GREEN ENGINEERING

Environmentally Conscious Design of Chemical Processes

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Preface

- Facts
  - Chemical processes provide both products and wastes and emissions
  - Rising costs and increasingly stringent performance standards and regulations
  - End-of-pipe waste management approaches less attractive
  - Gaining prominence of
    - ► environmentally conscious manufacturing
    - ► eco-efficient production
    - ► pollution prevention

- Basic Premise of Green Engineering

  Avoiding waste generation be more cost effective and better for environment than controlling or disposing pollutants once they are formed

1

An Introduction to Environmental Issues

By the end of this section you should:

- **be aware of the major environmental issues that impact the design of chemical and processes**
- **be familiar with the scientific issues and the emissions associated with:**

  energy consumption
  global warming
  stratospheric ozone depletion
  resource depletion
  land use
  air quality
  waste generation
  water quality
  ecosystem health

1.1 Introduction

- Environmental issues are related to global population growth
  - increasing demand of natural resources and industrial chemicals
  - Benefit (standard of living, prolong human life)
  - Problems (environmental and human health impacts)
- Well understanding of mechanisms that determine
  - How chemicals are transported and transformed in the environ.
  - What their environmental and human health impacts are.
- It is possible to incorporate environmental objectives into design of chemical processes and products.
- The challenge for chemical engineers is to develop and master technical tools and approaches that will integrate environmental objectives into design decision of chemical processes and products.

The purpose of Chap 1

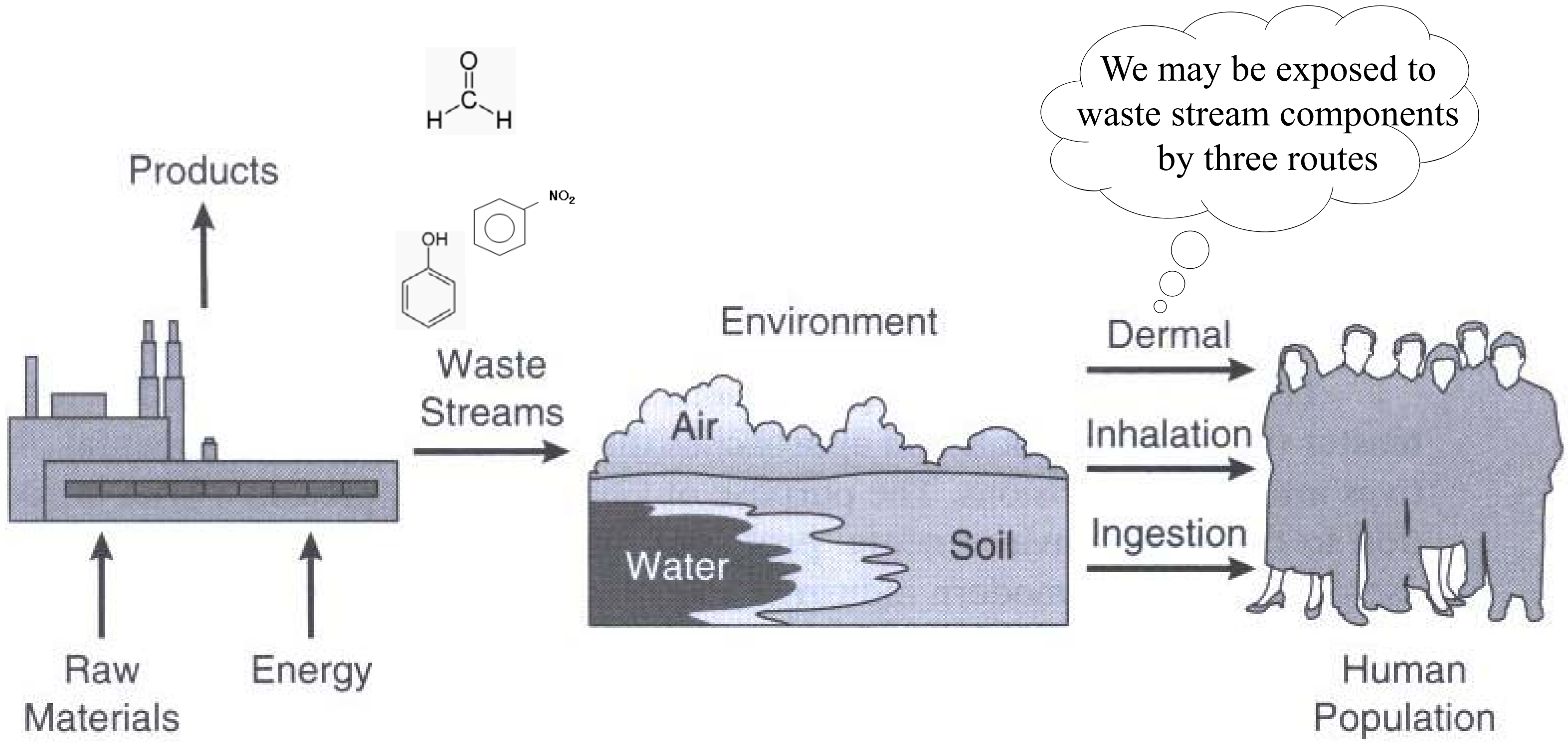
- To present a brief introduction to the major environmental issues that are caused by the production and use of chemicals in modern industrial societies.

- To identify the chemicals implicated in the each environmental problem.

- To present a brief summary of adverse health effect

1.2 Role of Chemical Processes and Chemical Products

Generalized scenario for exposure by human to environmental pollutants released from chemical processes



The route and magnitude of exposure is influenced by the physical, chemical, and reactivity properties of the waste component. In addition, waste components may affect the water quality of streams and rivers, breathability of ambient air, and the well-being of terrestrial flora and fauna.

1.2 Role of Chemical Processes and Chemical Products

What information will a chemical engineer need to make informed pollution prevention and risk reduction decisions?

A few generalized examples will aid in answering such a question.

- **Formulation of an Industrial Cleaner**
- **Formulation of a Paint Solvent**
- **Choice of Refrigerant for a Low-T Condenser**

Formulation of an Industrial Cleaner

- ***Company Plan***

  Formulated a concentrated, industrial cleaner, and need to incorporate a solvent within product to meet customer performance criteria and cost.

- ***Known facts***

  - number of solvents will meet cost and performance specifications
  - cleaning product with solvent will be discharged to water and is concerned about the aquatic toxicity of solvent.

- ***The company conducts a review of the pertinent data to aid in making the choice. In aquatic environments, a chemical will have low risk potential to aquatic environments if a solvent has***

  - **High Henry's Law constant** (substance will volatile into air than stay in water)
  - **High degradation rate** (dissipate before affect to health)
  - **Low fish toxicity parameter** (LC_{50})
  - **Low Bioconcentration Factor, BCF** (low tendency for chemicals to partition into fatty tissue of fish, leading to exposure and adverse health effects upon consumption by humans)

Choose a solvent with the least adverse environmental consequences

Formulation of a Paint Solvent

- ***Company Plans***

  Formulating a paint for automobile refinishing with fast-drying solvent to ensure uniform coating during application.

- ***Known facts***

  - Fast-drying solvents volatilize and are exhausted by fan
  - Workers may be exposed to solvents
  - Nearby residents may inhale contaminated air

- ***The company is concerned above problems. A number of solvents having acceptable cost and coating performance is identified. A chemical will low risk potential in the air if it has***

  - **Low toxicity properties** (high Reference Dose [RfD] for inhalation toxicity to human or a low cancer potential)
  - **Low activity for smog formation** (ground level ozone production)

↓

Candidate solvents may be screened for these properties to identify the environmentally optimal candidate

Choice of Refrigerant for a Low-T Condenser

- ***Redesign a process for expanded capacity***

  Decide to use a refrigerant of low potential for stratospheric ozone depletion in redesign a vapor stream heat exchanger and a refrigeration cycle

- ***Constraints***

  - refrigeration process acceptable performance such as thermodynamic properties, material compatibility, and thermal stability

- ***Estimate from the list of refrigerants that meet acceptable process performance criteria***

- atmospheric reaction rate constant
- global warming potential (GWP)
- ozone depletion potential (ODP)

Choose an ideal refrigerant with low ozone depletion, low global warming while not persisting in the atmosphere

These three examples illustrate the role the chemical engineer plays by assessing the potential environmental impacts of product and process changes.

One important impact the chemical engineer must be aware of its human exposure, when can occur by a number of routes. **The magnitude of exposure** can be affected by any number of reactive processes occurring in the air, water, and soil compartments in the environment.

The severity of the toxic response in humans is determined by toxicology properties of the emitted chemicals.

The chemical engineer must also be aware of **the life cycle of a chemical.** What if the chemical volatiles but is an air toxicants? What if the biodegradation products are the real concern? For example, terpenes were touted as a replacement for chlorinated solvents to avoid stratospheric ozone depletion, but terpenes are highly reactive and volatile and can contribute to photochemcial smog formation.

Tout=권유하다

1.3 Overview of Major Environmental Issues

- In scope, Impact of waste release on the environment can be
  global (green house gases ▶ global warming, climate change)
  regional (hydrocarbon releases ▶ smog)
  local (chemical disposed of in the soil ▶ spoil of groundwater).

- The environment is also a source of raw materials, energy, food, clean air, water, and soil for useful human purposes. Maintenance of healthy ecosystem is therefore essential if a sustainable flow of these materials is to continue. Depletion of natural resources due to population pressure and/or unwise resource management threatens the availability of these materials for future use.

1.4 Global Environmental Issues

1.4.1 Global Energy Issues

1.4.2. Global Warming

1.4.3. Ozone Depletion in the Stratosphere

1.4 Global Energy Issues

ENERGY

- essential for most economic activity and high standard of living
- oil and coal are non-renewable, and others(solar), although inexhaustible, are not currently cost effective

Limited Availability

An understanding of global energy usage patterns, energy conservation, and the environmental impacts associated with the production and use of energy are very important !

1.4.1 Global Energy Issues

In many ways, energy consumption can be viewed as the most basic of all environmental concerns. Almost all other environmental concerns could be abated or remediated if energy could be produced and consumed cleanly and at low cost. For example, water can be purified using reverse osmosis membranes if the pumping costs can be tolerated. Trace organic contaminants could be removed from gas streams if refrigeration were clean and inexpensive.

Unfortunately, most of our energy consumption involves significant costs and results in emissions to the environment.

In addition, our utilization of energy is often inefficient. Often, primary energy sources such as fossil fuels must be converted into another form such as heat or electricity, As the 2nd law of thermodynamics dictates, such conversions will be less than 100% efficient. An inefficient user of primary energy is the typical automobile, which convert into motion about 10% of the energy available in crude oil.

Ex. 1.4-1 Energy Conversion

(the 2nd law of thermodynamics)

Efficiency of Primary and Secondary Energy:

Determine the efficiency of primary energy utilization for a pump.
Assume the following efficiencies in the energy conversion;

- crude oil to fuel oil is 90% (.90)
- fuel oil to electricity is 40% (.40)
- electricity transmission and distributions is 90% (.90)
- conversion of electrical energy into mech. energy of the fluid being pumped is 40% (.40)

Solution : The overall efficiency for the primary energy source
is the product of all the individual conversion efficiencies.

