



Sustainable Energy

Alternatives for the Future

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Environmental Effects of Energy

- Every step in the production, modification and use of energy impacts the environment.
- Energy can also be used to reduce environmental impacts.

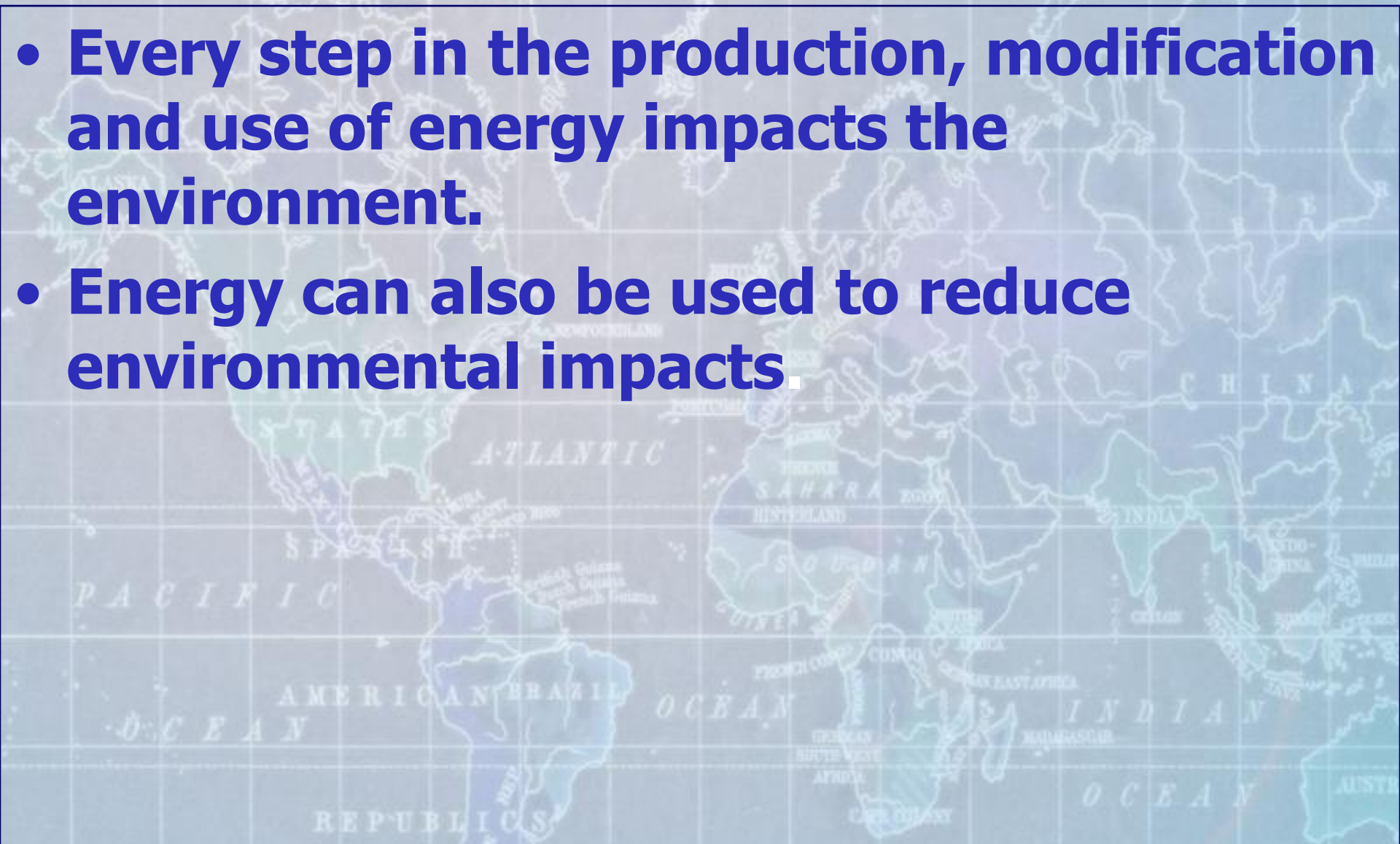


Figure 4.1

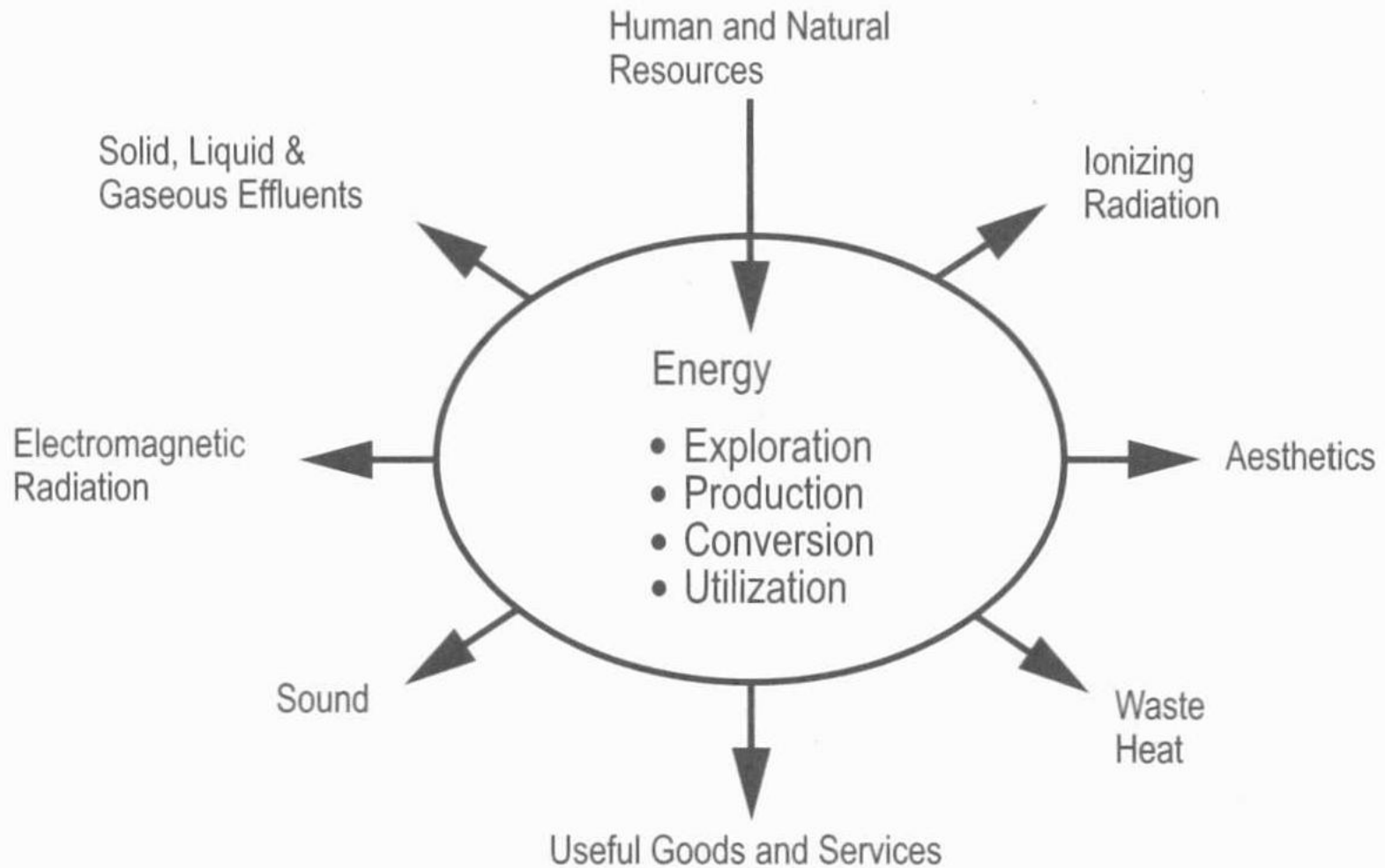


Figure 4.1. Important interactions of energy systems with the environment.

Adverse Environmental Effects Over Local and Regional Length Scales

- **Ambient Air Pollution**

- **National Ambient Air Quality Standards (NAAQS) list six criteria air pollutants:**

- CO
 - Lead
 - NO₂
 - O₃
 - SO₂
 - Particulates
- **NAAQS are further divided into primary and secondary standards**

Standards continued...

