda Road, Shanghai 200444, China*

Materials	Before mixing	After mixing at 90 °C	After mixing at 150 °C	After cooling to 25 °C
Coal+ [Bmim]Cl				
Coal+ [Bmim]BF <sub>4</sub>				
Coal+ [Bmim]OTf				

# Fine particles (Particulate Matter PM)

- Atmospheric particles
- Effects on
  - *human health,*
  - *visibility,*
  - *acid deposition and*
  - *global climate*
- Arise from
  - *natural and anthropogenic,*
  - *primary and secondary sources*

*Table 2.1* Dose-response relationships between PM exposure and health effects (derived from HEI (2002) which includes details of the references listed)

Region	Reference	PM size fraction	Increased risk in mortality per 10 µg/m <sup>3</sup> of PM (95% confidence interval)		
<b>Short term</b>					
3 Australian cities	Simpson <i>et al.</i> , 2005	PM <sub>2.5</sub> PM <sub>10</sub>	Short term All-cause 0.9% (-0.7–2.5%) 0.2% (-0.8–1.2%)	Cardiovascular	Respiratory
29 European cities (APHEA-2 project)	Pope and Dockery, 2006/Analitis	PM <sub>10</sub>		0.76% (0.47–1.05%)	0.58% (0.21–0.95%)
	Katsouyanni <i>et al.</i> , 2001		0.6% (0.4–0.8%)		
29 studies from outside Western Europe and North America	Cohen <i>et al.</i> , 2004	PM <sub>10</sub>	0.5% (0.4–0.6%)	0.6% (0.2–1.1%)	0.3% (0.1–0.5%)
90 US Cities (NMMAPS Project)	Samet <i>et al.</i> , 2000	PM <sub>10</sub>	0.5%		
Four Asian cities	Health Effects Institute, 2010	PM <sub>10</sub>	0.6% (0.3–0.9%)		
<b>Long term</b>					
Meta-analysis of six cohort studies (five North America, one Europe)	Chen <i>et al.</i> , 2008	PM <sub>2.5</sub>	All-cause 6% (3–10%)	Cardiopulmonary	Lung Cancer
Harvard Six Cities – extended analysis	Laden <i>et al.</i> , 2006	PM <sub>2.5</sub>	16% (7%–26%)		
Los Angeles (ACS study)	Jerrett <i>et al.</i> , 2005	PM <sub>2.5</sub>	17% (5–30%)	12% (-3–30%)	44% (-2–211%)
ACS Study	Pope <i>et al.</i> , 2002	PM <sub>2.5</sub>	6% (2–11%)	9% (3–16%)	14% (4–23%)

Table 2.2 Chemical components of PM10 and their biological effects

Component	Major subcomponents	Described biological effects
Metals	Iron, vanadium, nickel, copper, platinum and others	Can trigger inflammation, cause DNA damage, and alter cell permeability by inducing production of reactive oxygen species (particularly hydroxyl free radicals) in tissues.
Organic compounds	Many are adsorbed onto particles; some volatile or semi volatile organic species form particles themselves.	Some may cause mutations, some may cause cancer, and others can act as irritants and induce allergic reactions.
Biological origin	Viruses, bacteria and their endotoxins, animal and plant debris (such as pollen fragments) and fungal spores.	Plant pollens can trigger allergic responses in the airways of sensitive individuals; viruses and bacteria can provoke immune defence responses in the airways.

Table 2.2 Chemical components of PM10 and their biological effects

Component	Major subcomponents	Described biological effects
Metals	Iron, vanadium, nickel, copper, platinum and others	Can trigger inflammation, cause DNA damage, and alter cell permeability by inducing production of reactive oxygen species (particularly hydroxyl free radicals) in tissues.
Organic compounds	Many are adsorbed onto particles; some volatile or semi volatile organic species form particles themselves.	Some may cause mutations, some may cause cancer, and others can act as irritants and induce allergic reactions.
Biological origin	Viruses, bacteria and their endotoxins, animal and plant debris (such as pollen fragments) and fungal spores.	Plant pollens can trigger allergic responses in the airways of sensitive individuals; viruses and bacteria can provoke immune defence responses in the airways.

*Table 2.2* Chemical components of PM10 and their biological effects

Component	Major subcomponents	Described biological effects
Metals	Iron, vanadium, nickel, copper, platinum and others	Can trigger inflammation, cause DNA damage, and alter cell permeability by inducing production of reactive oxygen species (particularly hydroxyl free radicals) in tissues.
Organic compounds	Many are adsorbed onto particles; some volatile or semi volatile organic species form particles themselves.	Some may cause mutations, some may cause cancer, and others can act as irritants and induce allergic reactions.
Biological origin	Viruses, bacteria and their endotoxins, animal and plant debris (such as pollen fragments) and fungal spores.	Plant pollens can trigger allergic responses in the airways of sensitive individuals; viruses and bacteria can provoke immune defence responses in the airways.

Ions	Sulfate (usually as ammonium sulfate) Nitrate (usually as ammonium/sodium nitrate) Acidity (H <sup>+</sup> )	Sulfuric acid at relatively high concentrations can impair mucociliary clearance and increase airway resistance in people with asthma; acidity may change the solubility (and availability of metals and other compounds adsorbed onto particles).
Reactive gases	Ozone, peroxides, aldehydes	May adsorb onto particles and be transported into lower airways, causing injury.
Particle core	Carbonaceous material	Carbon induces lung irritation, epithelial cell proliferation, and fibrosis after long-term exposure.

