POLITECNICO DI MILANO

School of Industrial and Information Engineering

Course 096125 (095857)

Introduction to Green and Sustainable Chemistry





Survey of Modern Concerns Related to Chemicals and Materials.

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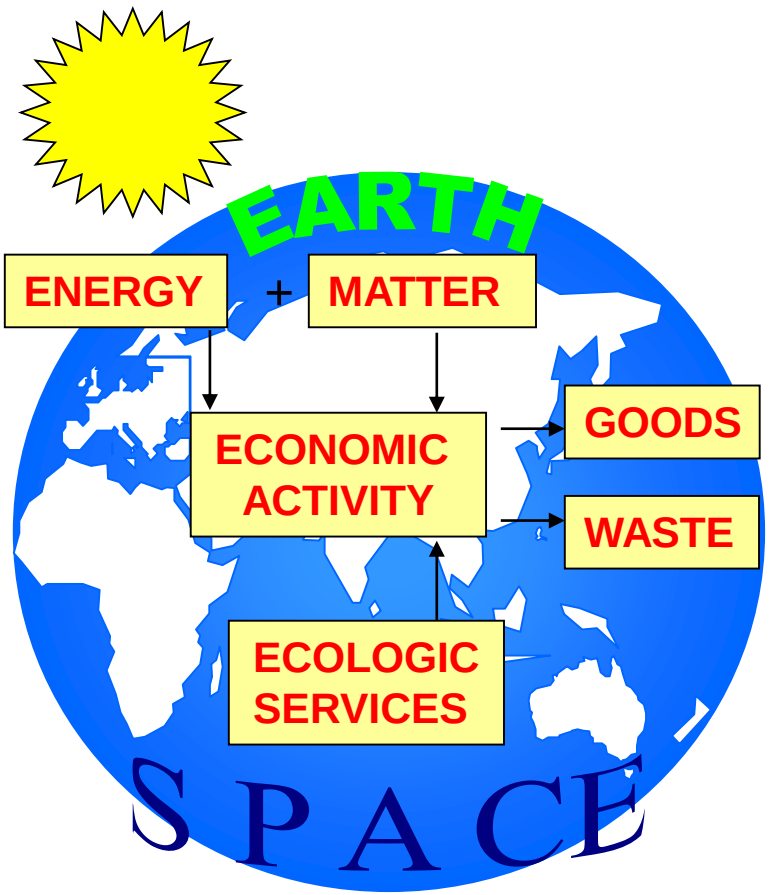
https://iscamapweb.chem.polimi.it/citterio/it/education/course-topics/

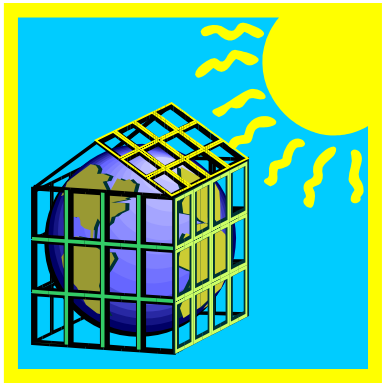
Economy and Environment: Key Connections.



The economic activity depend on:

- Energy Sources and Raw Materials
- Transformation Efficiency/effectiveness
- Waste elimination/reuse
- Available services
- Space for economical activity and goods trade

But also from global factors



Environmental Issues.

POLITICAL DEVELOPMENT

- During the 1970's the environmental movement emerged, led by Greenpeace and Friends of the Earth and other organizations
- At early 1980's, the environment moved towards the political mainstream
  - “Green parties”
  - Environmental protection and management became major issue
- Nowadays, environmental policies
  - Are like all other policies
  - Are created through the political process in one form or another
  - Had been mapped
  - The theoretical basis for many of the possible strategies defined
  - Agreement for some limitations (i.e. 1.5 degree in temperature increase) was established in 2015.

Some Facts About The State of the World (2003)*.

Energy/Atmosphere

- Fossil fuel use grows 1.5%
  - Oil - .5%. Coal – 1.9%, Gas, Natural gas 2%
- Nuclear power capacity grows 1.5%
- Wind energy capacity grows 27%
- Atmospheric CO_2 level up 18% since 1960
  - Most likely highest level in 20M yrs.
- Severe weather events on the rise
  - 31% since 1750
  - Weather disaster economic losses grow 93% over 2001 to $53B
  - Cyclone intensity increases 10-20% with increasing temperature

Economic

- Humanity withdrawing earth resources 20% faster then renewal rate (45% in the US)

Nature

- 12% of 9800 bird species threatened with extinction in this century
  - Causes are habitat loss, exotic species, poorly regulated hunting, long line fishing
  - Birds disperse seeds, pollinate flowers, control insect & rodent populations

Transportation/Communication

- Vehicle production grows 2%
- Number of mobile & cell phone subscribers increases 21% to 1.15B
- Ratio of internet users between industrial & developing countries is 17:1 (40:1 in 1995)

Health & Social

- World births exceeded deaths by **74M** leading to population of 6.23B
- Population of the 49 poorest countries grows 2.4%, 10 times the rate of industrial countries
- Number of people with HIV/AIDS rose to 42M
  - 5M became infected and **3.1M** died
  - 70% in sub-Saharan Africa
- Cigarette production down .5% to 5.6T
  - 82% of 1.1B smokers in low/middle income countries; expected hi growth due to marketing focus
  - Smoking killed **4.9M** (more than HIV/AIDS)
- Consumption patterns contribute to mortality,
  - Heart condition and stroke kill 16.7M
  - Infectious & parasitic disease kill 14.4M
  - Cancer kills 6.9M

Military

- Resource wars plague developing nations (funds from resource extraction fund armed conflict)

*Data from State of the World 2003 published by the Worldwatch Institute, Washington, D.C.

Some Facts About The State of the World (2013)*.

Energy/Atmosphere

- Fossil fuel use grows 1.9%
  - Oil - .1.2%. Coal – 2.2%, Gas, Natural gas 1.2%, Electricity 2.2%
- Nuclear power capacity stop in 2010
- Wind energy capacity grows 27%
- Atmospheric CO_2 level rise up to a 400 ppm since 1960
  - Most likely highest level in 20M yrs.
- Severe weather events on the rise
  - 15% since 1750
  - Weather disaster economic losses grow 103% over 2001
  - Cyclone intensity increases 10-20% with increasing temperature

Economic

- Humanity withdrawing earth resources 20% faster then renewal rate (35% in the US)

Nature

- 12% of 9800 bird species threatened with extinction in this century
  - Causes are habitat loss, exotic species, poorly regulated hunting, long line fishing
  - Birds disperse seeds, pollinate flowers, control insect & rodent populations

Transportation/Communication

- Vehicle production grows 0.3%
- Number of mobile & cell phone subscribers increases 50% to 200 B.
- Ratio of internet users between industrial & developing countries is 2,5:1 (40:1 in 2003)

Health & Social

t

- Increase of population (7.1B):
  - More developed country 1.2 %
  - Less developed country: 5.9 %
- Africa's population is estimated o increase to 2.4 billion, from 1.1 billion in 2013.
- The average life expectancy at birth for women in Japan is 86, one of the highest in the world
- In 1950, 117 million people lived in the top 30 metros but that number rose to 426 million by 2013.
  - Heart condition and stroke kill 16.7M

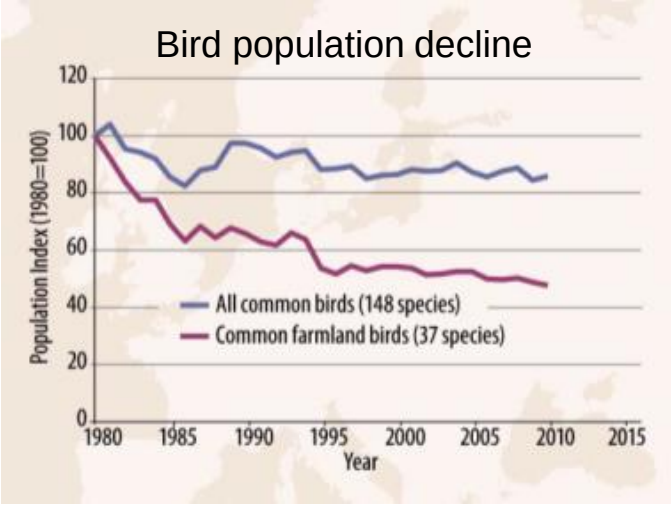
Military

- Resource wars plague developing nations (funds from resource extraction fund armed conflict)

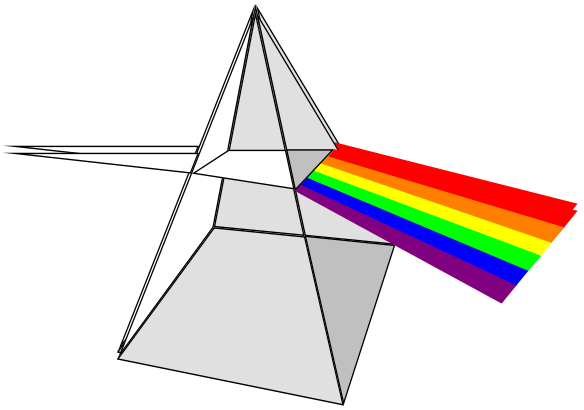
*Data from State of the World 2013 published by the Worldwatch Institute, Washington, D.C.

Global Threats to Ecosystem Viability.

- loss of crop & grazing land
- depletion of world's tropical forests
- extinction of species
- rapid population growth
- shortage of fresh water resources
- over-fishing, habitat destruction



- pollution in the fresh water and marine environment
- threats to human health
- climate change, GW
- acid rain
- ozone layer depletion
- pressures on energy resources
- solid waste pollution
- ……..

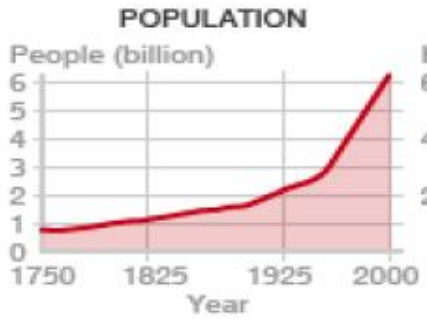


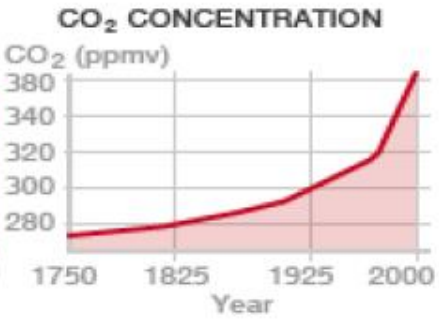
State of the World Environment Warrants Attention.

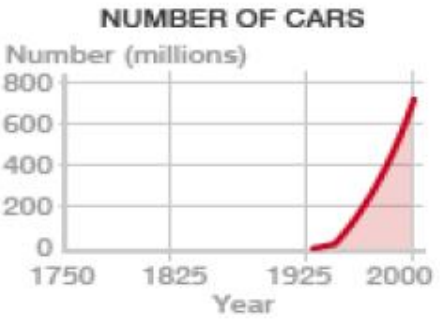
	1950	1972	1997	2050
1. Population (x billion people)	2.5	3.8	5.8	10.7
2. Megacities (>8 million)	2	9	25	200
3. Food (calories/capita)	1980	2450	2770	2200
4. Fisheries (Million ton·yr^{-1})	19	58	91	35
5. Water use ($km^3 \cdot yr^{-1}$)	1300	2600	4200	7500
6. Rainforest (1950=100)	100	85	70	45
7. CO_2 Emissions (billion ton·yr^{-1})	1.6	4.9	7.0	14.0
8. Ozone Layer (CFC in ppb)	–	1.4	3.0	7.0

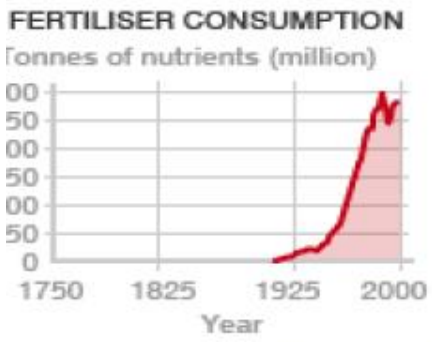
Source: World Resource Institute, 1996

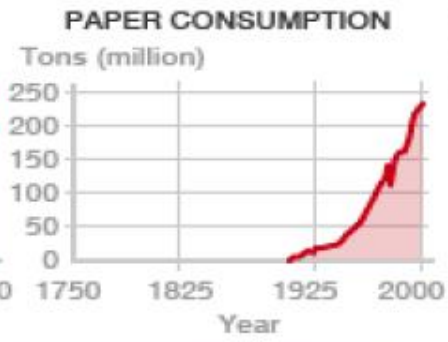
Unsustainable Place.