- **Primary standards protect human health**
- **Secondary standards protect welfare effects (degradation of visibility, damage to buildings, crops, vegetation and ecosystems).**
- **Table 4.1 shows the above standards.**
- **Figure 4.3 shows the source of the criteria air pollutants and VOCs.**

Table 4.1

Table 4.1. National Ambient Air Quality Standards for the US EPA Criteria Pollutants as of December 1999

Pollutant	Primary Standard (Health Related)		Secondary Standard (Welfare Related)	
	Type of Average	Standard Level Concentration ^c	Type of Average	Standard Level Concentration ^a
CO	8-hour ^b	9 ppm (10 mg/m ³)	No Secondary Standard	
	1-hour ^b	35 ppm (40 mg/m ³)	No Secondary Standard	
Pb	Maximum Quarterly Average	1.5 µg/m ³	Same as Primary Standard	
NO ₂	Annual Arithmetic Mean	0.053 ppm (100 µg/m ³)	Same as Primary Standard	
O ₃	Maximum Daily 1-hour Average ^c	0.12 ppm (235 µg/m ³)	Same as Primary Standard	
	4th Maximum Daily ^d	0.08 ppm (157 µg/m ³)	Same as Primary Standard	
	8-hour Average			
PM ₁₀	Annual Arithmetic Mean	50 µg/m ³	Same as Primary Standard	
	24-hour ^b	150 µg/m ³	Same as Primary Standard	
PM _{2.5}	Annual Arithmetic Mean ^e	15 µg/m ³	Same as Primary Standard	
	24-hour ^f	65 µg/m ³	Same as Primary Standard	
SO ₂	Annual Arithmetic Mean	(80 µg/m ³)	3-hour ^b	0.50 ppm (1,300 µg/m ³)
	24-hour ^b	0.14 ppm (365 µg/m ³)		