Overall Efficiency = (.90)(.40)(.90)(.40) = (.13) or 13 %

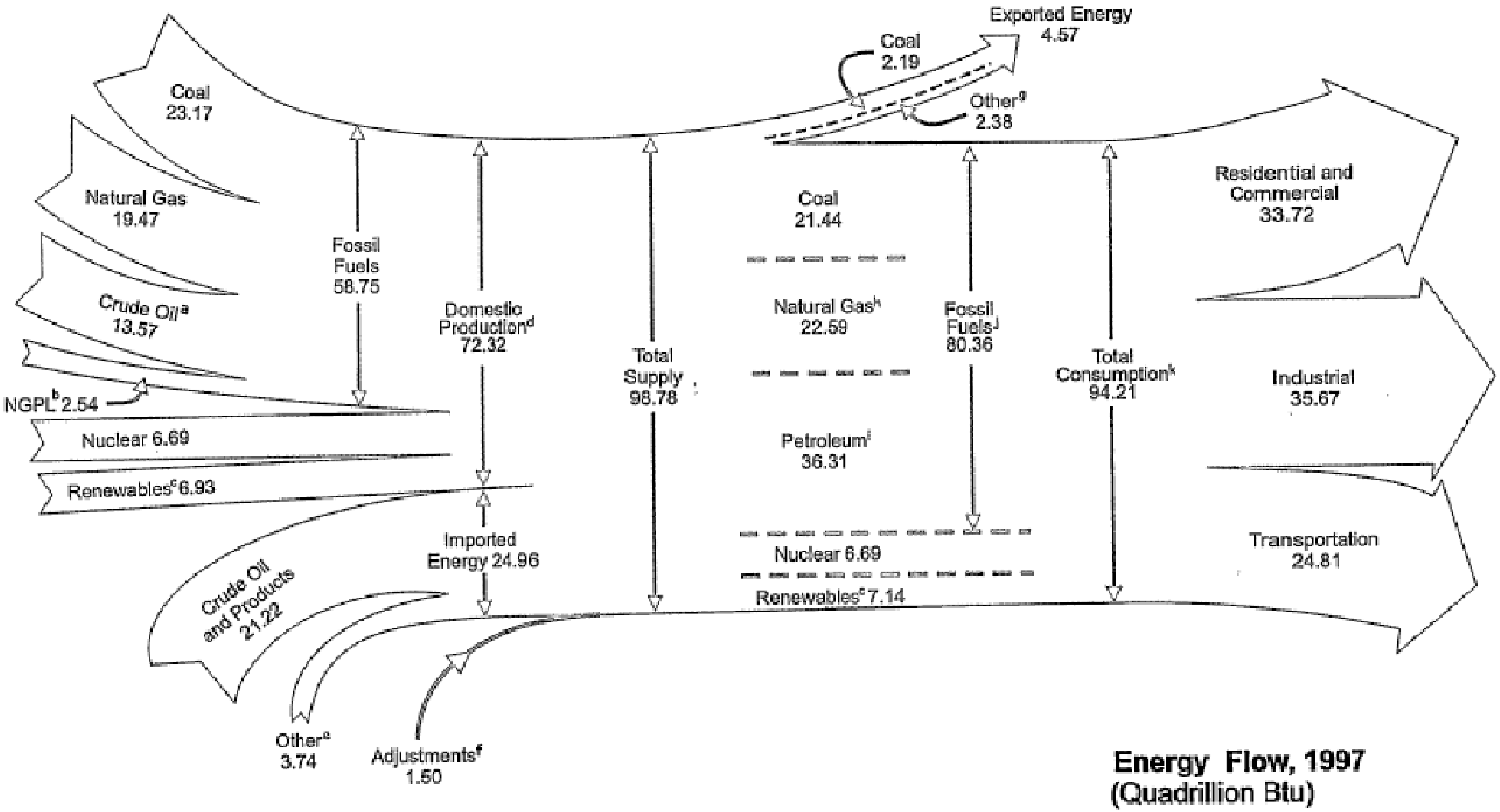
Our utilization of energy is often inefficient !

Current world energy consumption
~5.5 *gtoe* (1998)

- fossil fuels : ~85 %
- renewables *(hydraulic, solar, wind power, etc.):* ~8 %
- nuclear : ~6 %

gtoe: gigatonnes oil equivalent

Energy generation and use patterns in USA



Global Energy Issues *(continued)*

Disparity in Global Energy Use

- 65~70 % of the energy is used by ~25 % of the world's population
  (USA, Europe, Japan ; American 15 times consumed than African)
- Energy consumed per GDP *(Gross Domestic Product)* advanced countries are expect to continue to fall (30% ↓ 1980-1990 in USA)
  (role of engineers)

Energy Consumption and Environmental Effects

- Many are associated with energy consumption
  - fossil fuels *release CO_2 ~absorbs infrared ~ global warming*
  - combustion processes *~NOx, SOx~photochemistry~ozone and acid rain*
  - Hydropower*~land inundation, habitat destruction, alteration of water flows*
  - Nuclear power*~uranium mining, spent nuclear rod disposal*
  - "Renewable fuels" are not benign either
  - Traditional energy usage*~deforestation*
  - Solar power panels*~energy intensive use of heavy metals*

1.4.2 Global Warming

Green House Effect

- *solar radiation from the sun*
  ~ some solar energy reached on earth is absorbed
  ~ heating land and water~IR is emitted from surface
  ~ certain gases in atmosphere absorb this IR re-direct a portion back to surface
  ~ warming the planet ~ making life possible.
- *Surface temp will rise until a radiative equilibrium is achieved between rate of solar radiation absorption and IR emission*
- ***Human activities** (fuel combustion, deforestation, agriculture, chemical production) have altered the composition gases ~ lead warming earth*

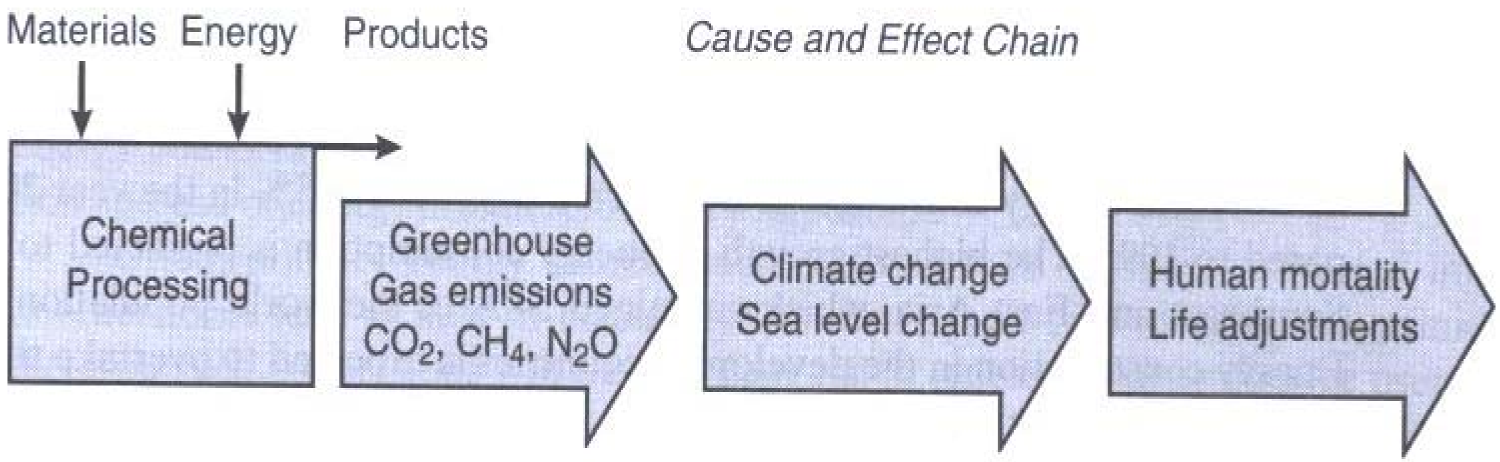


Fig. 1.4-1 *Greenhouse emission from chemical processes and the major cause and environmental effect chain*

Table 1.4-1 *Greenhouse gases and global warming contribution*

Table 1.4-1 Greenhouse Gases and Global Warming Contribution. M stands for million. Phipps (1996), IPCC (1996).

Gas	Source (Natural and Anthropogenic)	Estimated Anthropogenic Emission Rate	Pre-Industrial Global Concentration	Approximate Current Concentration	Estimated Residence Time in the Atmosphere	Radiative Forcing Efficiency (absorptivity capacity) (CO_2 = 1)	Estimated Contribution to Global Warming
Carbon Dioxide (CO_2)	Fossil fuel combustion; deforestation	6,000 M tons/yr	280 ppm	355 ppm	50–200 yrs	1	50 %
Methane (CH_4)	Anaerobic decay (wetlands, landfills, rice paddies), ruminants, termites, natural gas, coal mining, biomass burning	300–400 M tons/yr	0.8 ppm	1.7 ppm	10 yrs	58	12–19 %
Nitrous Oxide (N_2O)	Estuaries and tropical forests; agricultural practices, deforestation, land clearing, low-temperature fuel combustion	4–6M tons/yr	0.285 ppm	0.31 ppm	140–190 yrs	206	4–6 %
Chlorofluoro-carbons (CFC-11 & CFC-12)	Refrigerants, air conditioners, foam-blowing agents, aerosol cans, solvents	1 M tons/yr	0	.0004–.001 ppm	65–110 yrs	4,860	17–21 %
Tropospheric Ozone (O_3)	Photochemical reactions involving VOCs and NOx from transportation and industrial sources	not emitted directly	NA	.022 ppm	hours–days	2,000	8 %

Green House Gases *(Table 1.4-1)*

- **Man-made** *CO_2, CH_4, N_2O, CFC, O_3, etc. and Water vapor :*

  emission rates, concentrations, residence time in air,
  relative radiative forcing efficiencies, etc.

  - **CO_2** : high emission rate and concentration
  - **CFCs** : high IR absorptive capacity and long RTD (1000 times than CO_2)

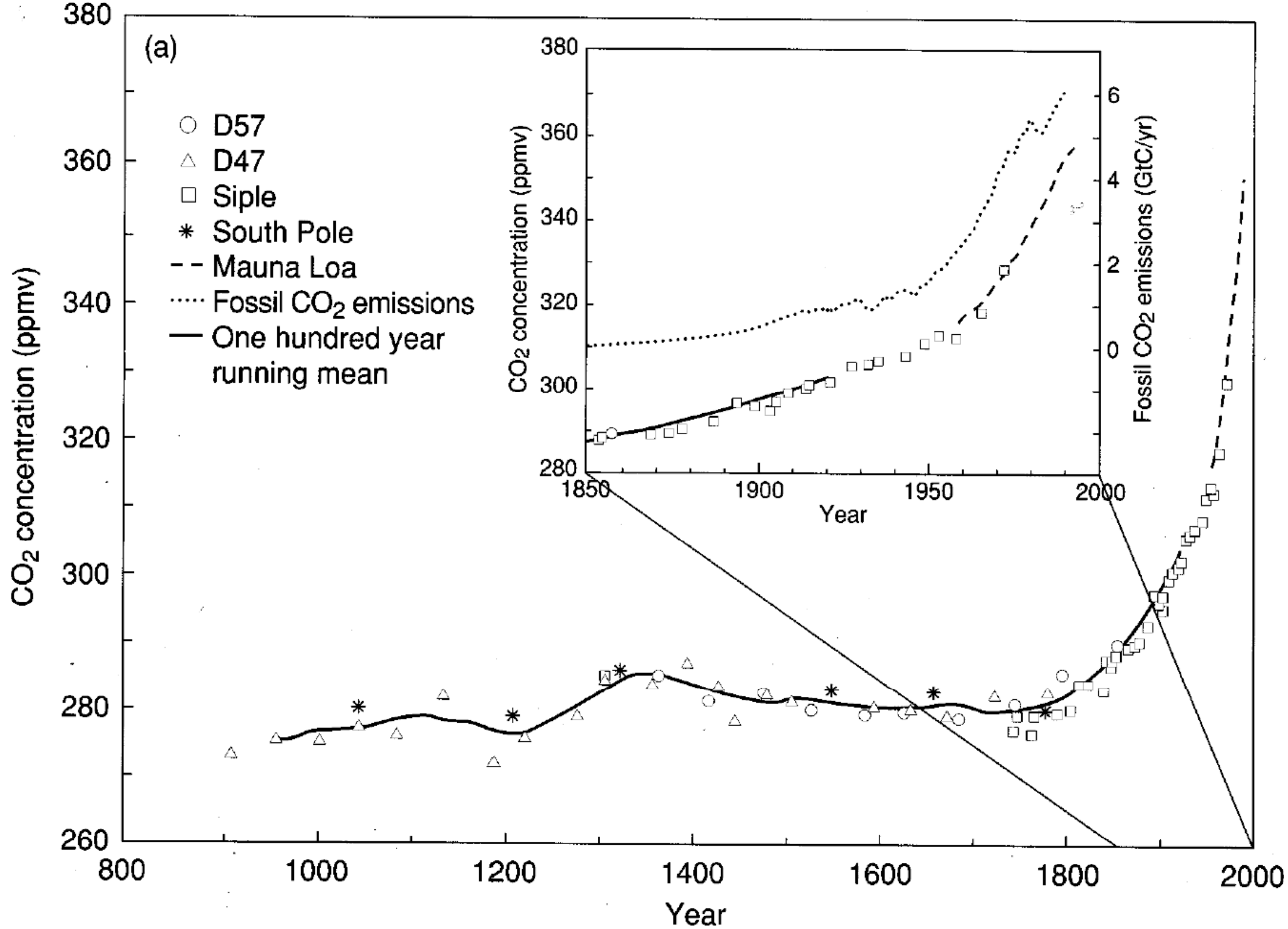
- Current level *(of concentration of gases in air)*

  - *CO_2 : 360 ppm, level is increasing by 0.5 %/year*

    (from about 320 ppm in 1960)

  - *CH_4 : 700 ppb in pre-industrial times to 1721 ppb in 1994*
  - *N_2O : from 275 ppb to 311 ppb over the same period*