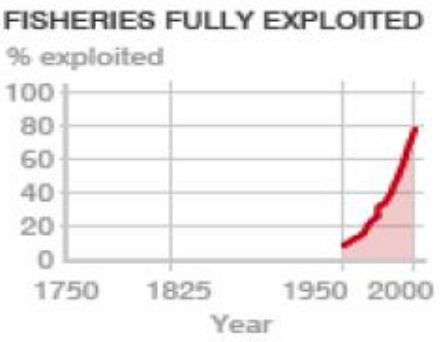


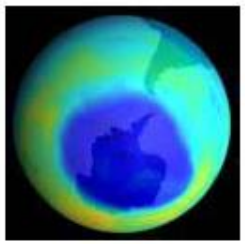












Major Trends Affecting the Bio-economy.

1. Changing trade patterns:

- globalisation
- Common Agricultural Policy (CAP) reform
- consumer-led production

2. Climate change:

- spread of plant diseases (e.g. fungi affecting banana, olive and rubber farms)
- new varieties/crops
- water and temperature issues
- soil degradation

3. World population trends:

- 6.5 bn in 2005 - 8.3 bn in 2030
- increasing calorie consumption per capital
- rising meat demand – up 70% by 2030

4. Environmental considerations:

- land use and reduction of inputs
- habitat protection
- maintaining biodiversity

5. Shifts in energy supply:

- higher costs of fossil fuels/scarcity
- security of supply
- reduction of GHG emissions

Concerns Related to Human Activity.

- Global issues
  - Greenhouse gas emission and global warming
  - Ozone depletion in the stratosphere
  - Global population growth
  - Resource depletion
- Environmental issues
  - Air and water pollution
  - Acid and base deposition
  - VOC and photochemical smog
- Health and Safety issues
  - Particulate matter
  - Freshwater contamination by hazardous wastes
  - At work accidents and disasters

The 21 Emerging issues. (UNEP 2012)

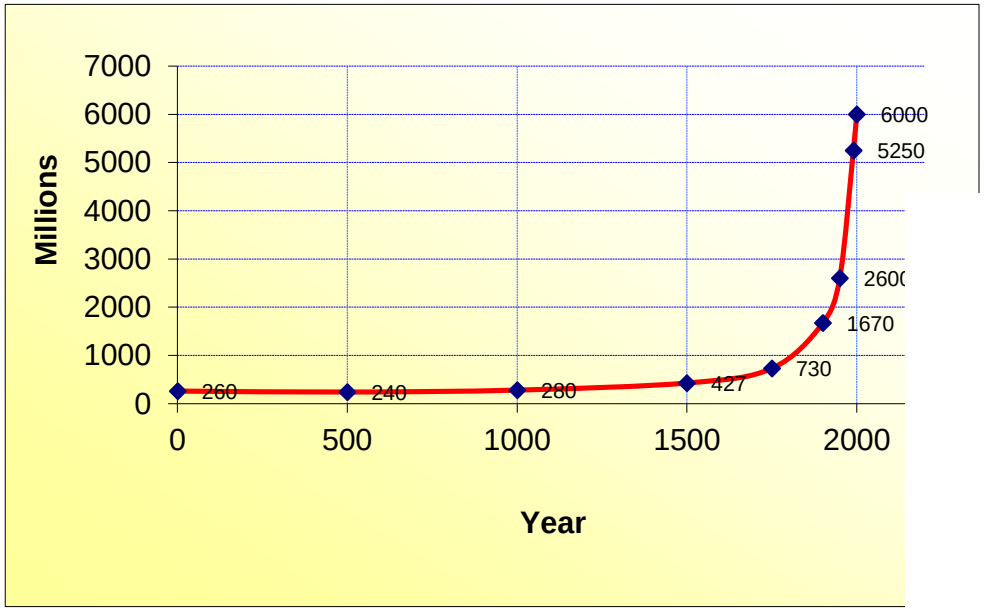
Issue ID	Issue Title	Ranking
Cross-cutting issues		
001	Aligning Governance to the Challenges of Global Sustainability	1
002	Transforming Human Capabilities for the 21st Century: Meeting Global Environmental Challenges and Moving Towards a Green Economy	2
003	Broken Bridges: Reconnecting Science and Policy	4
004	Social Tipping Points? Catalyzing Rapid and Transformative Changes in Human Behavior towards the Environment	5
005	New Concepts for Coping with Creeping Changes and Imminent Thresholds	18
006	Coping with Migration Caused by New Aspects of Environmental Change	20
Food, biodiversity and land issues		
007	New Challenges for Ensuring Food Safety and Food Security for 9 Billion People	3
008	Beyond Conservation: Integrating Biodiversity Across Environmental and Economic Agendas	7
009	Boosting Urban Sustainability and Resilience	11
010	The New Rush for Land: Responding to New National and International Pressures	12
Freshwater and marine issues		
011	New Insights on Water-Land Interactions: Shift in the Management Paradigm?	6
012	Shortcutting the Degradation of Inland Waters in Developing Countries	15
013	Potential Collapse of Oceanic Systems Requires Integrated Ocean Governance	13
014	Coastal Ecosystems: Addressing Increasing Pressures with Adaptive Governance	19

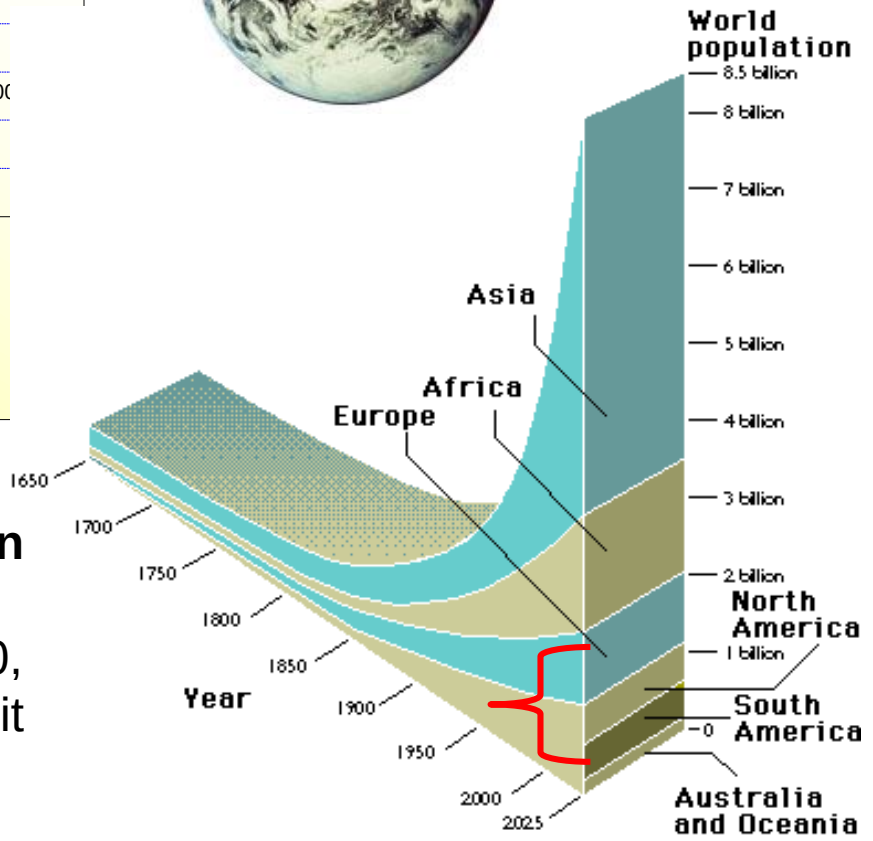
The 21 Emerging issues (UNEP 2012) - cont.

Issue ID	Issue Title	Ranking
Climate change issues		
015	New Challenges for Climate Change Mitigation and Adaptation: Managing the Unintended Consequences	7
016	Acting on the Signal of Climate Change in the Changing Frequency of Extreme Events	16
017	Managing the Impacts of Glacier Retreat	21
Energy, technology, and waste issues		
018	Accelerating the Implementation of Environmentally-Friendly Renewable Energy Systems	7
019	Greater Risk than Necessary? The Need for a New Approach for Minimizing Risks of Novel Technologies and Chemicals	10
020	Changing the Face of Waste: Solving the Impending Scarcity of Strategic Minerals and Avoiding Electronic Waste	14
021	The Environmental Consequences of Decommissioning Nuclear Reactors	17

* Ranking based on scoring by the UNEP Foresight Panel and after considering the polling results of more than 400 scientists worldwide.

Population Boom.





The world will need to support 5 billion more people.

World population passed 6 billion in 2000, up from 2.5 in 1850 and 4.4 in 1950 and it is projected to grow to about 8 billion in 2025 and 11 billion in 2050.

Materials and Energy Use under Socio-Ecological Regimes in World History.

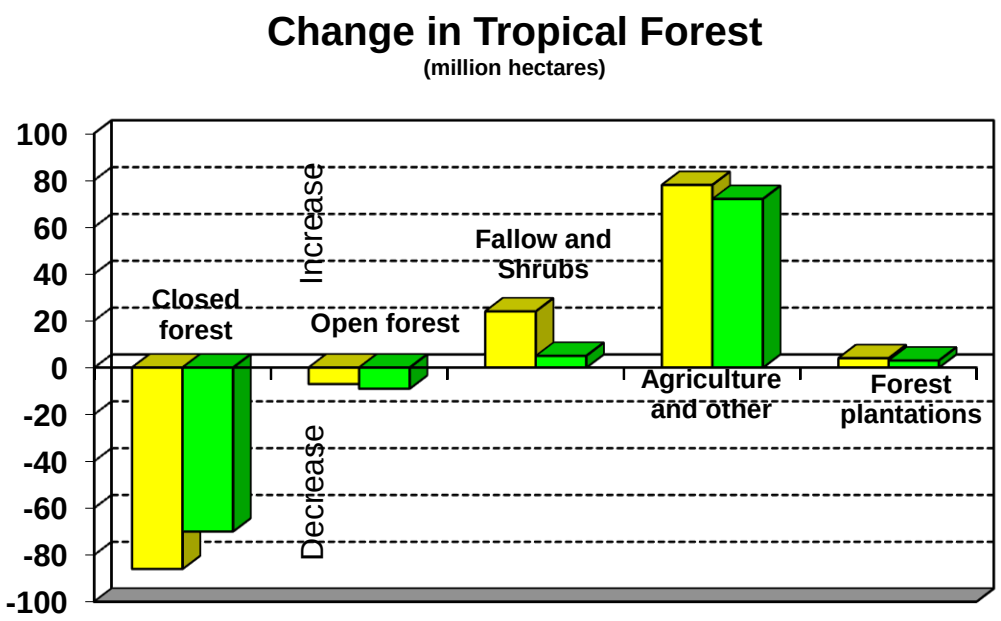
	per capita annual use	
	Energy	Material
Basic human metabolism (biomass intake by nutrition)	3,5 *GJ*	1 *t*
Hunter-gatherers (uncontrolled solar energy use)	10-20 *GJ*	2-3 *t*
Agrarian societies (controlled solar energy use)	60-80 *GJ*	4-5 *t*
Industrial/Technological societies (fossil energy use)	250 *GJ*	20-22 *t*

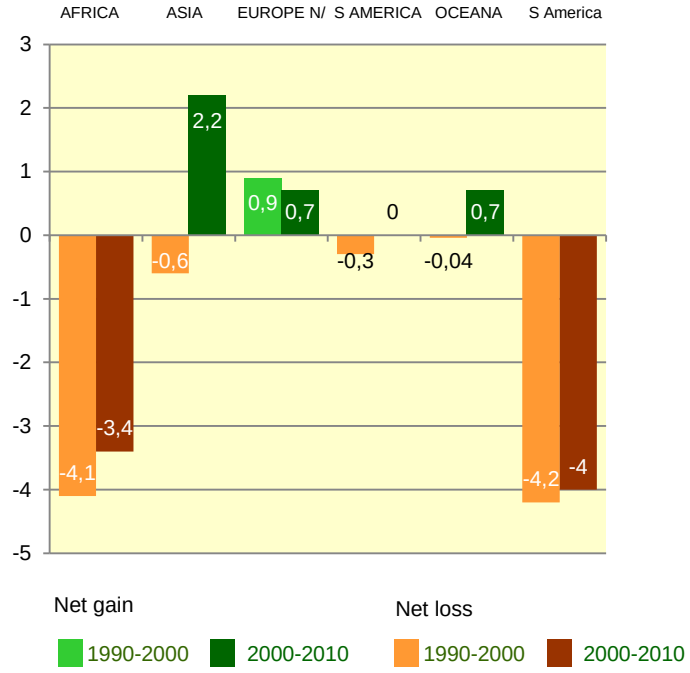
Deforestation.