Figure 4.3

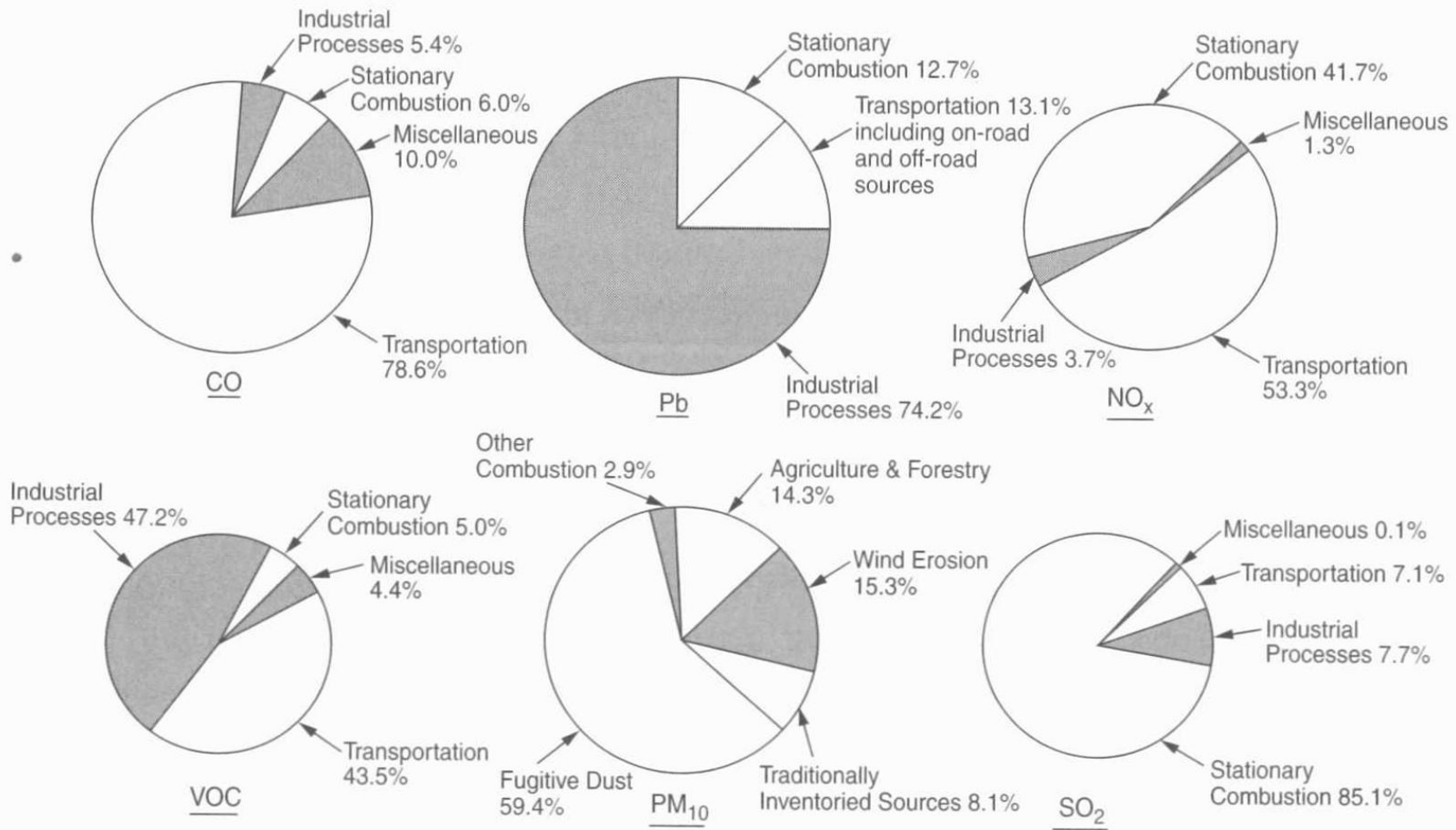


Figure 4.3. US EPA data for source apportionment of 1998 ambient air emissions of VOCs and five criteria pollutants. Source: EPA (2000).

Table 4.2 and Table 4.3

Table 4.2. Examples of Volatile Organic Compounds (VOCs) in US Ambient Air

Propane	Isobutane	Isoprene
Isopentane	Benzene	Methylcyclopentane
Toluene	Acetylene	3-Methylhexane
Ethane	n-Hexane	Ethylbenzene
n-Butane	2,2,4-Trimethylpentane	m-Ethyltoluene
n-Pentane	Propylene	Formaldehyde
Ethylene	3-Methylpentane	Acetaldehyde
o, m, and p-Xylenes	1,2,4-Trimethylbenzene	Monoterpenes

Source: EPA (2000).

Table 4.3. Examples of Biogenic Sources of VOCs in the US

Region	VOC	Source
Southwestern United States	Isoprene	Oak (mostly), citrus, eucalyptus
	Monoterpenes	Pine, citrus, eucalyptus
Northeastern United States	Isoprene	Oak (mostly), spruce
	Monoterpenes	Maple, hickory, pine, spruce, fir, cottonwood

Energy effects continued

- **Energy is a source for another class of air pollutants: hazardous air pollutants (HAPs)**
 - **HAPs are chemicals known or suspected to damage ecosystems or cause serious human health effects.**
 - **Table 4.4 contains a list of common types of HAPs**

Table 4.4

Table 4.4. Examples of Various Substances in the US EPA List of Hazardous Air Pollutants (HAPs)

Trace Metals¹	Various Organic Compounds
Nickel (fine)	1,2-Dibromoethane
Cadmium (PM ₁₀)	Ethylene dichloride
Arsenic (fine)	Styrene
Lead (fine)	Trichloroethylene
Manganese (fine)	Vinyl chloride
Lead (coarse)	1,2-Dichloropropane
Nickel (pm10)	Tetrachloroethylene
Nickel (tsp)	1,3-Butadiene
Manganese (PM ₁₀)	1,1,2,2-Tetrachloroethane
Chromium (coarse)	trans-1,3-Dichloropropene
Chromium (PM ₁₀)	Chloroform
Beryllium (tsp)	Carbon tetrachloride
Chromium (tsp)	Acrolein
Nickel (coarse)	Toluene
Chromium (fine)	Benzene
Lead (PM ₁₀)	Formaldehyde
Manganese (coarse)	Acetaldehyde
Chromium VI	Acrylonitrile
Arsenic (PM ₁₀)	Benzo(a)pyrene (total PM ₁₀ & vapor)
Arsenic (coarse)	Dibenz(a,h)anthracene (total PM ₁₀ & vapor)
Beryllium (PM ₁₀)	Indeno(1,2,3-cd)pyrene (total PM ₁₀ & vapor)
Mercury (coarse)	Benzo(k)fluoranthene (total PM ₁₀ & vapor)
Mercury (fine)	
Manganese (tsp)	
Mercury (PM ₁₀)	
Mercury (tsp)	
Arsenic (tsp)	
Lead (tsp)	
Cadmium (tsp)	