CO_2 level is increasing by 0.5 %/year



1.4.3 Ozone Depletion in the Stratosphere

Ozone, Smog and Health Hazard

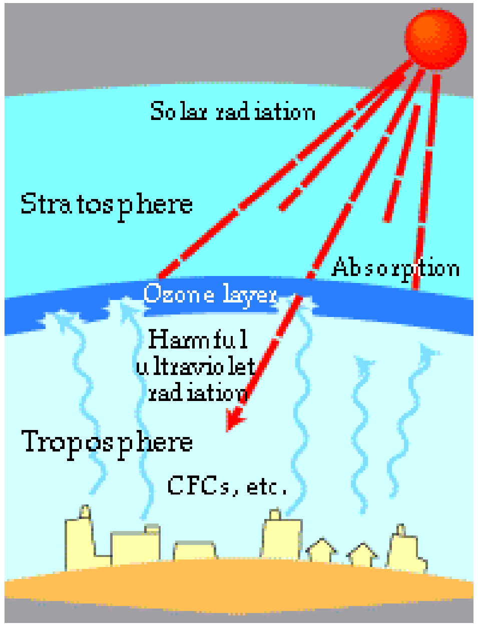
- O_3 is created by photochemical rxns involving NO_x and hydrocarbons at earth surface *(major component of smog)*
- irritates the breathing passages, leak to lung damage
- harmful to crops and trees
- Stratospheric ozone performs a vital and beneficial function for all life on earth *(absorbing harmful UV radiation)*
- Stratospheric ozone layer : 20-50 km above ground level : ~10 ppm. *(formed at 25-35 km in tropical regions and migrate to polar regions)*

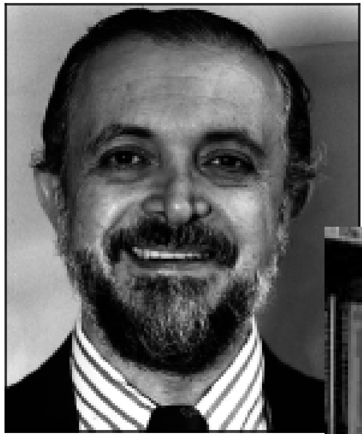
Equilibration of ozone concentration in stratosphere

- natural formation and destruction rxns initiated by solar energy
- natural ozone cycle is altering by man-made chemicals

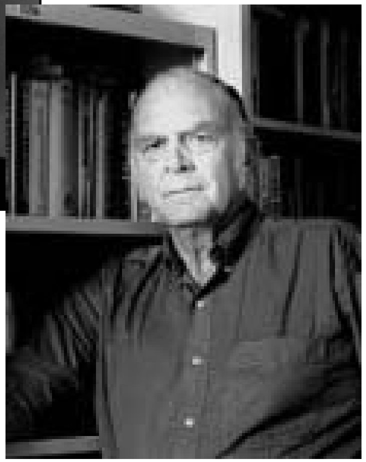
(effect of CFC, M. Molina & S. Rowland , Nobel Prize in 1995)

Ozone Depletion Reaction in Stratosphere



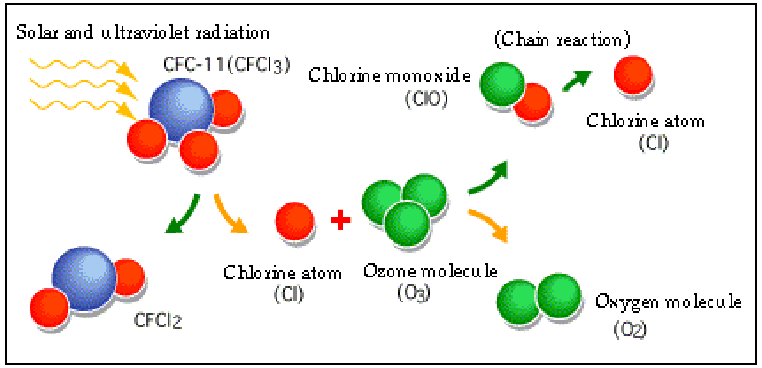


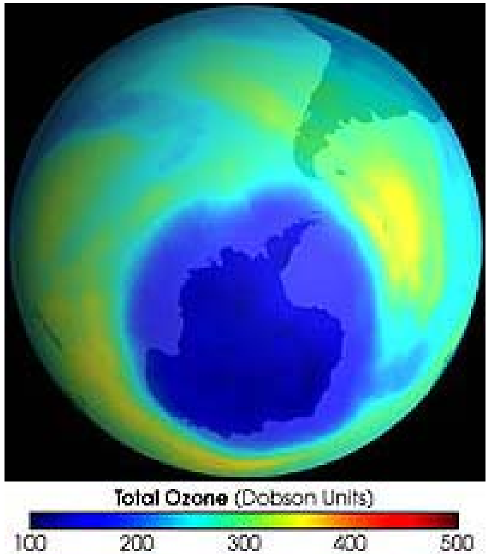
Mario Molina
(MIT)



F. Sherwood Rowland
(U. C. Irvine)

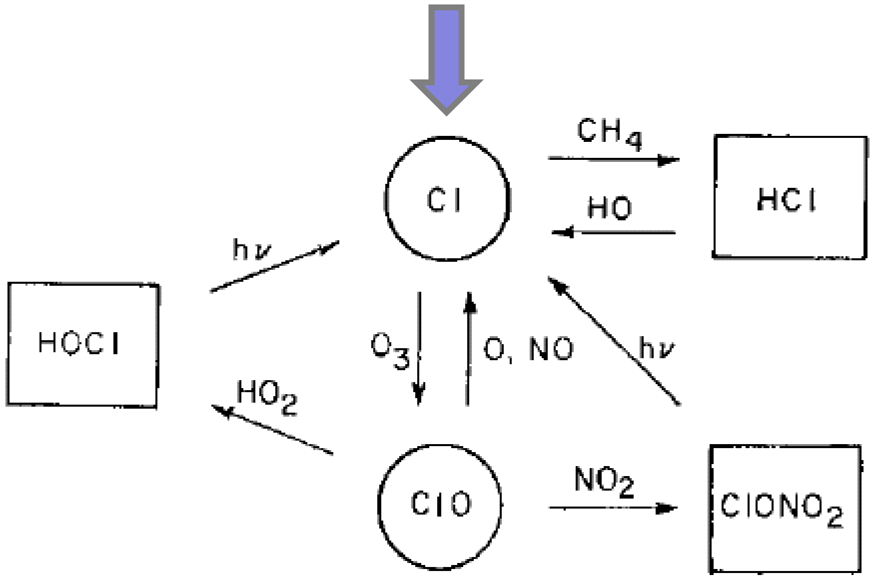
Paul Crutzen
(Max Planck Institute for Chemistry)





Ozone destruction mechanism

CCl_3F + UV light → Cl + CCl_2F
CCl_2F_2 + UV light → Cl + $CClF_2$



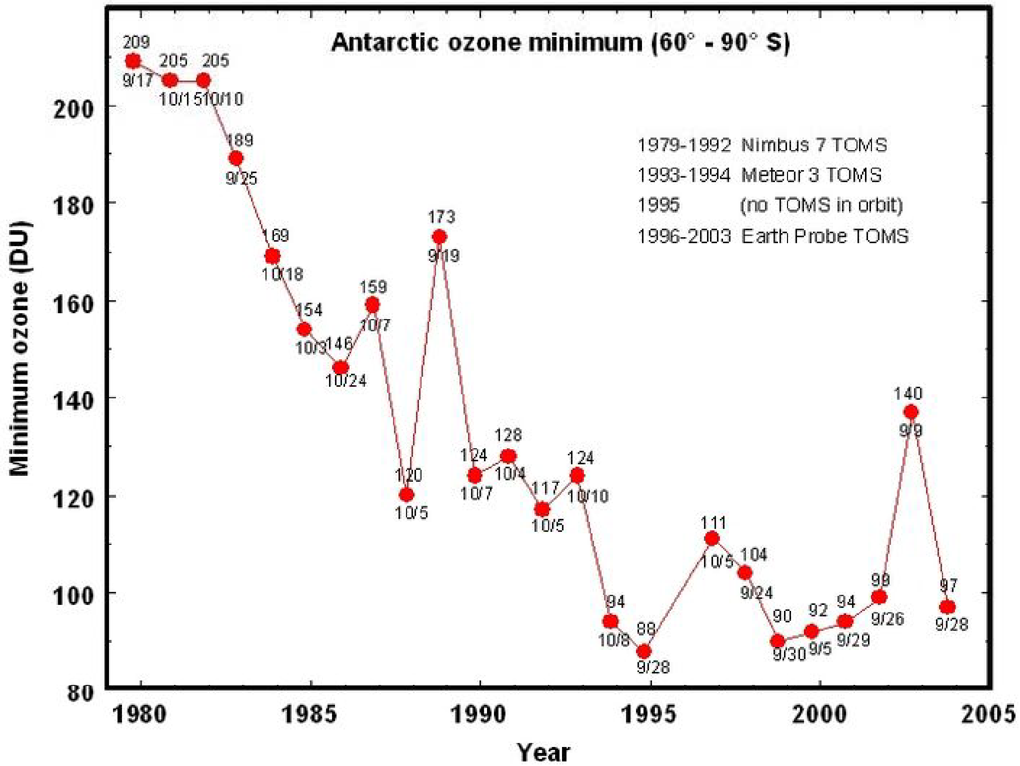
Overall reaction

$$Cl + O_3 \longrightarrow ClO + O_2$$
$$ClO + O \longrightarrow O_2 + Cl$$

$$O_3 + O \longrightarrow O_2 + O_2$$

One Chlorine atom can cause the destruction of up to 10,000 O_3 before forming HCl by reacting with hydrocarbons. HCl eventually precipitates from the atmosphere.

Lowest value of ozone measured by TOMS each year in the ozone hole



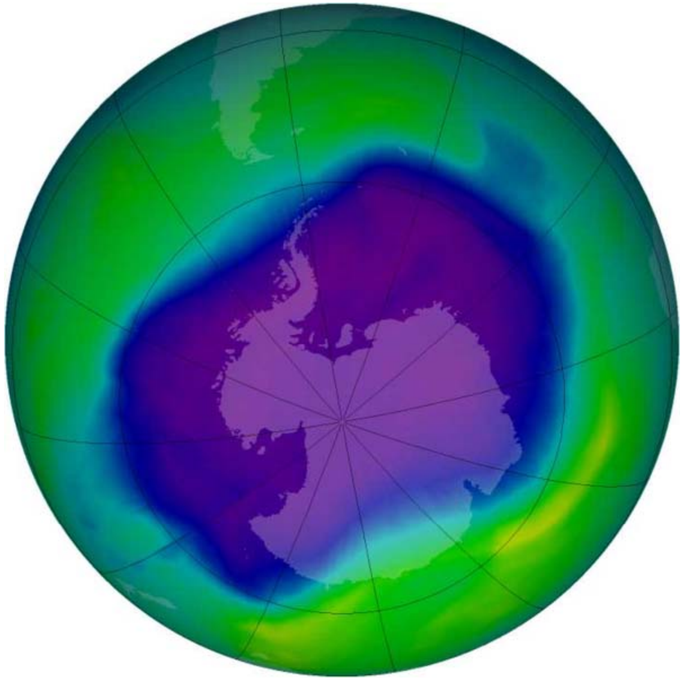
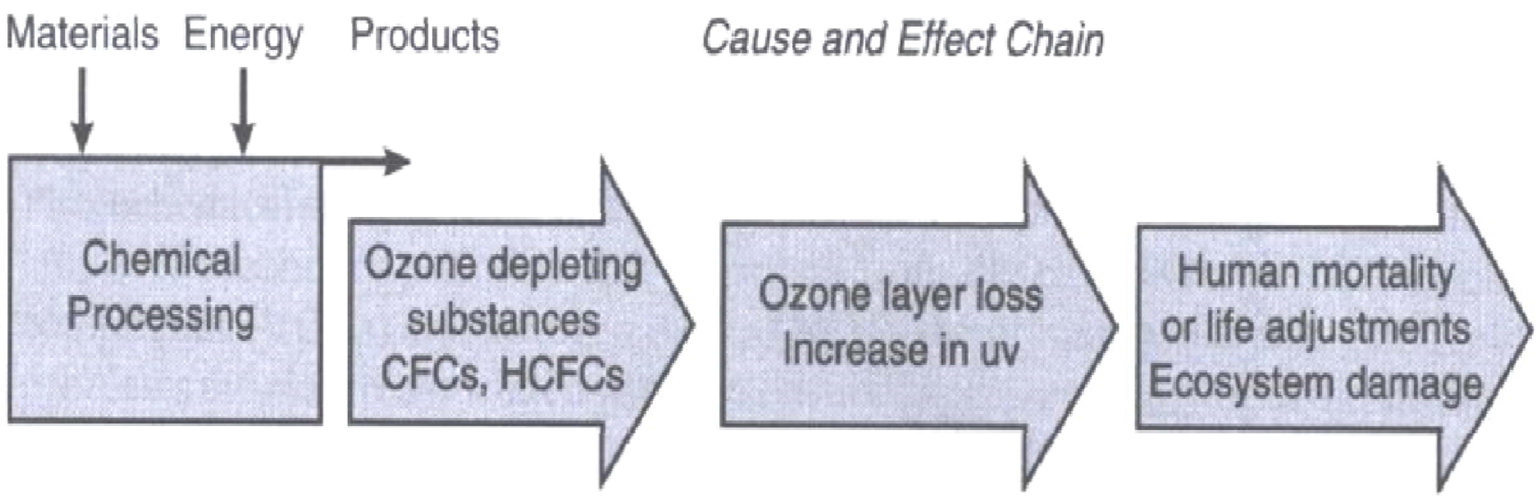
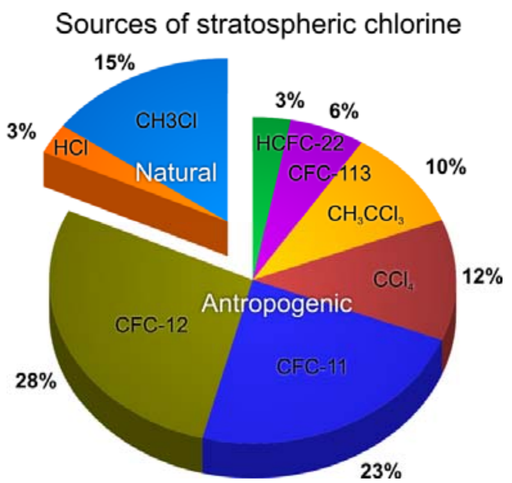


Image of the largest Antarctic ozone hole ever recorded (September 2006).

