Environmental chemistry and biology
HSLU, Semester 1

Matteo Frongillo

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Contents

Preamble (Week 0)

1 Learning objectives

We should be able to:

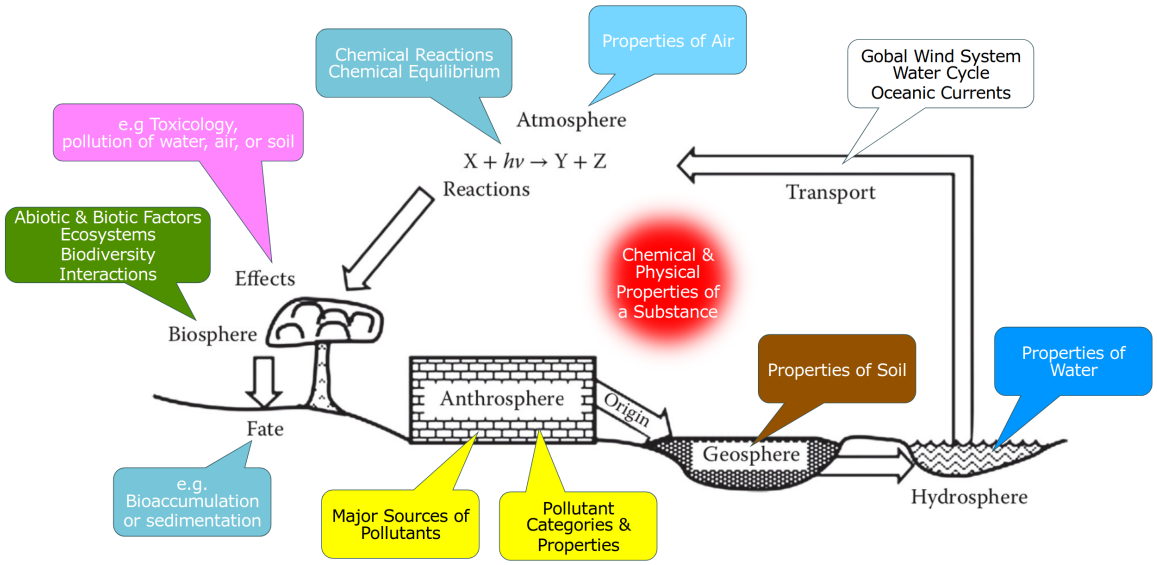
- define the term “Environment”;
- define the term “Environmental chemistry”;
- define the term “Environmental biology”;
- know the physical and chemical properties, defining the environemntal behavior of a substance;
- apply the concept of partitioning to analyze and understan the behavior of an organic substance in the environment, with the provided values.

2 Introduction SW 0

2.1 Definitions

2.1.1 Environmental Chemistry

Environmental chemistry is the discipline that describes the **origin, transport, reactions, effects and fate** of chemical species in the hydro-, atmo-, geo-, bio- and anthrosphere.



2.1.2 Enviromental Biology

Environmental biology is the study of **the relationships between living organisms and their environment**, including the impacts of human activities.

In an ecosystem, biotic factors include all living organisms and microorganisms. These organisms interact through predation, competition, and sysmbiosis, forming a complex web of life.
Abiotic factors, lie water, sunlight, temperature, pH levels, and minerals, influence the biotic components.

Human activities, such as the introduction of radioactive wastes, can disrupt the balance by altering the chemistry of the environment and harming living organisms.

2.2 Chemical structure and Environmental behavior

We consider two groups of properties of chemicals:

2.2.1 Physical properties

- Vapor pressure (mp, bp);
- Solubility (H_2O, ...);
- Acid / Base strength (pK_a, pK_b);
- Partition coefficients (e.g. K_{OW}).

These properties describe **Dispersion** in different compartments ⇒ Mobility and Toxicity.