Table 4.7

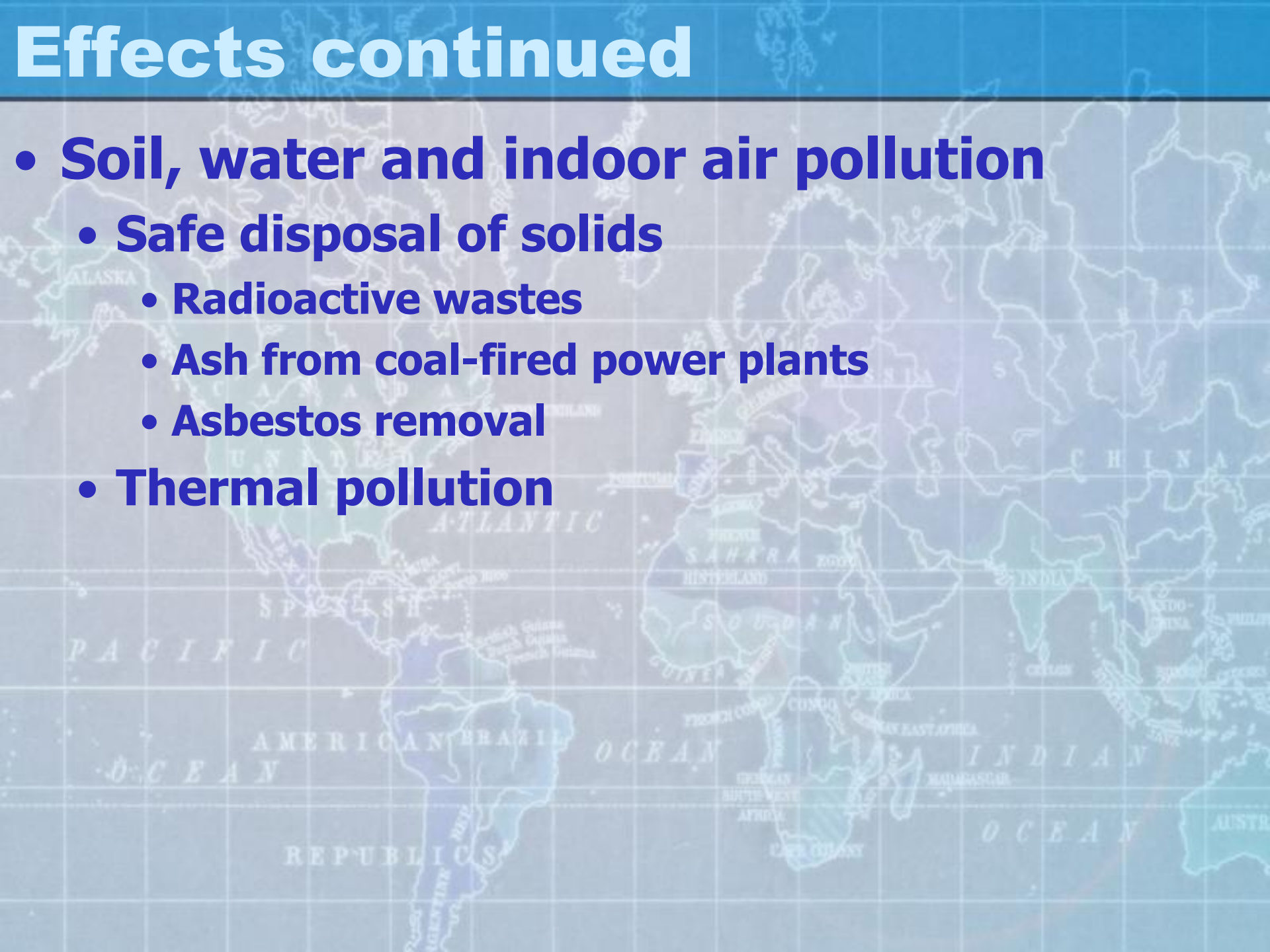
Table 4.7. Examples of Atmospheric Emissions Sources and Pollutants Regulated Under US NSPS