---

# The coal industry's contribution to fine particles

- Generation of dust and fine particles during open cut coal mining.



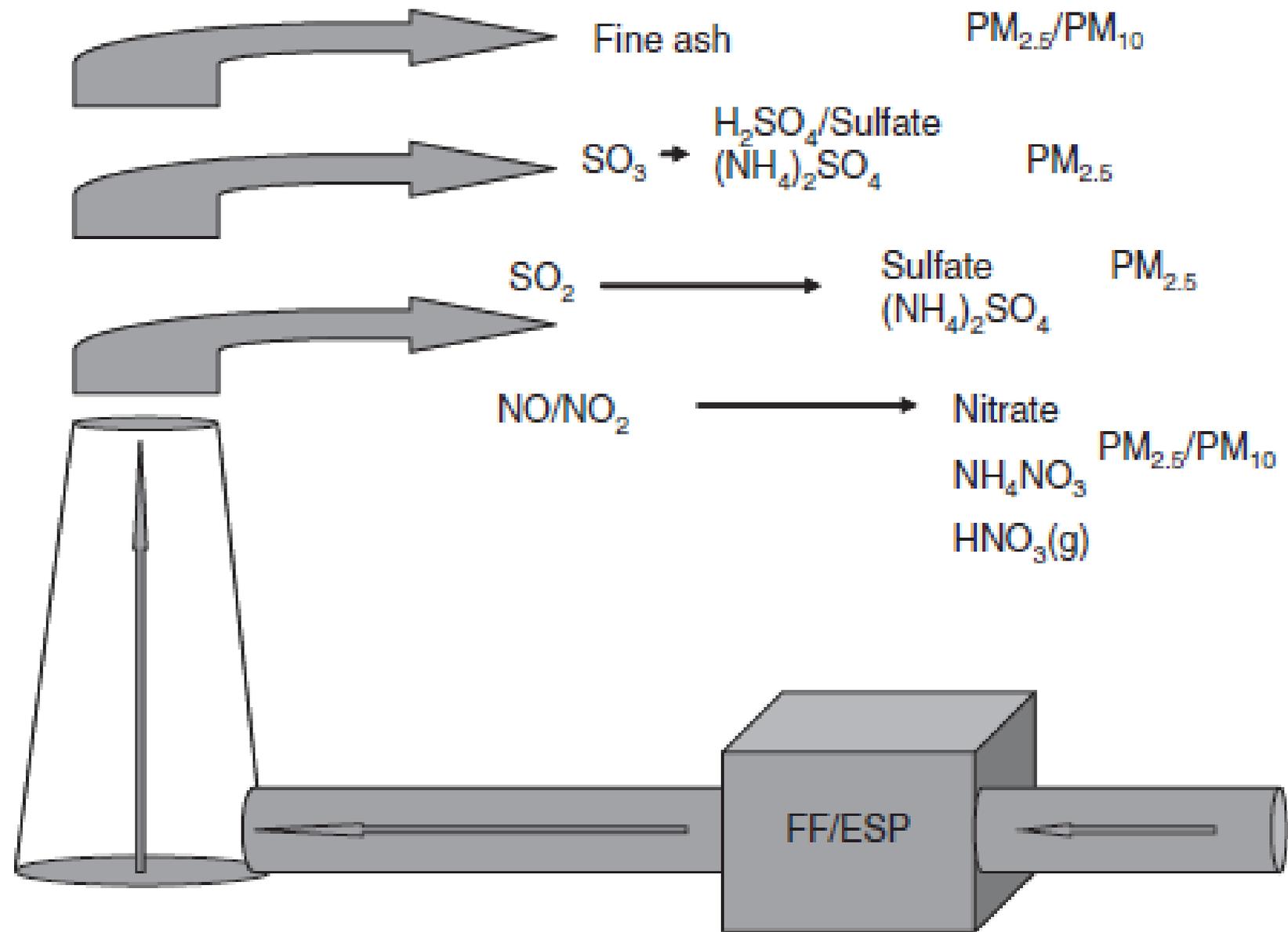
# The coal industry's contribution to fine particles

- Direct emissions of fine particles from coal-fired power stations and other industrial processes which use coal.



# The coal industry's contribution to fine particles

- Indirect contributions to fine particle loadings through conversion of gas phase emissions of  $SO_2$  and  $NO_x$  to sulfate and nitrate.



2.4 Schematic of fine particle formation mechanisms from the gas and particulate phase emissions from coal-fired power stations.