Agricultural expansion is the main cause of deforestation.

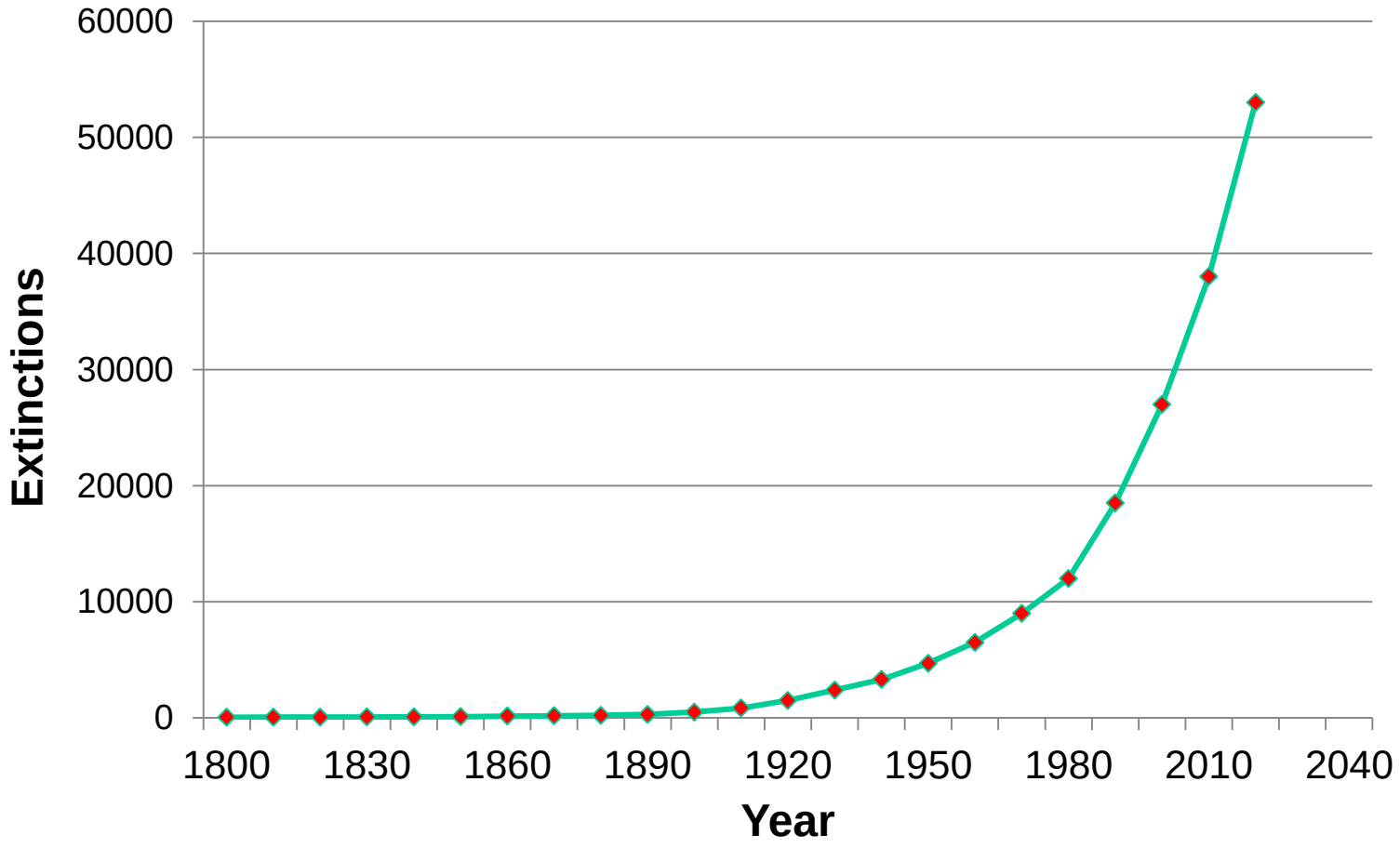
Permanent cultivation and shifting agricultural and pastures are the main contributes to deforestation. In tropical areas, the major change has been a decline in closed forest, in case with urban expansion. In developing regions, continuing population growth and increased demand for food, combined with declining in agricultural productivity, increase pressure for deforestation.

The capacity of forest to provide goods and services is decreasing (U.N. - The Millennium Development Goals Report 2011)



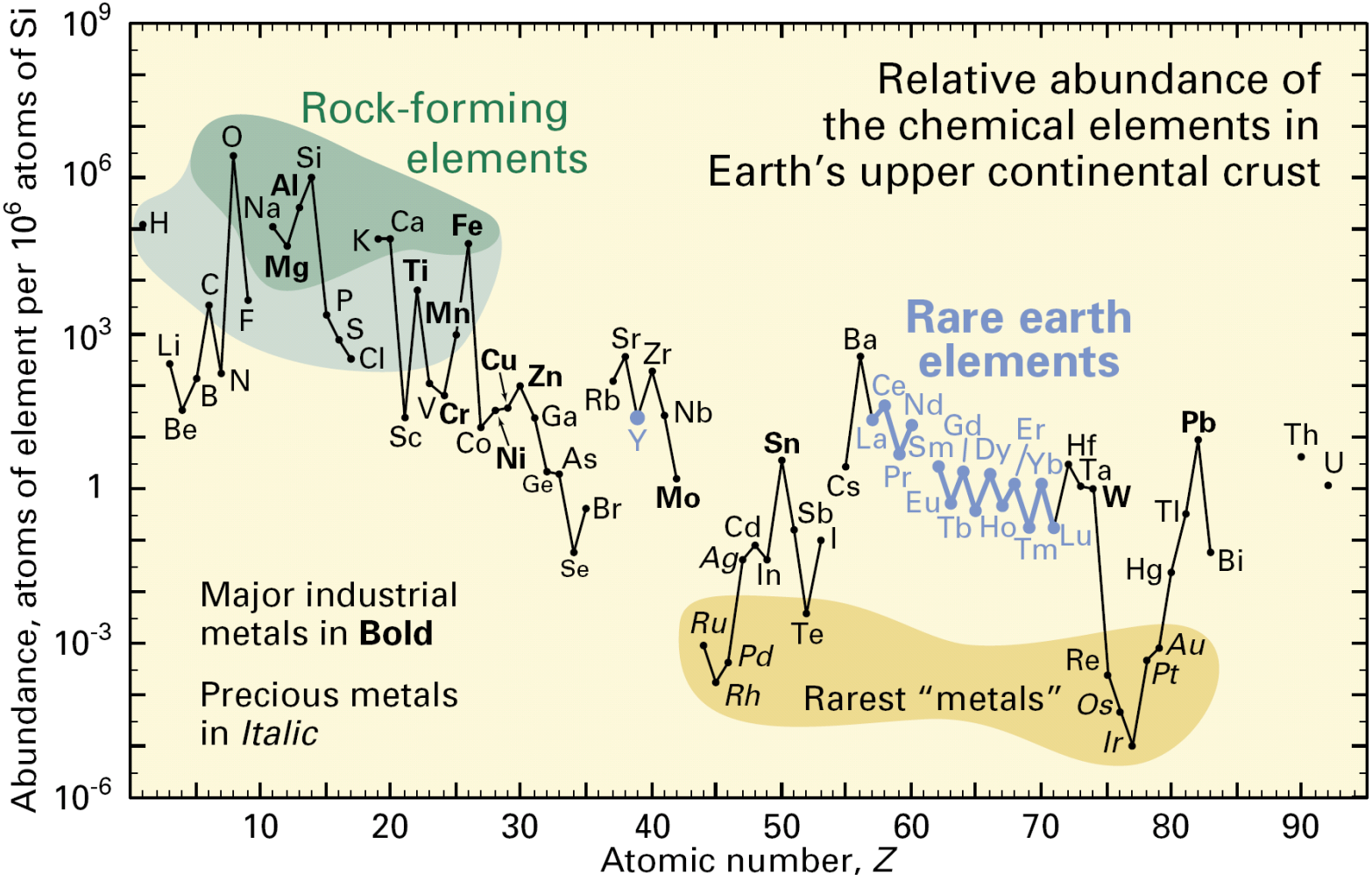


Species Extinctions Since 1800.



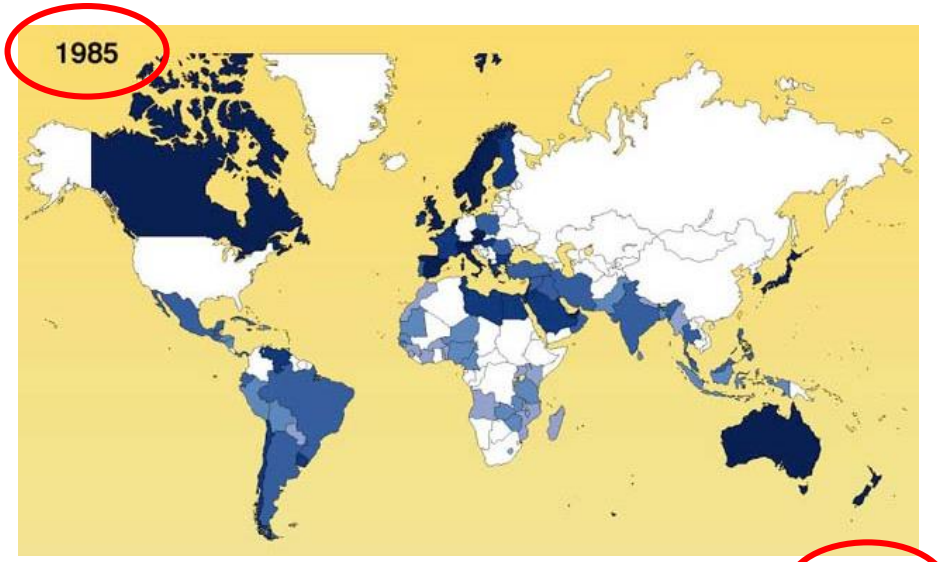
http://www.whole-systems.org/extinctions.html

The Element Shortage – Some Element are Rare on the Earth.