Sources	Pollutants
Fossil fuel-fired steam generators	Particulate matter, opacity, SO ₂ , NO _x
Coal preparation plants	Particulate matter, opacity
Incinerators	Particulate matter, opacity
Primary lead, zinc, and copper smelters	Particulate matter, SO ₂ , opacity
Secondary lead smelters	Particulate matter, opacity
Secondary bronze and brass smelters	Particulate matter, opacity
Primary aluminum reduction plants	Fluorides
Iron and steel plants	Particulate matter, opacity
Ferroalloy production facilities	Particulate matter, opacity, CO
Steel plants—electric arc furnaces	Particulate matter, opacity
Sulfuric acid plants	SO ₂ , acid mist, opacity
Nitric acid plants	NO _x
Portland cement plants	Particulate matter, opacity
Asphalt concrete plants	Particulate matter, opacity
Sewage treatment plants	Particulate matter, opacity
Petroleum refineries	Particulate matter, SO _x , CO, reduced sulfur
Kraft pulp mills	Reduced sulfur, particulate matter, opacity
Grain elevators	Particulate matter, opacity
Lime manufacturing plants	Particulate matter
Phosphate fertilizer industry	Fluorides

Source: Godish (1997).

Effects continued

- **Soil, water and indoor air pollution**
 - **Safe disposal of solids**
 - **Radioactive wastes**
 - **Ash from coal-fired power plants**
 - **Asbestos removal**
 - **Thermal pollution**



Global Climate Change

- Human caused addition of carbon dioxide to the atmosphere is causing global climate change.
- Humans are burning increasing levels of fossil fuels which increases the amount of greenhouse gases to the atmosphere.

Carbon Dioxide levels (NASA)