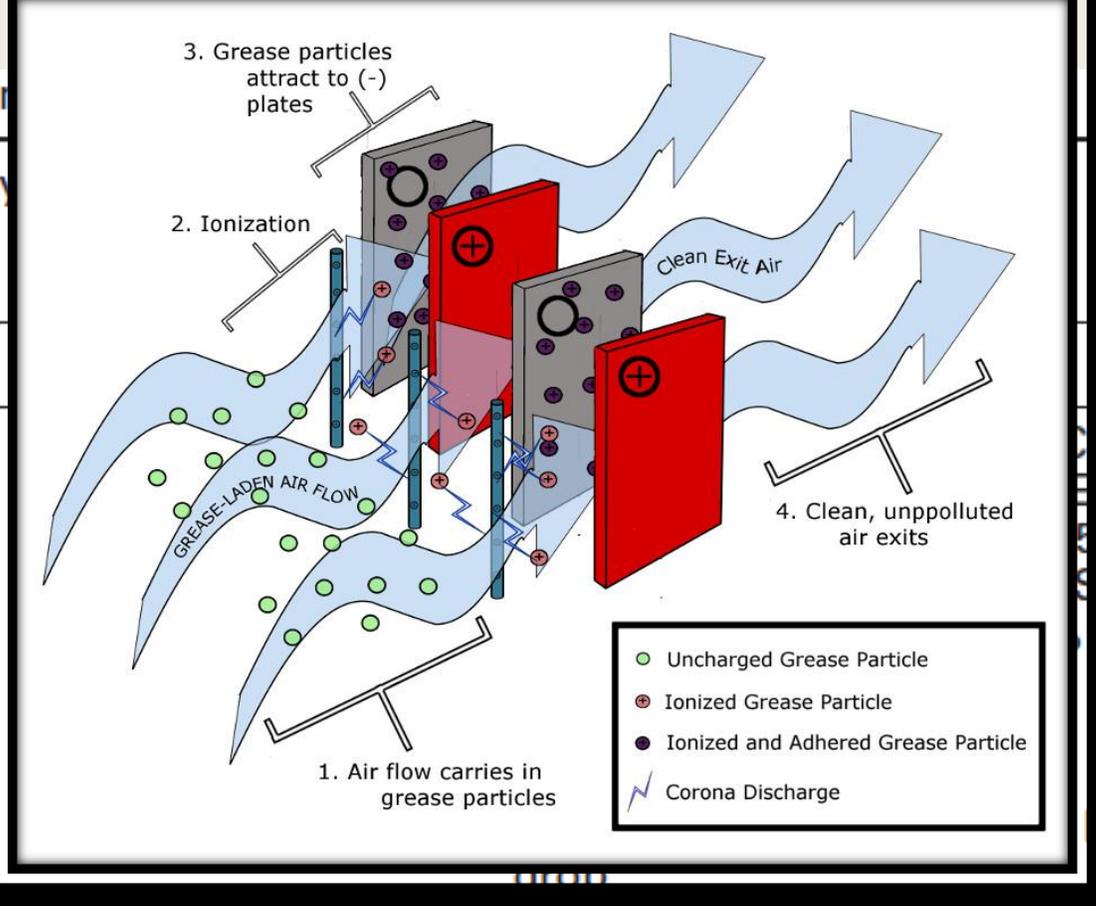
Table 2.7 Comparison of particulate matter air pollution control devices

Technology	Removal efficiency %				Other performance parameters		Remarks
	<1 $\mu\text{m}$	2 $\mu\text{m}$	5 $\mu\text{m}$	>10 $\mu\text{m}$	Parameter	Value	
Electrostatic Precipitator (ESP)	>96.5	>98.3	>99.95	>99.95	Operating temperature	80–220°C (cold ESP) 300–450°C (hot eSP)	Can handle very large gas volumes with low pressure drops Low operating costs except at very high removal rates May not work very efficiently with ash having very high electrical resistivity
					Energy consumption (% of electric capacity)	0.1–1.8%	
					Pressure drop	0.15–0.3 kPa	
Fabric filter	>99.6	>99.6	>99.9	>99.95	Operating temperature	150°C (polyester) 260°C (fibreglass)	Bag life decreases as coal sulfur content increases and as the filtering velocity increases Individual bags fail at an average annual rate of about 1% of installed bags The pressure drop increases as the particle size decreases for a given flue gas throughput
					Energy consumption (% of electric capacity)	0.2–3%	
					Pressure drop	0.5–2 kPa	

Table 2.7 Comparison of particulate

Technology	Removal efficiency
------------	--------------------

Electrostatic Precipitator (ESP)	<1 $\mu\text{m}$	2 $\mu\text{m}$
	>96.5	>98.3



Remarks

Can handle very large gas volumes with low pressure drops  
 Low operating costs except at very high removal rates  
 May not work very efficiently with ash having very high electrical resistivity

Fabric filter	>99.6	>99.6
---------------	-------	-------

Operating temperature	150°C (polyester) 260°C (fibreglass)
Energy consumption (% of electric capacity)	0.2–3%
Pressure drop	0.5–2 kPa

Bag life decreases as coal sulfur content increases and as the filtering velocity increases  
 Individual bags fail at an average annual rate of about 1% of installed bags  
 The pressure drop increases as the particle size decreases for a given flue gas throughput

Table 2.7 Comparison of particulate matter air pollution control devices

Technology	Removal efficiency %				Other performance parameters		Remarks
	<1 $\mu\text{m}$	2 $\mu\text{m}$	5 $\mu\text{m}$	>10 $\mu\text{m}$	Parameter	Value	
Electrostatic Precipitator (ESP)	>96.5	>98.3	>99.95	>99.95	Operating temperature	80–220°C (cold ESP) 300–450°C (hot eSP)	Can handle very large gas volumes with low pressure drops Low operating costs except at very high removal rates May not work very efficiently with ash having very high electrical resistivity
					Energy consumption (% of electric capacity)	0.1–1.8%	
					Pressure drop	0.15–0.3 kPa	
Fabric filter	>99.6	>99.6	>99.9	>99.95	Operating temperature	150°C (polyester) 260°C (fibreglass)	Bag life decreases as coal sulfur content increases and as the filtering velocity increases Individual bags fail at an average annual rate of about 1% of installed bags The pressure drop increases as the particle size decreases for a given flue gas throughput
					Energy consumption (% of electric capacity)	0.2–3%	
					Pressure drop	0.5–2 kPa	