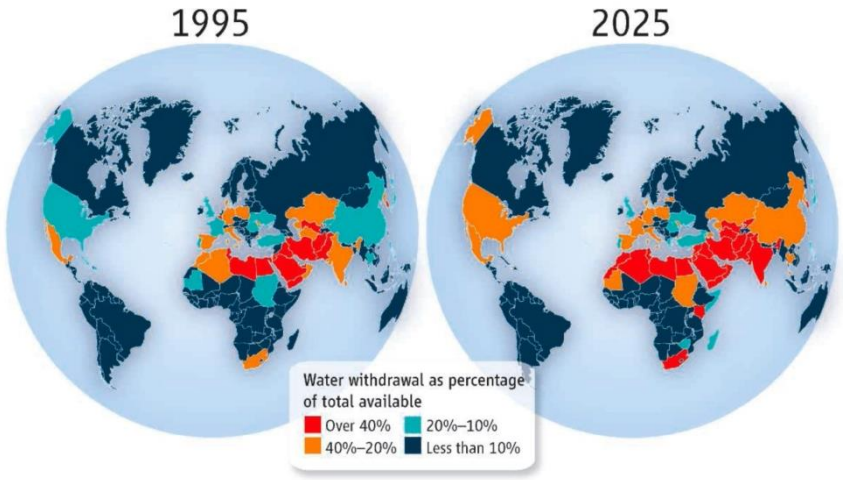


U.S. Geological Survey Fact Sheet 087-02

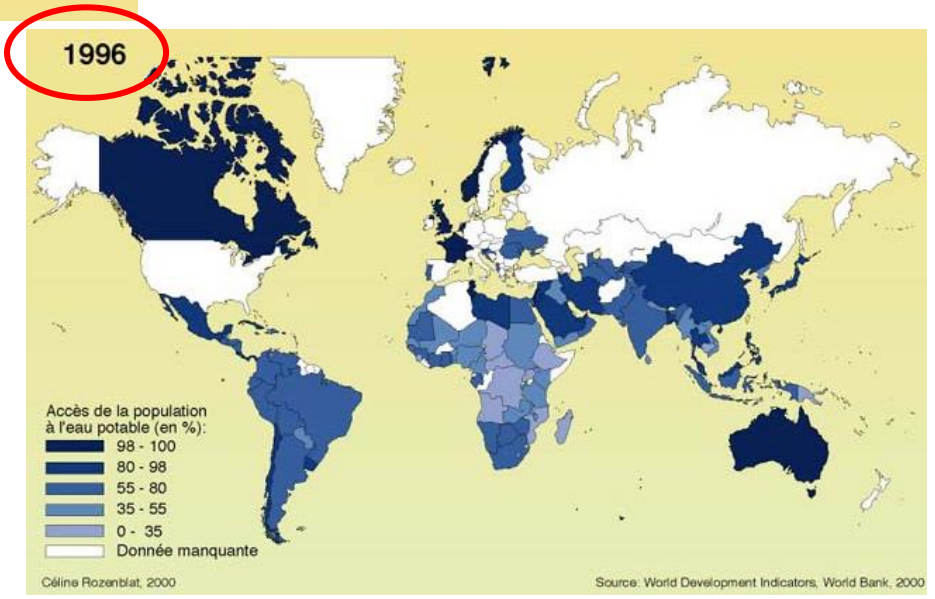
Also the most Abundant Compounds need Attention, i.e. Water.



Access to fresh water was widen in several country in the last 20 years, but pollution has also remarkably increased.



Science 313, 1088-1090, 2006



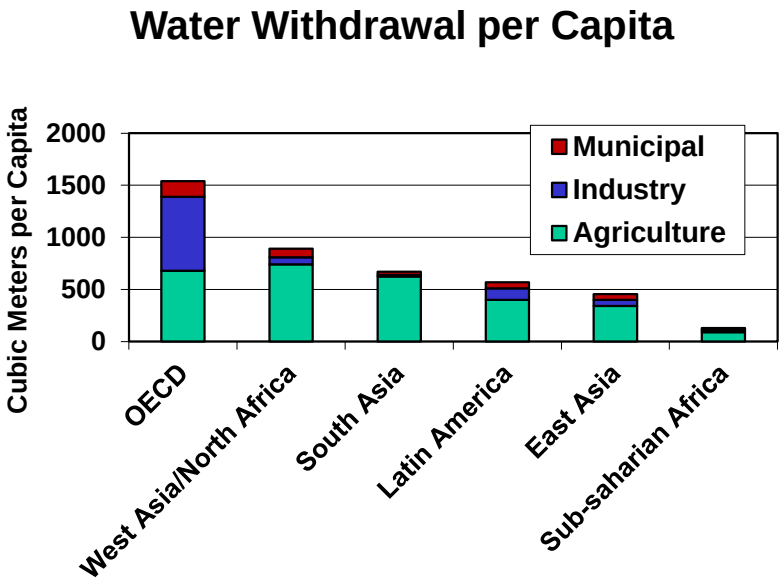
Increasing Water Use.

Industrial water use increases with development.

Water use generally increases with economic development, particularly for industrial and municipal use. Industry requires water for cooling, washing and processing with major uses including power generation, steel, chemicals, paper and petroleum refining. People require water also for drinking, food preparation, sanitation, etc.. Industrial and municipal uses generally have much higher economic value than agricultural use.

Services provided by freshwater ecosystems are threatened.

Freshwater ecosystems (likes, rivers, etc.) provide a variety of critical services, including water supply, water purification, flood control, recycling and transport of nutrients, fish production and protection of biodiversity. But many freshwater systems are being degraded through excessive water withdrawals, pollution and introduction of invasive species. Worldwide, about half of all wetlands have been lost and more than 20% of the 10,000 known freshwater species are extinct.



Water Shortages.

Nearly half of the world's people will experience water shortages by 2030.

On a global basis, water withdrawal amount to only 10-20% of total renewable water resources. However, water supply is very unequally distributed and conveniently cannot be moved over long distances. About 40% of the world population already live in river basins with less than 2000 m^3 of water per person per year for all purposes. By 2030, about half of the world population will live in areas facing such water shortages.

The Impact of Buildings.

In developed country houses need:

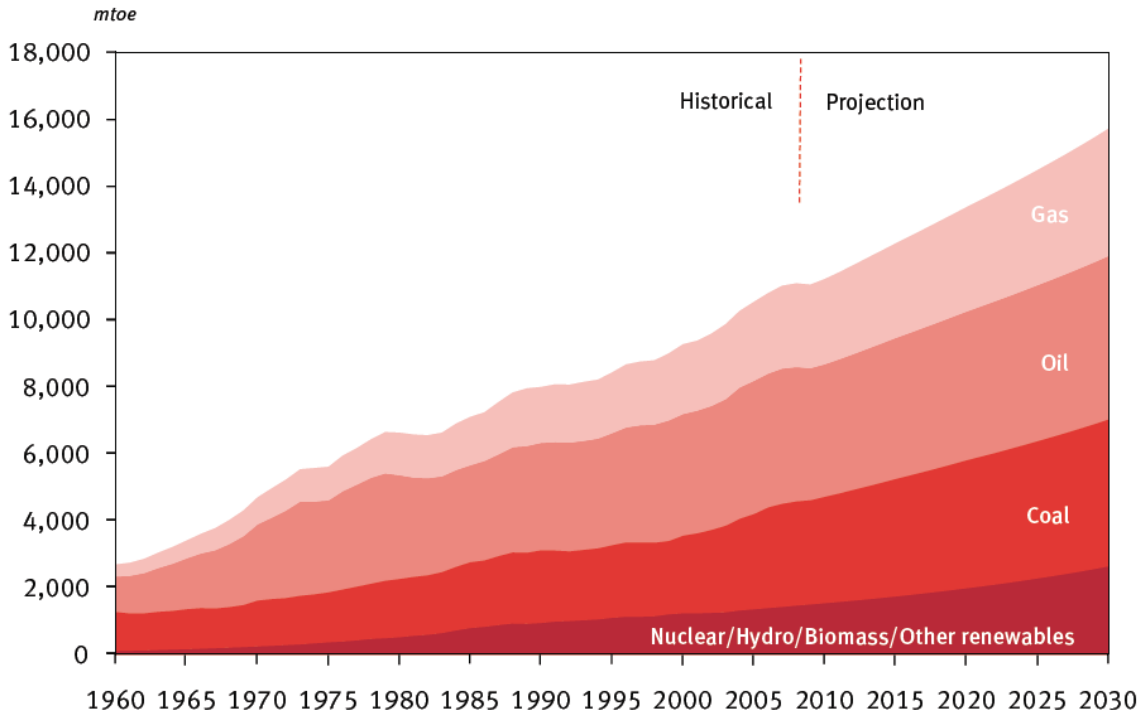
- 65.2% of total electricity consumption
- > 36% of total primary energy use
- 30% of total greenhouse gas emissions
- 136 million tons of construction and demolition waste (approx. 1.26 $kg \cdot person^{-1} \cdot day^{-1}$)
- 12% of potable water
- 40% (3 billion $tons \cdot yr^{-1}$) of raw materials use globally

Indoor Air Pollution.

- Bacteria
- Molds and mildews
- Viruses
- Animal dander and cat saliva
- Plants
- House dust
- Mites
- Cockroaches
- Pollen

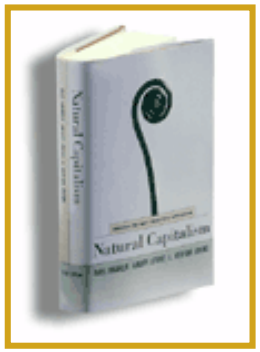
More than 3 million deaths each year are caused by air pollution, mostly due to particulate pollution. Acute respiratory infections due to indoor pollution are mainly responsible for these deaths.

Increasing Energy Consumption.



Global population and consumption of energy has increased steadily in the last 100 years. This has occurred mainly from nonrenewable fossil sources!

“It is cheaper to save fuel than to buy it, no matter what kind it is”



Natural Capital
by A. Lovins 2000

Fossil Fuel Processing has Environmental Consequences…

Effects of Fossil Fuel Combustion.

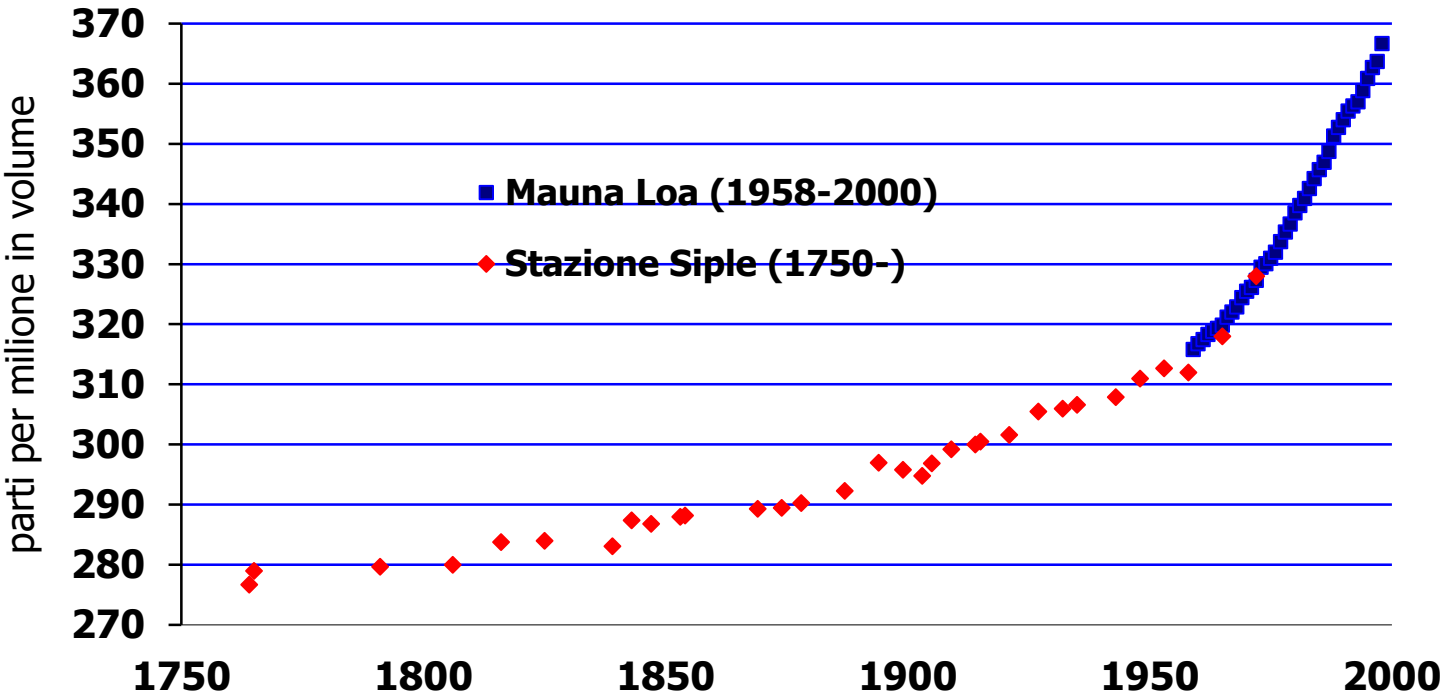
- Fossil fuels are hydrocarbons containing traces of nitrogen, sulfur and other elements.
- Typical combustion reaction:

$$C_wH_xO_zN_aS_b + O_2 + cN_2 \rightarrow w(CO_2+CO) + x/2\ H_2O + (a+c/2)NO_x + bSO_2 + \ldots$$

- Only H_2O is essentially benign ...
- CO and many HC's are toxic to humans.
- NO_x and SO_2 combine with rainwater to form nitric and sulfuric acids, i.e., "acid rain".
- CO_2 is the primary culprit in global warming, but other GHG gases are also important.
- Stratospheric Ozone Depletion (if halogen are present).
- Transition metal pollution from ashes.