2.2.2 Chemical properties → Reactivity

- Functional groups (-OH, -NH_2, ...);
- Electronic substituent effects (push/pull of electrons);

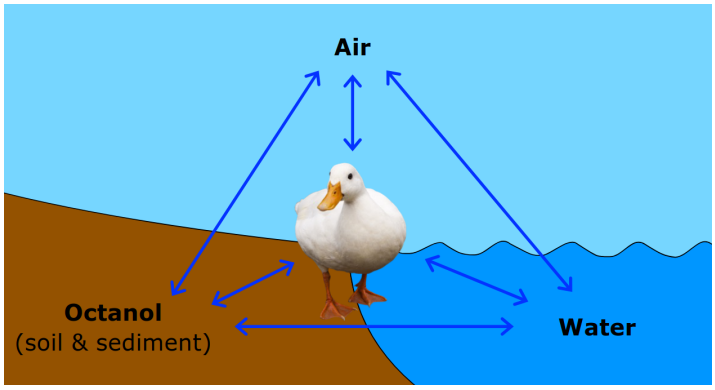
- Reaction mechanisms.

These properties describe **Transformation** of products ⇒ Degradation

2.3 Partitioning of organic substances in the environment

The partitioning is the passage of an organic substance from one environmental compartment to another. It's a physical process and does not involve a chemical reaction:

1. air ⟷ water:
   - volatility / vapor pressure;
   - water solubility;
2. water ⟷ soil:
   - adsorption (sticking to particles);
   - water solubility;
3. soil ⟷ air:
   - adsorption;
   - volatility / vapor pressure;
4. all phases ⟷ biota:
   - lipophilicity (fat solubility).



2.4 Chemical transformations under environmental conditions

There are two fundamental pathways:

2.4.1 Abiotic

In compartments Air, Water, Soil → **Energy source: temperature, light**

1. Hydrolysis: water breaks down a compound;
2. Oxidation: process where a substance loses electrons, often involving oxygen;
3. Reduction: process where a substance gains electrons, often involving the breakdown of pollutant in low-oxygen conditions;
4. Photochemical reactions: reaction driven by sunlight, where light energy breaks down chemicals.

2.4.2 Biotic

In organisms → **Catalyst: enzymes**

1. Oxidation: enzymes help break down organic molecules within organisms;
2. Reduction: in organisms, reduction reactions often involve energy production, such as anaerobic environments;
3. Hydrolysis: enzymes within organisms facilitate hydrolysis to break down larger molecules, like proteins or carbohydrates;
4. Secundary reactions: additional reactions that happen following primary processes.

2.5 Biological transformations

2.5.1 Abiotic transformations

- These occur in the non-living components of the environment.
  Energy for these transformations often comes from higher temperatures or sunlight;
- Photochemical reactions are particularly important in atmosphere, driven by sunlight. They can lead to the breakdown of pollutant, through some compounds like PCBs (polychlorinated biphenyls) are resistant to degradation, causing persistance in the environment.

2.5.2 Biotic transformations

- These occur within living organisms and are often enzyme-driven;
- Persistent pollutants like PCBs, biotic transformations tend to be slow, leading to accumulation in organisms. This results in **bioaccumulation** up the foodchain.

Part I

Week 1

3 Learning objectives

We should be able to:

- provide for at least 5 of the 8 primary sources of pollutants;
- apply the 5-key aspects of a pollutant to predict its behaviour in the environemnt;
- discuss how pollutants move through different environmental compartments;
- briefly describe with one example the pollutant categories;
- recognize the pollutant classes by their Lewis structure;
- compare and contrast the similarities and differences among various pollutant categories, including their sources, chemical properties, environmental impact, and persistence.