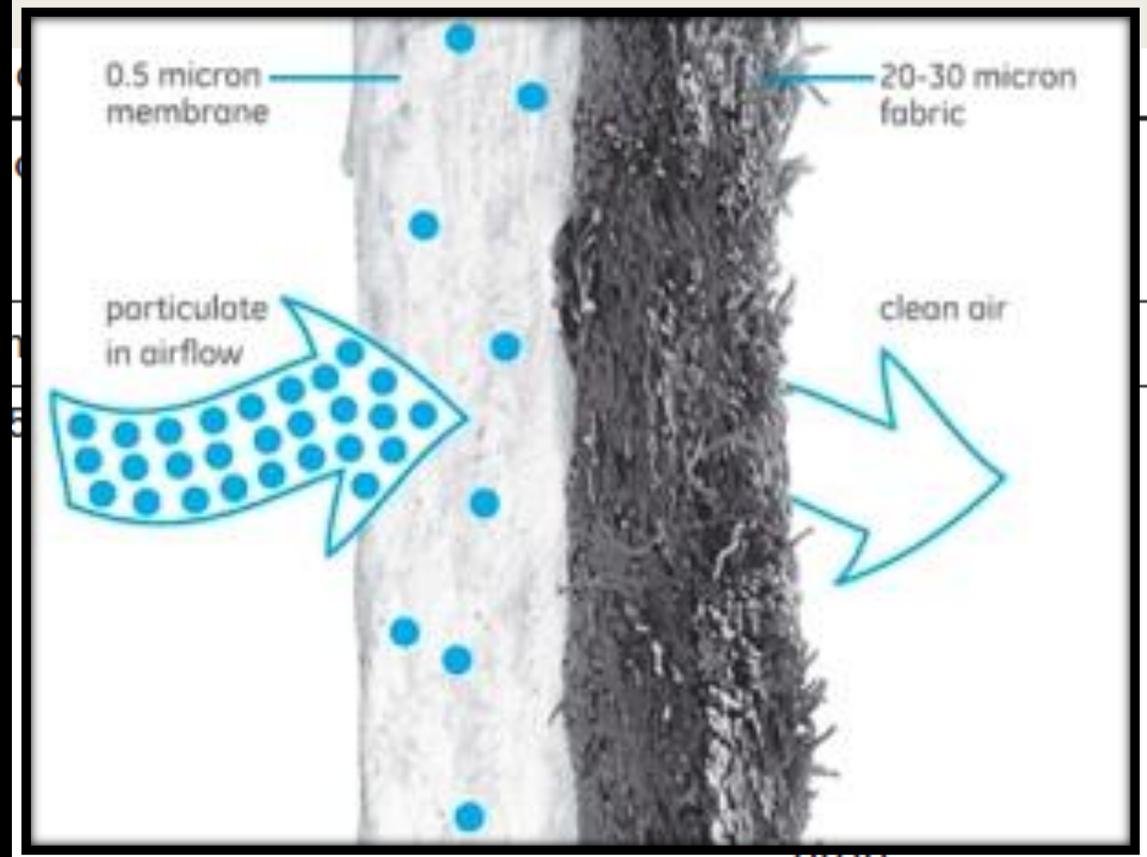
Table 2.7 Comparison

Technology Removal

<1

Electrostatic Precipitator (ESP)

Fabric filter



>99.6 >99.6 >99.9 >99.95

Remarks

Value

80–220°C (cold ESP)  
300–450°C (hot eSP)

0.1–1.8%

0.15–0.3 kPa

150°C (polyester)  
260°C (fibreglass)

0.2–3%

0.5–2 kPa

Operating temperature

Energy consumption (% of electric capacity)

Pressure drop

Can handle very large gas volumes with low pressure drops  
Low operating costs except at very high removal rates  
May not work very efficiently with ash having very high electrical resistivity  
Bag life decreases as coal sulfur content increases and as the filtering velocity increases  
Individual bags fail at an average annual rate of about 1% of installed bags  
The pressure drop increases as the particle size decreases for a given flue gas throughput

Table 2.7 Comparison of particulate matter air pollution control devices

Technology	Removal efficiency %				Other performance parameters		Remarks
	<1 $\mu\text{m}$	2 $\mu\text{m}$	5 $\mu\text{m}$	>10 $\mu\text{m}$	Parameter	Value	
Electrostatic Precipitator (ESP)	>96.5	>98.3	>99.95	>99.95	Operating temperature	80–220°C (cold ESP) 300–450°C (hot eSP)	Can handle very large gas volumes with low pressure drops Low operating costs except at very high removal rates May not work very efficiently with ash having very high electrical resistivity
					Energy consumption (% of electric capacity)	0.1–1.8%	
					Pressure drop	0.15–0.3 kPa	
Fabric filter	>99.6	>99.6	>99.9	>99.95	Operating temperature	150°C (polyester) 260°C (fibreglass)	Bag life decreases as coal sulfur content increases and as the filtering velocity increases Individual bags fail at an average annual rate of about 1% of installed bags The pressure drop increases as the particle size decreases for a given flue gas throughput
					Energy consumption (% of electric capacity)	0.2–3%	
					Pressure drop	0.5–2 kPa	

# Trace elements

- *Trace toxic metals and elements* are also present in coals in varying concentrations
- gas phase for some very volatile compounds
- Inorganic material present in the original sediment layers which formed the organic structure of the coal. This is usually organically bound and described as an *inherently-bound metal*
- Some inorganic material may not be incorporated into the organic structure; instead the structure forms around it; this is described as a *mineral inclusion*
- Some material enters the sediment layers after they have decomposed, or mix into the coal during geological events after the coal seam has formed and during mining operations; these are described as *mineral exclusions*