Ozone-depleting chemical emissions and the major steps in the environmental cause and effect chain





Effects of ozone layer depletion on Humans
1. Basal and Squamous Cell Carcinomas
2. Malignant Melanoma
3. Cortical Cataracts
4. Increased Tropospheric Ozone

Effects on Crops
Effects on Plankton

Fig. 1.4-2

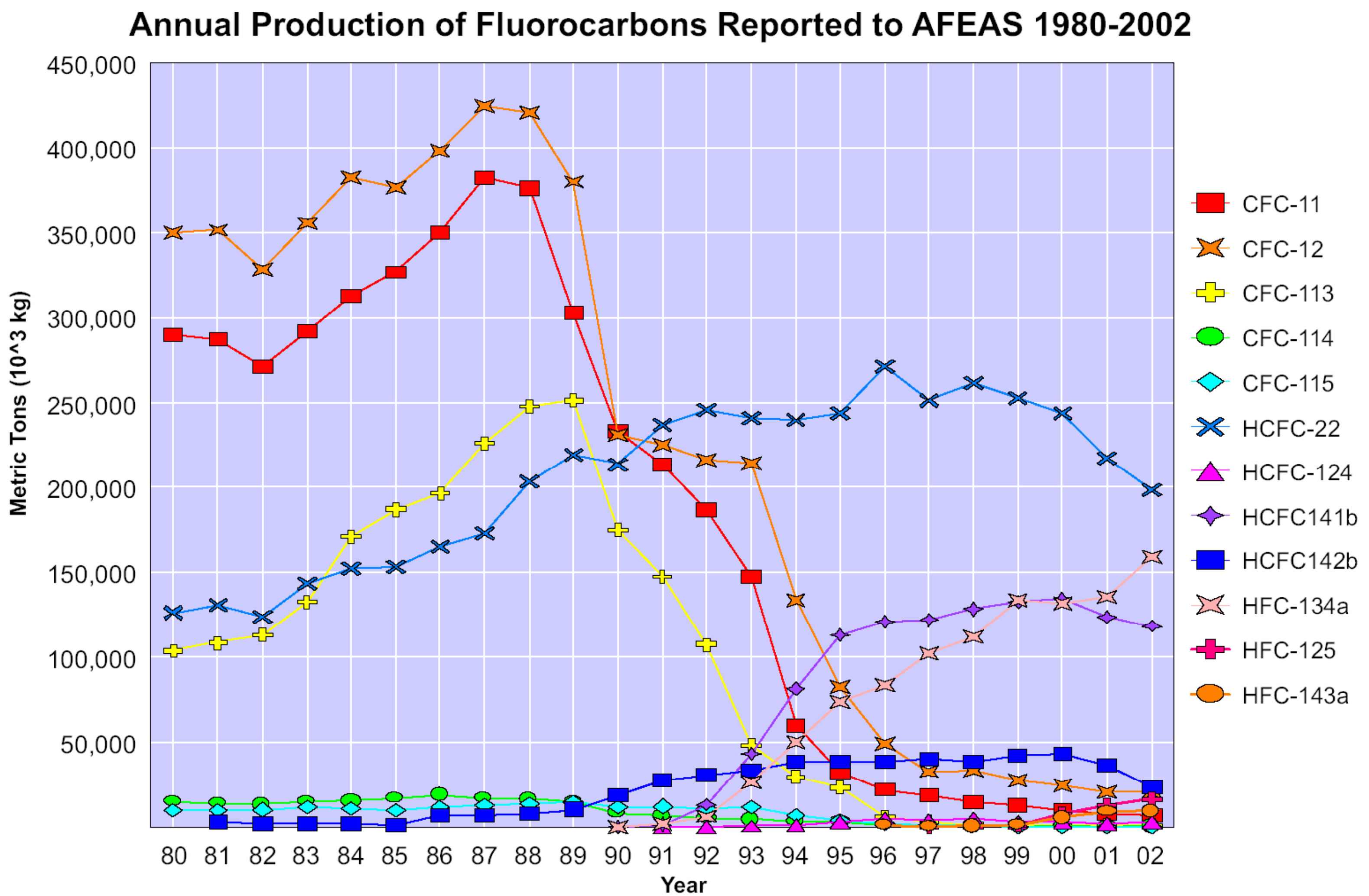
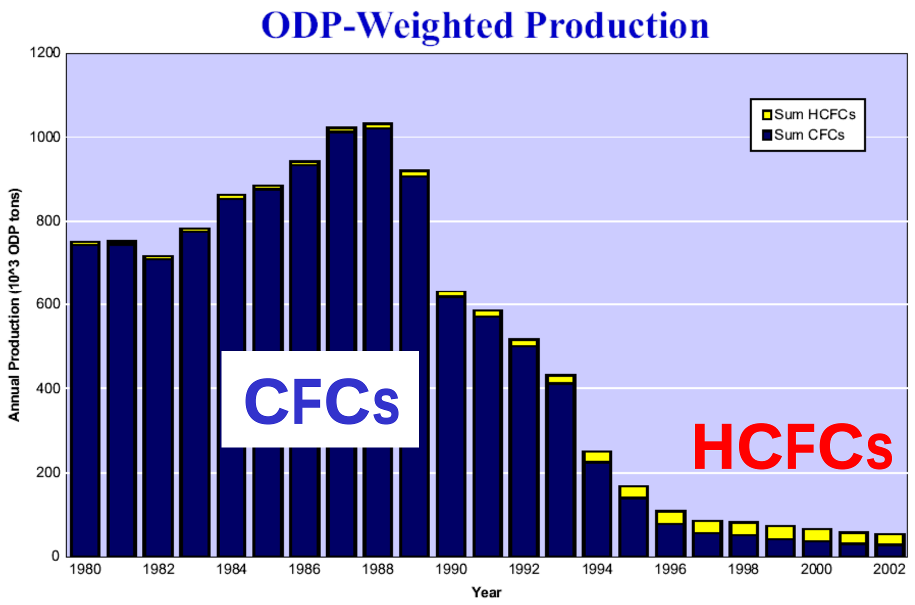
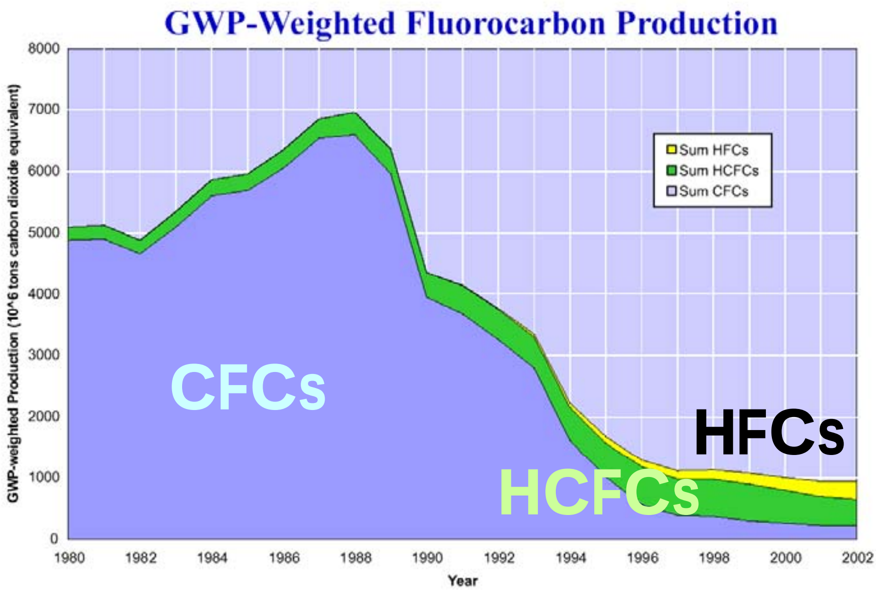


Fig. 1.4-3 *Recent trends in the production of CFCs and HCFCs*

www.afeas.org (Alternative Fluorocarbons Environmental Acceptability Study)

Recent trends in the production of CFCs and HCFCs

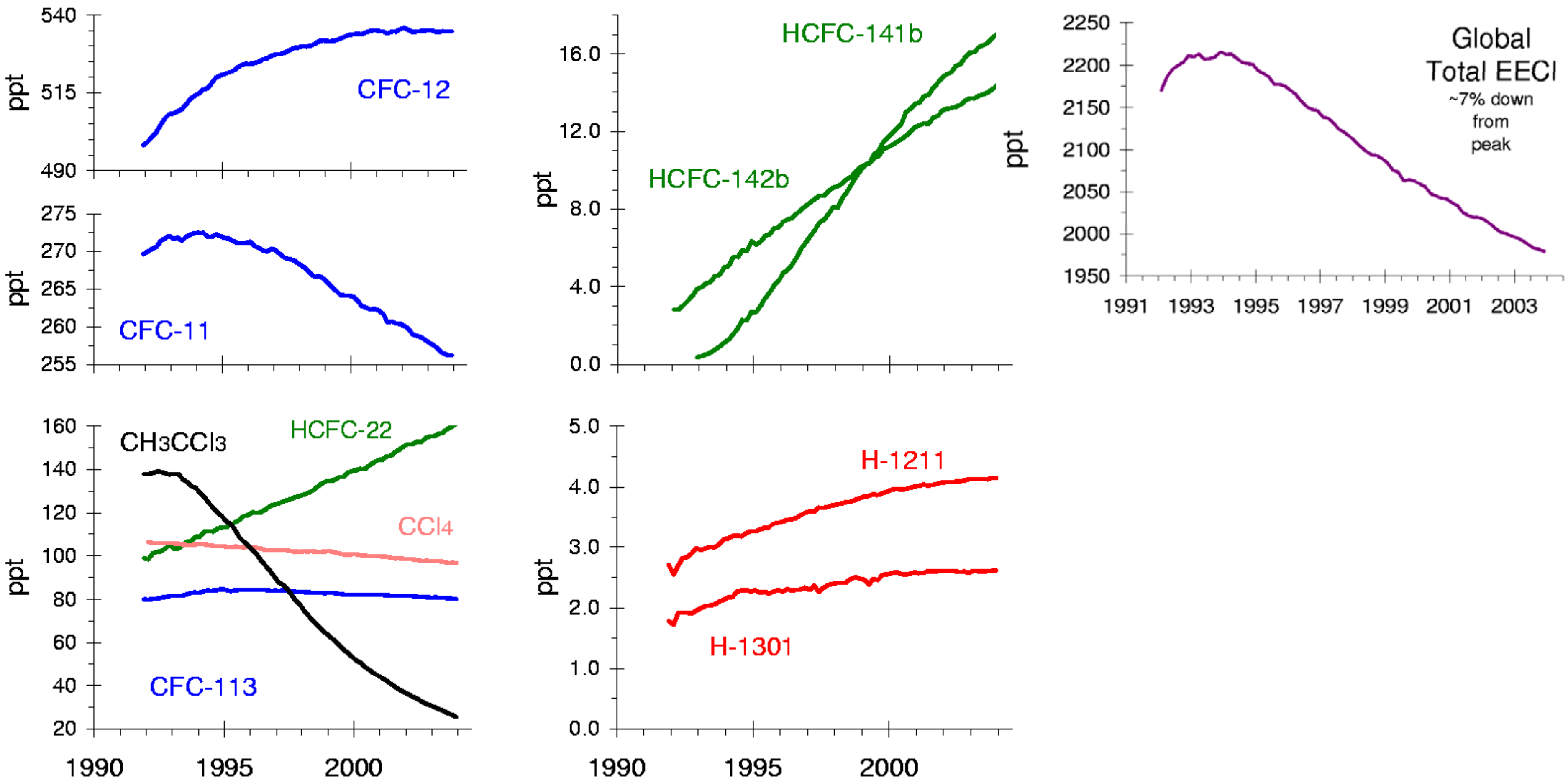




www.afeas.org (Alternative Fluorocarbons Environmental Acceptability Study)

Global Mixing Ratios of Anthropogenic Halocarbons

Since the adoption and strengthening of the Montreal Protocol has led to reductions in the emissions of CFCs, atmospheric concentrations of the most significant compounds have been declining. These substances are being gradually removed from the atmosphere.