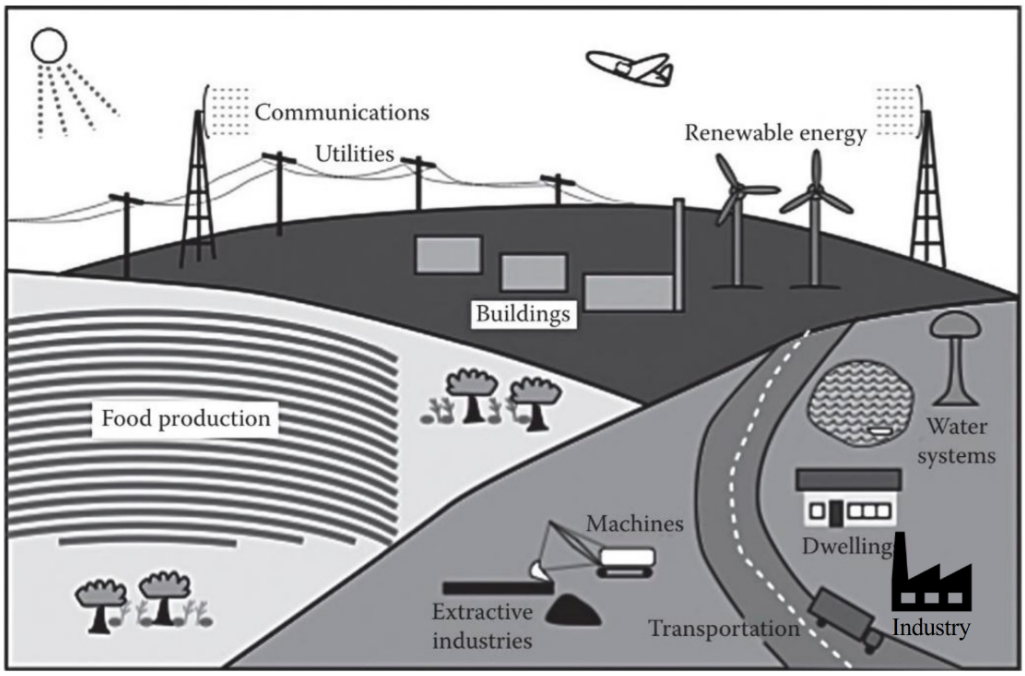
4 Anthrosphere and Environmental impact

Definition:
The anthrosphere is the part of the environment that's **made or operated by humans**. The anthrosphere is where **pollutants are made** and from which they are released with profound effect on all other environmental spheres.

It also strongly affected by pollutants, e.g. acid rains, which cause deterioration of stone structures and corrosion of metal components.

Impact:
It is essential to view the anthrosphere as a distinct environmental sphere, when considering environmental chemistry and sustainability. Just a look around us shows the dwellings, buildings, roads, factories, power lines, and numerous other things constructed and operated by human as a visible evidence of the existence of the anthrosphere of Earth.

4.1 Human primary sources



1. Industrial activities: factories, mining and processing plants release air, water, and soil pollutants (SO_2, NO_x, PM, VOCs), including chemicals and heavy metals (Hg);
2. Transportation: vehicles and ships emit harmful gases (CO_2, CO, NO_x), and particulate matter, contibuting to air pollution and climate change;
3. Agriculture: farming activities generate pollutants such as pesticides (Glyphosate, Atrazin), fertilizers (NH_3), and methane (CH_3), leading to water contamination and greenhouse gas emissions;
4. Energy production: burning fossil fuels for energy emits CO_2, SO_2, and other pollutants, driving air pollution and global warming;
5. Urban development: construction and waste management in cities produce dust, noise, and runoff pollution, impacting air and water quality;
6. Deforestation and Land Use changes: clearing forests releases CO_2 and causes soil erosion, contributing to climate change, habitat and biodiversity loss;
7. Household activities: residential heating, cooking, and consumer products emit indoor and outdoor air pollutants like VOCs and particulate matter;
8. Waterwaste and Sewage: inadequate treatment of sewage and industrial wastewater pollutes water bodies with pathogens, nutrients (PO_4^{3-}), chemicals and heavy metals.

5 Pollutants and hazardous

5.1 Pollutants

A pollutant is a substance or energy introduced into the environment that has undesired effects, or adversely affects the useflness of a resource.