# Mercury Emission from Coal

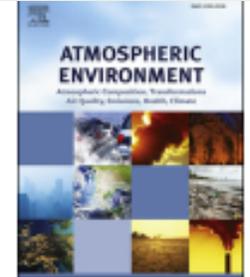


ELSEVIER

Contents lists available at [ScienceDirect](#)

Atmospheric Environment

journal homepage: [www.elsevier.com/locate/atmosenv](http://www.elsevier.com/locate/atmosenv)



## Atmospheric emission of mercury due to combustion of steam coal and domestic coal in China



Shaobin Wang, Kunli Luo\*

*Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China*

### H I G H L I G H T S

- We quantified Hg emission rates from steam coal, domestic coal combustion and coal gangue.
- Hg emission into the atmosphere is estimated to be 292 tons in China in 2014.
- The trend of Hg emission shows an accelerating growth after 2002.
- Hg emission due to coal utilization and coal gangue should draw more attention in the future.

# Mercury Emission from Coal

**Table 3**

Mercury emission per ton of coal combustion in steam boilers in Shanxi Province

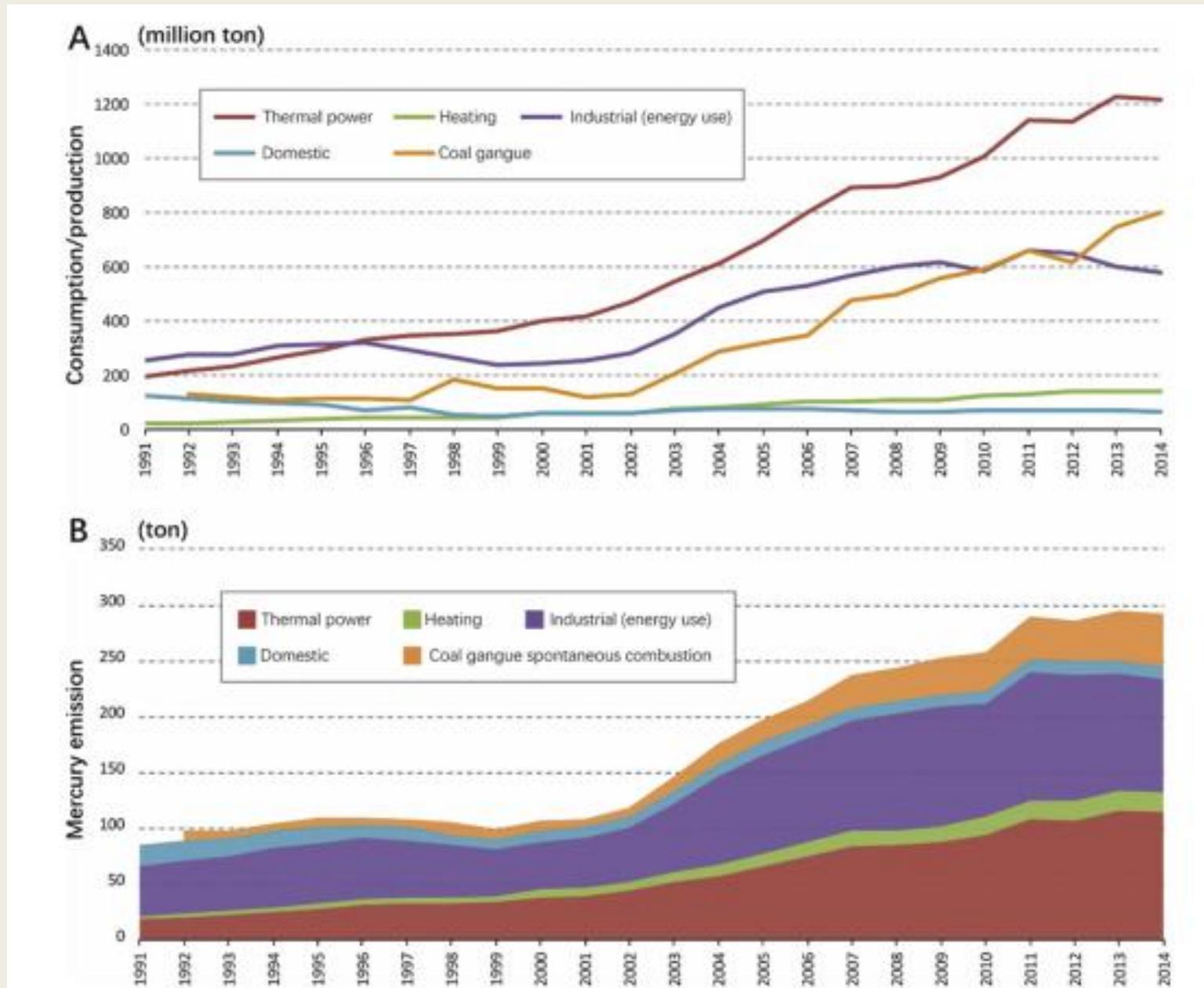
Sampling points	Coal no.	Average mercury in coal (g·t <sup>-1</sup> )	Mercury in bottom ash (B) (g·t <sup>-1</sup> )	Mercury in fly ash (C) (g·t <sup>-1</sup> )	Mercury to atmosphere (g·t <sup>-1</sup> )	Ash content (%)	Mercury emission rate (%)
Wangcun	5#	0.198	0.130	0.480	0.109	10.85	74.41
Duerping	8#	0.177	0.021	0.339	0.247	22.51	66.06
Dongqu	8#	0.177	0.087	0.295	0.247	20.76	68.16
Tunlan	8#	0.177	0.137	0.528	0.214	15.59	60.27
<b>Average</b>							<b>67.23</b>

**Table 4**

Mercury emission from coal combustion in coal-stoves in Zhaotong Prefecture, Yunnan Province.

