Reasons why we have ever increasing energy production and consumption (energy conversion):

1. Population increase (8 billion -> levels off at 10.5 billion)
2. Technological advance
3. Others ...?

Aftermaths:

1. Shortages of Food and Fresh Water (for drinking and cooling of PP's)
2. Global warming
3. Waste (nuclear, etc.)
4. Adverse effects on environment and ecology
5. Others ...?

} Sustainable development HOW?

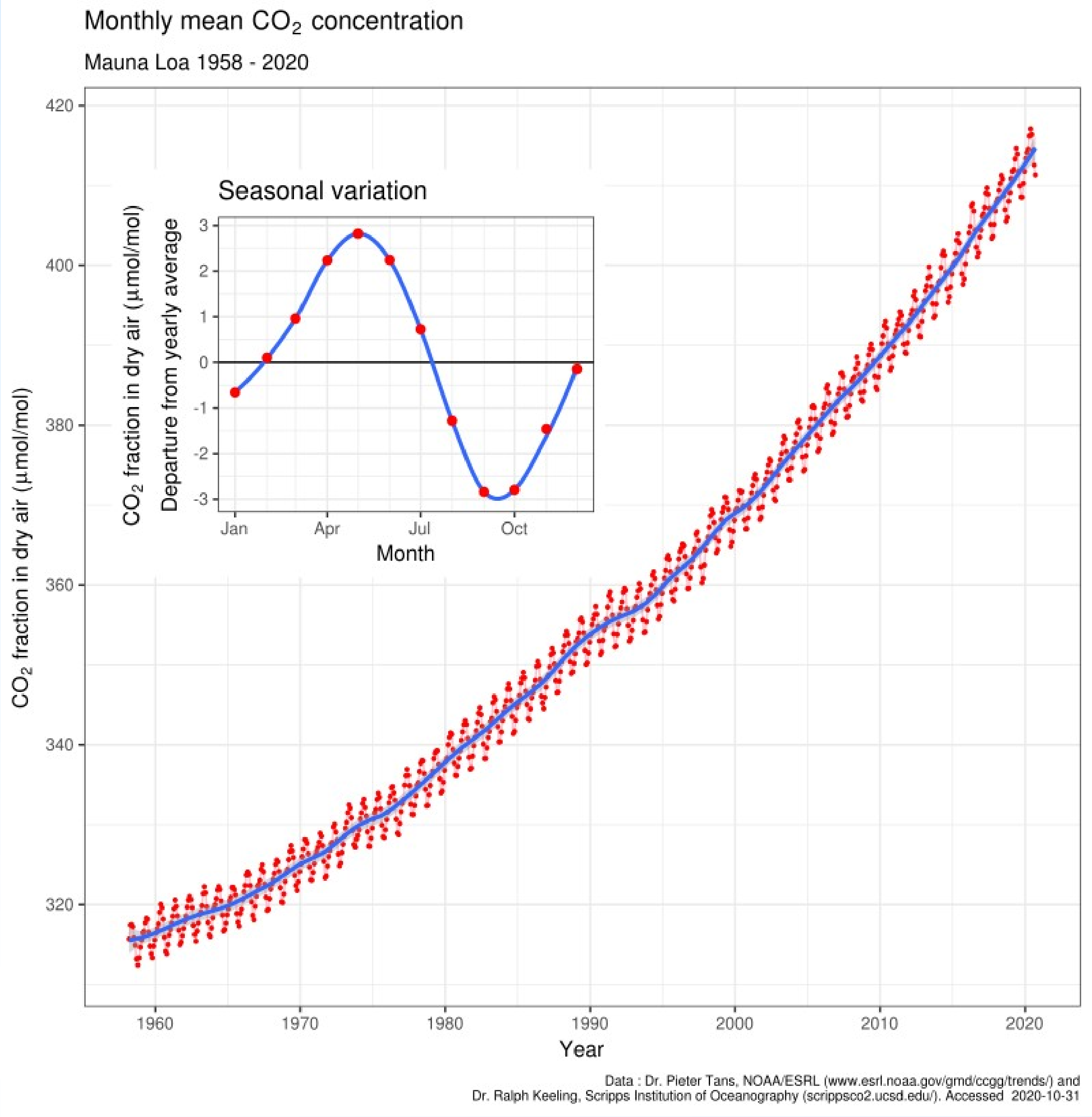
Carbon Dioxide – Is it a real threat?

The exponential increase of energy consumption, since the beginning of the industrial revolution, has produced significant changes in the global environment, chief among which is the increase of the average concentration of **carbon dioxide** in the atmosphere from 280 ppm in 1750 to more than 390 ppm in 2011.

Climatologists predict that this change will cause an increase of the average temperature of the planet as well as regional and global and climatic changes. Is CO_2 is the cause of this **global warming**?

Read the Maruyama's article on OdtuClass on global warming.

See: https://www.nationalgeographic.com/environment/global-warming/global-warming-overview/


Monthly mean CO2 concentration
Mauna Loa 1958 - 2020
420
400
380
360
340
320
CO2 fraction in dry air (μmol/mol)
1960
1970
1980
1990
2000
2010
2020
Year
Seasonal variation
3
2
1
0
-1
-2
-3
CO2 fraction in dry air (μmol/mol)
Departure from yearly average
Jan
Apr
Jul
Oct
Month
Data : Dr. Pieter Tans, NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/) and
Dr. Ralph Keeling, Scripps Institution of Oceanography (scrippsco2.ucsd.edu/). Accessed 2020-10-31

In science and engineering, the "**parts-per**" **notation** is a set of pseudo-units to describe small values of miscellaneous dimensionless quantities, e.g. mole fraction or mass fraction. Since these fractions are quantity-per-quantity measures, they are pure numbers with no associated units of measurement. This notation is not part of the International System of Units (SI system), and its meaning is ambiguous.

It is often used describing dilute solutions in chemistry, for instance, the relative abundance of dissolved minerals or pollutants in water. The quantity "1 ppm" can be used for a mass fraction if a water-borne pollutant is present at one-millionth of a gram per gram of sample solution.

400 ppm CO_2 in atmosphere is on molar basis.

Environmental threats are neutralized by public policy, national policy, or concerted international efforts and protocols that are ratified by several countries.

Despite the efforts of the environmental community, there is not yet a global agreement for the mitigation of the effects of high CO_2 concentration, which poses the principal environmental threat of the twenty-first century.

The problem of nuclear waste is being addressed at several national and regional levels and it appears that solutions for the long term storage of radionuclides will become available in the near future.

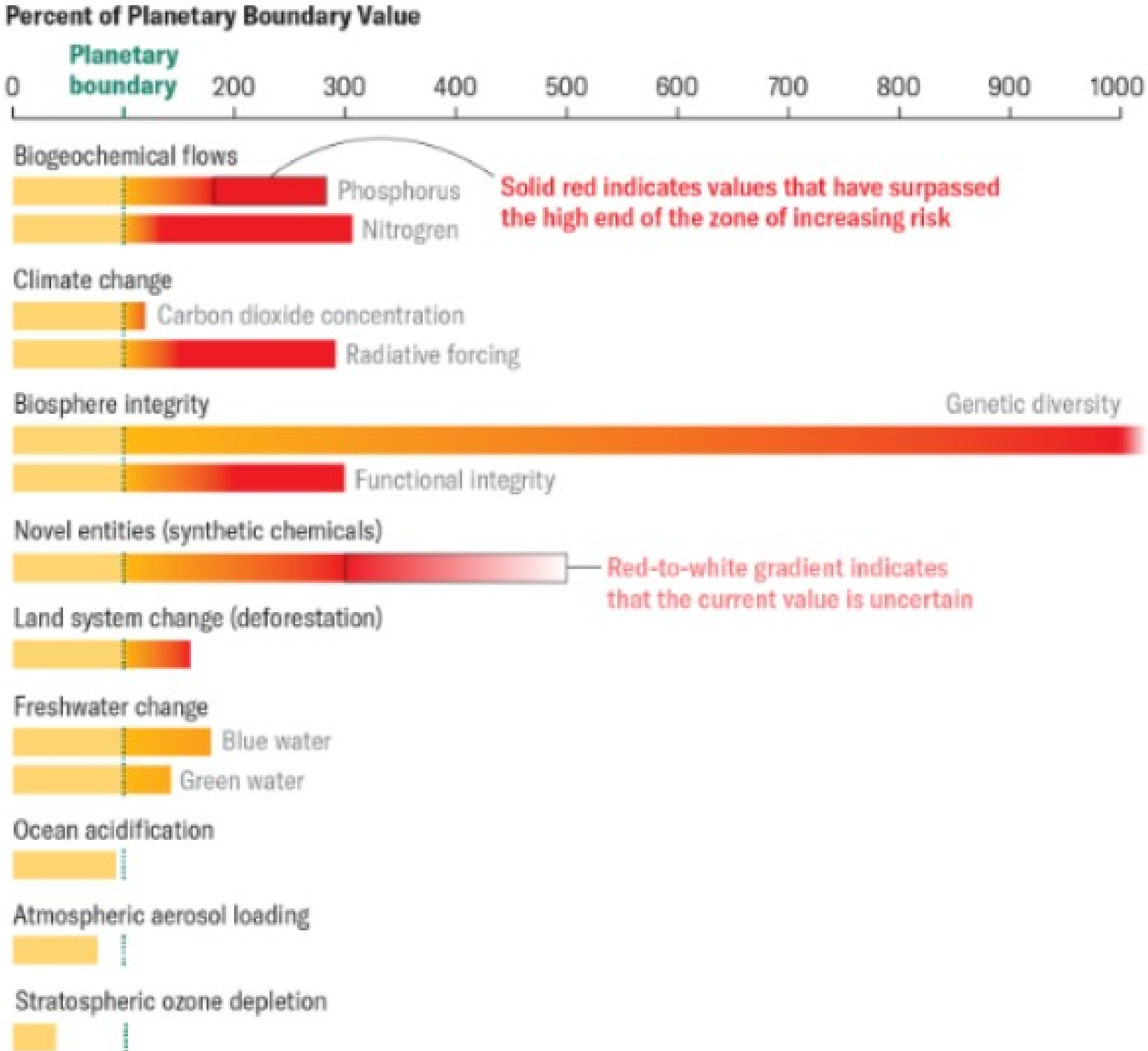
National public policies and international collaboration has almost solved the acid rain, lead contamination and ozone layer problems. These are viewed as success stories stemming from international collaboration and successful public policy.

See the article on «Odtuclass»: Humans Have Crossed 6 of 9 Planetary Boundaries

By Meghan Bartels, September 13, 2023

- Biogeochemical Flows: Phosphorous and Nitrogen
- Climate Change: CO_2 Concentration and Radiative Forcing
- Biosphere Integrity: Genetic Diversity and Functional Integrity
- Novel Entities (Synthetic Chemicals)
- Land System Change (Deforestation)
- Fresh Water Change: Blue and Green
- Ocean Acidification
- Atmospheric Aerosol Loading
- Stratospheric Ozone Depletion

} Not yet exceeded



Credit: Amanda Montañez; Source: "Earth Beyond Six of Nine Planetary Boundaries," by Katherine Richardson et al., in *Science Advances*, Vol. 9, No. 37; September 15, 2023

Environmental and Ecological Effects of Energy Production, Energy Consumption & Other Human Activities

1. Environment, Ecology and Ecosystems
2. Global Climate Change
3. Ozone Layer Depletion
4. Acid Rain
5. Lead Abatement
6. Thermal Pollution and Fresh-Water Use
7. Nuclear Waste
8. Sustainable Development

1. Environment, Ecology and Ecosystems

The environment is everything that surrounds the humans and where all the economic activity occurs. The lithosphere, the atmosphere and the hydrosphere are the three distinct components of the environment.

Processes and events interact in different ways with the environment. For example, a hurricane is formed in the atmosphere and encompasses water that comes from the hydrosphere. When the hurricane washes over land, it dumps to the ground very high quantities of water as rain, which causes local flooding, erodes the soil and caries it into the sea. These types of interactions produce environmental changes, most of which are undesirable.

Ecology is the study of the relationships of organisms with one another and the relationship of organisms to their environment. This subject incorporates principles from the scientific disciplines of biological sciences, physics, physiology, and chemistry.

Ecosystem is a rather loose concept that refers to a subdivision of the landscape or a geographic region that is relatively homogeneous. An ecosystem is made up of organisms, environmental factors, and physical or ecological processes. Hence, the concept of ecosystem comprises organisms, species and populations; soil and water; climate and other physical factors; and processes, such as nutrient cycles, energy flow, water flow, freezing, and thawing.

There is a clear distinction between environmental and ecological processes as well as between the environmental and ecological concerns.

The ecological concerns always involve effects on ecosystems. For example, a hurricane will wash a great deal of soil into the sea and will change the coastline of an entire region.