Increase of Global CO_2 Emissions.

Atmospheric carbon dioxide concentrations (from 1750 to 2000 ac).
N.B. In 2013 the CO_2 level growths to 400 ppm!!!



Source: C.D. Keeling and T.P. Whorf, Atmospheric CO_2 Concentrations (ppmv) derived from in situ air samples collected at Mauna Loa Observatory, Hawaii, Scripps Institute of Oceanography, 1998. A. Neftel et al, Historical CO_2 Record from the Siple Station Ice Core, Physics Institute, University of Bern, Switzerland, 1994.

The Effect of Industrial Revolution on Atmospheric CO_2 Concentration.

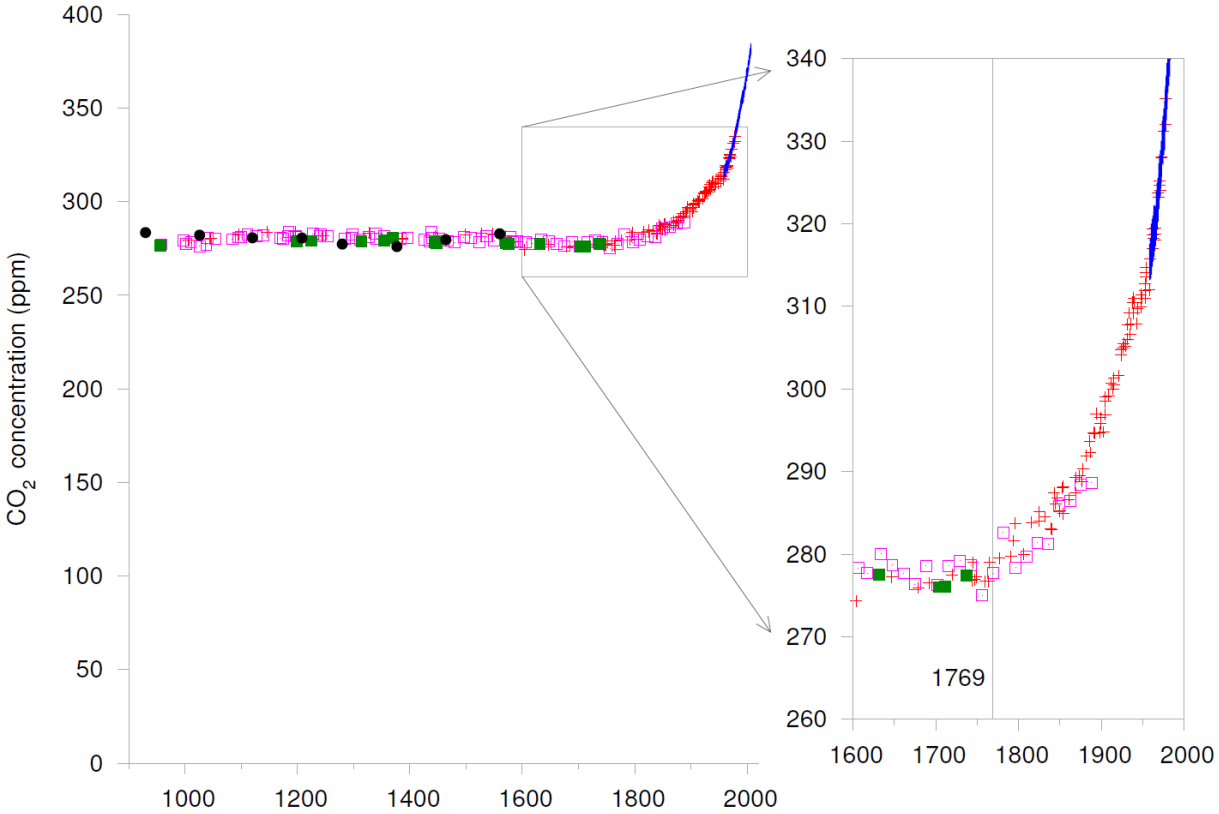
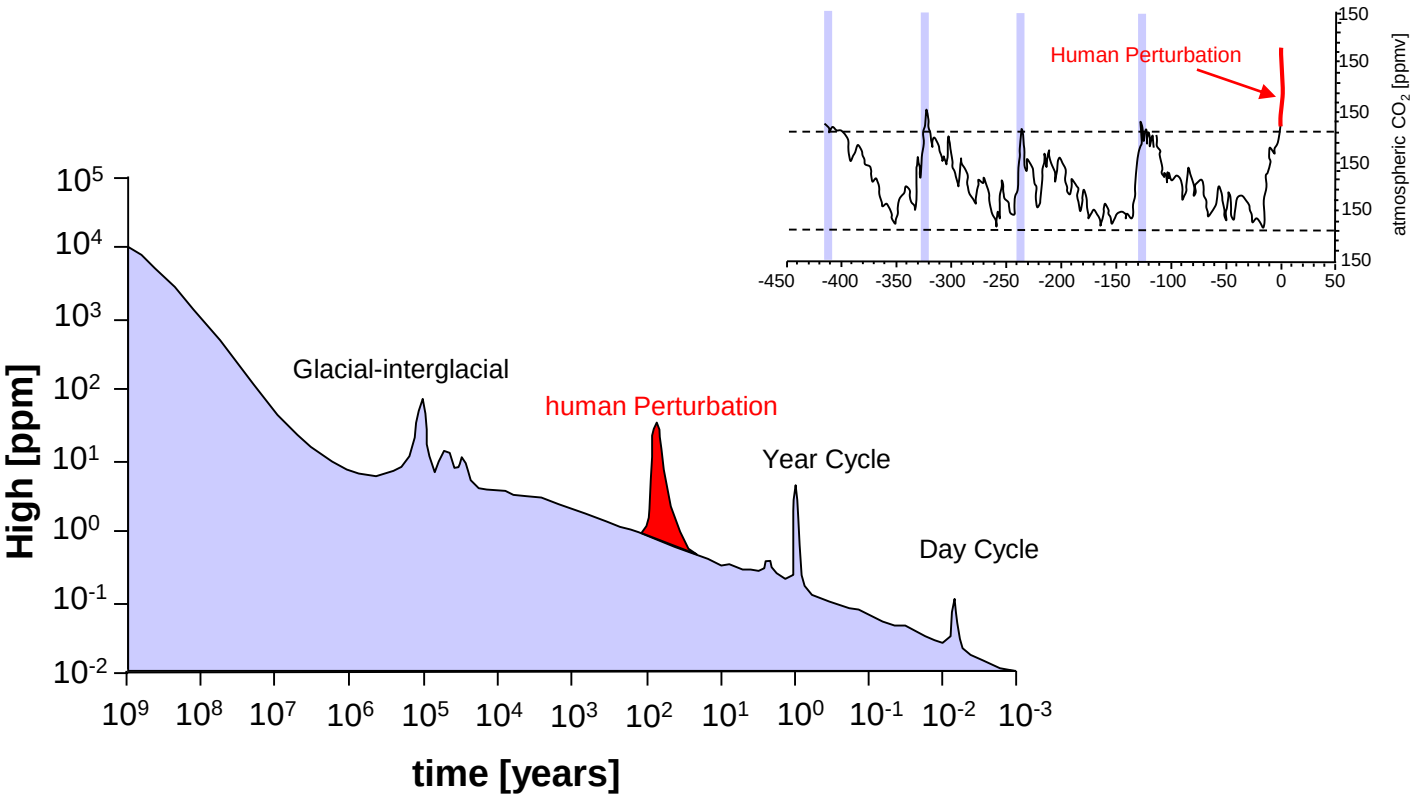


Figure. Carbon dioxide (CO_2) concentrations (in parts per million) for the last 1100 years, measured from air trapped in ice cores (up to 1977) and directly in Hawaii (from 1958 onwards).

Source: D.J.C. Mackay sewtha.pdf : Sustainable Energy — without the hot air Version 3.5.2. Nov. 3, 2008.

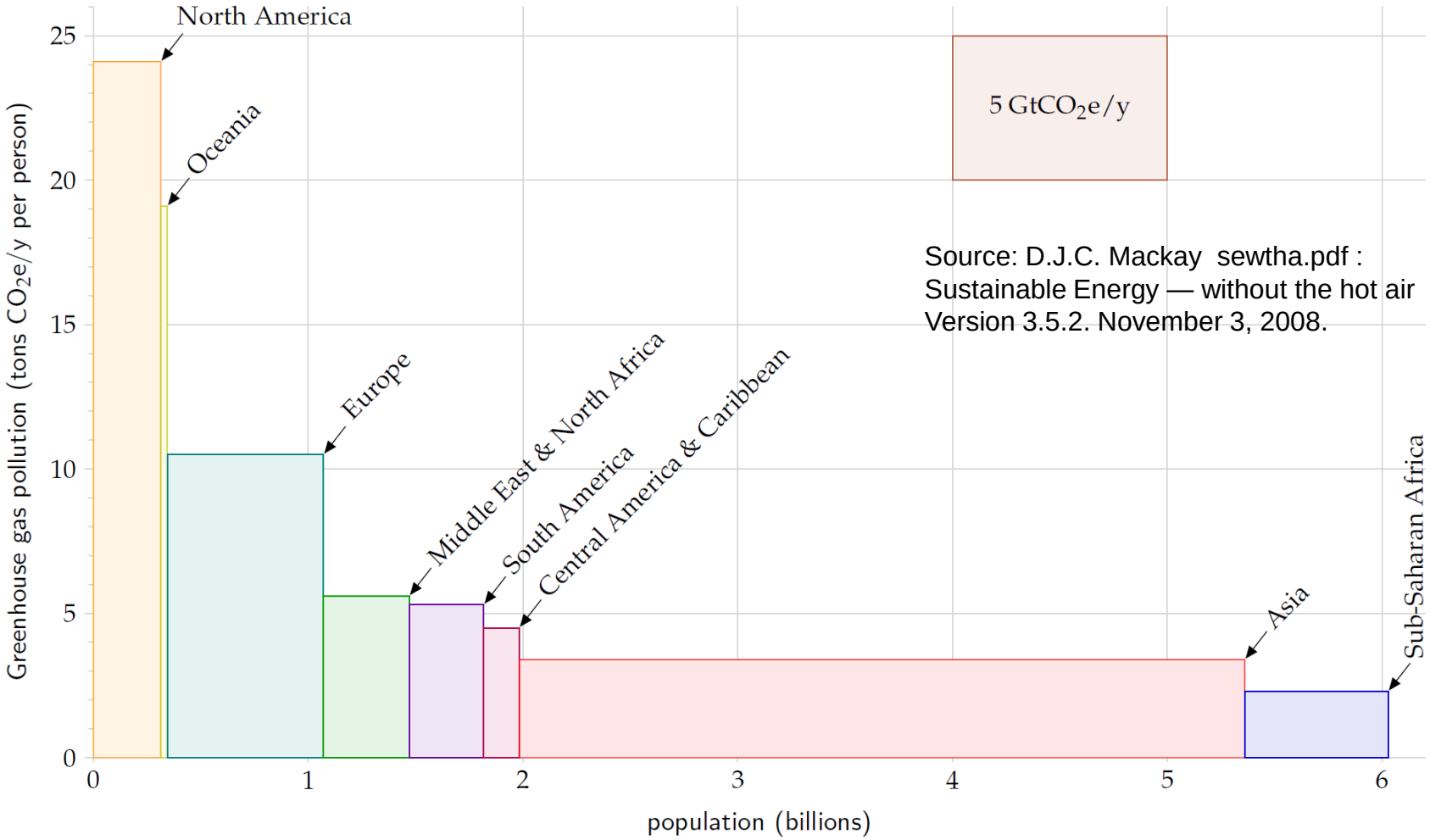
Something new may have happened between 1800 AD and 2000 AD. The year 1769 is marked because in that year James Watt patented his steam engine. (The first practical steam engine was invented 70 years earlier in 1698, but Watt's was much more efficient)

Time Dependence of Atmospheric CO_2 Fluctuation Width.