Sampling points	Ash content (%)	Mercury content in briquette (g·t <sup>-1</sup> )	Mercury in bottom ash (g·t <sup>-1</sup> )	Mercury to atmosphere (g·t <sup>-1</sup> )	Mercury emission rate (%)	
Weixin county	Sample 1	37.83	0.0749	0.0073	0.0626	83.53
	Sample 2	36.37	0.0575	0.0064	0.0480	83.39
	Sample 3	31.52	0.0285	0.0049	0.0236	82.83
	Sample 4	43.59	0.0766	0.0047	0.0643	83.93
	Sample 5	36.02	0.0730	0.0059	0.0612	83.84
	Sample 6	56.65	0.0641	0.0058	0.0531	82.94
	Sample 7	42.04	0.0740	0.0045	0.0622	83.98
	Sample 8	42.18	0.0961	0.0051	0.0809	84.11
	Sample 9	41.12	0.1729	0.0053	0.1461	84.50
	Sample 10	56.12	0.0734	0.0054	0.0612	83.35
	Sample 11	32.41	0.1508	0.0058	0.1274	84.50
	Sample 12	59.39	0.0577	0.0082	0.0471	81.62
	Sample 13	45.53	0.0940	0.0070	0.0786	83.64
	Sample 14	48.33	0.1216	0.0117	0.1011	83.14
	Sample 15	37.23	0.1047	0.0066	0.0881	84.06
	Sample 16	36.08	0.1215	0.0111	0.1017	83.69
	Sample 17	39.56	0.0880	0.0069	0.0738	83.76

# Mercury Emission from Coal





## Environmental issues from coal mining and their solutions

BIAN Zhengfu<sup>1,\*</sup>, INYANG Hilary I<sup>2</sup>, DANIELS John L<sup>2,3</sup>, OTTO Frank<sup>4</sup>, STRUTHERS Sue<sup>5</sup>

<sup>1</sup>*Institute of Land Resources, China University of Mining & Technology, Xuzhou 221008, China*

<sup>2</sup>*Global Institute for Energy and Environmental Systems, University of North Carolina, Charlotte NC 28223, USA*

<sup>3</sup>*Natural Science Foundation of the USA, Arlington VA 22230, USA*

<sup>4</sup>*Department of Geoengineering and Mining, University of Applied Science, Bochum 44801, Germany*

<sup>5</sup>*Skapa Mining Services, Orkney KW17 2SX, UK*

**Abstract:** The environmental challenges from coal mining include coal mine accidents, land subsidence, damage to the water environment, mining waste disposal and air pollution. These are either environmental pollution or landscape change. A conceptual framework for solving mine environmental issues is proposed. Clean processes, or remediation measures, are designed to address environmental pollution. Restoration measures are proposed to handle landscape change. The total methane drainage from 56 Chinese high methane concentration coal mines is about 101.94 million cubic meters. Of this methane, 19.32 million, 35.58 million and 6.97 million cubic meters are utilized for electricity generation, civil fuel supplies and other industrial purposes, respectively. About 39% of the methane is emitted into the atmosphere. The production of coal mining wastes can be decreased 10% by reuse of mining wastes as underground fills, or by using the waste as fuel for power plants or for raw material to make bricks or other infrastructure materials. The proper use of mined land must be decided in terms of local physical and socio-economical conditions. In European countries more than 50% of previously mined lands are reclaimed as forest or grass lands. However, in China more than 70% of the mined lands are reclaimed for agricultural purposes because the large population and a shortage of farmlands make this necessary. Reconstruction of rural communities or native residential improvement is one environmental problem arising from min-



Table 2.5 Coal-fired power plant emission limits for several countries

	Date plant commenced/ licensed	Emission limits (plant size)		
		Solid particles	NO <sub>x</sub>	SO <sub>2</sub>
Australia/New South Wales (Protection of the Environment Operations (Clean Air) Regulation 2010)	Before 1972 1972–Aug 1987 Aug 1987–Sep 2005 After Sep 2005	400 mg/m <sup>3</sup> 250 mg/m <sup>3</sup> 100 mg/m <sup>3</sup> 50 mg/m <sup>3</sup>	2500 mg/m <sup>3</sup> 800 mg/m <sup>3</sup> 500 mg/m <sup>3</sup>	No limits
Europe (Directive 2001/80/EC)	Before 27 Nov 2002	100 mg/m <sup>3</sup> (<500 MWth) 50 mg/m <sup>3</sup> (≥500 MWth)	600 mg/m <sup>3</sup> (≤500 MWth) 500 mg/m <sup>3</sup> (>500 MWth) (currently) 200 mg/m <sup>3</sup> (>500 MWth) (from 1 Jan 2016)	2000–400 mg/ m <sup>3</sup> (sliding scale inversely proportional to plant size below 500 MWth and above 100 MWth)
(Directive 2010/75/EU, applies fully in 2020; linear decrease from '2001/80/EC' limits between 2016 and 2020)	After 27 Nov 2002 Before 7 Jan 2013	30 mg/m <sup>3</sup> 25 mg/m <sup>3</sup> (<300 MWth) 20 mg/m <sup>3</sup> (≥300 MWth)	200 mg/m <sup>3</sup> 200 mg/m <sup>3</sup>	200 mg/m <sup>3</sup> 250 mg/m <sup>3</sup> (<300 MWth) 200 mg/m <sup>3</sup> (≥300 MWth)
	After 7 Jan 2013	20 mg/m <sup>3</sup> (<300 MWth) 10 mg/m <sup>3</sup> (≥300 MWth)	200 mg/m <sup>3</sup> (<300 MWth) 150 mg/m <sup>3</sup> (≥300 MWth)	200 mg/m <sup>3</sup> (<300 MWth) 150 mg/m <sup>3</sup> (≥300 MWth)
USA (New Source Performance Standards: Federal Register/Vol. 71, No. 38 /27 Feb 2006)	Before 28 Feb 2005 After 28 Feb 2005	0.05 g/kWh 0.023 g/kWh	0.73 g/kWh 0.47 g/kWh	0.93 g/kWh 0.65 g/kWh