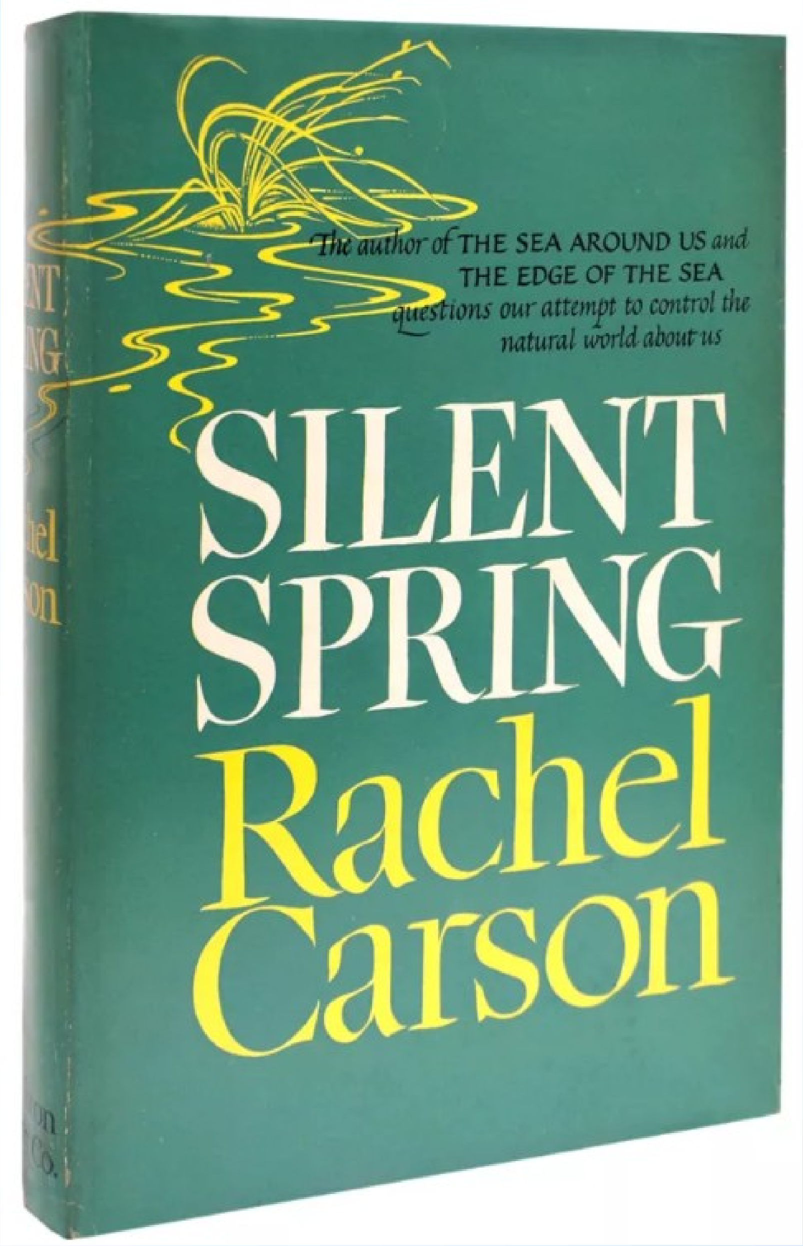
If we are only concerned with the physical process of soil erosion, the suspension sediment in the water, and its subsequent deposition on the bottom of the sea, three purely physical processes, then we have an environmental concern. If we are concerned about the effect of the erosion on the crops, the loss of habitat of subsurface organisms, or about the effect of the increased concentration of pesticides that accompanies soil erosion on the aquatic life, then we have an ecological concern.

DDT (Dichlorodiphenyltrichloroethane)

- Synthetic organic compound used as an insecticide
- Very effective at killing mosquitoes that spread disease
- Had unintended environmental consequences, especially to birds
- Toxic to humans at high doses

Read about Rachel Carson and *Silent Spring*

- Carson, a biologist and writer, raised the alarm on synthetic pesticides like DDT and the harm they had on the environment
- She called for a more thoughtful approach to pest management
- The book (1962) was a significant factor in stimulating the modern environmental movement


The author of THE SEA AROUND US and
THE EDGE OF THE SEA
questions our attempt to control the
natural world about us
SILENT
SPRING
Rachel
Carson

Some Common Environmental Contaminants:

- **Arsenic** - naturally occurring metalloid
- **Mercury -** naturally occurring metal
- **Bisphenol A -** synthetic organic compound
- **Phthalates -** synthetic organic compound
- **Lead -** naturally occurring metal
- **Formaldehyde -** naturally occurring organic compound in low concentrations, but also made synthetic in large concentrations

The Chernobyl nuclear power plant accident occurred in 1986. The steam explosions in the reactor released into the environment a great deal of radionuclides, which were accumulated in the region or were transported to other areas by atmospheric currents. As a result of run-off from the rainfall, a great deal of radioactive cesium and strontium is now physically buried in the bottom of rivers and lakes or in the subsurface of the land. These are environmental changes.

The ecological effects that are consequences of these environmental changes include the mutations in the cells of living species that absorbed radionuclides via the food chain; the decimation of herds of reindeer in Lapland, which consumed grass contaminated with radionuclides; the forests with trees that have radioactive bark; and the significant increase of childhood leukemia and cancer incidents in the human populations, which were severely affected by the release of the radioactivity.

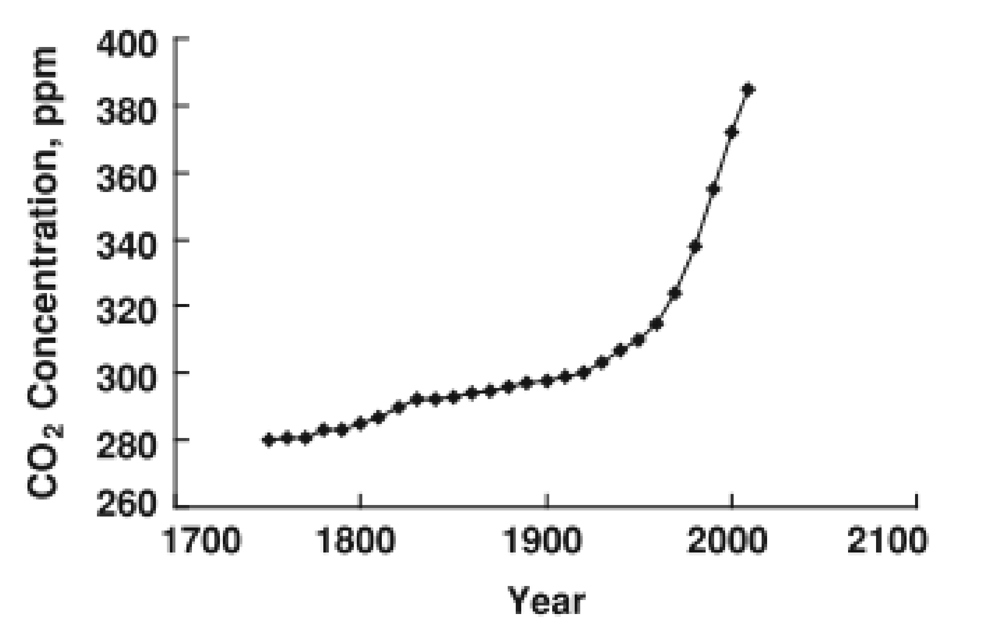
2. Global Climate Change

The most pressing environmental issue of the early twenty-first century is the accumulation of carbon dioxide (CO_2) and the expected global warming. The issue is often debated, frequently divides the experts and has affected several national elections. By the term global warming we define all the effects of the expected increase of the average temperature of the planet, which are due to the increase of the atmospheric concentration of CO_2 and other similar gases.

$$C + O_2 \rightarrow CO_2 \qquad\qquad CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_20$$

While the concentration of CO_2 was almost constant for centuries before 1750, at approximately 280 ppm, the concentration started rising with the increased use of fossil fuels and reached the level 391 ppm in April 2010, a 40 % increase from its historical level.

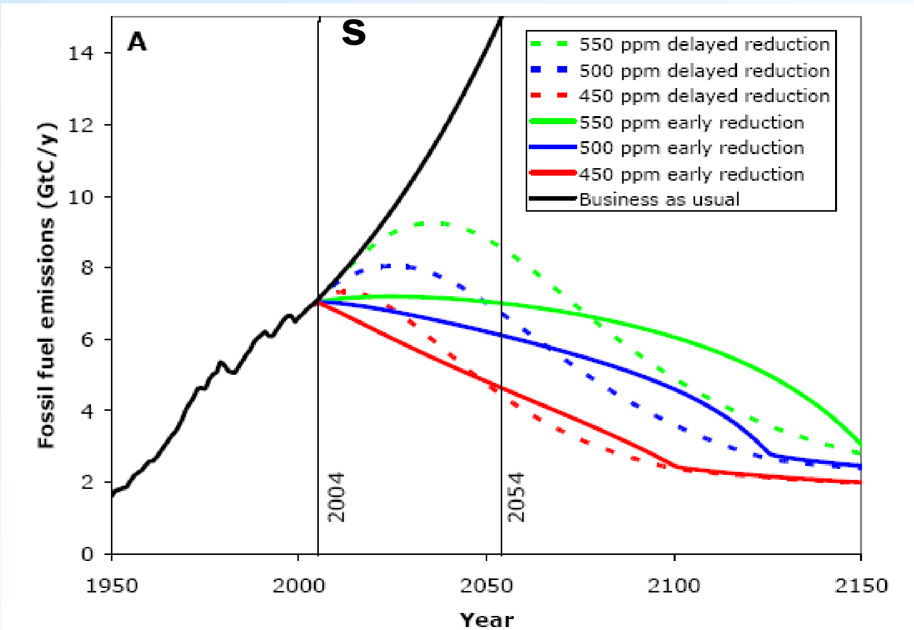
Average atmospheric concentration of CO_2 , since the beginning of the industrial revolution (data from Mauna Loa Observatory)



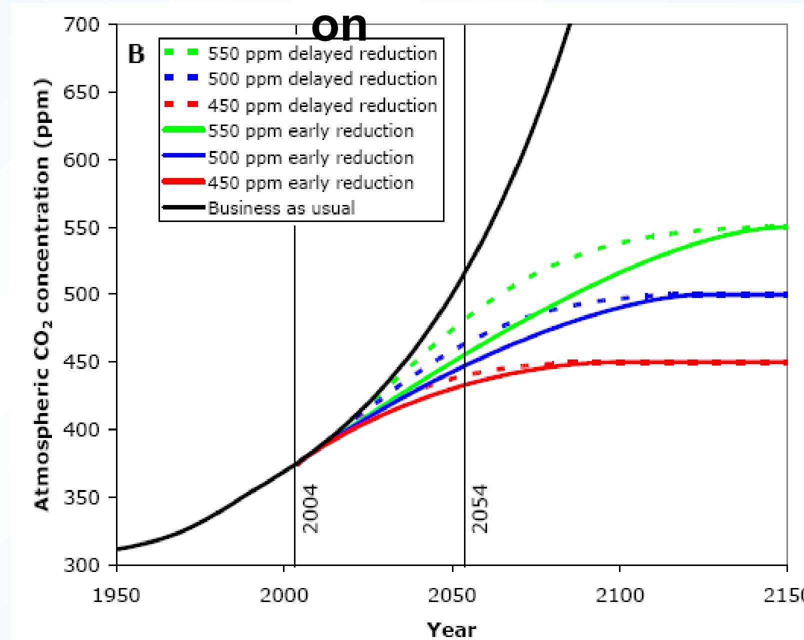
Most climatologists and the vast majority of the scientific community expect that this significant change in the planet's outer "blanket" will also have a significant impact on the Earth's climate, globally and regionally as well as on human economic activities.

Things to Know About CO_2 In the Atmosphere in Order to Solve Problem

Emissions



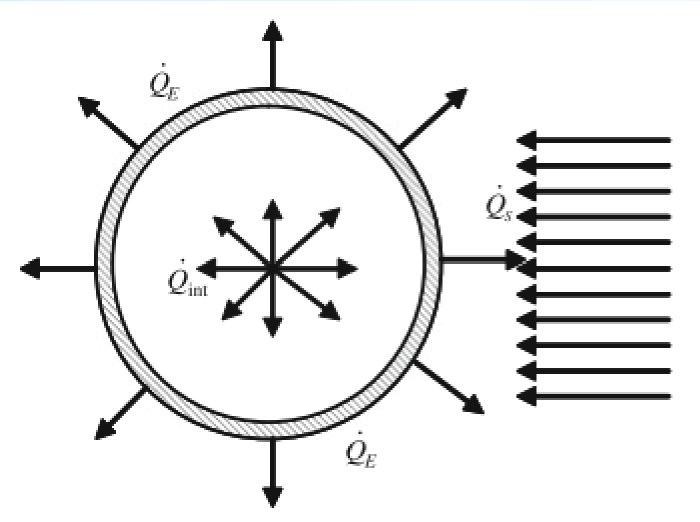
Concentration



- The lifetime of CO_2 in the atmosphere is about 100 years.
- About half of what we put up there stays up there.
- A bend in the emissions graph will just delay the time that we cross the dangerous CO_2 level threshold.
- Rule of thumb: every 10 percent reduction in emissions buys you about 7 years before reaching the max.
- We need to reduce emissions by a factor of two from current levels to remain stable at the 550 ppm level, and this in the face of doubling the demand of energy by the middle of the century, so we need to cut the common intensity of our energy system by a factor of four.