1.5 Air Quality Issues

Pollutants can be classified *as*

- ***Primary*** *- emitted directly to air*
- ***Secondary*** *– formed in the air after emission of precursor compds*

  example: ***photochemical smog (2nd)*** **⇐ VOC, NOx** ***(1st)***

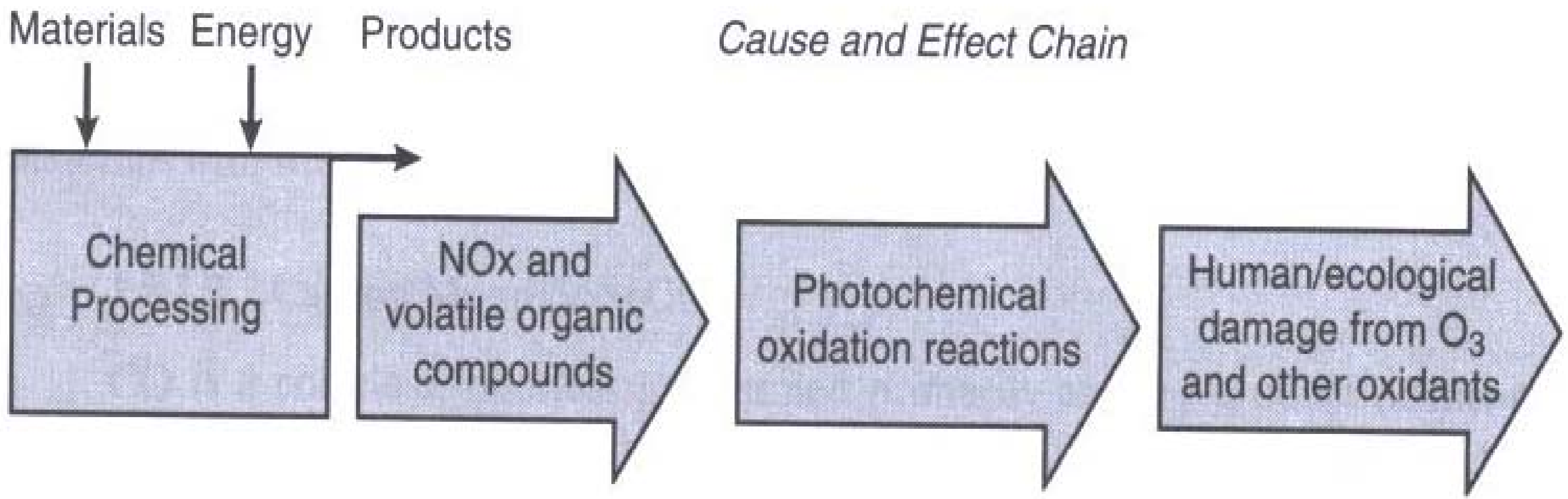
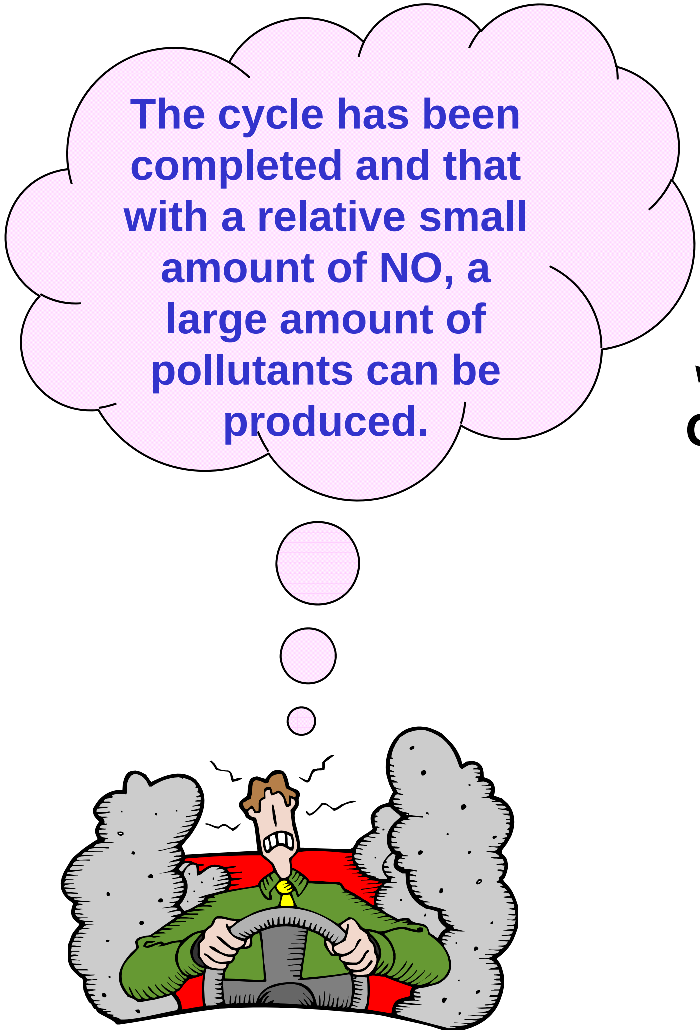
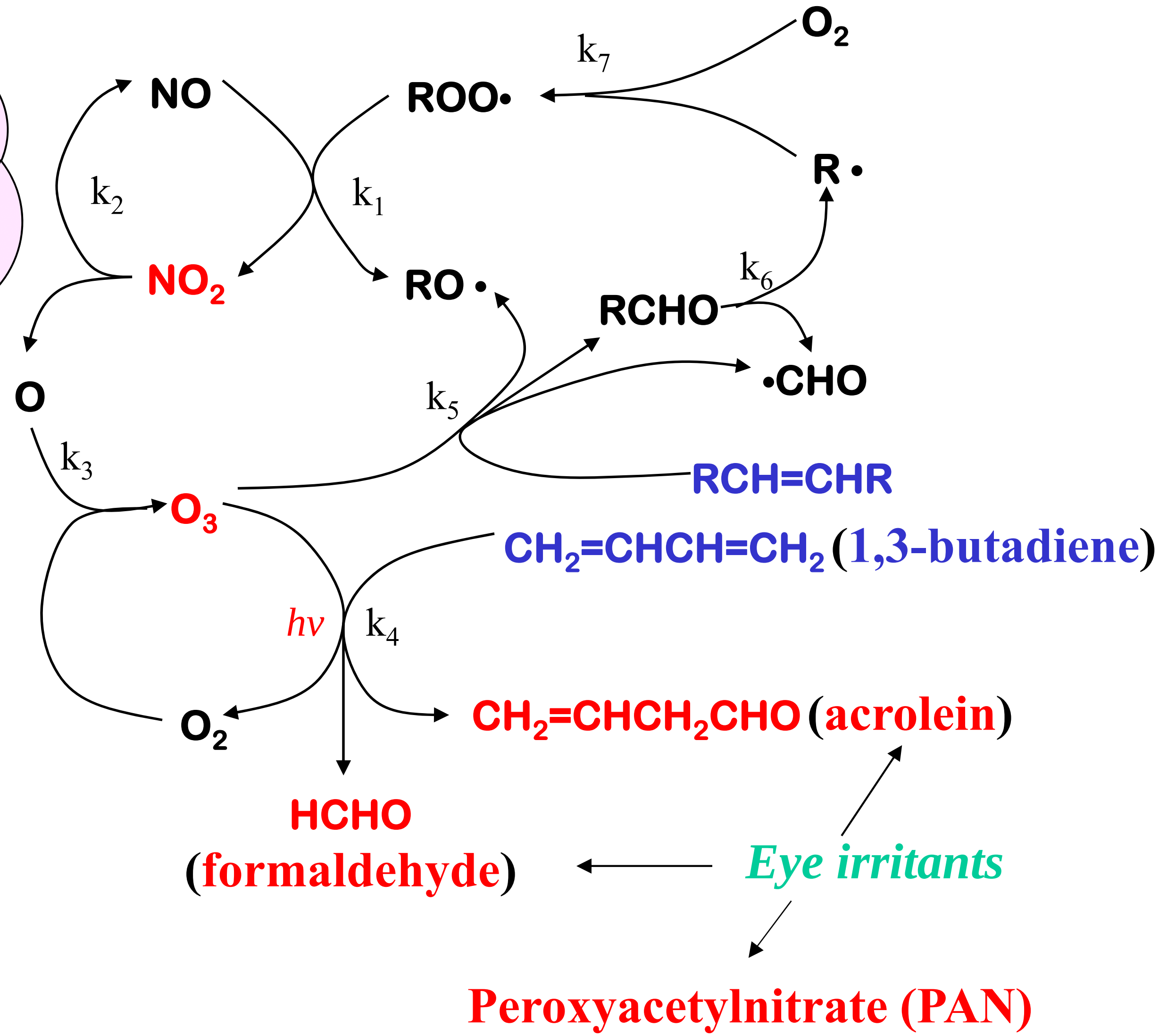


Fig. 1.5-1 *Primary environmental cause and effect chain for photochemical smog formation*

Reaction Pathways in smog formation





Smog (smoke and fog)

1.5.1 Criteria Air Pollutants

- Congress in 1970 passes the **Clean Air Act (CAA)**
- CAA charged the EPA with identifying those air pollutants which are most deleterious to public health and welfare
- Congress empowered EPA to set **maximum allowable ambient air concentrations** for these criteria air pollutants.
- EPA identified six substances as criteria air pollutants.
- EPA promulgated primary and secondary standards that make up the **National Ambient Air Quality Standards (NAAQS)**

EPA: Environmental Protection Agency

Promulgate: 법을 공포하다.

1.5.1 Criteria Air Pollutants

NAAQS *(National Ambient Air Quality Standards)*

- **Primary Standards: protect public health with adequate margin of safety**
- **Secondary Standards: protect public welfare**
  (damage to crops, vegetation, ecosystems, or reduction in visibility)
- Owing to NAAQS, overall emission of critical pollutants have decreased 31% despite significant growth in the U.S. population and economy.

Criteria Pollutants

- **Chemical species of serious adverse health impacts, *especially in susceptible populations***

(see Table 1.5-1)

Table 1.5-1 *Six Criteria pollutants and NAAQ standards*

Pollutant	Primary Standard (Human Health Related)		Secondary (Welfare Related)	
	Type of Average	*Concentration*[a]	*Type of Average*	*Concentration*
CO				
[-38%][h]	8-hour[b]	9 ppm (10 mg/m^3)	No Secondary Standard	
{-25%}[i]	1-hour[b]	35 ppm (40 mg/m^3)	No Secondary Standard	
Pb				
[-67%] {-44%}	Maximum Quarterly Average	1.5 mg/m^3	Same as Primary Standard	
NO_2				
[-14%] {-1%}	Annual Arithmetic Mean	0.053 ppm (100 μg/m^3)	Same as Primary Standard	
O_3				
[-19%]	1-hour[c]	0.12 ppm (235 μg/m^3)	Same as Primary Standard	
	8-hour[d]	0.08 ppm (157 μg/m^3)	Same as Primary Standard	
PM_{10}				
[-26%]	Annual Arithmetic Mean	50 μg/m^3	Same as Primary Standard	
{-12%}	24-hour[e]	150 μg/m^3	Same as Primary Standard	
$PM_{2.5}$	Annual Arithmetic Mean[f]	15 μg/m^3	Same as Primary Standard	
	24-hour[g]	65 μg/m^3	Same as Primary Standard	
SO_2				
[-39%] {-12%}	Annual Arithmetic Mean	0.03 ppm (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)		

✸ NO_x, HCs, VOCs - Ground Level O_3

"Bad" and "Good" Ozone

- Good O_3 : Stratospheric O_3 that protects us from UV radiation

  Bad O_3 : created at ground level by photochemical smog

  (due to NO_x such as NO, NO_2 and Hydrocarbons; strong lung irritant, destroy crop chlorophyll and disrupting photosynthesis)

NO_x

- NO_x are formed in high-T industrial(49.2 %) and transportation combustion(45.4 %) processes 🡐 *respiratory illness in children*
- Emission trends and major sources ***(Fig. 1.5.-2)***

Hydrocarbons and VOCs (1988 – 1997)

- *Major emission sources : chemical and oil refining, motor vehicles (Non-biogenic: industries - 51.2 % ; vehicles – 39.9 %)*
- *Industries : solvent 66%, VOC 34%*
- *Natural sources (biogenics): isoprene, monoterterpenes*
- *Recent trends in VOC emissions* ***(Fig. 1.5-3)***

Emission trends for major categories of NO_x emission sources (EPA, 1998)