South Korea (Sloss, 2009)	Before 1995	250 mg/m <sup>3</sup>	719 mg/m <sup>3</sup> (350 ppmv)	3429 mg/m <sup>3</sup> (1200 ppmv)
	1995–1998	150 mg/m <sup>3</sup> (<30 000 m <sup>3</sup> /h)		1429 mg/m <sup>3</sup> (500 ppmv)
	after 1998	100 mg/m <sup>3</sup> (>30000 m <sup>3</sup> /h) 50 mg/m <sup>3</sup>		772 mg/m <sup>3</sup> (270 ppmv) (<500 MWe) 429 mg/m <sup>3</sup> (150 ppmv) (>500 MWe)
China (Steinfeld <i>et al.</i> , 2009)	Before 1997	200 mg/m <sup>3</sup>	1100 mg/m <sup>3</sup> 650 mg/m <sup>3</sup> 450 or 650 <sup>b</sup> mg/m <sup>3</sup>	1200 mg/m <sup>3</sup>
	1997–2003	50 <sup>a</sup> mg/m <sup>3</sup>		400 <sup>a</sup> mg/m <sup>3</sup>
	After 2003			400 <sup>a</sup> mg/m <sup>3</sup>

<sup>a</sup> Higher limits apply in mine-mouth stations in the western region, as well as for plants with FGD installed before regulation commenced, as well as for those using low-quality waste coal.

<sup>b</sup> 450 for >20% volatile matter (dry ash free).

Table 2.6 Primary measures for pollutant reduction and emission control

Combustion modifications	Capacity derating	Air and fuel modifications	Burner modifications	In-furnace combustion modifications
Solid fuels PM control	Lower volume flow and higher oxygen surplus reduces temperature and slagging	Pre-drying, gasification, pyrolysis of fuel, fuel additives, i.e. low melting additives for slag tap furnace with liquid ash removal (tested for pressurised coal combustion for gas turbines)	Liquid ash removal, cyclone burner in slag tap furnace	Liquid ash removal, slag tap furnace; circulating fluidised bed combustion, coarse ash control

Table 2.6 Primary measures for pollutant reduction and emission control

Combustion modifications	Capacity derating	Air and fuel modifications	Burner modifications	In-furnace combustion modifications
Solid fuels PM control	Lower volume flow and higher oxygen surplus reduces temperature and slagging	Pre-drying, gasification, pyrolysis of fuel, fuel additives, i.e. low melting additives for slag tap furnace with liquid ash removal (tested for pressurised coal combustion for gas turbines)	Liquid ash removal, cyclone burner in slag tap furnace	Liquid ash removal, slag tap furnace; circulating fluidised bed combustion, coarse ash control

Table 2.6 Primary measures for pollutant reduction and emission control

Combustion modifications	Capacity derating	Air and fuel modifications	Burner modifications	In-furnace combustion modifications
Solid fuels PM control	Lower volume flow and higher oxygen surplus reduces temperature and slagging	Pre-drying, gasification, pyrolysis of fuel, fuel additives, i.e. low melting additives for slag tap furnace with liquid ash removal (tested for pressurised coal combustion for gas turbines)	Liquid ash removal, cyclone burner in slag tap furnace	Liquid ash removal, slag tap furnace; circulating fluidised bed combustion, coarse ash control

Table 2.6 Primary measures for pollutant reduction and emission control

Combustion modifications	Capacity derating	Air and fuel modifications	Burner modifications	In-furnace combustion modifications
Solid fuels PM control	Lower volume flow and higher oxygen surplus reduces temperature and slagging	Pre-drying, gasification, pyrolysis of fuel, fuel additives, i.e. low melting additives for slag tap furnace with liquid ash removal (tested for pressurised coal combustion for gas turbines)	Liquid ash removal, cyclone burner in slag tap furnace	Liquid ash removal, slag tap furnace; circulating fluidised bed combustion, coarse ash control

Table 2.6 Primary measures for pollutant reduction and emission control

Combustion modifications	Capacity derating	Air and fuel modifications	Burner modifications	In-furnace combustion modifications
Solid fuels PM control	Lower volume flow and higher oxygen surplus reduces temperature and slagging	Pre-drying, gasification, pyrolysis of fuel, fuel additives, i.e. low melting additives for slag tap furnace with liquid ash removal (tested for pressurised coal combustion for gas turbines)	Liquid ash removal, cyclone burner in slag tap furnace	Liquid ash removal, slag tap furnace; circulating fluidised bed combustion, coarse ash control