2.1. The Energy Balance of the Earth

The Earth's surface layer as a closed system and its heat balance



$\dot{Q}_S$: Heat flow rate incoming from the Sun

$\dot{Q}_E$: Heat flow rate emitted from the Earth

$\dot{Q}_{int}$: Heat generation rate in the Earth due to radioisotopes

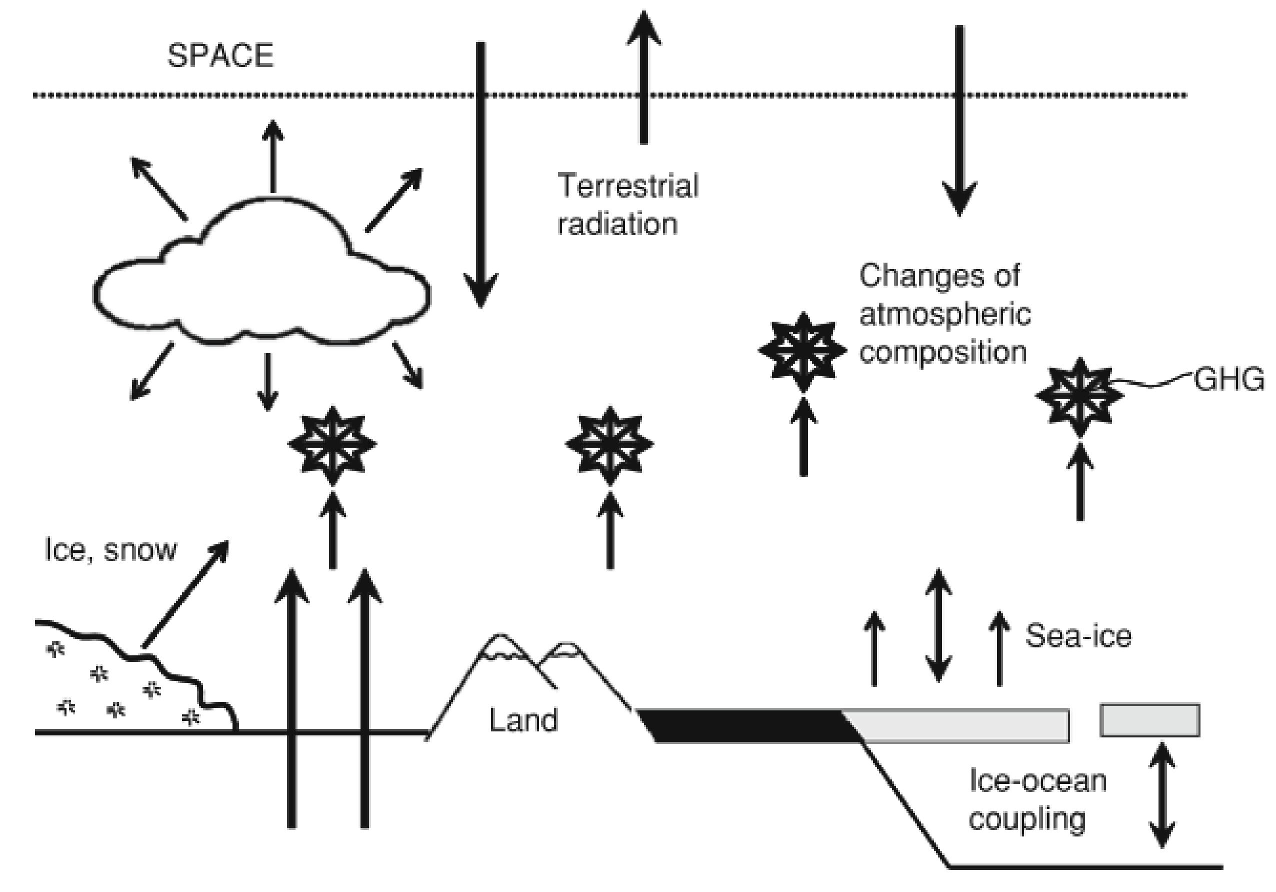
$$\underbrace{m_E\ c_E}_{\text{Mass and heat capacity of the atmosphere}} \frac{dT_E}{dt} = \sum \dot{Q}_i = \dot{Q}_S - \dot{Q}_E + \dot{Q}_{int}$$

$$4\,\pi\,R^2\,H\,\rho\,c_E \frac{dT_E}{dt} = \pi\,R^2\,S\,\alpha_E - 4\,\pi\,R^2\,\sigma\,\varepsilon_E\,T_E^4 + 4\,\pi\,R^2\,k_E \frac{T_{int} - T_E}{H}$$

This is a very crude model. Solve for T_E

2.2. The Greenhouse Effect

Radiation exchange between the surface of the Earth, the atmosphere and the outer space



GHG –Greenhouse Gases

- Water vapor
- CO_2
- CH_4
- N_2O
- O_3

freely absorb infrared radiation

It is the presence of GHG's in the atmosphere that keeps the average temperature of the Earth at its current value (300 K).

Accurate climatic models show that, in the absence of GHG's, the average temperature, T_E, would have been approximately 33 °C lower than what it is at present. Without the GHG's (at their historical levels), most of the oceans and the surface waters would have frozen and the climate of the Earth would have been inhospitable to life in its current forms. Without the benign warming effect of the GHG's it is doubtful that human life would have evolved in this planet.

While the low concentration of the GHG's is necessary for the life on the planet Earth, significantly higher concentrations (a thicker blanket) of these gases will have a detrimental effect to the ecology and the economic activities of the human society.

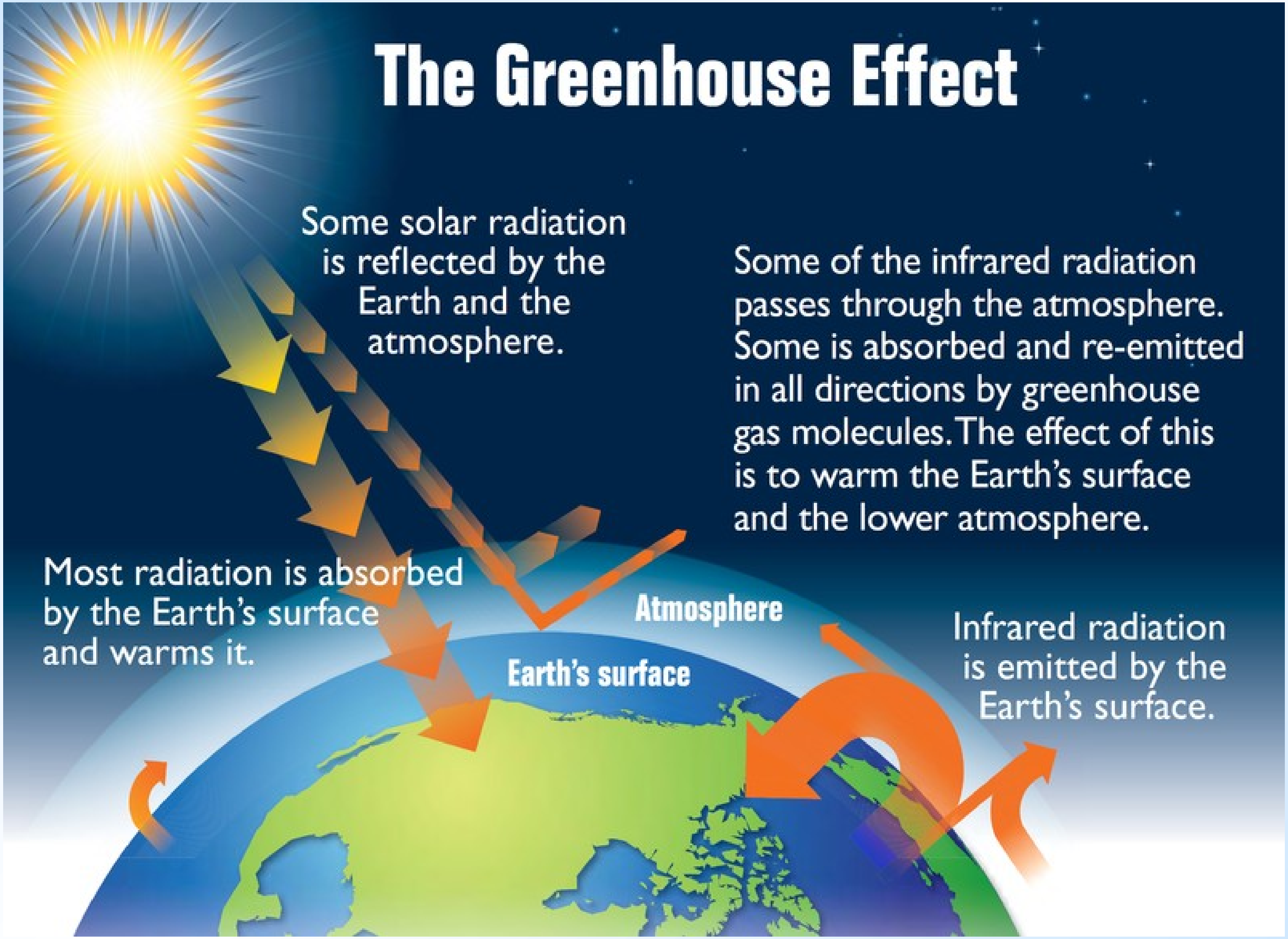
The term **Greenhouse Effect** is neither new nor a product of the twentieth century environmentalists. The effect was first predicted analytically by Jean-Batiste Jaques Fourier, the founder of the modern heat transfer theory, in 1824. The Greenhouse Effect was verified experimentally in the laboratory by the British physicist John Tyndall in the 1850s and was quantitatively validated for the atmospheric temperature in the 1890s by S. Arrhenius, a Nobel laureate and one of the founders of Physical Chemistry.

While not all the climate models agree on the exact value of the average temperature rise, all the reliable models converge in predicting a significant average global temperature rise accompanied by significant regional changes of the temperature and severe weather changes that have the potential to disrupt the human economic activities.

Svante Arrhenius

Swedish Scientist

1859 - 1927


The Greenhouse Effect
Some solar radiation is reflected by the Earth and the atmosphere.
Some of the infrared radiation passes through the atmosphere. Some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.
Most radiation is absorbed by the Earth's surface and warms it.
Atmosphere
Earth's surface
Infrared radiation is emitted by the Earth's surface.

2.3. Major Consequences of the Greenhouse Effect

The Greenhouse Effect threatens to change the entire global climate.

The weather is the short-term product of all the complex interactions between the Sun, the atmosphere, the hydrosphere, the continents and their features, such as mountains, vegetation, and ice sheets. Weather is a short-term phenomenon that results from the temporary thermal interactions between the solar radiation, the atmosphere and the hydrosphere. The weather may be predictable over short times, e.g. a few days, but is unpredictable over long periods of time, e.g. months or years.

The climate is the long-term result of the weather. It may be said that climate is the average weather, taken over a period of several years and decades.

The weather phenomena are brief and do not impact significantly the environment and the human activities. On the contrary, climate changes, whether regional or global, will affect significantly the environment, the ecosystems and the human economic activities.

The important effects of higher T_E and the consequent climate change are:

- Melting of the polar ice caps
- Sea level rise
- Regional climate change

Read «Rapid Antarctic Melting» on OdtuClass. It is the newspaper article on the New York Times, 2023.

Read «Rusy Rivers», an article in the January 2024 issue of the Scientific American. It is on «OdtuClass».

2.4. Remedial Actions for Global Warming

For nearly three decades the UN has been bringing together almost every country on earth for global climate summits called «**COP**» meetings.

In that time, the climate change has gone from being a fringe issue to a global priority.

COP => Conference of Parties

The Kyoto protocol, signed in 1997, which was created within the United Nations Framework Convention on Climate Change, is an agreement reached between several nations, both developed and developing, for the reduction of the CO_2 global emissions.

The Kyoto protocol, which was created within the United Nations Framework Convention on Climate Change, is an agreement reached between several nations, both developed and developing, for the reduction of the CO_2 global emissions.

The United Nations Intergovernmental Panel on Climate Change (IPCC) confirmed in 2007 that the average global temperature has increased during the Twentieth century by 0.74 ± 0.18 $^{\circ}$C. This is a rate that is much higher than that of previous centuries.

The pertinent IPCC report also attributed most of the measured temperature rise to the observed increase of the GHG concentrations.

The members of the IPCC shared the 2008 Nobel Peace Prize.

The Kyoto protocol, signed in December 1997, calls for the industrialized countries to reduce their collective greenhouse gas emissions by 5.2 % from the level in 1990 and also has provisions for the transfer of energy conservation technology to the developing nations. The Kyoto protocol asked for a CO_2 reduction of 8 % for the European Union countries, a reduction of 7 % for the USA, 6 % for Japan and 0 % for Russia.

The protocol has been signed and ratified by most countries, with two most notable exceptions: the U.S.A. and the People's Republic of China (PRC).

While most of the signatories, and especially the European Union countries, have taken meaningful steps for the reduction of their GHG emissions, between 1997 and 2010, the USA has actually increased its emissions by 16 % and the PRC by 130 %.

So, the Kyoto protocol was ineffective and the GHG concentration in the atmosphere has continued to increase at an alarming rate.

The following list includes some of the actions individual nations and the global community may take to, first, reduce the growth of CO_2 emissions and, secondly, to reduce the actual concentration of the gas in the atmosphere.

- 1. Reduction of energy consumption per capita – inexpensive and feasible with conservation and higher efficiency methods especially for developed nations.

- 2. Sequestration of CO_2 (such as liquefaction) at the production sites, that is at the power plants, and subsequent storage – requires large amount of energy, very expensive, and runs the risk of leakage from storage sites.

- 3. Substitution of coal with nuclear fuel for the production of electricity – nuclear energy has its own problems.