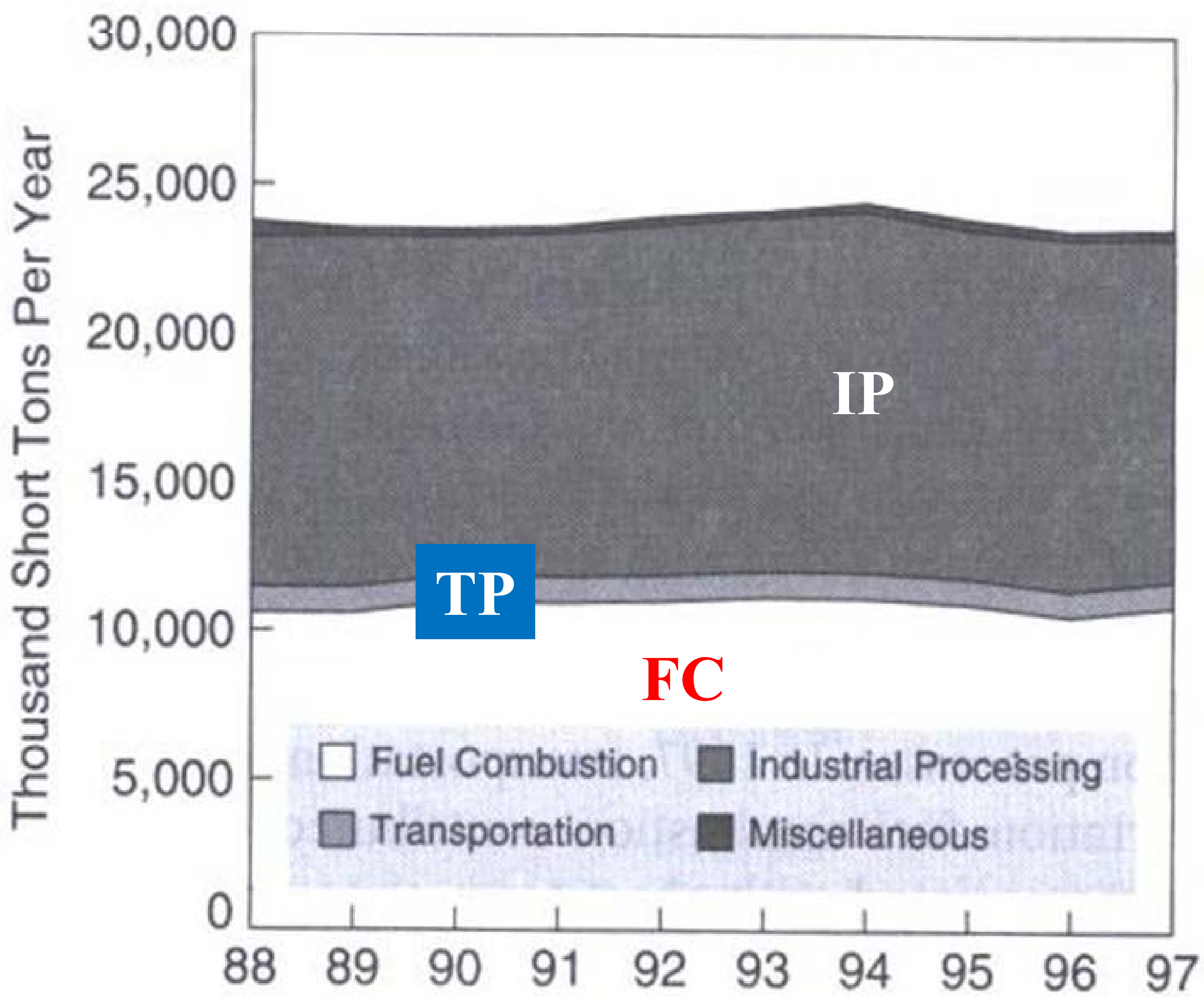


Fig. 1.5-2

Emission trends for major categories of VOC emission sources(EPA, 1998)

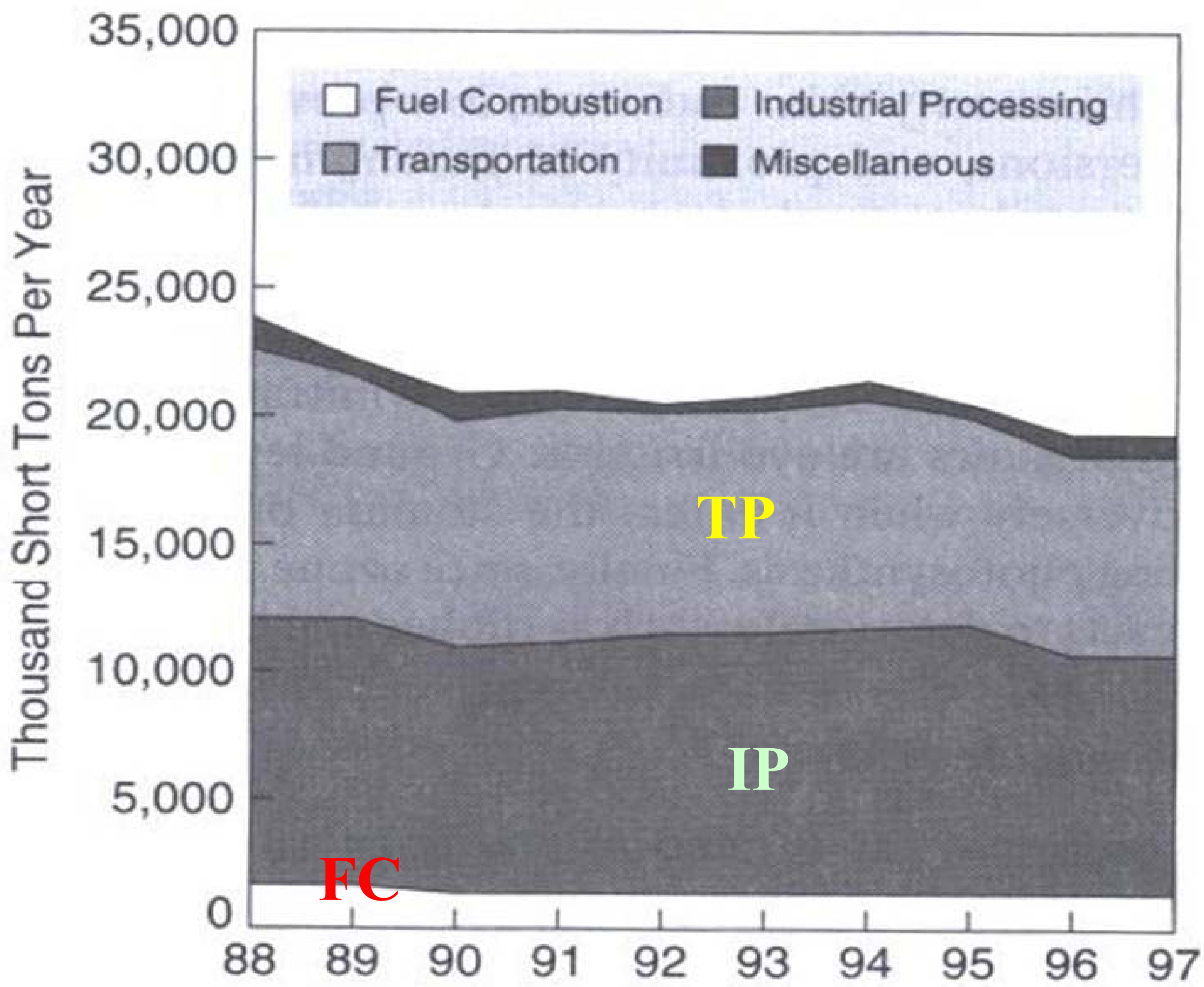


Fig. 1

✸ Carbon Monoxide (CO)

Property

- a colorless, odorless from incomplete combustion
- bind with hemoglobin and reduce O_2-carrying ability of blood

Sources

- traffic congestion of vehicles
- cigarettes (second-hand smoke), wood-burning fire place, kerosene heaters

(See Table 1.5-1)

✸ Lead

- Lead stay in air as suspended fine particulates ~10 micron.
- Tetraethyl lead, $(CH_3CH_2)_4$-Pb was used as an octane booster and antiknock compounds *(1970 Clean Air Act improves significantly)*
- Lead enters waterways in urban runoff and industrial effluents, adheres to sediment particles in the receiving water body. (*Uptake by aquatic species results in malformations, death and ecosystems instability)*
- Level of lead increased due to acid precipitation → increases bioavailability
- Lead entered the body by inhalation and ingestion of food (contaminated fish), water, soil and airborne dust. (*high level of lead in blood may decrease IQ.*)

✸ Particulate Matter (PM)

NAAQS (National Ambient Air Quality Standards)

- PM is microscopic solid or liquid phase(aerosol) particles suspended in air *(various primary and secondary sources)*
- "fine" particles ($PM_{2.5}$) are inorganic salts(Ammonium sulfate and nitrate), organic species and trace metals
  (can deposit deep in lung and is difficult to remove)
  (asbestos, coal mine dust, or textile fiber cause cancer)
- "coarse" particles (PM_{10}) are suspended dust
  (deposit in upper respiratory tract, cause asthma, and removable)

Environmental Effect

- limited visibility
- N- and S-containing particles deposit on land and increase soil acidity and alter nutrient balance
- Alter pH of water and lead to death of aquatic organisms
- corrosion of cultural monuments made by limestone

✸ SO_2, NO_x, and Acid Deposition

SO_x

- formed upon combustion of S-containing fuels *(coal, oil)*
- generated by electric utilities, metal smeltering, industrial processes
  transported long distances and transformed into H_2SO_4 in air

NO_x

- combustion reactions *(oxidation of N_2 in combusting air)*
- transformed into HNO_3 in air

Acid Deposition

- gas-phase reactions produce microscopic aerosols of acid-containing compounds while aqueous phase reactions occur inside existing particles
- acid is deposited to land as *dry deposition* (aerosols) and *wet deposition* (acid rains and precipitation)

(Fig. 1.5-4)

What is the natural background pH of rain?

- Water in equilibrium with CO_2 : 330ppm, pH=5.6
- Natural sources of sulfur and nitrogen acid rain precursor: pH=5.0
- Acid rain: <pH 5.0

Major Sources *(SO_2)*

- non-transportation fuel *(84.7 %),* industrial processes *(8.4 %)* transportation *(6.8 %),* miscellaneous *(0.1 %)*

Environmental Effect of Acid deposition

- SO_2 is absorbed readily into the moist tissue lining the upper respiratory system, leading to irritation and swelling of this tissue. Long exposure leads to lung disease and aggravate cardiovascular disease (심혈관질환).
- Acid deposition causes acidification of water and low buffering and ion exchange capacity of soil and surface water.
- Acidification of water can harm fish by exposure to heavy metals (Aluminum) which is leached from soil.
- Decrease number and variety of plant species (Plant growth, yield)

Environmental cause and effect for acid rain

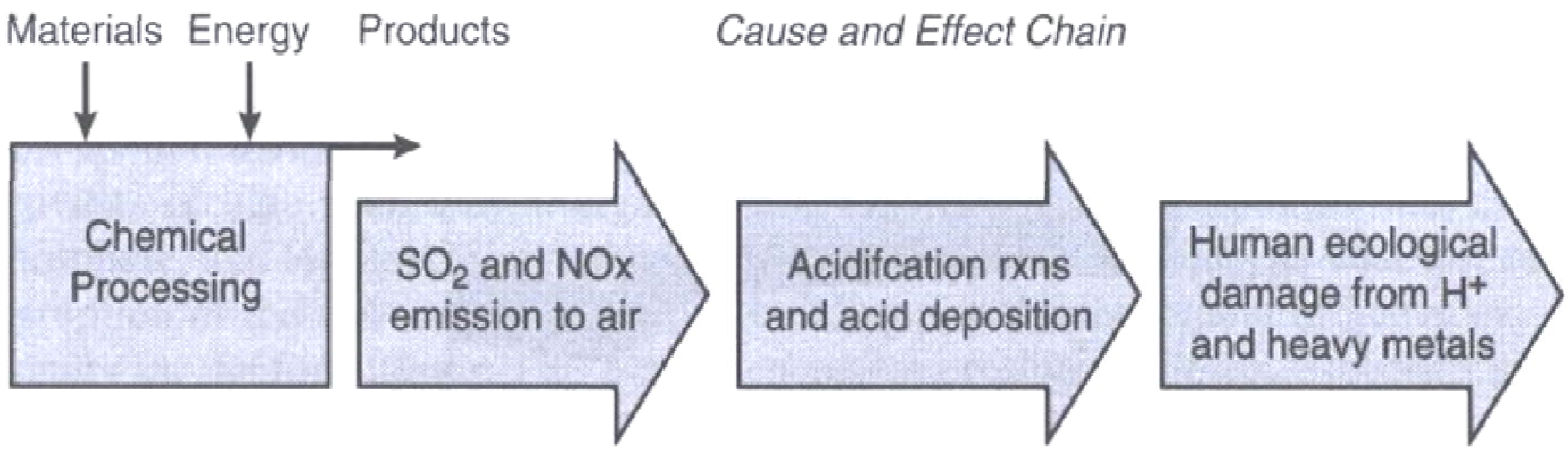


Figure 1.5-4 Environmental cause and effect for acid rain.