Solid fuels

SO<sub>2</sub>  
control

Reduced  
temperature  
reduces  
sulfur  
volatilisation

Use of low  
sulfur fuel  
and sorbent  
fuel  
additives, i.e.  
lime and  
limestone for  
fluidised  
bed  
combustion

Burner with  
separate  
additive  
injection

Over fire air  
injection of  
absorbents,  
i.e.  
limestone

Solid fuels

NO<sub>x</sub>  
Control  
(reduction  
of NO<sub>x</sub>  
production)

Reduced  
temperature

Mixing and finer  
grinding of  
fuel, flue-  
gas recycling  
reduces  
NO<sub>x</sub> production

Low NO<sub>x</sub>  
burners

Staged  
combustion  
and  
reburning

Solid fuels  
SO<sub>2</sub>  
control

Reduced  
temperature  
reduces  
sulfur  
volatilisation

Use of low  
sulfur fuel  
and sorbent  
fuel  
additives, i.e.  
lime and  
limestone for  
fluidised  
bed  
combustion

Burner with  
separate  
additive  
injection

Over fire air  
injection of  
absorbents,  
i.e.  
limestone

Solid fuels  
NO<sub>x</sub>  
Control  
(reduction  
of NO<sub>x</sub>  
production)

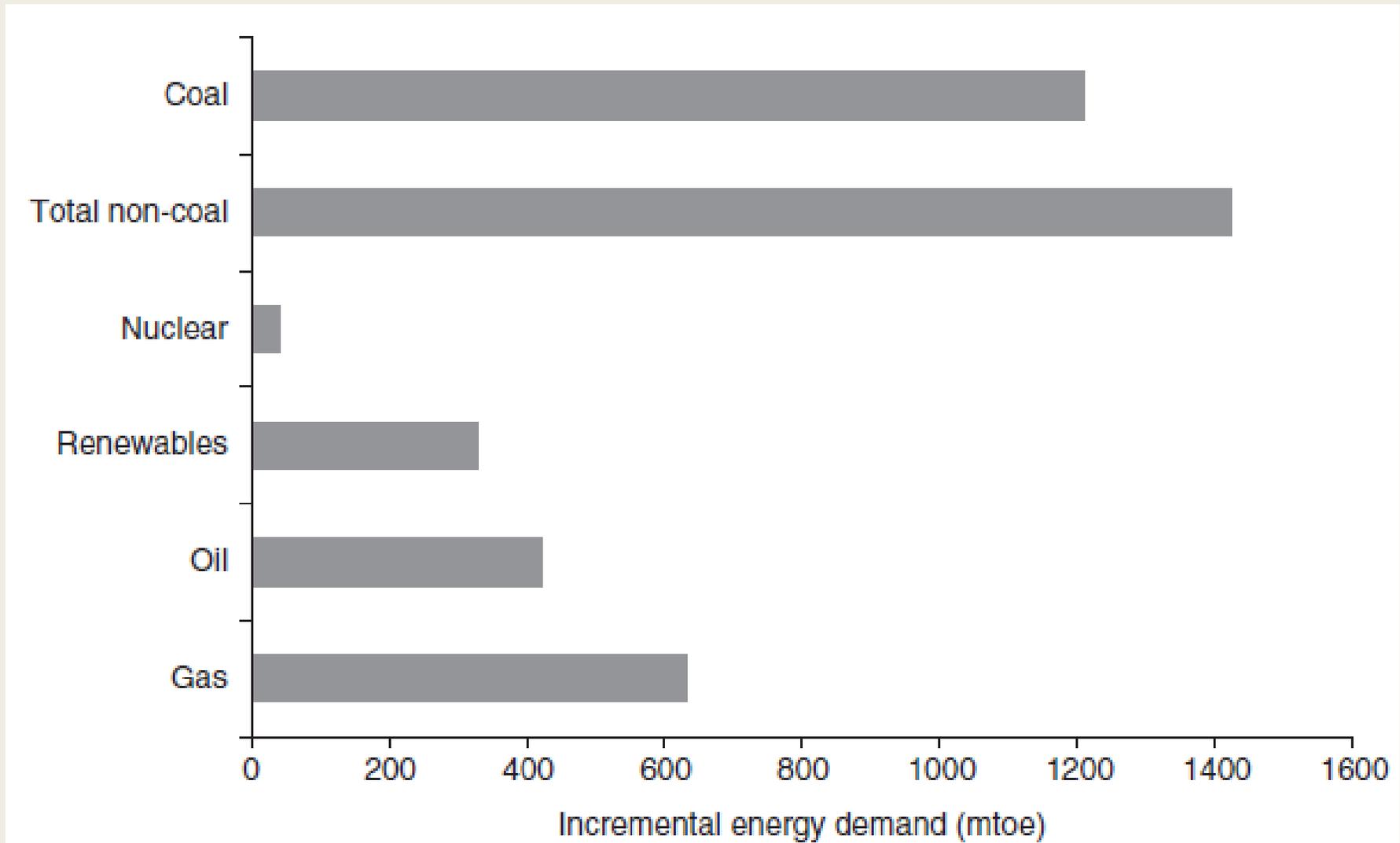
Reduced  
temperature

Mixing and finer  
grinding of  
fuel, flue-  
gas recycling  
reduces  
NO<sub>x</sub> production

Low NO<sub>x</sub>  
burners

Staged  
combustion  
and  
reburning

# Future Trends



2.5 Incremental world primary energy demand by fuel, 2000–2010.  
(Source: From IEA, 2011.)

Thank You!