- 4. Reforestation - It will take 8,900 fully grown pine trees to remove the CO_2 produced by a single 400 MW coal power plant during a single day. it will take 8 fully grown eucalyptus trees to remove the CO_2 emissions caused by the engine of a single sport utility vehicle (SUV) which runs for 15,000 miles. So, it is a desired activity and beneficial to the environment, but it does not substitute for all the fossil fuels our society currently uses.

- 5. Higher use of renewable energy sources - Reliable and economical methods for energy storage will benefit significantly the increased use of these energy sources, which are to a great extend benign to the environment.

- 6. Removing CO_2 from the atmosphere

See the article on OdtuClass "Pulling CO_2 from Thin Air", September 2024 issue of the Scientific American

2.5. The Failure of the Copenhagen Summit

A very much advertised United Nations environmental summit took place in Copenhagen, Denmark during December 2009.

It is unfortunate that the entire world population became spectators of a well-orchestrated, politically-driven and acrimonious spectacle, where nothing of substance for the environment was achieved. Several reasons contributed to this, among which are the following:

1. The debate on global warming has been framed in many countries, including the EU and the USA, as a debate of "personal belief" rather than as an indisputable effect of well-researched scientific causes, supported by long-term scientific observations. The immediate result is that several global powers do not espouse the idea that hard decisions and strict measures need to be taken for the "beliefs" of other people or nations.

2. The 2008–09 severe global economic recession has diverted a great deal of the attention from remedies for the global warming to the economic realities of high unemployment and lower GDP in most nations. So, global environmental concerns were relegated to more immediate secondary national issues such as high unemployment rates and overall citizenry dissatisfaction in the OECD countries, and expectations of African countries and other developing nations to have increased economic aid from the developed nations, which was not apparently forthcoming.

3. There were no framework of solutions, that were supposed to be developed beforehand (during the preliminary international negotiations which were taking place for a couple of years) acceptable to the majority of the participating nations.

4. China and India, two developing nations that have made great strides towards industrialization in the first decade of the twenty-first century and account for most of the growth rate in carbon emissions have refused to make any binding concessions for the long-term reduction of CO_2 emissions.

A subsequent summit that took place in Cancun, Mexico in December 2010 was not attended by any world leaders. Its activities were largely symbolic and did not result in anything definitive, substantial or committing for the climate change.

The scientific and engineering community must play a leading role in the arena of global change by doing the following:

a) Continuing to make accurate global measurements;

b) Communicating these measurements and the pertinent conclusions to the public in an unbiased and honest (that is, scientific) manner;

c) Developing reliable measures of accountability for GHG emissions;

d) Developing methods and building meaningful engineering projects for the mitigation of the adverse effects of the global climate change;

e) Improving the efficiency of power production plants and internal combustion engines; and

f) Continuing the research and development efforts on alternative sources for energy that would reduce and would finally nullify the global GHG emissions.

Paris Agreement (COP 21, December 2015) aims to hold the increase in the global average temperature to “well below” 2°C above pre-industrial levels.

COP 26 was in Glascow, 31 October – 12 November 2021

COP 26 is the most important climate meeting since Paris (it was delayed by a year owing to the pandemic).

World leaders arrived in Scotland, alongside tens of thousands of negotiators, government representatives, businesses and citizens for twelve days of talks.

COP 21 in Paris was a milestone. Read about COP’s.

At its heart is a “ratchet mechanism” which requires that every five years parties to the agreement come forward with more ambitious national climate goals.

On January 27, 2021, President Biden of the US has issued an Executive Order on "Tackling the Climate Crisis at Home and Abroad". This Executive Order is part of the Biden Administration's larger agenda to achieve a carbon-pollution-free power sector by 2035 and reach net-zero emissions by 2050. The Executive Order comes quickly after President Biden fulfilled his campaign promise to rejoin the Paris Agreement on his first day in office. Additionally, Biden has already begun to review Trump-era rollbacks of Obama-era environmental protection standards.

Read Barack Obama's article about global warming, published in the Science – Policy Forum magazine on January 9, 2017:
http://science.sciencemag.org/content/early/2017/01/06/science.aam6284.full

To read the Executive Order in its entirety, visit:

https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/.

For a summary prepared by the White House, visit:

https://www.whitehouse.gov/briefing-room/statements-releases/2021/01/27/fact-sheet-president-biden-takes-executive-actions-to-tackle-the-climate-crisis-at-home-and-abroad-create-jobs-and-restore-scientific-integrity-across-federal-government/.

COP 27 was held in Sharm el Sheikh, Egypt, in November 2022.

COP 27 Agreement: Provide “loss and damage” funding for vulnerable countries (in Africa) hit hard by climate disasters.

See the «UN Press Release on Climate Change – November 2022» on OdtuClass.

See the article «The Paris Agreement» on OdtuClass

See the article «COP 26 – The Guardian» on OdtuClass

COP 28 was held in Dubai, UAE, 30 November - 12 December 2023

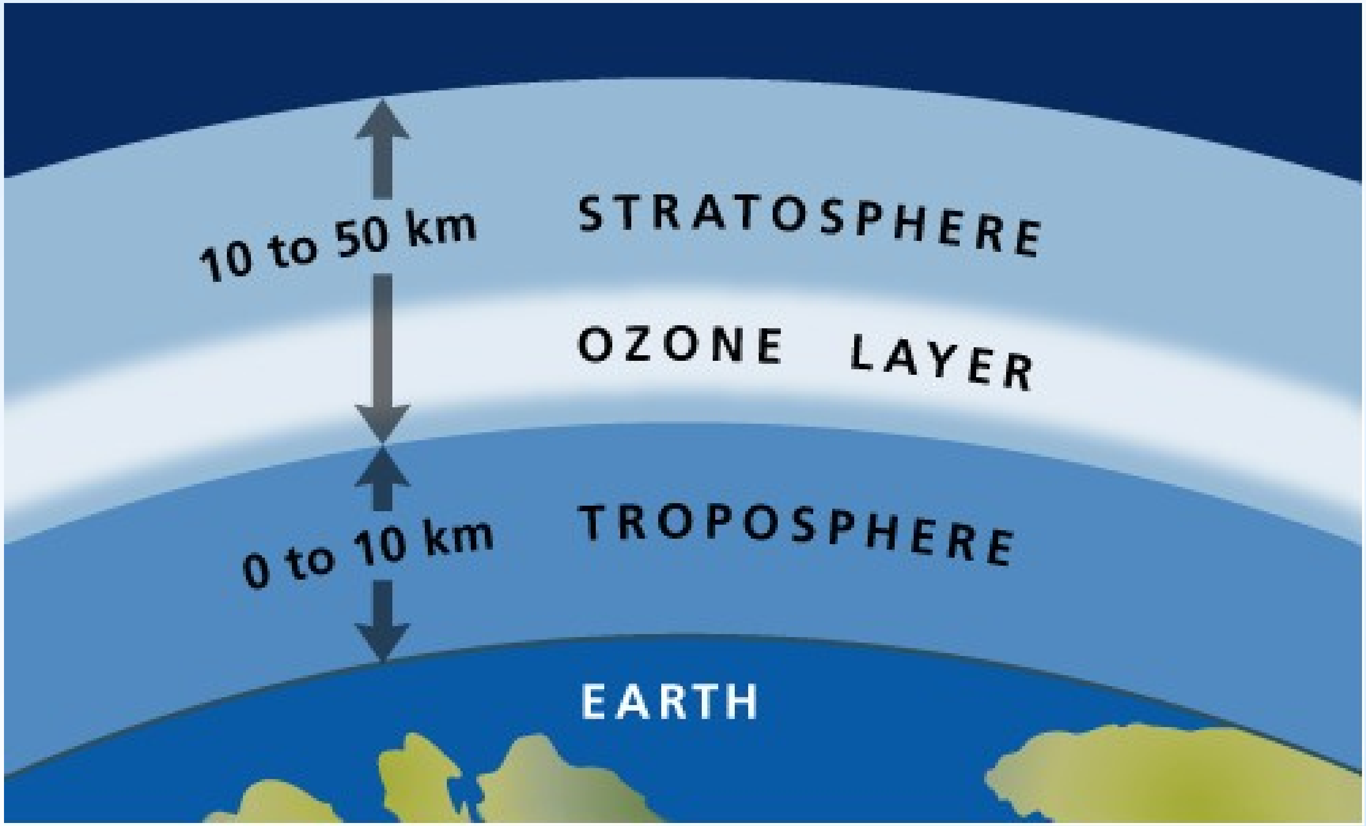
See: COP 28: What Was Achieved and What Happens Next? | UNFCCC

COP29 (November 2024) brought together nearly 200 countries in Baku, Azerbaijan, and reached a breakthrough agreement that will:

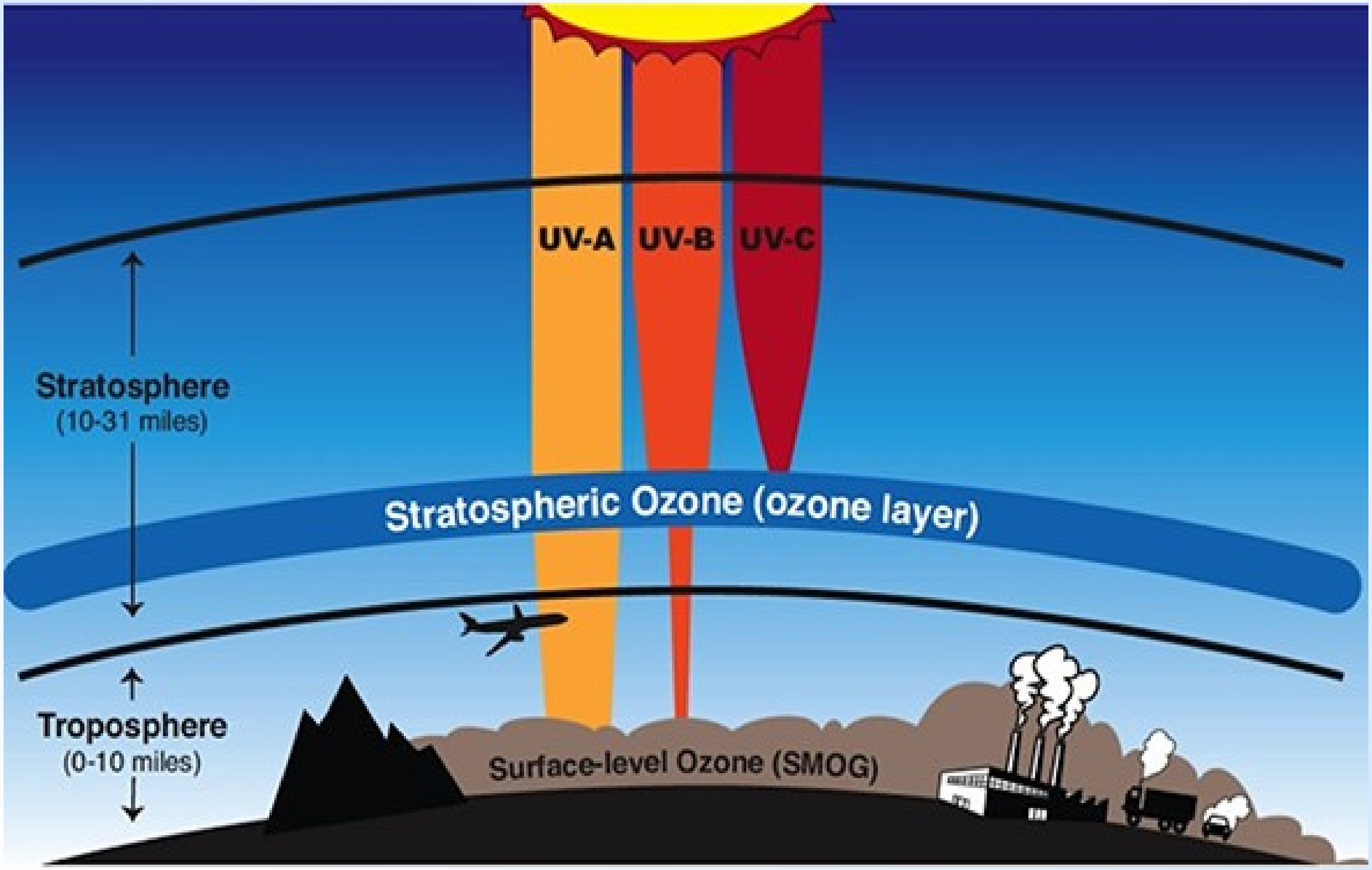
- Triple finance to developing countries, from the previous goal of USD 100 billion annually, to USD 300 billion annually by 2035.
- Secure efforts of all actors to work together to scale up finance to developing countries, from public and private sources, to the amount of USD 1.3 trillion per year by 2035.