Fig. 1.5-4

Emmision Trends for SO2

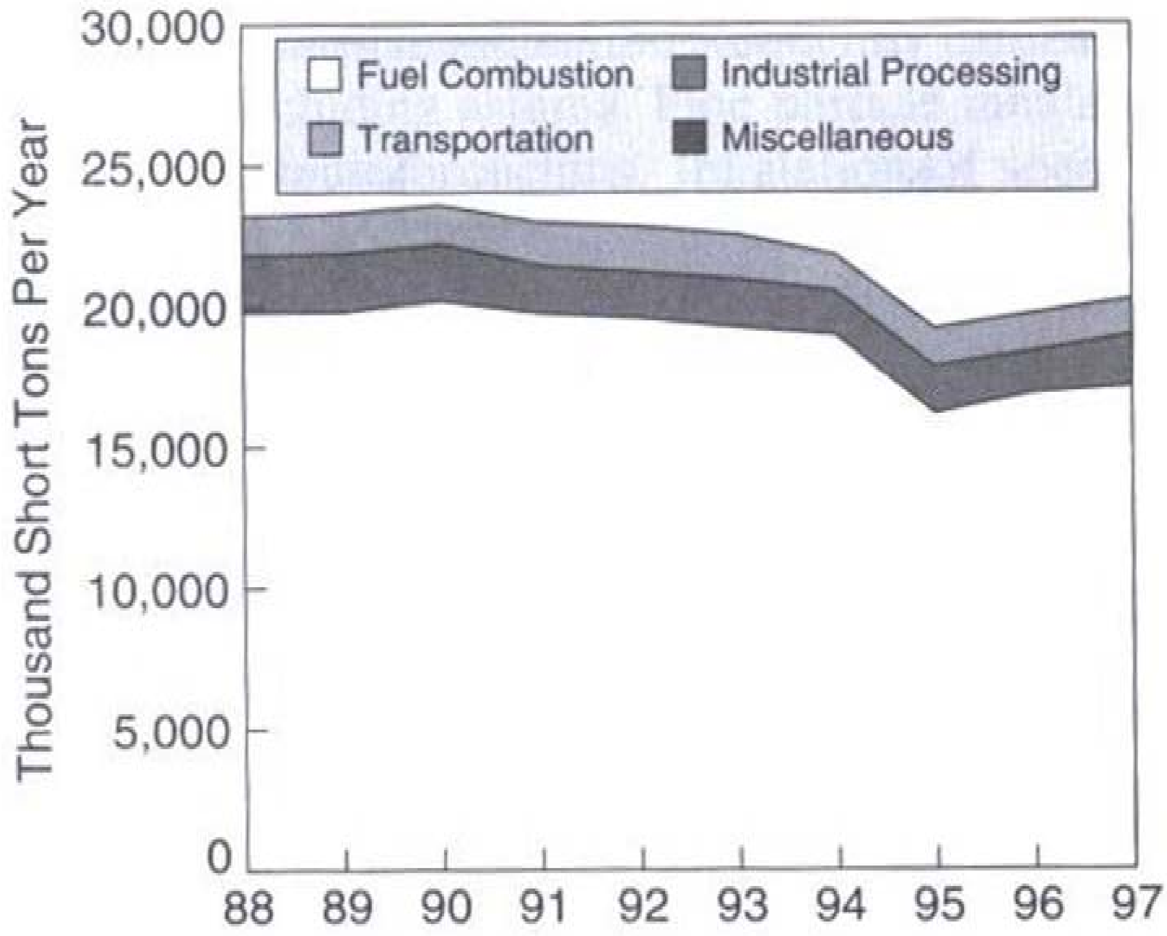


Fig. 1.5-5

1.5.2 Air Toxics (HAP: Hazardous Air Pollutants)

- HAPs are airborne pollutants known to have adverse human health effects such as cancer

  There are over 180 chemicals set by EPA (Hg, Cr, benzene, hexane, perc, 1,3-butadiene, dioxins, polycyclic aromatic hydrocarbons(PAHs)

- **Major sources** : stationary source that has the potential to emit 10 tons/yr of any one HAP or 25 tons/yr of any combination of HAPs from chemical complexes and oil refineries. The CAA prescribes a very high level of pollution control technology for HAPs (MACT: Maximum Achievable Control Technology)
- **Minor sources** : small area sources, such as dry cleaners, emit lower HAP tonnages but taken together are a significant source of HAPs. Emission reductions can be achieved by changes in work practices.

- Health Effect :

  Many of these persistent and bioaccumulative chemicals are carcinogens.

1.6 Water Quality Issues

Availability of Freshwater

- 1.36 billion km^3 water on earth: 97 % is ocean, 2 % is in glaciers, 0.31 % is in deep ground and 0.32 % is readily accessible freshwater *(4.2 million km^3)*
- Use Freshwater by hydrologic cycle:
  agricultural irrigation (42 %), electric generation (38 %)
  public supply (11 %), industry (7 %), rural uses (2 %)

Contamination

- Agricultural activities : pesticide, ammonium nitrate, phosphate, animal waste leachate, Forestry practices, etc.
- Municipal and industrial sources : wastewater, sewer outfalls, industrial discharges, urban runoff, mine drainage, etc.
- Transportation sources: coastal shipping, oil spill, precipitation runoff from roads *(oil, heavy metals, salt)*

  Ex: The Exxon Valdes oil spill in Alaska (1989)

Leachate: 침출액

1.7 Ecology

Eco-System Study

- **Ecology** is the study of material flows and energy utilization patterns in communities of living organisms in the ecosystems
- Study of the possibility that pollutants enter sensitive ecosystems might disrupt cycling of essential elements for life
- *Photosynthesis* : extract energy from sun and store as the form of carbon-based biomass.
- cycling elements and molecules through environment
  (altering between organic and inorganic forms of C, N, P, and S)

Primary Producer

- Organisms that capture solar energy which inhabit the first trophic levels of the food chain in ecosystems
  (1st, 2nd, and 3rd trophic levels)

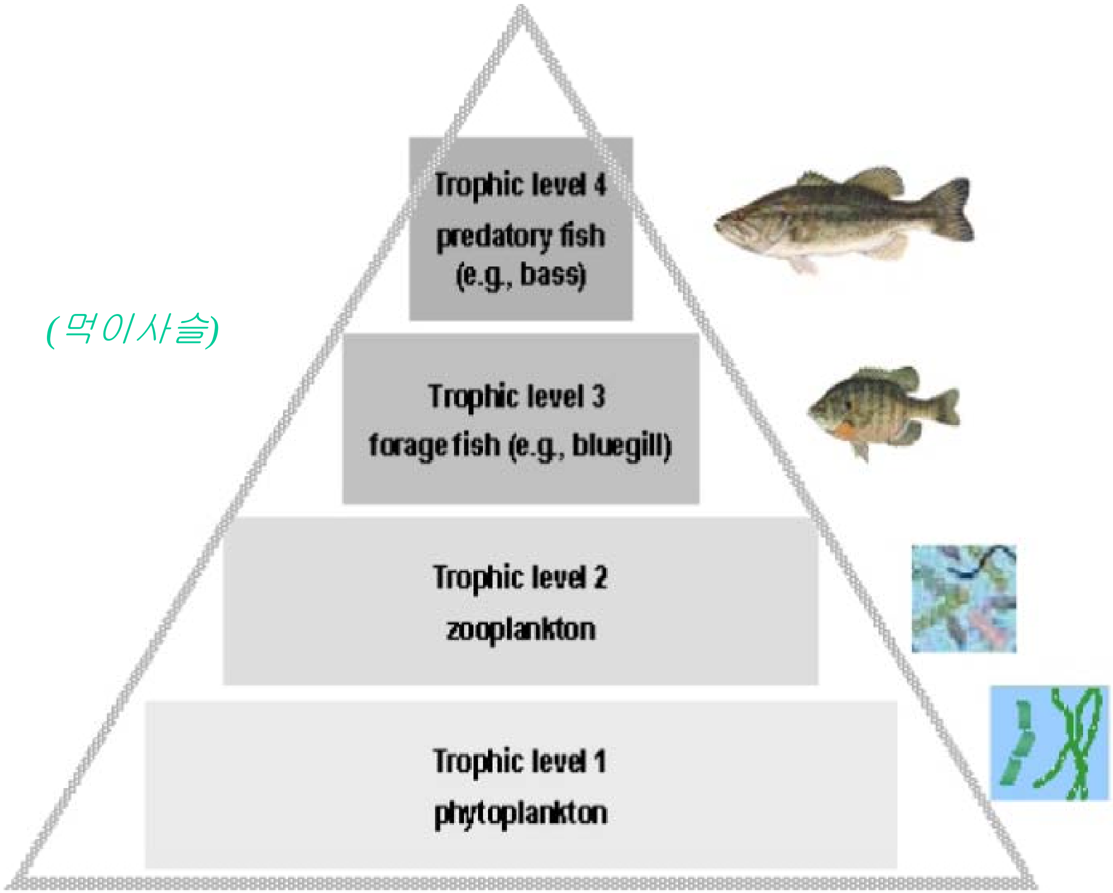
Trophic Level of the fool chain in ecosystems

- 1st trophic level : plants in terrestrial ecosystems, aquatic members as plants, algae, phytoplankton, etc.
- 2nd trophic level: primary consumers as grazing animals on land, zooplankton and insects in aquatic environments
- 3rd trophic level : secondary consumers as birds of prey, mammalian carnivores, fish, etc.
- Higher trophic level : humans in food chain

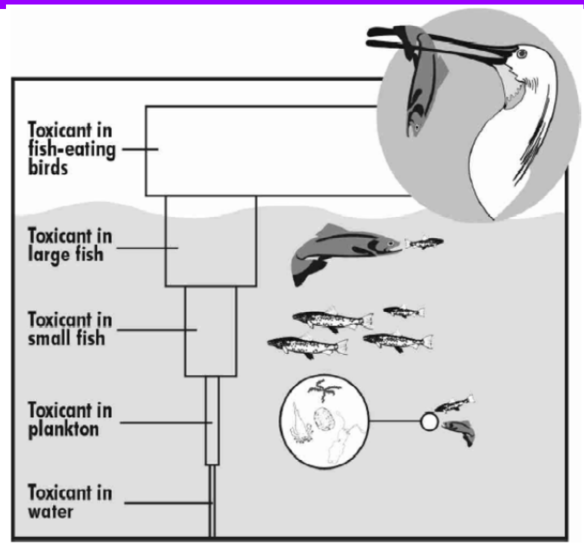
(먹이사슬)

Trophic Level of the fool chain in ecosystems

(먹이사슬)



http://www.epa.gov/ttnmain1/fera/data/risk/vol_1/chapter_17.pdf



Trophic Levels and Biomagnification

The trophic level is a way to describe where an organism may be located within an aquatic or terrestrial food web. The lowest trophic level consists of primary producers, the green plants that convert sunlight into carbohydrates via photosynthesis. The next trophic level generally consists of primary consumers, or the organisms that feed directly on green plants. The next level up, often termed secondary consumers, represents animals that feed on primary consumers. The highest trophic level consists of the top predators in the food web. For some chemicals, the concentration in biological tissue can increase as it moves up the food chain, a process called **biomagnification**.

Carnivores :육식류

ECOLOGY

- Carnivores at the highest trophic levels in ecosystem food chain can encounter increased exposure to certain classes of anthropogenic pollutant.

Anthropogenic:인위적인

- Chemicals that are hydrophobic, persistent, and toxic are of particular concern because these chemicals bioaccumulate in animal fat tissue and are transferred from lower to higher trophic levels in food chain.

- Pollutant accumulation in level transport:
PCB (polychlorinated biphenyls), DDT, certain pesticides, mercury compounds in fish.

DDT

$$2C_6H_5Cl \quad + \quad CCl_3CHO \quad \rightarrow \quad (C_6H_4Cl)_2CHCCl_3 \quad + \quad H_2O$$

Chlorobenzene | Chloral | DDT(dichlorodiphenyltrichloroethane)

First synthesis in1874 by O.Zeidler

Paul Hermann Müller (1899-1965)
The Nobel Prize in Physiology or Medicine 1948
"for his discovery of the high efficiency of DDT as a contact poison against several arthropods"

Endocrine distruptor

Dramatic reductions in birth rate of birds of prey

Alternatives: carbaryl (Sevin, NAC) ,aldicarb, carbofuran, BPMC, methomyl

1.8 Natural Resources

Production Materials

- Production of industrial materials and products begins with the extraction of natural resources from the environment
- Availability of these resources is vital for sustaining functioning of society
- *Examples* : water, minerals, fossil fuels, solar radiation, wind, lumber, etc.
- Non-renewable resources: oil, coal, natural gas

  (most energy requirements)

Resource Management for future

- As the availability of resources is diminished, the cost and energy consumption for producing these materials are likely to increase.
- Conservation, recycling materials, improved technologies

  (lead from batteries, steel from scrap cars, etc.)