Note: Human perturbation, occurred in the last 200 years, is now close to CO_2 changes of glacial-interglacial cycles, occurred in ten of Townshend years. In the insert the time trend of CO_2 vs. time in the last 400,000 years is reported as estimated from glass carrots (Petit et al.1999, Indermuehle et al., 1999) and direct atmospheric observations (Keeling e al., 1995, Tans e al., 1999).

Greenhouse Gas Emissions for Earth Regions vs. Population.

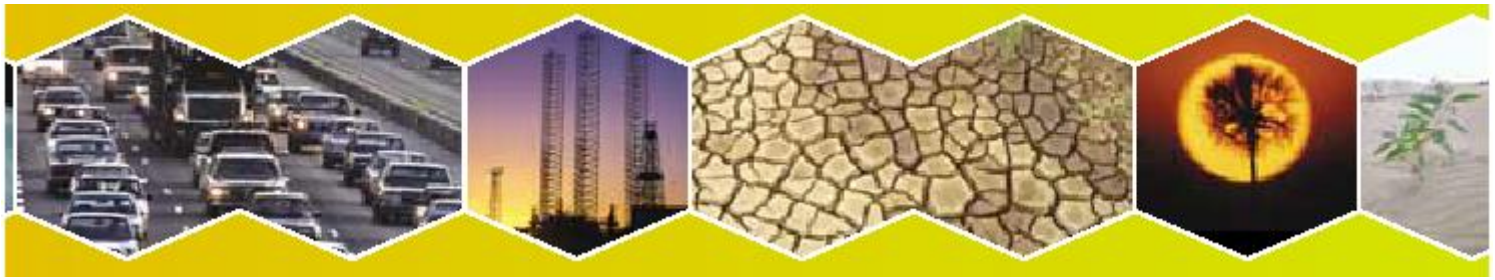


Each rectangle's area represents the greenhouse gas emissions of one region. The width of the rectangle is the population of the region, and the height is the average per-capita emissions in that region.

Climate Change.

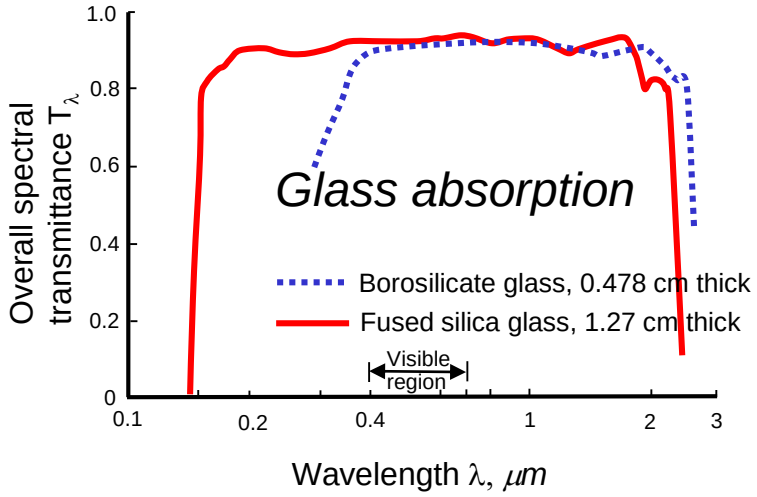
There are many signs of climate change

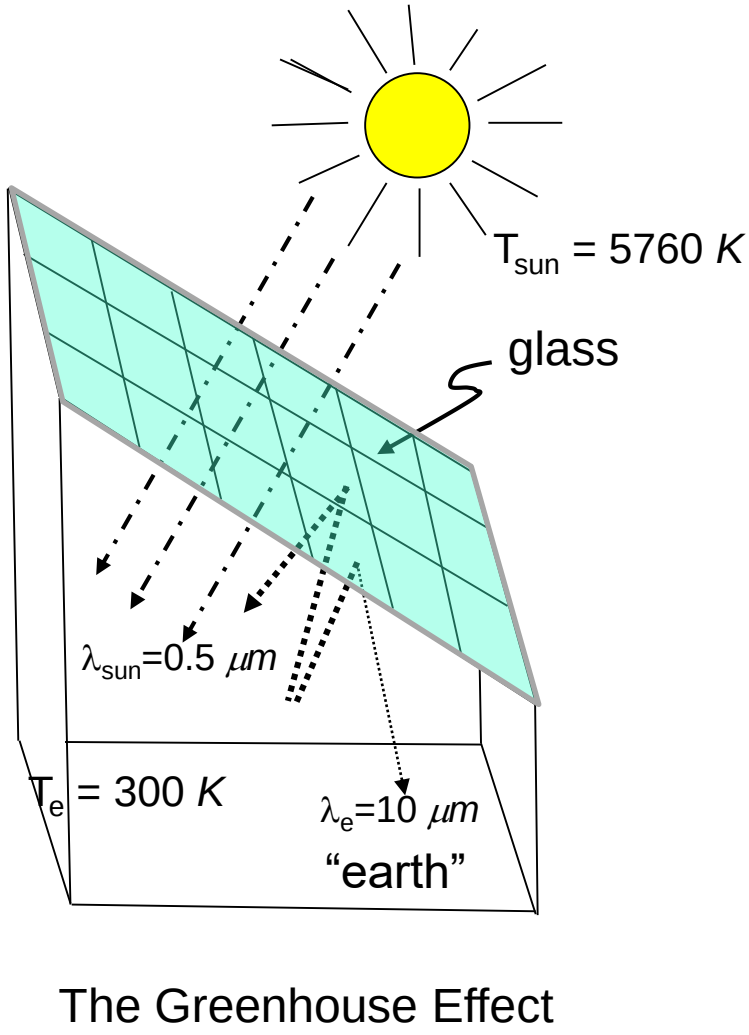
- Global average surface temperature have increased by about 0.6 °C since 1900
- Sea levels are rising by about 1 cm per decade.
- Arctic see ice thickness has declined 40 cm in the past 40 years
- Major glaciers throughout the world are retreating.
- Nordic lake ice is forming late in the autumn and melts early in the spring.
- Precipitations in the Northern Hemisphere are increased, particularly strong rainfall.
- El Nino events have become more common and more intense
- In part of Asia and Africa, droughts have increased in frequency and intensity.
- Insurance payments for damage from floods and storms from about $2 billion annually in the 1980s to $30 billion in the early 1990s and to $120 billion in 2015.



A Greenhouse...

- Sunlight at $\lambda = 0.5\ \mu m$ mostly passes through the glass
- Re-emitted radiant energy from the ~300 *K* interior is at $\lambda \cong 10\ \mu m$
- The glass is opaque to this infrared wavelength, so re-emitted energy cannot radiate away
- The greenhouse warms up





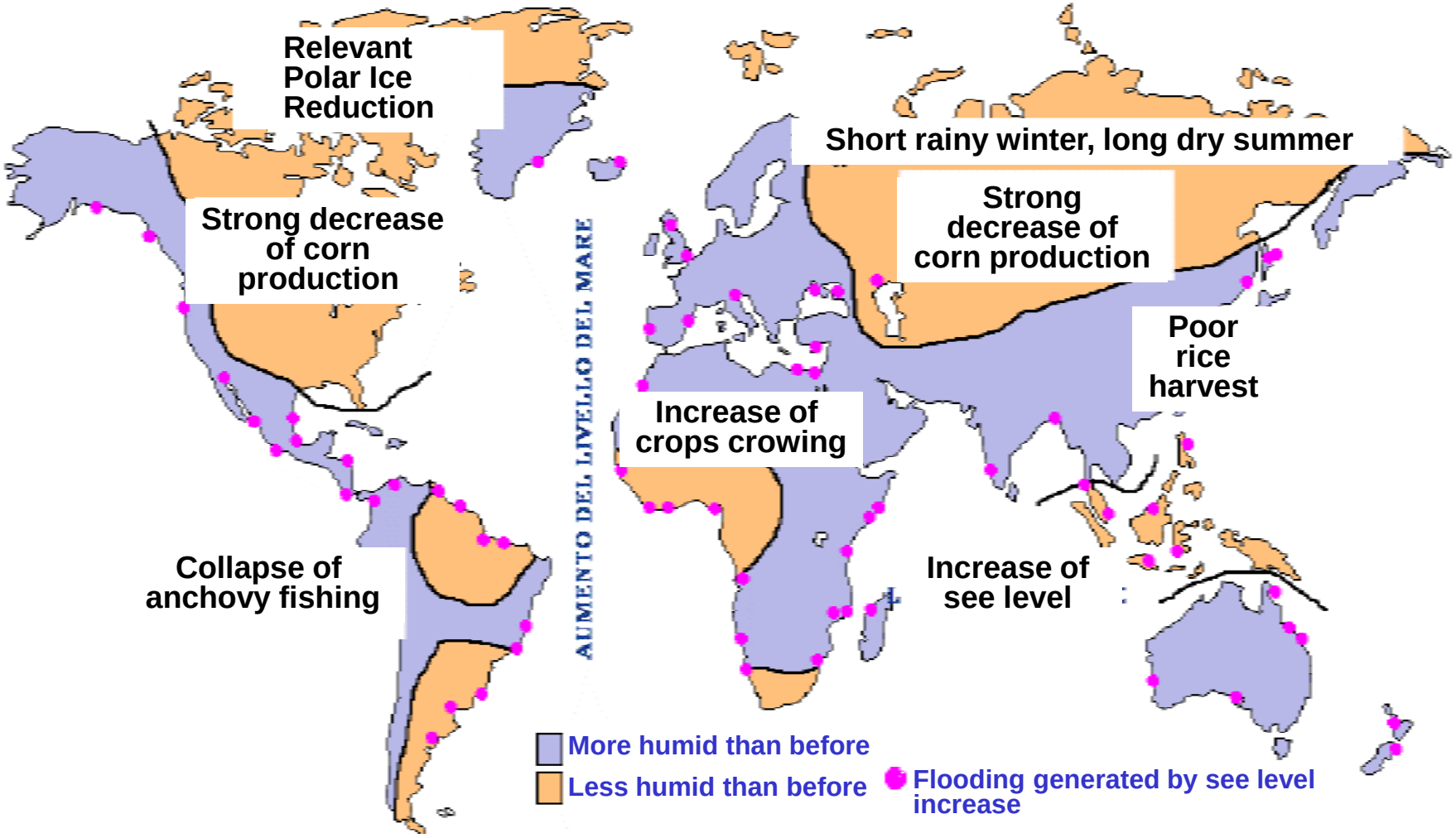
The Greenhouse Effect

Leading Facts about CO_2 Science.

- **The earth absorbs anthropogenic CO_2 at a limited rate**
  - Emissions would have to drop to about half of their current value to stabilize atmospheric concentration at 550 *ppm*
  - This in the face of a doubling of energy demand in the next 50 years (1.5% per year emissions growth)
- **The lifetime of CO_2 in the atmosphere is 200-300 years**
  - The atmosphere will accumulate emissions during the 21st Century
  - Near-term emissions growth can be offset by greater long-term reductions
  - Limited emissions reductions only delay the concentration growth (20% emissions reduction buys 15 years)

Effects of Mean World Temperature Increase.