3. Ozone later depletion

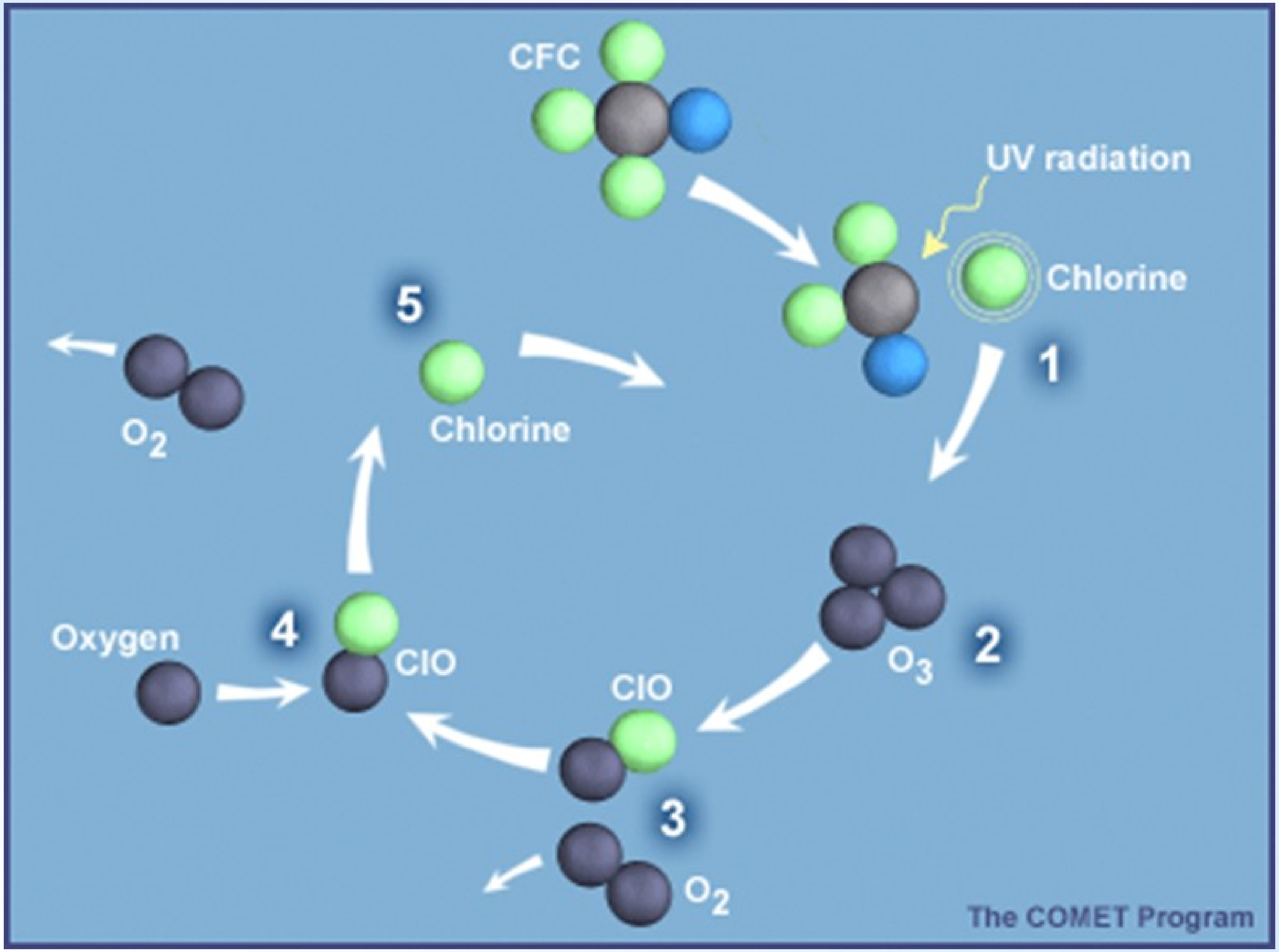
Ozone, O_3, is made from O_2 that breaks apart due to sunlight, and reforms into O_3



Ozone layer depletion process begins when CFCs (chlorofluorocarbons) and other ozone-depleting substances (ODS) are emitted into the atmosphere.



CFCs stay in atmosphere for a long time, destroy ozone molecules.



Thinning of the ozone layer:

“Holes” in the ozone layer are actually areas where they thickness has decreased, but not entirely absent.

Thinning has occurred across the globe, but is more concentrated in some regions, such as over Antarctica.

Increases in UV light exposure is harmful to life: it damages DNA (is mutagenic), can lead to cell death, tissue damage, and cancer.

1987 Montreal Protocol

The Montreal Protocol on Substances that Deplete the Ozone Layer is the landmark multilateral environmental agreement that regulates the production and consumption of nearly 100 man-made chemicals referred to as ozone depleting substances (ODS).

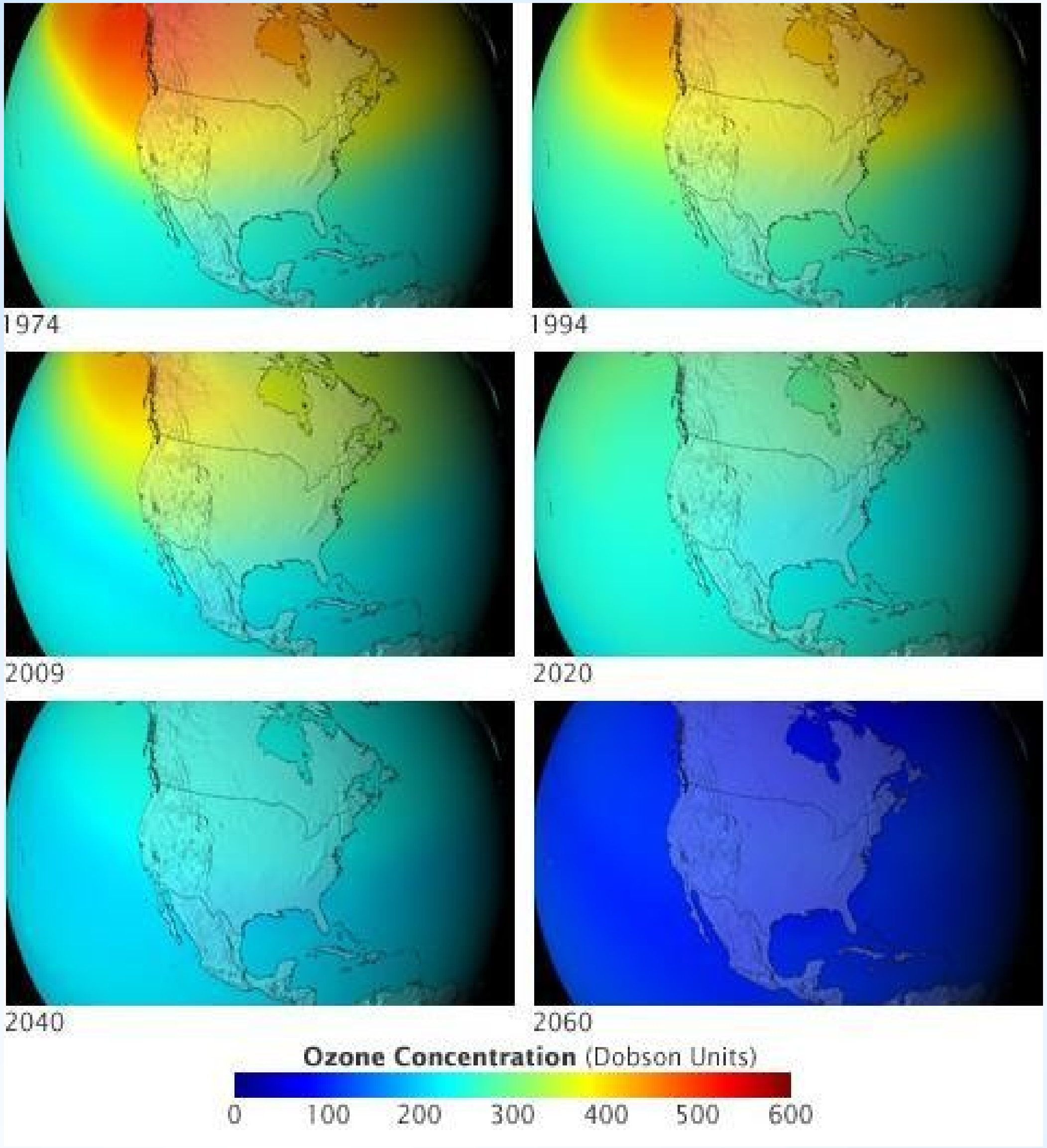
1987 Montreal Protocol

Adopted on 16 September 1987, the Protocol is to date one of the rare treaties to achieve universal ratification.

- Controls the production and consumption of 96 chemicals that damage the ozone layer
- CFCs have been mostly phased out since 1995, although they were used in developing nations until 2010.
- Some of the less hazardous substances will not be phased out until 2030. Requires that wealthier nations donate money to develop technologies that will replace these chemicals.

The Montreal Protocol worked!

- CFCs in the atmosphere have declined.
- Ozone layer is rebuilding itself.
- This is a great example of how the world can unite to face a global environmental problem.
- Can this be replicated for climate change?
- Why or why not?



Ozone levels over North America decreased between 1974 and 2020.

Models of the future predict what ozone levels would have been <u>if</u> CFCs were not being phased out.

4. Acid Rain

Acid rain or acid precipitation is the return to the terrestrial aquatic environment of the oxides of carbon, nitrogen and sulfur in an acidic form.

Acid rain is closely related to the combustion of fossil fuels. Fossil fuels, and especially coal, contain large quantities of sulfur which forms SO_2 upon combustion. In addition CO_2 and a series of nitrogen oxides with the general formula NO_x (or, commonly, NOX) are formed during coal combustion. These oxides combine with water vapor in the atmosphere to form mild acids.

$$SO_2 + H_2O \rightarrow H_2SO_3 \quad \text{weak}$$

$$SO_2 + O_3 \rightarrow SO_3 + O_2$$

$$SO_3 + H_2O \rightarrow H_2SO_4 \quad \text{strong}$$

$$CO_2 + H_2O \rightarrow H_2CO_3 \quad \text{weak}$$

$$NO_x + H_2O \rightarrow \rightarrow HNO_2 \quad \text{weak}$$
$$NO_x + H_2O \rightarrow \rightarrow HNO_3 \quad \text{strong}$$

Typically the acidic chemicals in the atmosphere are formed within small droplets or on the side of very fine particles, which are called aerosol particles. The sizes of these droplets and particles are in the submicron range. This implies that they settle extremely slowly and, may remain airborne in the atmosphere for weeks or months following the air currents and turbulence. During rain or snow precipitation, the aerosols combine with the larger rain drops or snow flakes, precipitate faster on the ground and, thus, are removed from the atmosphere.

The rain or snow runoff, which eventually feeds rivers and lakes, contains higher concentration of the acids and for this reason it has been called acid rain, acid snow or in general, acid precipitation. In the aquatic environments, H^+ ions are released from these acids according to the following chemical reactions:

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$
$$H_2SO_3 \rightarrow H^+ + HSO_3^-$$
$$H_2SO_4 \rightarrow 2\,H^+ + SO_4^{-2}$$

As a consequence of acid precipitation, the concentration of the H^+ increases significantly and the pH of these bodies of water drops from its natural range of 6.8 – 7.4 to significantly lower values. Some of the more dramatic acid precipitation observations are listed below:

1. A storm in Scotland in 1974 dropped rain with pH 2.4.
2. The pH of rain in Kane, Pennsylvania on September 19, 1978, was 2.32. This is lower than the pH of vinegar.
3. For the entire year of 1975, rains in Norway and Sweden recorded pH less than 4.6.
4. During the 1970s the pH of 80% of drizzles in Holland was less than 3.5, and sometimes as low as 2.5. This is the pH of common vinegar.

The drop of the pH has significant adverse effects on the ecosystems of the rivers and lakes, because many animal species cannot survive at these low (as well as very high) pH levels. As a result, several of the species may disappear, either because of the direct effect of a lower pH or because of lack of nutrients.

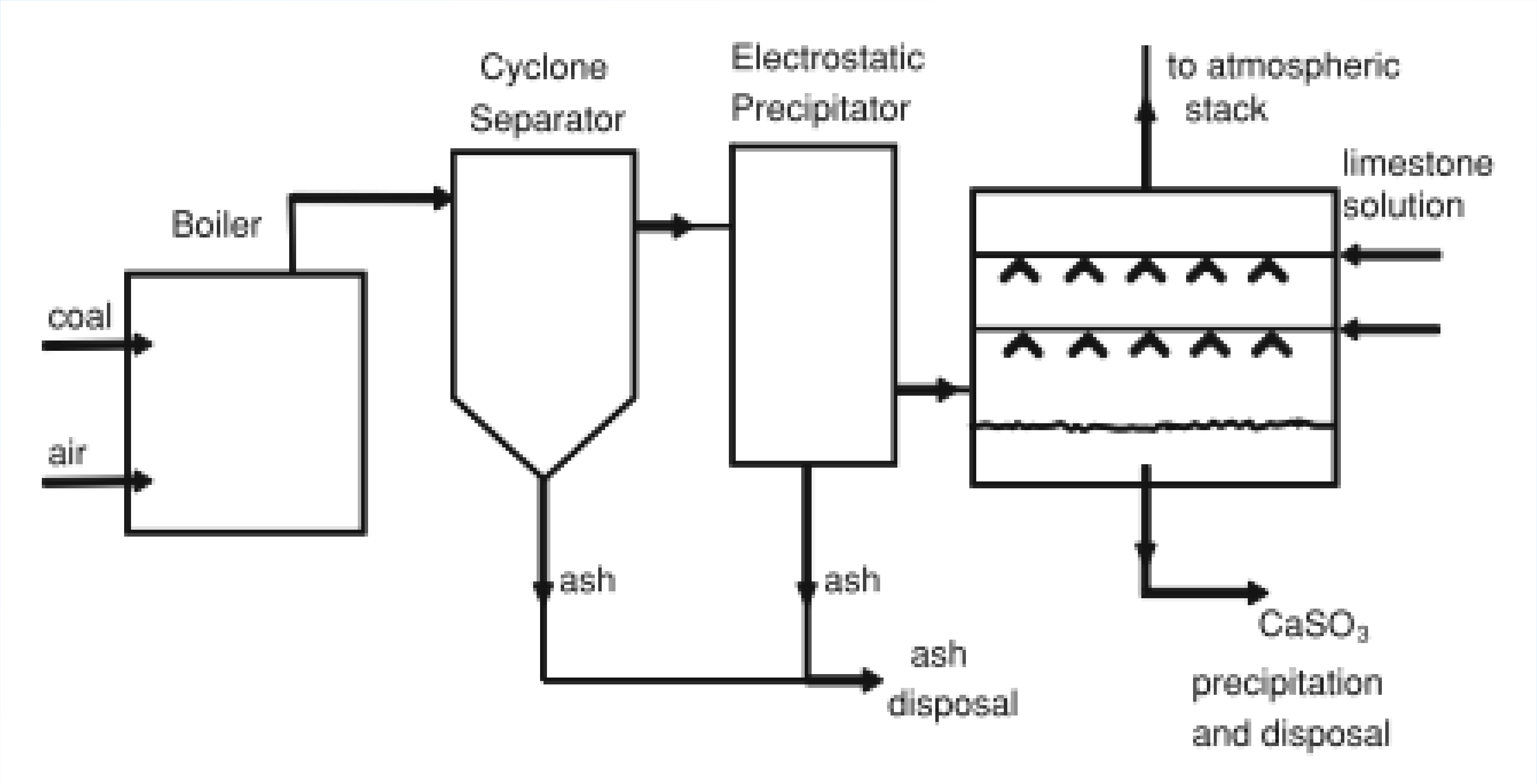
The low pH resulting from acid deposition decimated the fish population in several lakes in the 1970s and 1980s. In addition, high acidity precipitation rendered the soil acidic with a significantly adverse effect on crops as well as on forests. Some of the environmental and ecological effects of acid precipitation are:

1. As the water of the streams becomes more acidic, a shift to acid-tolerant plants occurs, such as green algae.
2. Acid sensitive species, such as snails, clams and amphipods disappear.
3. Higher concentrations of Al^{3+} and other metal ions are observed. These ions damage the gills of fish and also enhance the precipitation of dissolved organic matter in the water, which is a source of food for fish. With decreased food supply, fish become emaciated or die.

What accentuated the environmental problems of acid deposition is that, in most cases, the production of SO_2 and the other oxides actually occurred in other, neighboring countries.

A concerted international effort to mitigate acid rain started in the 1970s and continued in the 1980s and 1990s with great success. Despite the protests of the coal industry and several electricity generating corporations, one after another, national governments enacted regulations to limit the emissions of SO_2.

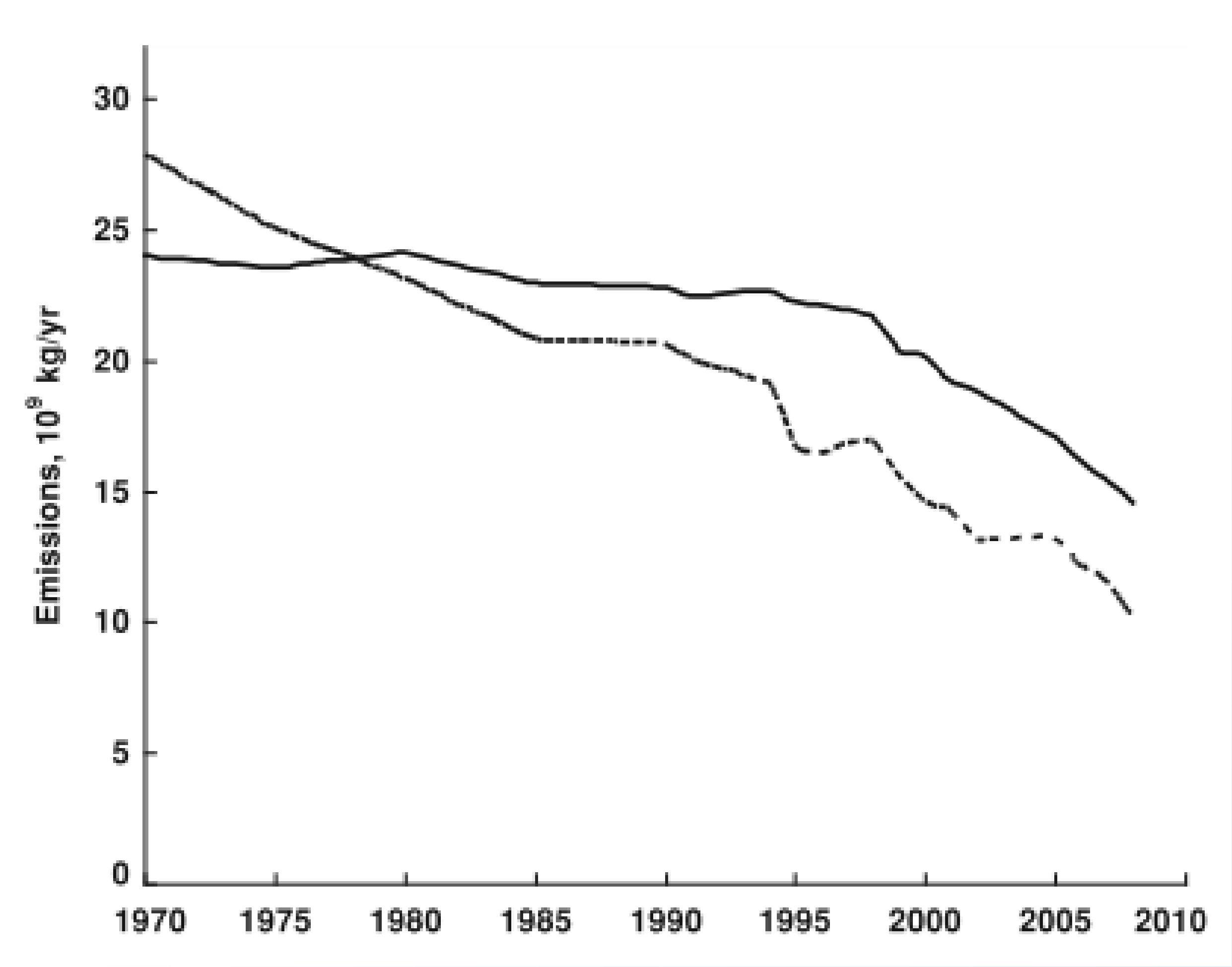
In the USA and the European Union the principal technical approach that was used to reduce the SO_2 emissions has been flue gas desulphurization (FGD) that removes SO_2 from the stack gases by scrubbers before they are discharged to the atmosphere.


Cyclone
Separator
Electrostatic
Precipitator
to atmospheric
stack
limestone
solution
Boiler
coal
air
ash
ash
ash
disposal
$CaSO_3$
precipitation
and disposal

Some of the other methods that have resulted in the significant reduction of the SO_2 emissions (in Europe and the US) are:

1. Using Fluidized Bed Reactors (FBR) in new plants, which employ limestone particles in situ to remove SO_2 during the combustion by converting it to solid $CaSO_3$. The latter is removed with the solid materials of the ash.
2. Blending high-sulfur coal with low-sulfur coal.
3. Switching coal fuel to natural gas, or a mixture of coal and natural gas.
4. Retiring old electricity generation units and replacing them with FBR's or units with SO_2 scrubbers.
5. Purchasing or transferring emissions allowances from other units.
6. Increasing the demand-side management and conservation efforts to reduce the electric power consumption.
7. Power purchases from other utilities or non-utility generators that use low-sulfur coal or other fuels.

Emission reductions of SO_2 (dashed line) and NO_x (solid line) in the USA



5. Lead Abatement

Gasoline and diesel are mixtures of liquid hydrocarbons. While the diesel-air mixture in the diesel engines is designed to ignite by itself at the end of the compression stage, when high temperature is reached, the gasoline-air mixture is designed to ignite during the ignition stage by a spark. Because high temperatures are achieved during the compression stage, several of the hydrocarbons in the gasoline liquid mixture reach their own ignition point, auto-ignite and release heat prematurely. This has led to the “knocking” problem in gasoline engines where auto-ignition has caused premature engine detonation, severe vibrations, low cycle efficiency and subsequent engine damage.

Auto-ignition in gasoline engines may be prevented by chemical additives, the most common of which is tetra-ethyl lead, $Pb(C_2H_5)_4$. Tetra-ethyl lead, when added to the gasoline, prevents engine knocking and engine damage. The use of this chemical compound was widely adopted by the refining and automobile industries as an "anti-knock" additive to the gasoline in the early twentieth century.

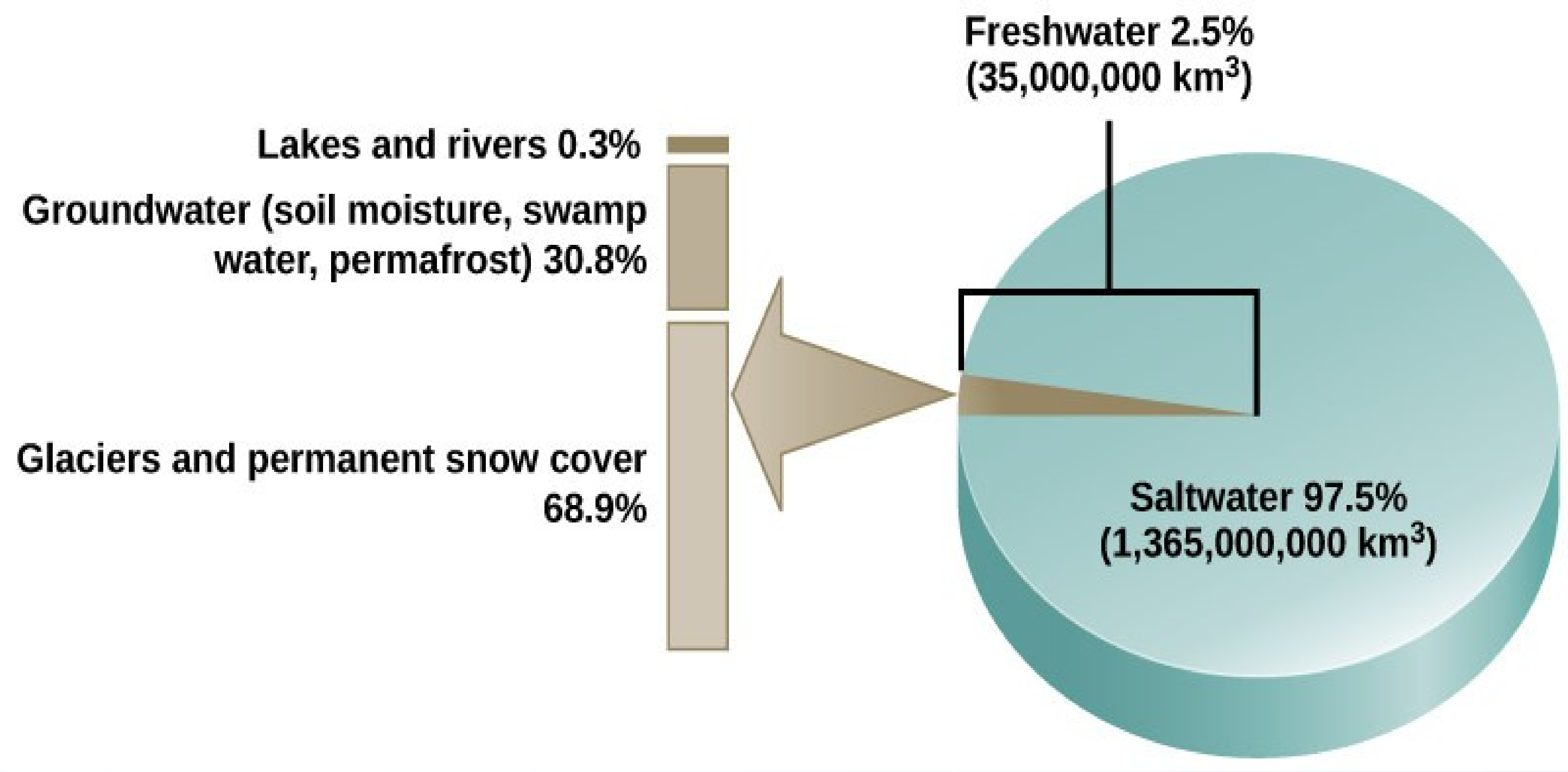
However, the $Pb(C_2H_5)_4$ burns with the fuel and its combustion releases lead oxides, primarily PbO and Pb_2O, as well as atomic Pb, to the environment. These chemicals were proven to be harmful to the health of the population. Lead compounds affect the synapses in brain cells, especially those of children. Prolonged exposure to lead has been proven to cause mental retardation and brain disorders.

Today, we no longer use lead additives, except marine engines, racing cars and certain farm equipment. It has now been replaced by other additives, typically made by aromatic hydrocarbons. It is anticipated that by 2020 the use of leaded gasoline will be banned globally.

The success stories of lead and acid reduction convey optimism that, despite the resistance of the fossil fuel industry and some electric utilities, a significant reduction of GHG emissions will be achieved in the near future without an undue economic disruption.

Although these have nothing to do with energy conversion, one may also mention the use the pesticide, DDT, and the drug, thalidomide, and Freon-12 refrigerant as other stories of international banned consumptions, applied rather late, long after the damages were done.