1.9 Waste Flows Data *(USA)*

Federal Agencies

- **EPA** (United States Environmental Protection Agency) which complies various national inventories in response to legislative statutes.

CAA *(Clean Air Act)*
RCRA *(Resource Conservation and Recovery Act)*
SARA *(Superfund Amendments and Reauthorization Act)*
EPCRA *(Emergency Planning and Community Right-to-Know Act)*

Industry Consortium

- **ACC** *(American Chemistry Council)*
- **API** *(American Petroleum Institute)*

Table 1.9-1 *Sources of Industrial Waste Trends Data*

Table 1.9-1 Sources of National Industrial Waste Trends Data. See Appendix F for additional information.

Non-Hazardous Solid Waste

Report to Congress: Solid Waste Disposal in the United States, Volumes I and II, US Environmental Protection Agency, EPA/530-SW-88-011 and EPA/530-SW-88-011B, 1988.

Criteria Air Pollutants

Aerometric Information Retrieval System (AIRS); US EPA Office of Air Quality Planning and Standards, Research Triangle Park, NC.

National Air Pollutant Emission Estimates; US EPA Office of Air Quality Planning and Standards, Research Triangle Park, NC.

Hazardous Waste (Air Releases, Wastewater, and Solids)

Biennial Report System (BRS); available through TRK NET, Washington, DC.

National Biennial Report of Hazardous Waste Treatment, Storage, and Disposal Facilities Regulated under RCRA; US EPA Office of Solid Waste, Washington, DC.

National Survey of Hazardous Waste Generators and Treatment, Storage, Disposal and Recycling Facilities in 1986; available through National Technical Information Service (NTIS) as PB92-123025.

Generation and Management of Residual Materials; Petroleum Refining Performance (replaces *The Generation and Management of Wastes and Secondary Materials* series); American Petroleum Institute, Washington, DC.

Preventing Pollution in the Chemical Industry: Five Years of Progress (replaces the *CMA Hazardous Waste Survey* series); Chemical Manufacturers Association (CMA), Washington, DC.

Report to Congress on Special Wastes from Mineral Processing; US EPA Office of Solid Waste, Washington, DC.

Report to Congress: Management of Wastes from the Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy, Vol. 1, *Oil and Gas*; US EPA Office of Solid Waste, Washington, DC.

Toxic Chemical Release Inventory (TRI); available through National Library of Medicine, Bethesda, Maryland and RTK NET, Washington, DC.

Toxic Release Inventory: Public Data Release (replaces *Toxics in the Community: National and Local Perspectives)*; EPCRA hotline (800)-535-0202. www.epa.gov/TRI

Permit Compliance System; US EPA Office of Water Enforcement and Permits, Washington, DC.

Economic Aspects of Pollution Abatement

Manufacturers' Pollution Abatement Capital Expenditures and Operating Costs; Department of Commerce, Bureau of the Census, Washington, DC.

Minerals Yearbook, Volume 1 Metals and Minerals; Department of the Interior, Bureau of Mines, Washington, DC. Census Series: *Agriculture, Construction Industries, Manufacturers-Industry, Mineral Industries*; Department of Commerce, Bureau of the Census, Washington, DC.

Source: US Department of Energy (DOE), "Characterization of Major Waste Data Sources," DOE/CE-40762T-H2, 1991.

Industrial hazardous waste generation in USA

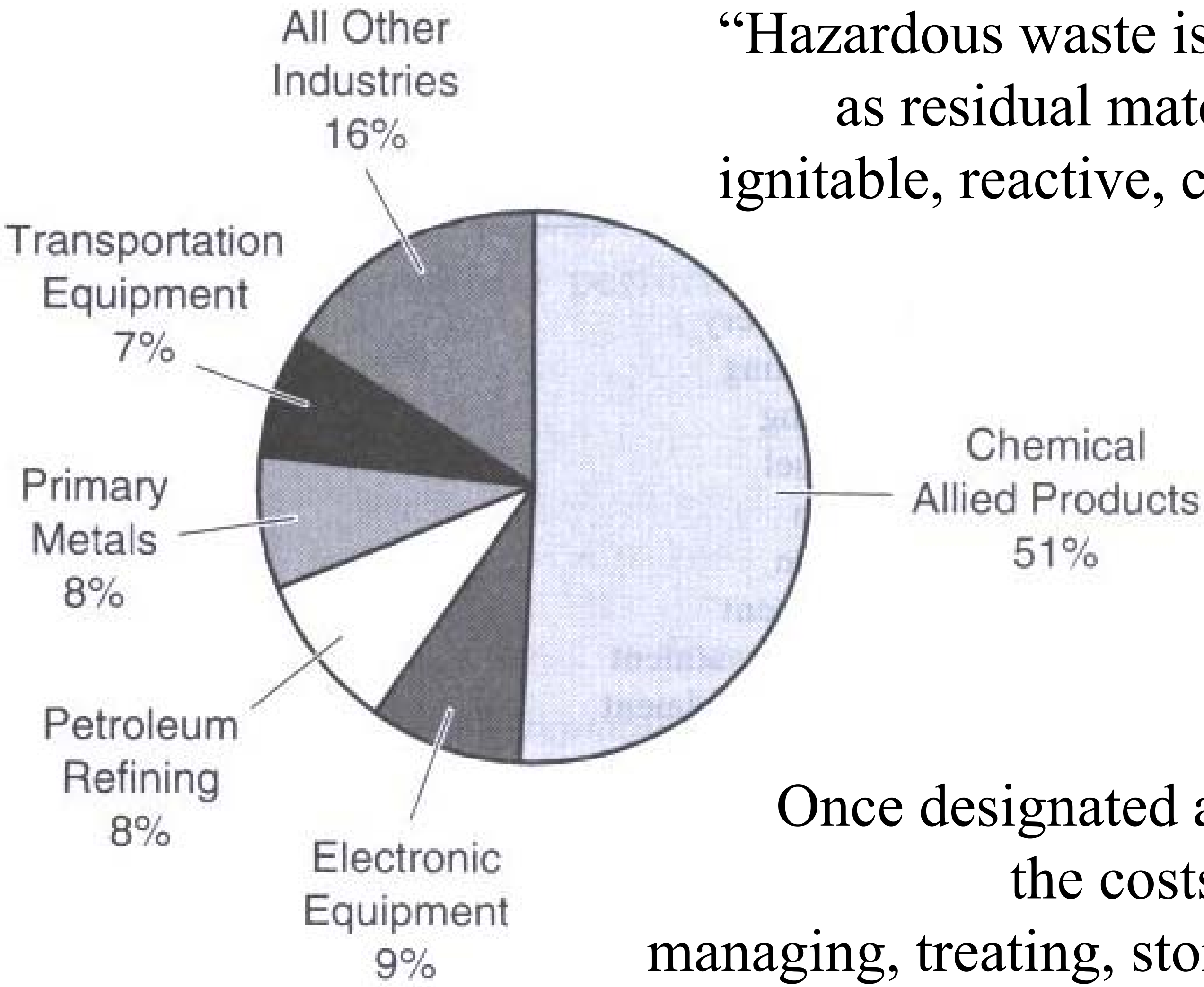


Fig. 1.9-1

"Hazardous waste is defined by RCRA as residual materials which is ignitable, reactive, corrosive, or toxic."

Once designated as hazardous, the costs of managing, treating, storing, and disposing of this material increase dramatically.

Toxic chemical release from USA

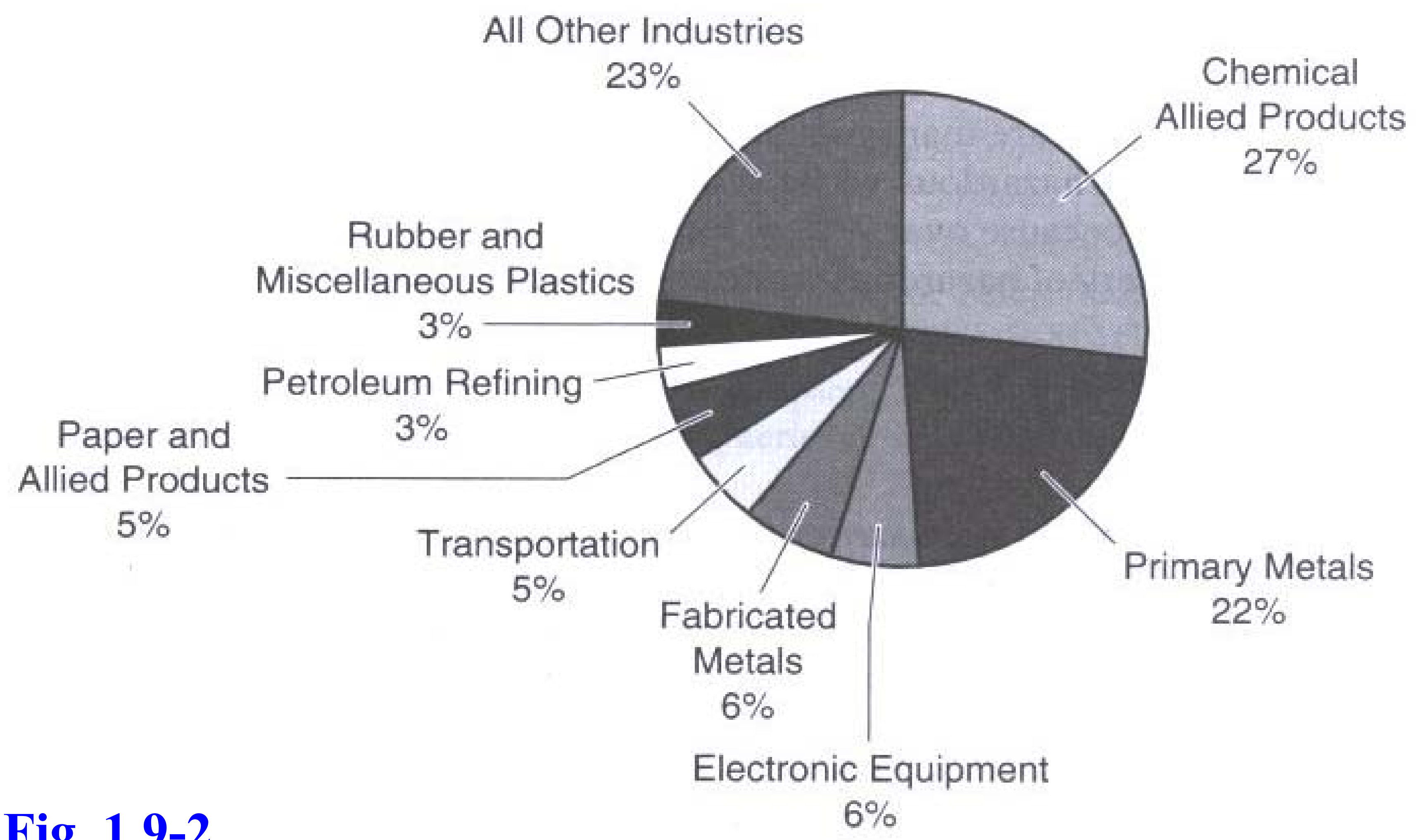


Fig. 1.9-2

Hazardous waste managed for each management technology

Table 1.9-2 Hazardous Waste Managed for Each Management Technology (1986 data).

Management Method	Quantity Managed in 1986 (million tons)	Number of Facilities
Metal Recovery	1.4	330
Solvent Recovery	1.2	1,500
Other Recycling	0.96	240
Fuel Blending	0.75	180
Reuse as Fuel	1.4	300
Incineration	1.1	200
Solidification	0.77	120
Land Treatment	0.38	58
Wastewater Treatment	730	4,400
Disposal Impoundment	4.6	70
Surface Impoundment	230	300
Landfill	3.2	120
Waste Pile	0.68	71
Underground Injection	29	63
Storage (RCRA permitted)	190	1,800
Other Treatment	2.0	130

Summary of Environmental Issues

- **Environment is a complex system with a large number of transport and transformation processes occurring simultaneously.**

- **Focal point for improving processes designs is to understand that the properties of chemicals can have an important influence on their ultimate fate in the environment and on their potential impact on the environment and human health.**

- **With a basic understanding of environmental issues, the chemical engineer will be able to spot environmental problems earlier and will contribute to the solution of those problems by improving the environmental performance of chemical processes and products**

Homework #1

Solve the Problems in Chapter 1:

5. Ozone Depletion Potential of Substitute Refrigerants (hint: read page 12 carefully)

Due date: March 17, 2011


I put my heart and my soul into my work,
and have lost my mind in the process.
Thank you