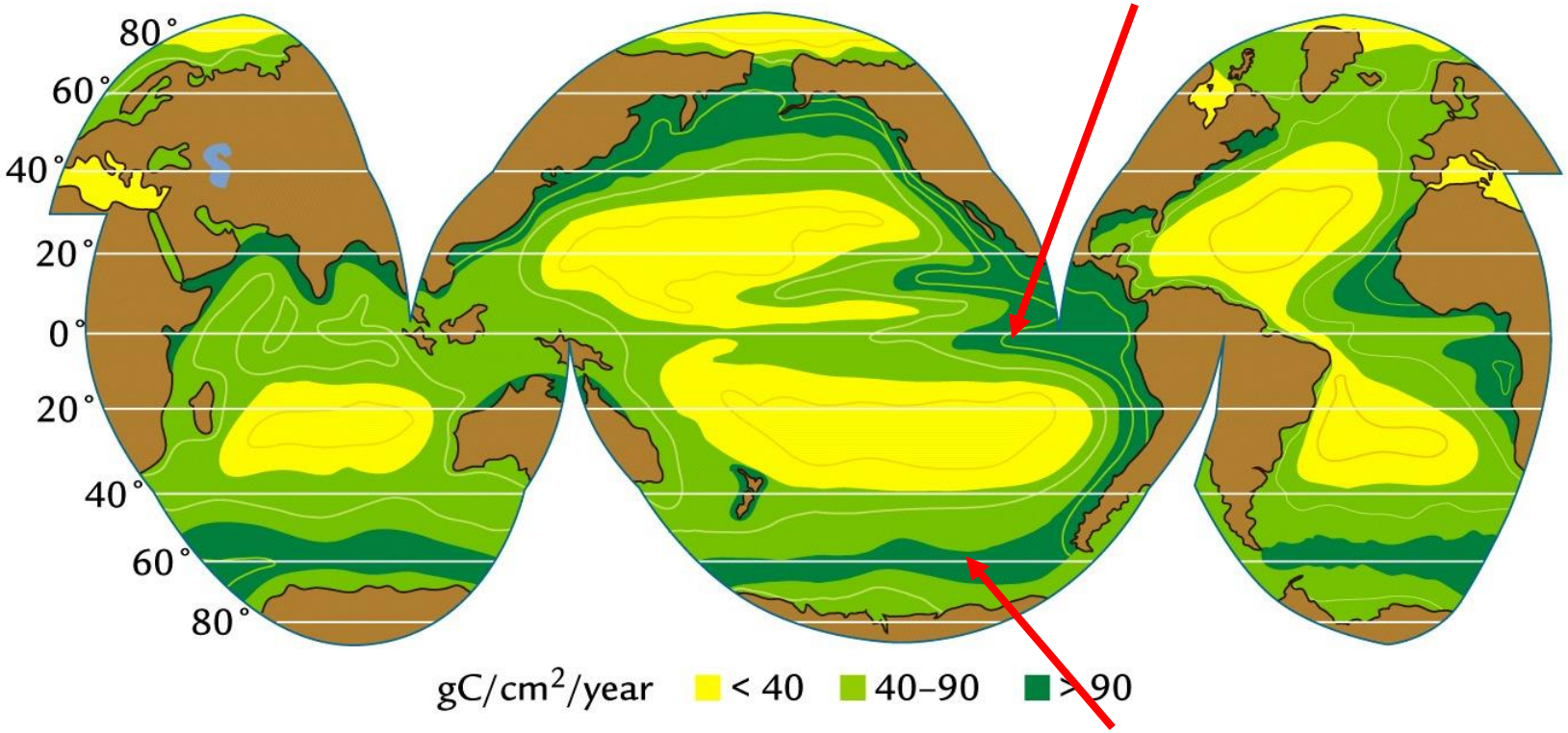
What can occur if surface hearth temperature will increase 1-2 degree, in mean.



Actual Primary Production and Nutrients.

Annual carbon production in modern ocean: coastal, equator, southern ocean

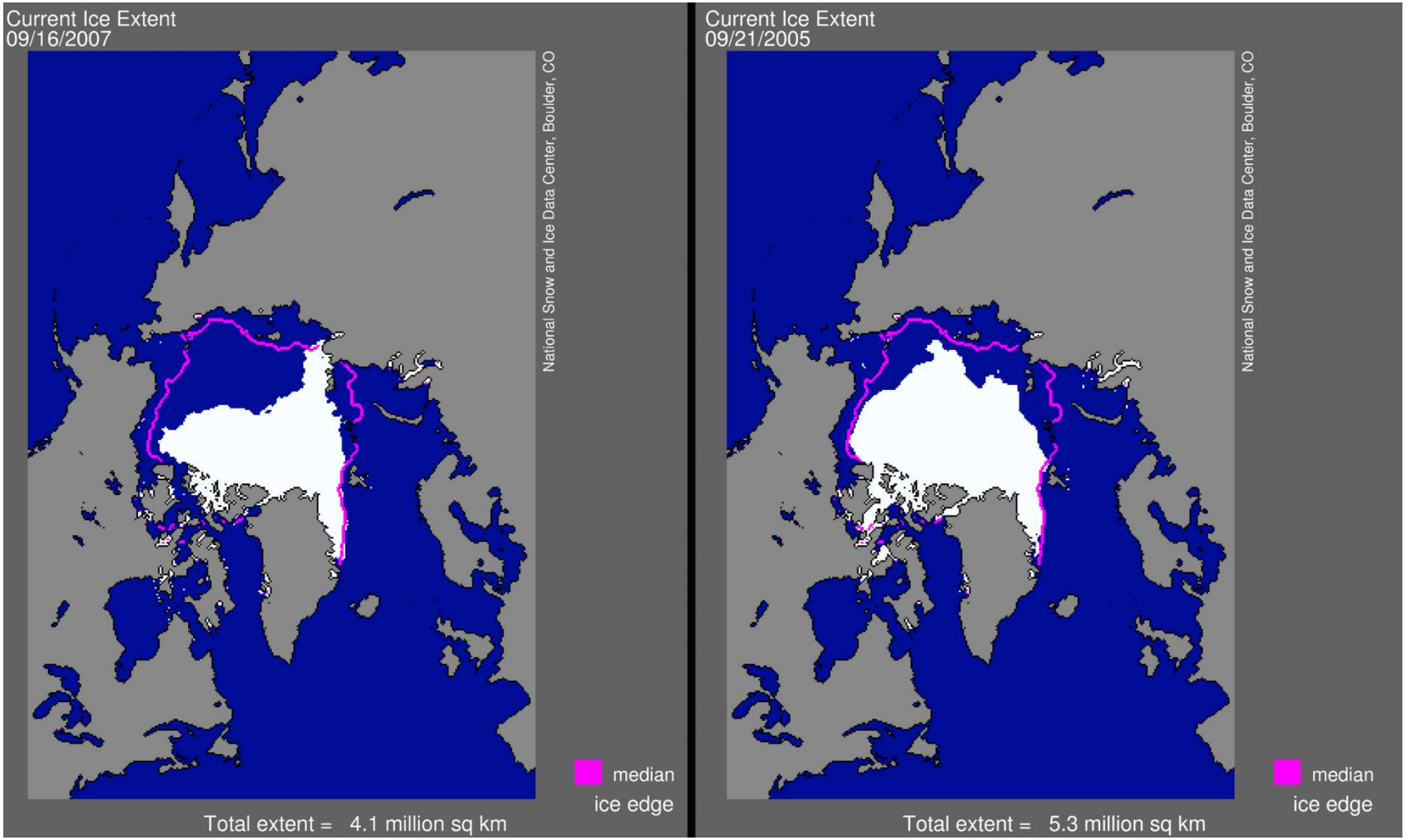
Tropical pump, enough light, so nutrient (N, P) limited



Southern ocean pump,

Not enough light, excess nutrients, but. **iron limited**.

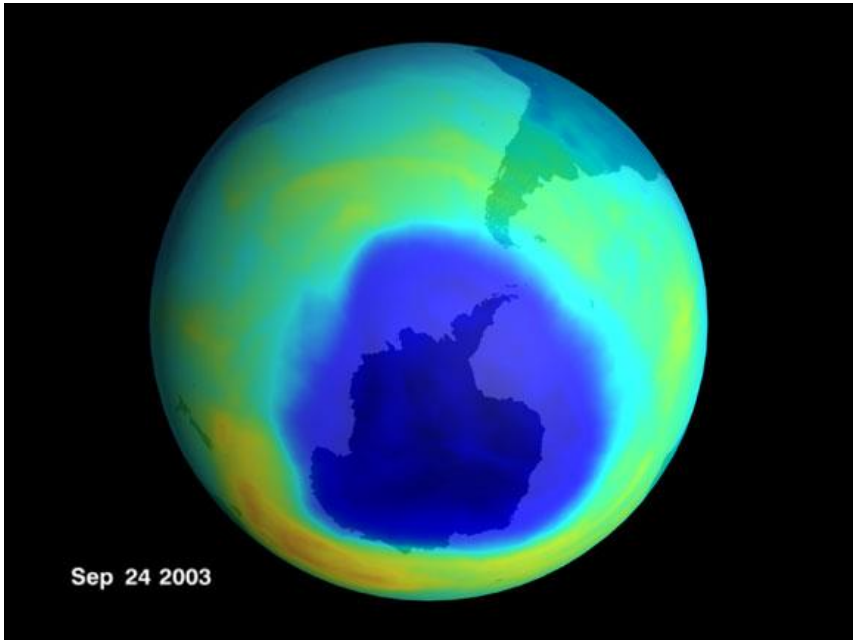
Minimum of Summer Arctic Ice 2007 vs. 2005.



Stratospheric Ozone Depletion.

- Ozone is a good absorber of solar ultraviolet radiation, and depletion of upper atmosphere ozone results in increased surface levels of UV radiation.
- Increased levels of UV can result to increased human skin cancer and plant damage.
- CFC compounds decompose ozone by generation of chlorine atoms in the stratosphere

The ozone hole at its peak in 2003 over Antarctica



cycle $Cl^{\bullet}/ClO^{\bullet}$

$$Cl^{\bullet} + O_3 \rightarrow ClO^{\bullet} + O_2 \qquad k_1 = 2.9\times10^{-11}\, e^{-260/T}\ cm^3\cdot molec^{-1}\cdot s^{-1}$$

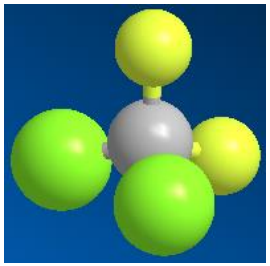
$$ClO^{\bullet} + O \rightarrow Cl^{\bullet} + O_2 \qquad k_2 = 7.7\times10^{-11} e^{-130/T}\ cm^3\cdot molec^{-1}\cdot s^{-1}$$

$$O + O_3 \rightarrow 2\,O_2 \qquad \text{(net)}$$

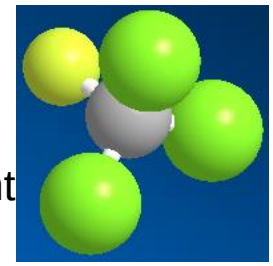
CFC from HVAC Equipment and Ozone.

- Refrigerators, air conditioners and heat pumps have used chlorofluorocarbons (CFC's) as their working fluids (refrigerants).
- CFC's at normal conditions are extremely inert, stable and non-toxic. Their use leads to good equipment **efficiency and safety.**
- Because they are so inert, CFC's are not destroyed in the lower atmosphere and eventually rise to upper atmosphere (stratosphere).
- UV light in the stratosphere breaks down the CFC molecule, releasing chlorine atoms, which attacks ozone (O_3) converting to O_2 and O.
- The Cl atoms are released after breaking down an O_3 molecule, and both the O and the Cl are free to attack other O_3 molecules.
- Release of CFCs has already caused significant stratospheric ozone depletion, particularly in the South and North Polar regions.

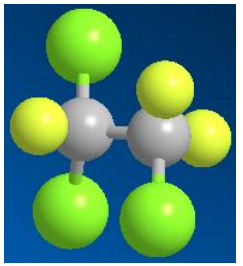
CFC-12
CF_2Cl_2
Refrigerant



CFC-11
$CFCl_3$
Blowing agent

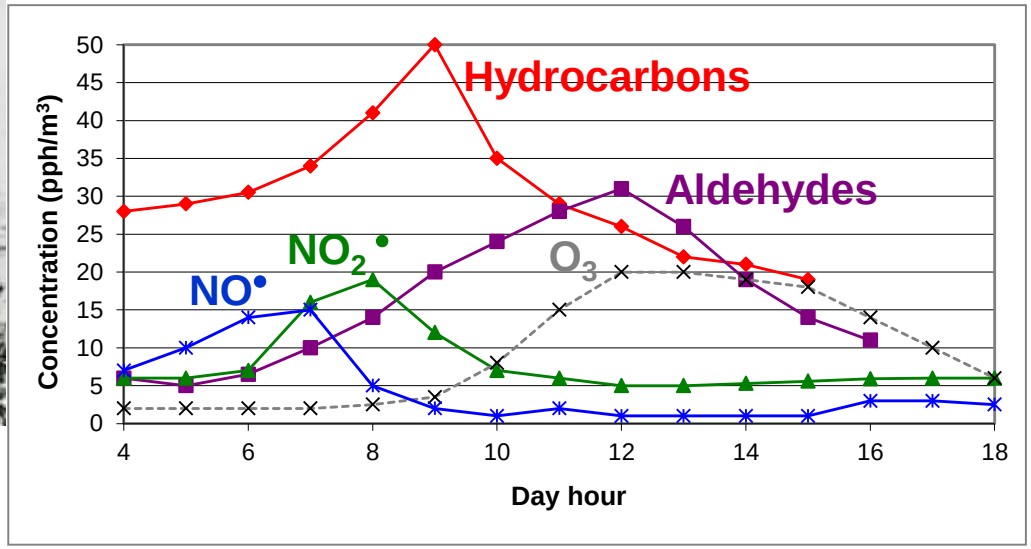


CFC-113
$CF_2ClCFCl_2$
Cleaning agent



Outdoor Air Quality Issues: Smog Formation.