Water resources on Earth



Environmental and Ecological Effects of Energy Production, Energy Consumption & Other Human Activities

1. Environment, Ecology and Ecosystems

   - Crossing planetary boundaries

2. Global Climate Change

   - Energy balance of the Earth-Atmosphere system
   - Green House effect and GHG's; CO_2 (300 => 400 ppm)
   - COP's - Paris Agreement; COP29 in Baku, Azerbaijan, November 2024

3. Ozone Layer Depletion

   - 1987 Montreal protocol

4. Acid Rain

- National governments enacted regulations to limit the emissions of SO_2.
- Scubbers in power plants and additives in FBR's

5. Lead Abatement

- We no longer use lead additives, except marine engines, racing cars and certain farm equipment.

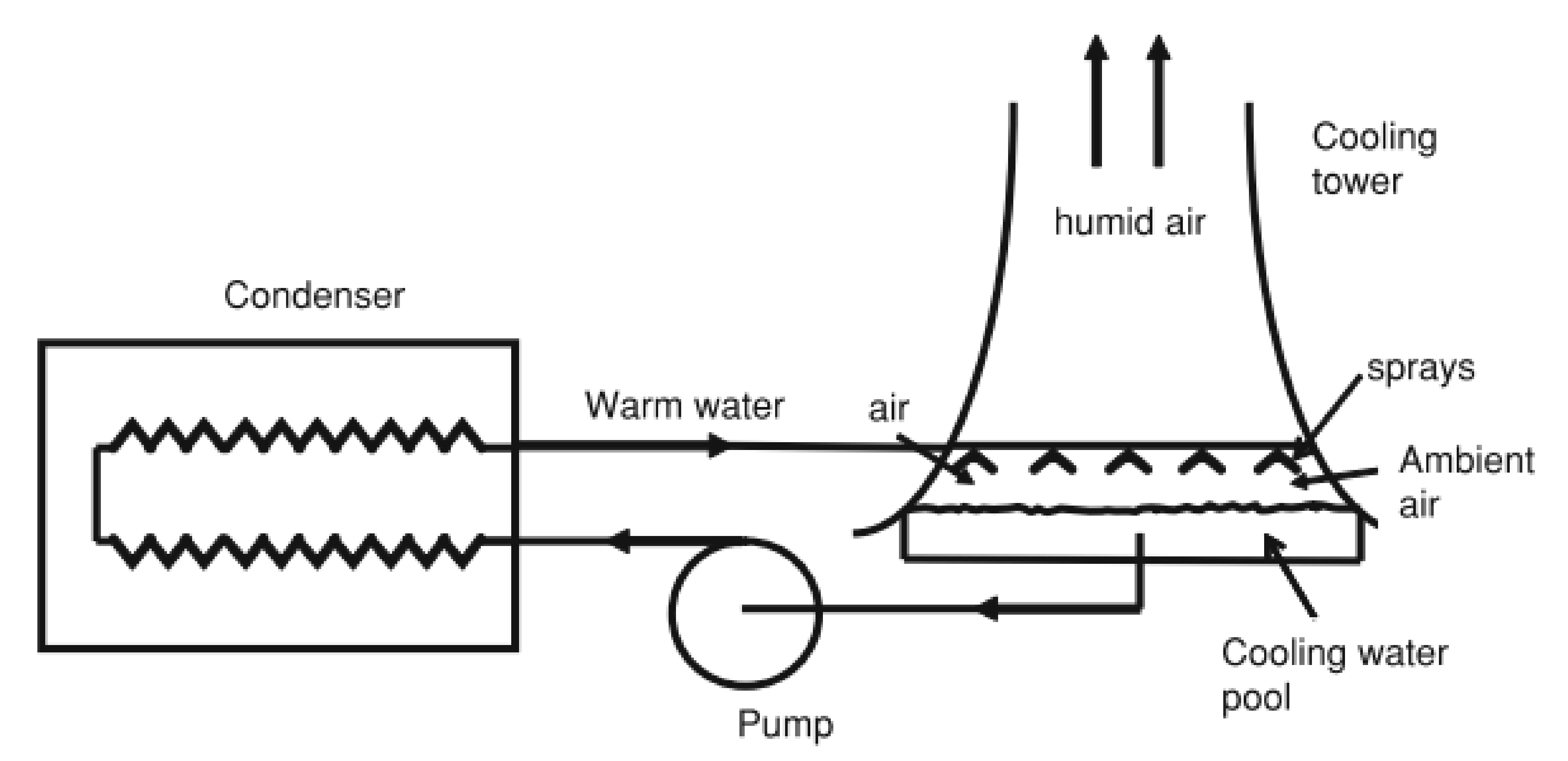
The use the pesticide, DDT, and the drug, thalidomide, and Freon-12 as refrigerant are the other stories of international banned consumptions, applied rather late, long after the damages were done.

6. Thermal Pollution and Fresh-Water Use

The thermal power plants reject a great deal of energy to the environment in the form of low-temperature heat. All processes in these power plants are subjected to the Second Law of Thermodynamics and, as a consequence, the power plants must reject a great deal of heat to their condensers and through their cooling system to their surroundings.

A typical 1000 MW fossil fuel plant has an overall efficiency close to 40 %. It receives 2500 MW of heat power, of which 1000 MW are converted to electric power and the remaining 1500 MW are rejected to the environment. A typical nuclear power plant, which has an overall efficiency close to 35 %. The reactor of this plant would produce approximately 3000 MW of heat, of which 1000 MW are typically converted to electricity and 2000 MW are rejected as waste heat to the environment.

The cooling system of a thermal power plant



The waste heat rejection by power plants does not contribute in any sizable measure to the global warming and does not pose a threat to be such a contributor in the near future. Actually, the calculated rate of heat that is absorbed and diffused in the atmosphere by the GHG's is higher than the entire waste heat production caused by anthropogenic activities by several orders of magnitude.

Their insignificant contributions to global warming notwithstanding, thermal power plants and the environmental heat rejection processes make a significant claim on the fresh water resources of the planet.

A quick computation proves that a typical nuclear power plant, which rejects 2000 MW of heat through a cooling tower, would need close to 95 000 kg/s of water. If instead of a cooling tower the nuclear power plant rejected this rate of heat to a river or a lake, the maximum ΔT would be 2.7 C and the actual need for cooling water would be close to 176 000 kg/s.

Fresh water availability for the production of electric power is fast becoming an environmental issue in the twenty-first century. Even though 71 % of the surface of the planet is covered by water, only 3 % of the water on the planet is fresh water and 90 % of it, or 2.7 % of the total, is in the form of ice glaciers and underground water aquifers. The remaining 0.3 % of the total water of the planet is fresh water in lakes (87 %) swamps (11 %) and rivers (2 %).

Large water consumers, such as large thermal power plants, must compete for this resource, which is becoming scarce in several parts of the planet,

Alternative energy sources for the production of electricity are very promising in this regard, either because they do not need cooling (photovoltaics, wind, hydroelectric, tidal, etc.) or because they produce sufficient water for the needs of their own cooling systems (geothermal).

7. Nuclear Waste

The transportation and storage of the waste materials produced in the nuclear power plants around the world is a significant global environmental threat because the uncontrolled release of radioactive compounds is harmful to all living animals

Nuclear waste isotopes and their characteristics

Isotope	Half-life (yrs)	Radioactivity (Bq)
Americium-231	433	$11.84*10^{10}$
Americium-234	7,900	$0.7*10^{10}$
Iodine-129	17,000,000	$5.9*10^{6}$
Plutonium-239	24,400	$0.23*10^{10}$
Plutonium-240	6,600	$0.81*10^{10}$
Technetium-99	210,000	$6.29*10^{8}$

Since the typical reactor is a closed system, the entire radioactivity remains inside the reactor until the next refueling period. During refueling, the spent fuel and fission products are removed from the reactor and stored temporarily, within the confines of the nuclear power plant. These materials constitute the nuclear waste from the reactor. Similar nuclear waste materials are produced in fuel reprocessing and fuel enrichment facilities.

Permanent storage facilities must be constructed that will be capable to store the radioactive waste for thousands of years, until the eventual residue does not pose a public health threat. This presents a significant scientific and engineering problem, simply because of the timescale of the storage.

7.1. Initial Treatment of the Waste

An initial treatment helps reduce the volume and radioactivity of the waste, while the waste is located in a controlled environment and the heat generated is removed in a controlled manner. Methods for the initial treatment are:

1. Vitrification, or glassification of the waste. The nuclear waste is mixed with sugar and heated until all the water and nitrates in it are evaporated. The mixture is then combined with glass and further heated until the glass melts. This melt is poured into stainless steel containers, where it solidifies and forms a glass-like substance, that is, "it vitrifies." The vitrified substance is then stored in a steel cylinder. Vitrified materials are very stable. They are hard, water resistant, have very low erosion or chipping and are believed that they are capable to last unaltered for thousands of years.

2. Concentration of the waste

The volume of the nuclear waste may be reduced by concentrating it into a smaller volume, which may be disposed of or stored better and more economically. Flocculation (concentration of fine particles) with ferric hydroxide is often used to remove highly radioactive metals from aqueous solutions. After the removal of these isotopes, the resulting low-level radioactive materials are stabilized and immobilized by mixing with ash and cement to form concrete. The low radiation levels of this concrete do not pose any threats to the environment or the population and may be stored anywhere.

3. Synrock

It is a complex chemical material of nuclear waste stabilization. Synrock consists of hollandite ($BaAl_2Ti_6O_{16}$), zirconolite ($CaZrTi_2O_7$) and perovskite ($CaTiO_3$). The zirconolite and perovskite become hosts and immobilize the actinide elements, that is elements with atomic number higher than 89, such as uranium and plutonium. The radioactive strontium and barium, which are produced in nuclear reactors, are also trapped and immobilized in the perovskite, while the hollandite immobilizes the cesium and similar lighter metals.

7.2. Long-Term Disposal

Immobilization stabilization or simply immobilization is the first stage in nuclear waste management. The long-term disposal of the nuclear waste includes the following suggestions:

1. Geologic disposal, either in deep and stable formations on the earth or in the deep sea. The proposed Yucca Mountain repository in the United States and the Schacht Asse repository in Germany, which operated briefly in the 1990s, are two examples of such ground disposal sites. These repositories are typically in stable, arid geological formations, where water leakage will not be a problem in the future.

1. Geologic disposal

One of the impediments for permanent geologic disposal is the legal problem of stewardship cessation of the materials. This legal term implies the shifting of the burden for the safe maintenance and perpetual management of nuclear waste from the producer to the one who undertakes the storage. The latter is typically the government or a smaller receiver corporation, which does not have the financial resources to guarantee stewardship in the long term and to compensate for damages that may potentially be incurred. Several environmentalists do not believe this is prudent and recommend perpetual management and monitoring of the waste by the producer.

2. Transmutation

Transmutation implies the transformation of radionuclides to other materials that are not radioactive. Special nuclear reactors will be needed for the transmutation processes. In the United States research activity on the transmutation has ceased since the late 1970s because plutonium is a byproduct of the process. Since plutonium is used in atomic bombs, its production raises concerns of atomic weapon proliferation. Relevant research work has continued in the European Union, where the reactor Myrrha has been built and may be used for transmutation purposes along with other high technology applications.

2. Waste re-use

Waste re-use usually accompanies the concentration process which was described in the previous section. The produced high-radioactivity materials may be re-used in a nuclear reactor for the production of additional power. Because a great deal of the current nuclear waste is the isotope uranium-238, it is envisioned that this isotope will be separated from the waste and will be used in the breeder reactors of the future.

3. Space disposal

Space disposal is a possible alternative that has been advocated by a few non-experts. Given that it costs more than $25,000 to lift a kg of mass to the space, this is extremely expensive and has not been proven to be a reliable way of nuclear waste storage.

8. Sustainable Development

Sustainable development or simply sustainability, is an all-encompassing concept, which basically advocates that the global economic development must be pursued without causing irreparable damage to the ecology and the environment.

Measures of sustainability include the calculation of pollutant emissions per unit of the desired product or service. Most notable among these measures is the carbon footprint.

Carbon footprint is the total greenhouse gas (GHG) emissions caused by an individual, event, organization, service, place or product, expressed as carbon dioxide equivalent (CO_2e).

The primary greenhouse gases in Earth's atmosphere are: water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3).

Greenhouse gases, including the carbon-containing gases carbon dioxide and methane, can be emitted through the burning of fossil fuels, land clearance, and the production and consumption of food, manufactured goods, materials, wood, roads, buildings, transportation and other services.

For example, the carbon footprint of driving 1000 km in a small car with mileage 30 km/L of gasoline (at the consumption of 23.3 kg of gasoline) is 9.0 kg of CO_2 while the carbon footprint of the same trip with a 5 km/lL in a SUV is 54.0 kg of CO_2.

The concept of sustainability advocates that, for the long-term environmental health, the economic activities must be re-engineered to ensure that their net effect on the environment is neutral. A simple example of the application of the sustainability concept is the removal of the 54.0 kg of CO_2 produced from the 1000 km trip in the SUV of the previous paragraph: the owner of the SUV may plant a tree that will absorb this amount of CO_2 from the atmosphere.

Sustainability encompasses ideas and concepts from several disciplines including engineering, environmental science, ecology, economics, sociology, anthropology, political science, and public policy. Central to this subject is the realization that significant global threats, such as global warming and pollution prevention, may only be tackled by a combination of technological advances, social awareness, and public policy.