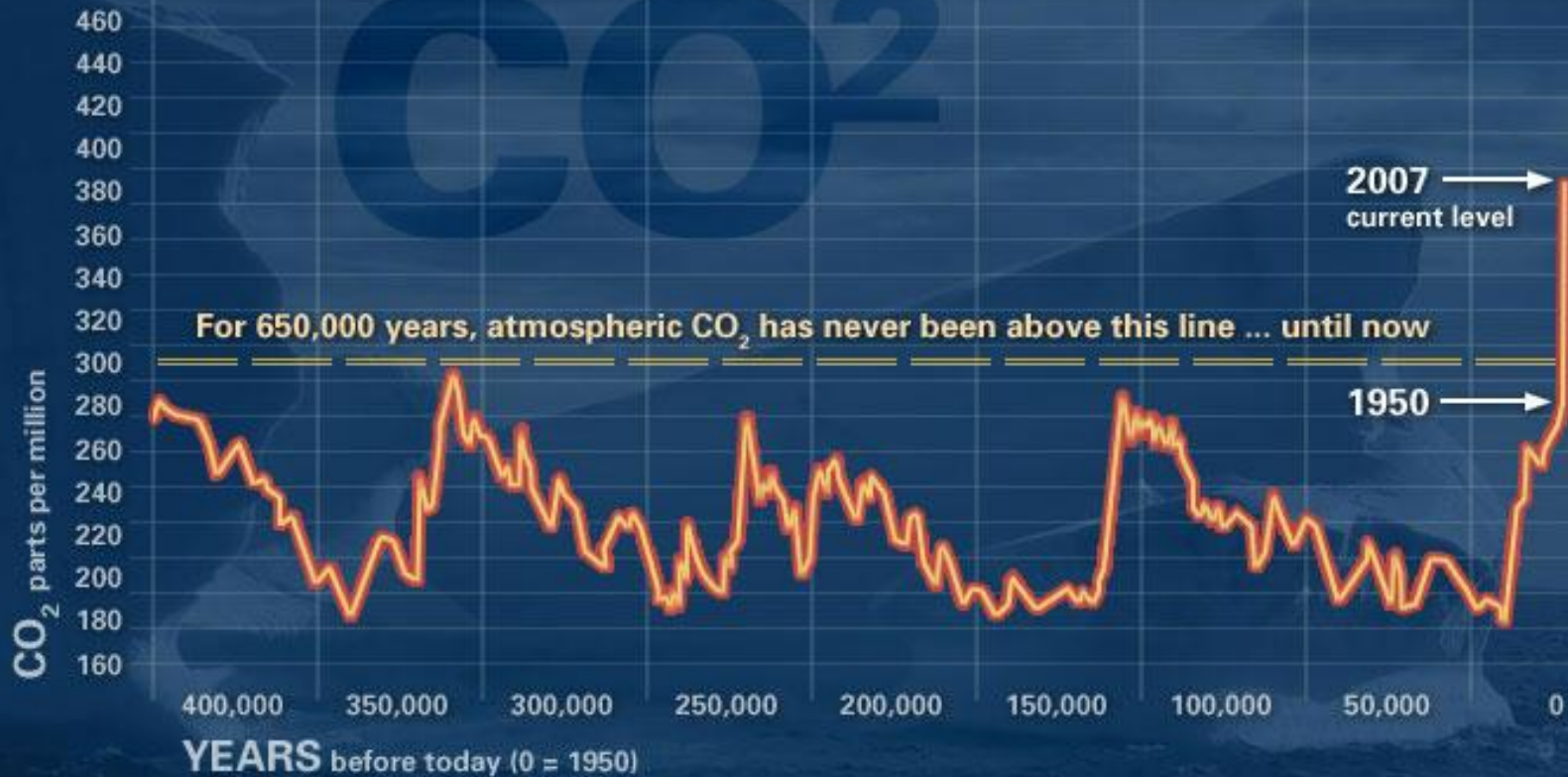


Figure 4.6 global temperature

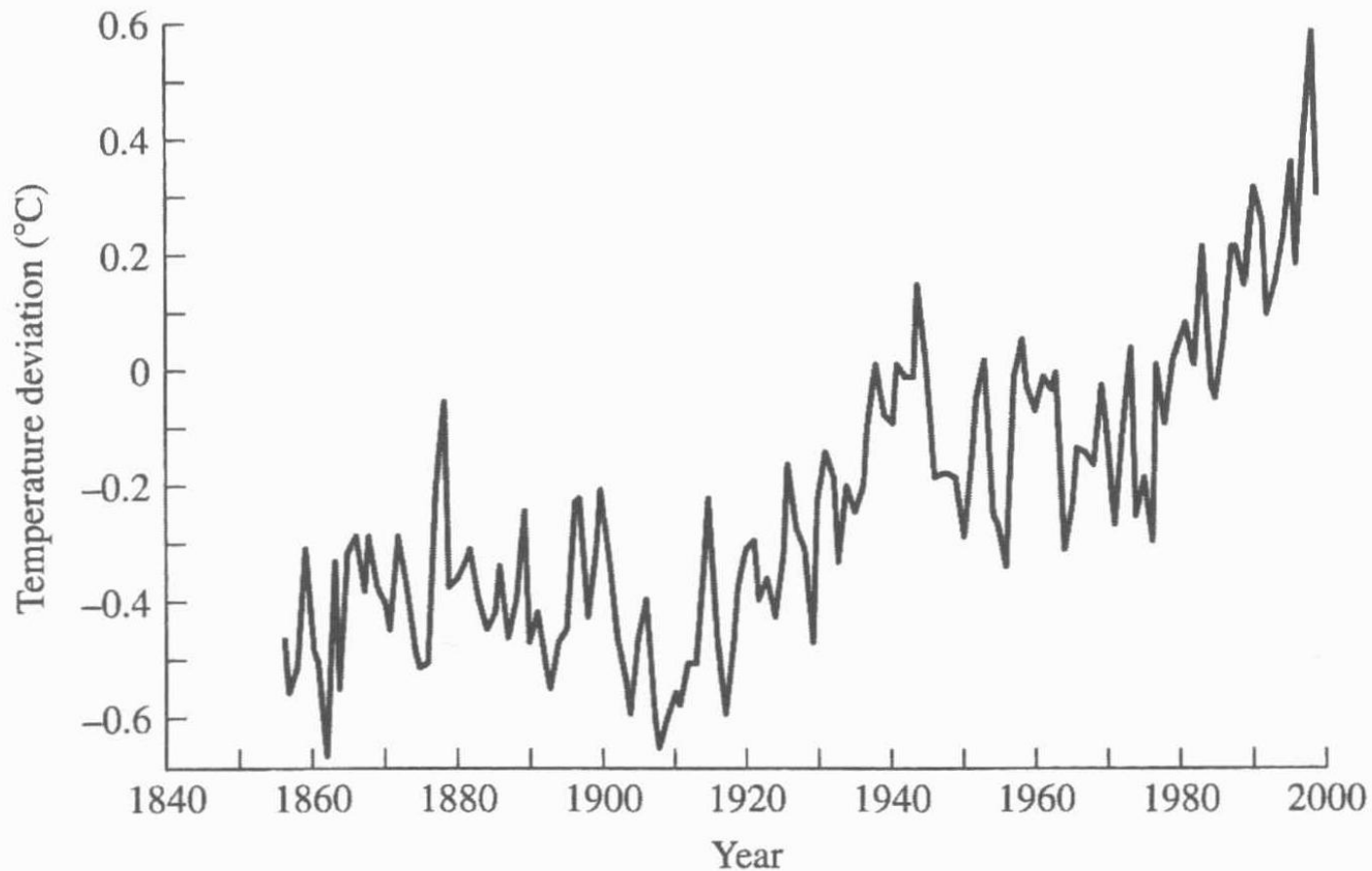


Figure 4.6. Observed average global surface temperature deviation 1855–1999. (Data from Carbon Dioxide Information Analysis Center, 2000. Source: Fay and Golomb (2002).

Technological and Policy Responses to Global Warming

- **Technological Approaches:**
 - **Efficiency of energy use.**
 - **Reducing Consumption**
 - **Reducing the carbon footprint**
 - **Alternative fuels (nuclear , renewable, etc.)**
 - **Carbon sequestration**
 - **Current estimated costs of sequestration would double to quadruple the kwh cost of electricity from a coal-fired power plant. (See Tables 4.8 and 4.9)**
 - **Technological development may lower those costs.**

Table 4.8

Table 4.8. Estimates of the CO₂ Capacity of Various Sequestration Options

Sequestration Option	Worldwide Capacity (Order of Magnitude)
Ocean	100,000 Gt
Aquifers	10,000 Gt
Depleted Oil and Gas	1,000 Gt
Active Oil	1 Gt/yr
Utilization	0.1 Gt/yr
Coal Seams	?

Notes:

Total CO₂ emissions worldwide = 22 Gt/yr

CO₂ emissions from US power plants = 1.7 Gt/yr

Source: Herzog (1998).

Table 4.9

Table 4.9. Projected costs of CO₂ capture and disposal^a

Power Plant Type	Capture Technology	CO ₂ Avoided (kg kWh ⁻¹)	Cost of Capture ^b (\$/tonne CO ₂ captured)	Cost of Capture ^b (¢ kWh ⁻¹)	Cost of Disposal ^{c,d} (¢ kWh ⁻¹)	Increase in Cost of Electricity ^e (%)
Gas turbine combined cycle (GTCC)	MEA ^f	0.36	33	1.4	0.6–2.2	40–70
Pulverized coal (PC)	MEA	0.79	37	4.8	1.9–6.5	130–230