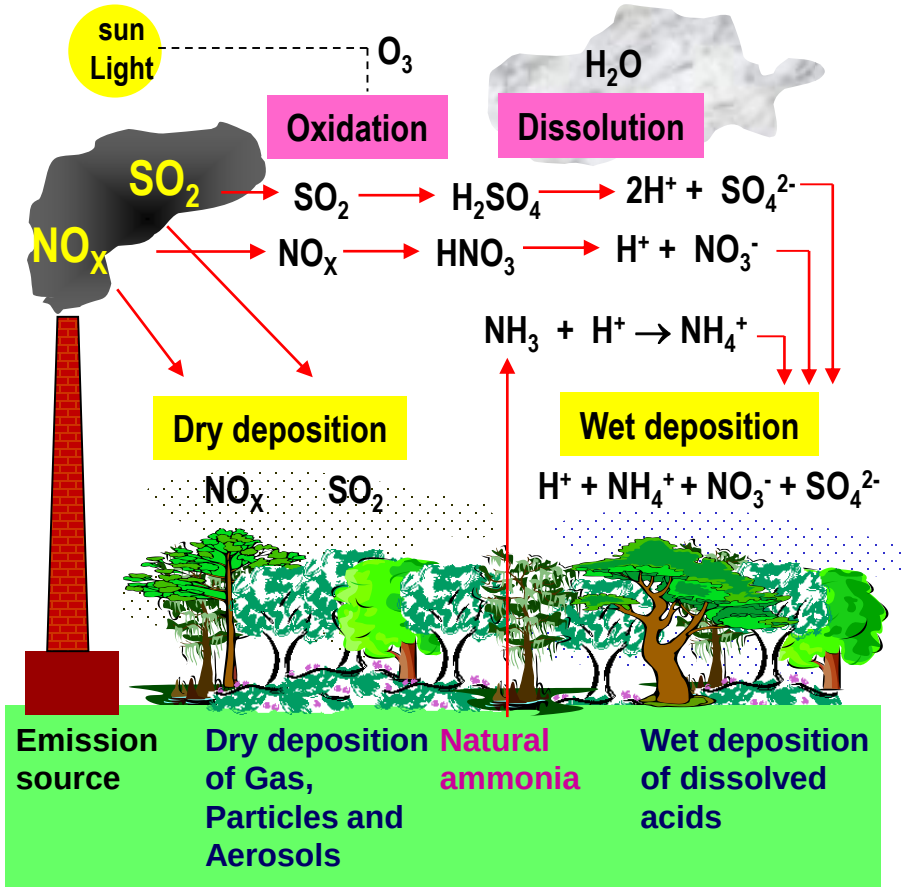
$$\left.\begin{matrix} NO^{\bullet} \\ HC \end{matrix}\right\} \xrightarrow[\text{sun}]{h\nu} NO_2^{\bullet} \xrightarrow[\text{sun}]{h\nu} O_3, \text{PAN, etc.}$$



"A smog inversion layer blanketing downtown Los Angeles in 1956." Source: www.epa.gov

Acid Rain: Defoliation – Corrosion.

Atmospheric intake of sulfur produce acid oxides SO_2 and SO_3 and then sulfuric acid (H_2SO_4) starting a process known as acid rain.



The Waste Concern.

- "E
- C

Hazardous Waste Landfill.

Relevant Industrial Accidents!

BASF,
Oppau/Ludwigshafen,
September 21, 1921

Crater: 80 m diameter,
16 m deep

450 dead

80 years

$NH_4NO_3 \rightarrow N_2 + ½O_2 + 2H_2O$
{300°, $\Delta G<0$}

AZF, Toulouse,
September 21, 2001

Crater: 50 m diameter,
10 m deep

29 dead

Level of Safety at Work.

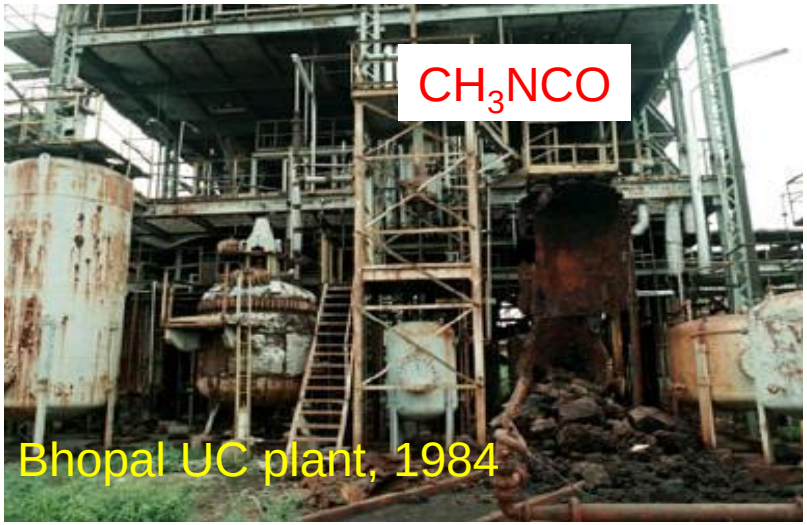
7.628.184	➢ number of reported accidents EU-15 2000
4.2	➢ million accidents at work with more than 3 days absence 2003
4.664	➢ fatal accidents at work EU-15 2003 (3 876 in the EU-28 during 2015, 102 deaths more than 2014)
54.250	➢ occupational diseases in 11 Member States 2003 (68.800 in EU-28 in 2015).

one accident at work in Europe every 5 seconds

4% of all workers are victims of an accident at work during the year

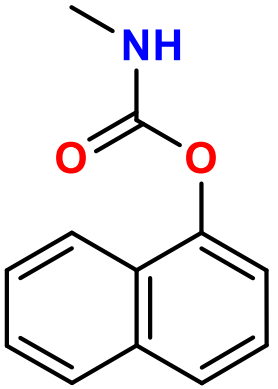
https://ec.europa.eu/eurostat/statistics-explained/index.php/Accidents_at_work_statistics#Accidents_2010_to_2015_-_absolute_changes

Relevant Accidents in Chemical Plants and Transport of Chemical Substances.



What Happened at Bhopal?

Methyl isocyanate ("MIC", CH_3NCO) used to manufacture carbaryl (Sevin®) at a Union Carbide plant in Bhopal, India.



Water (somehow) got into a storage tank containing 15 Tons of MIC

$CH_3NCO + H_2O \rightarrow CH_3OH + HNCO$

(b.p. 40ºC) (b.p. 100ºC) (b.p. 65ºC) (b.p. ca. 25ºC)

$\Delta H_{rxn} \approx -250\ kJ \cdot mol^{-1}$

T ↑, rate ↑ {Arrhenius Law, $k = \exp(-E_{act}/RT)$}

$\Delta P = (nR\Delta T)/V$ plus vaporization:

pressure valve burst open, backup scrubber did not work, flare tower did not work

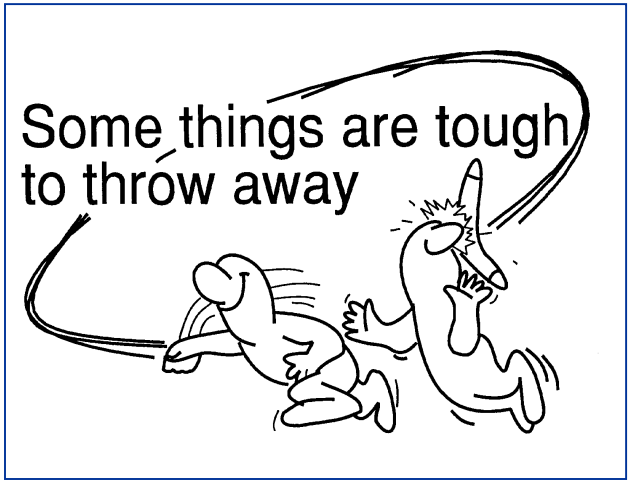
What could have been done differently?

4 Tons of MIC vaporized, wind carried vapor across the city. At least 3,800 people died, 1,000 more injured and blinded. Legal claims arose.

Unintended Consequences on Health.

- The Surprises (see REACh – EU regulation)
  - Persistent Organic Pollutants (POP e.g. DDT, PCB, Polyacrylates..)
  - Bioaccumulation
    - PCB at 1 ppb conc. in H_2O, accumulate to 6,400 in plankton, 240,000 in squid, 13,000,000 in dolphin and tuna
  - Atmospheric Distillation (especially in northern latitudes)
  - Endocrine disruption

- The Messes Left Behind
  - Thousands of tons of abandoned pesticides
  - Nuclear legacy with $300 billion price tag
  - Industrial contaminated sites
  - Spread of POP in environment and humans



Materials of Concern (Pratt & Whitney).

Prohibited - Higher Risk
Substitutes In Hand

- Arsenic & compounds
- Asbestos
- Benzene
- Beryllium (>2%)
- Cadmium & compounds
- Chlorinated solvents
- Ethyl alcohol (ash and wipe)
- Ethylene glycol ether compounds
- Formaldehyde
- Mercury & compounds
- Methanol (as handwipe)
- Methylene chloride
- Class I ozone depleting substances
- Radioactive materials, including
- Thoriated (TD) nickel
- Toluene diisocyanate

Restricted - Higher Risk
Substitutes Being Developed

- Beryllium (<2%)
- Chromium, hexavalent
- Class II ODS
- Cyanides
- Dimethylformamide
- HCFC-14 lb & HCFC-22
- Hydrazine
- Hydrofluoric acid - braze fluxes
- Hydrogen fluoride gas
- Lead & compounds
- Manmade fibers, e.g., cristobalite, fiberfrax
- MDA (4', 4'-Methylenedianiline)
- Methyl alcohol (methanol)
- Methyl ethyl ketone (MEK, 2-butanone)
- Methyl *iso*-butyl ketone (MIBK, 4-methyl-2-pentanone)
- Phenol
- Styrene
- Toluene
- Xylene

To Be Reduced - Lower Risk
Being Monitored

- Acetone
- Ammonia
- Butyl alcohol
- Ethyl benzene
- n-Hexane
- Hydrofluoric acid - cleaning
- Isocyanates
- n-methyl-2-pyrrolidone
- Isopropyl alcohol
- Nickel plate
- Nitric acid
- Petroleum distillates (e.g., naphtha, mineral spirits, Stoddard solvent, varsol, evaporative lubricants)
- Phosphoric acid
- Sec-butyl alcohol
- Sulfuric acid
- 1, 2, 4-Trimethylbenzene

ODS = Ozone-depleting Substances

Banned Chemicals.

- Atrazine: banned in EU in 2003 because of unavoidable water contamination
- Tributyltin (TBT): Most antifoulant uses phased out by 2003, remaining uses by 2008
- Alkyl phenols and their ethoxylates: EU Directive prevents use as co-formulants in new products from 2005; voluntary UK agreement to replace AP(E)s in existing pesticide formulations
- Lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated biphenyl ethers are banned from 2006 in electronic equipment (EU RoHS directory)
- Some fluorocarbons (i.e. HCFC-141b, CFC-11) are banned from 2004
- Vinclozolin, Procymidone, Fenarimol: EU discussing phasing out all uses.
- In Europe the REACh encourage new bans. (see https://echa.europa.eu/regulations/reach/understanding-reach)

Beyond the Environment: *the Triple Bottom Line.*

Living within environmental limits:

Ensure natural resources to support life remain unimpaired

Ensuring a strong, healthy & just society:

Meet diverse needs of all; promote wellbeing inclusion/opportunity

Achieving a sustainable economy:

Strong, stable, efficient & fair