A realistic alternative for sustainability, which may encompass the entire current population of the planet, is the wider use of alternative energy sources combined with increased efficiency and energy conservation. The use of alternative energy sources, including the nuclear option, is fundamental to tackling several pollution problems, most important of which is the increased global CO_2 concentration.

The substitution of a single 400 MW base-load coal-fired plant by twenty 20 MW geothermal plants will have the net effect of removing 3,530,000 tons of CO_2 annually from the atmosphere.

Similarly, the substitution of a 60 MW gas turbine for peak power generation that operates for 20 % of the year with solar power will have the effect of removing 20400 tons of CO_2 annually. Permanent reforestation, not simply for biomass-based fuel production, removes tons of CO_2 and other pollutants from the atmosphere for several decades.

Extensive use of the hydroelectric potential, tidal and wind power and a more widespread use of electric cars avert the further emissions of CO_2 , SO_2 , NO_x and other pollutants from an environment that 7 billion humans inhabit.

Therefore, energy production from alternative sources, energy conservation and higher efficiency are the principal long-term solutions to achieving global and sustainable development.

See: “https://time.com/person-of-the-year-2019-greta-thunberg-choice/”

for the article in Time magazine (December 30, 2019)

«2019 Person of the year, Greta Thunberg».

See «odtuclass» for TÜBA Report on Climate Change and Public Health

See «OdtuClass» for more problems on «Environment»

Metals under Threat

Meatls under Threath	World Total Reserve	Expected Time of Exhaustion with current rates of production in years	Principal Uses
Aluminum	32 350 million tonnes	1027	Transport, Electrical, Consumer-durables
Arsenic	1 million tonne	20	Semiconductors, Solar cells
Antimony	3.86 million tonnes	30	some pharmaceuticals and catalyst
Cadmium	1.6 million tonnes	70	Ni-Cd batteries
Chromium	779 million tonnes	143	Chrome plating
Copper	937 million tonnes	61	Wires, Coins, Plumbing
Germanium	500 000 US reserve base	5	Semiconductors, Solar cells
Gold	89 700 tonnes	45	Jewellery, Gold teeth
Hafnium	1124 tonnes	20	Computer chips, nuclear control rods
Indium	6000 tonnes	13	Solar cells and LCDs

Rhodes, C.J. (2008) Metals shortages. Chem. Indust., 25th August, 21 – 22.

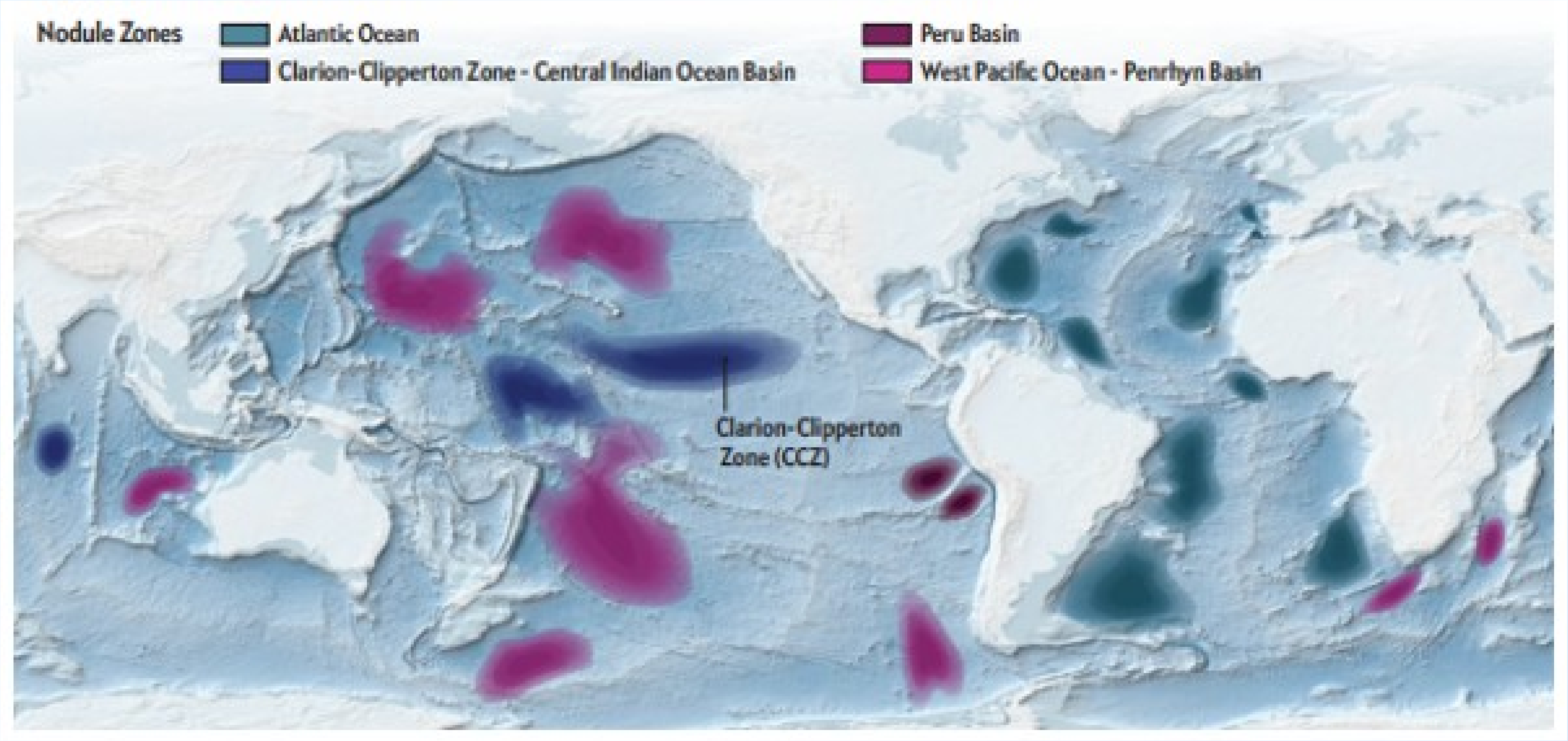
Metals under Threat

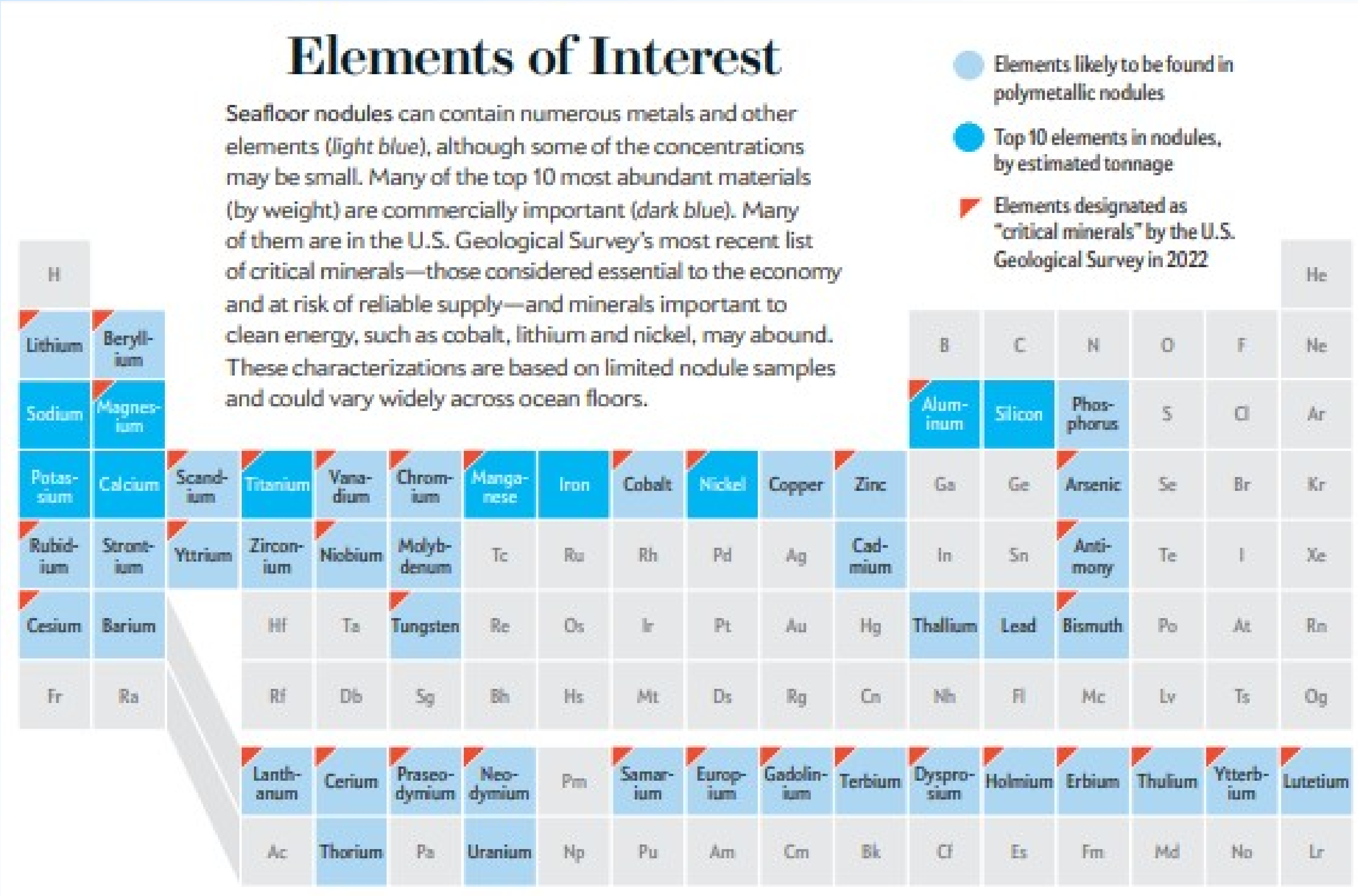
Meatls under Threath	World Total Reserve	Expected Time of Exhaustion with current rates of production in years	Principal Uses
Lead	144 million tonnes	42	Pipes, Lead acid batteries
Nickel	143 million tonnes	90	Batteries, Turbine blades
Phosphorus	49 750 million tonnes	345	Fertilizer, Animal food
Platinum / Rhodium	79 840 tonness	360 for Pt	Jewellery, Industrial catalysts, Fuel cells, Catalytic converters
Selenium	170 000 tonnes	120	Semiconductors, Solar cells
Silver	569 000 tonnes	29	Jewellery, Industrial catalyst
Tantalum	153 000 tonnes	116	Cell phones, Camera lenses
Thallium	650 000 tonnes	65	High-temperaature superconductors, Organic reagents
Tin	11.2 million tonnes	40	Cans, Solder
Uranium	3.3 million tonnes	59	Nuclear PPs, Weapons
Zinc	460 million tonnes	46	Galvanizing

Rhodes, C.J. (2008) Metals shortages. Chem. Indust., 25th August, 21 – 22.

See the article on «odtuclass»: Deep Sea Dilemma, by Olive Heffernan, 2023 Scientific American, September 2023

Mining the seafloor could boost production of clean energy technology. It might destroy irreplaceable ocean ecosystems in the process


Nodule Zones
Atlantic Ocean
Clarion-Clipperton Zone - Central Indian Ocean Basin
Peru Basin
West Pacific Ocean - Penrhyn Basin
Clarion-Clipperton
Zone (CCZ)


Elements of Interest
Seafloor nodules can contain numerous metals and other elements (light blue), although some of the concentrations may be small. Many of the top 10 most abundant materials (by weight) are commercially important (dark blue). Many of them are in the U.S. Geological Survey's most recent list of critical minerals—those considered essential to the economy and at risk of reliable supply—and minerals important to clean energy, such as cobalt, lithium and nickel, may abound. These characterizations are based on limited nodule samples and could vary widely across ocean floors.
Elements likely to be found in polymetallic nodules
Top 10 elements in nodules, by estimated tonnage
Elements designated as "critical minerals" by the U.S. Geological Survey in 2022
H
He
Lithium
Beryll-ium
B
C
N
O
F
Ne
Sodium
Magnes-ium
Alum-inum
Silicon
Phos-phorus
S
Cl
Ar
Potas-sium
Calcium
Scand-ium
Titanium
Vana-dium
Chrom-ium
Manga-nese
Iron
Cobalt
Nickel
Copper
Zinc
Ga
Ge
Arsenic
Se
Br
Kr
Rubid-ium
Stront-ium
Yttrium
Zircon-ium
Niobium
Molyb-denum
Tc
Ru
Rh
Pd
Ag
Cad-mium
In
Sn
Anti-mony
Te
I
Xe
Cesium
Barium
Hf
Ta
Tungsten
Re
Os
Ir
Pt
Au
Hg
Thallium
Lead
Bismuth
Po
At
Rn
Fr
Ra
Rf
Db
Sg
Bh
Hs
Mt
Ds
Rg
Cn
Nh
Fl
Mc
Lv
Ts
Og
Lanth-anum
Cerium
Praseo-dymium
Neo-dymium
Pm
Samar-ium
Europ-ium
Gadolin-ium
Terbium
Dyspro-sium
Holmium
Erbium
Thulium
Ytterb-ium
Lutetium
Ac
Thorium
Pa
Uranium
Np
Pu
Am
Cm
Bk
Cf
Es
Fm
Md
No
Lr