Pulverized coal (PC)	CO ₂ recycle	0.93	35	4.9	2.0–6.7	140–230
Integrated coal gasification combined cycle (IGCC)	Shift/Selexol	0.76	18	1.7	1.5–4.9	60–130
Coal gasification/fuel cells (FC)	Shift/membrane	0.49	21	1.1	0.8–2.7	40–80

^aFrom Herzog et al. (1993).

^bIncludes costs for compression (to over 100 bars) and dehydration.

^cIncludes transportation costs.

^dBased on nominal range of \$15–50 per tonne of CO₂ disposed.

^eBase electricity cost of 5¢ kWh⁻¹ assumed for all cases.

^fMonoethanolamine; a chemical solvent for CO₂.

Policy Responses

- Approaches can be government mandated, company-directed or voluntary.
- Government approaches:
 - Fines or carbon taxes
 - Green labeling/CAFE standards
 - Tax credits/subsidies
 - Market-based methods
 - Cap and Trade

Responses continued

- **Voluntary Responses**

- **Energy Efficiency**

- The Leadership in Energy and Environmental Design (LEED) Green Building Rating System, developed by the (USGBC), provides a suite of standards for environmentally sustainable construction. Since its inception in 1998, LEED has grown to encompass more than 14,000 projects in 50 US States and 30 countries covering 1.062 billion square feet (99 km²) of development area. [2] The hallmark of LEED is that it is an open and transparent process where the technical criteria proposed by the LEED committees are publicly reviewed for approval by the more than 10,000 membership organizations that currently constitute the USGBC.

- **Sustainability initiatives**