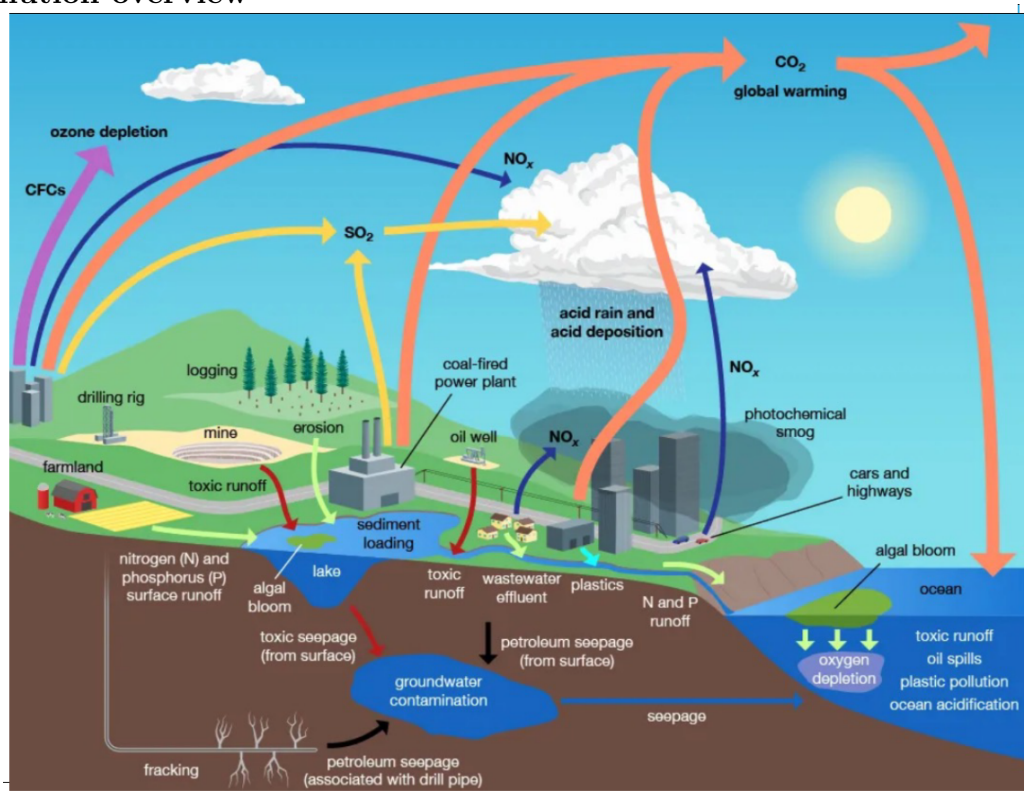
A pollutant may cause long- or short-therm damage by changing the growth rate or plants or animal species, or by interfering with human amenities, comfort, health, or property values.

5.2 Hazardous waste

Hazardous waste is a waste that is dangerous or potentially harmful to our health or the environment. Hazardous wastes can be liquids, solids, gases, or sludges.

They can be discarded commercial products, like cleaning fluids or pesticides, ore the by-products of manufacturing processes.

5.3 Pollution overview



Air pollution and climate changes:

1. Coal-fired power plants emit pollutants like sulfur dioxide (SO_2) and nitrogen oxides (NO_x) into the atmosphere, contributing to acid rain and acid deposition;
2. Cars and highways emit NO_x leading to photochemical smog and further contributing to air pollution;
3. Emission of carbon dioxide (CO_2) from these sources contribute to global warming;
4. Chlorofluorocarbons (CFCs) lead to ozone depletion.

Water pollution and Ecosystem impact:

1. Toxic runoff from mines and farmland introduces harmful substances into lakes, rivers, and oceans, causing algal blooms and leading to oxygen depletion in aquatic ecosystems;
2. Nitrogen (N) and phosphorus (P) from fertilizers in agricultural runoff also contribute to eutrophication in water bodies, exacerbating algal blooms;
3. Wastewater effluent, plastics, and petroleum seepage from oil swlls pollute lakes, oceans, and groundwater, leading to groundwater contamination and ocean acidification;
4. Oil spills, toxic runoff, and plastic pollution are shown to be harming ocean life.

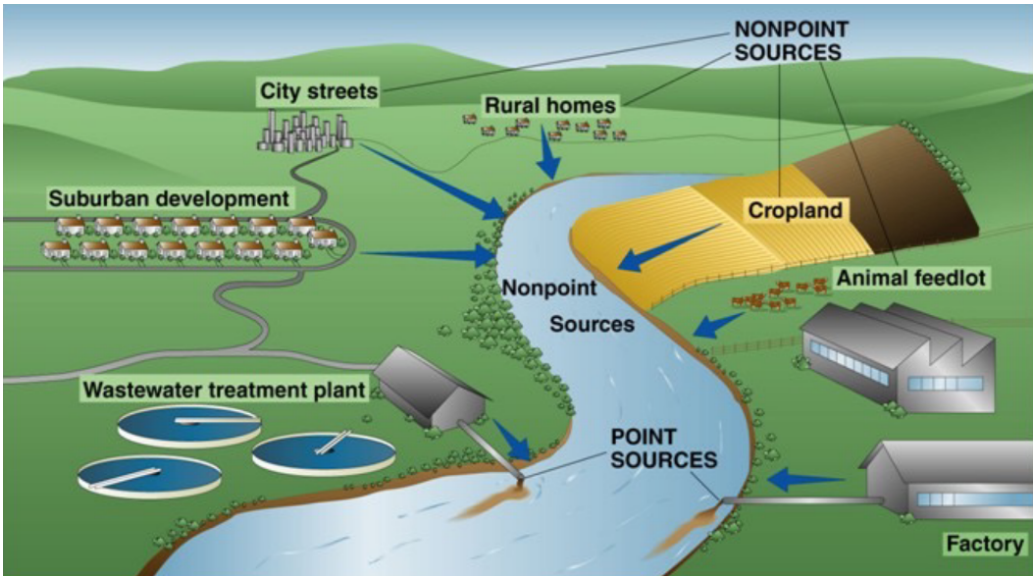
Land degradation:

1. Logging and mining activities result in erosion, causing sediment loading in nearby water bodies;
2. Fracking (hydraulic fracturing) is depicted as a source of petroleum seepage into groundwater.

Forests and Farmland:

1. The farmland in the diagram shows surface runoff of nitrogen and phosphorus into surrounding water systems, further contibuting to water pollution and ecological damate.

6 Point sources vs. Nonpoint sources



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7 Earth system and Pollution dynamics

7.1 Earth system and chemicals

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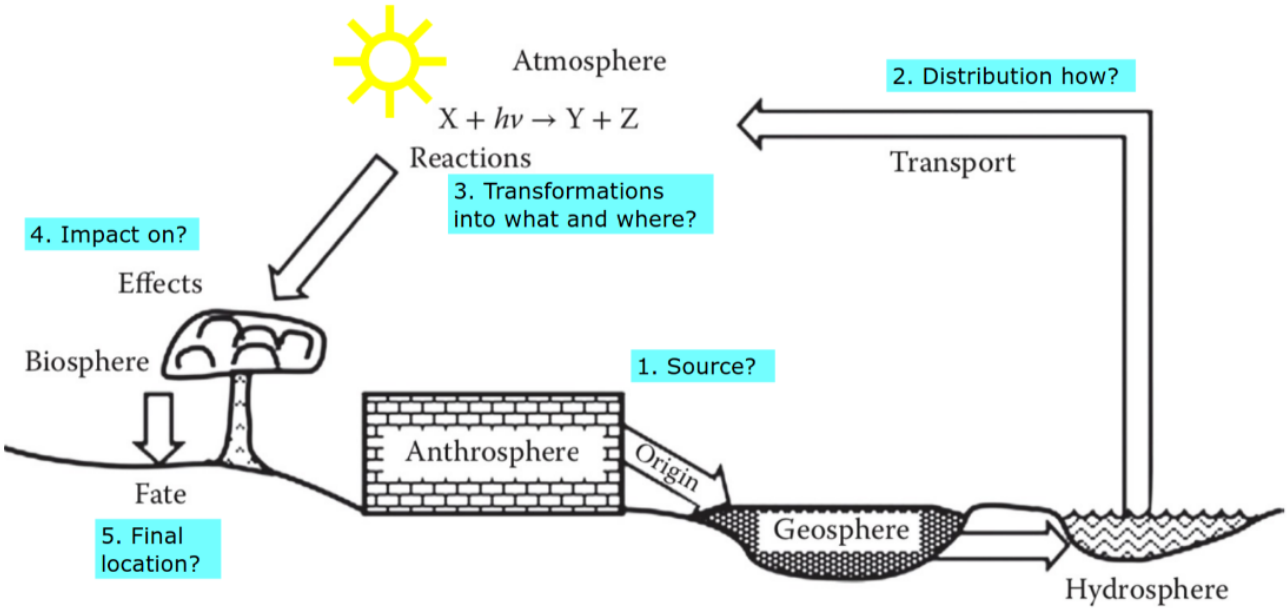
7.2 5-key aspects of pollutants



1. Origin: source of the chemical or pollutant;
2. Transport: distribution of the pollutant;

3. Reactions: trasformation of the pollutant;
4. Effects: impact of the pollutant;
5. Fate: whereabouts of the pollutant.

8 Important pollutant categories

8.1 Heavy metals

Heavy metals are material with very high densities.

8.1.1 Sources

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8.1.2 Reactions

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8.1.3 Effect

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8.1.4 Fate

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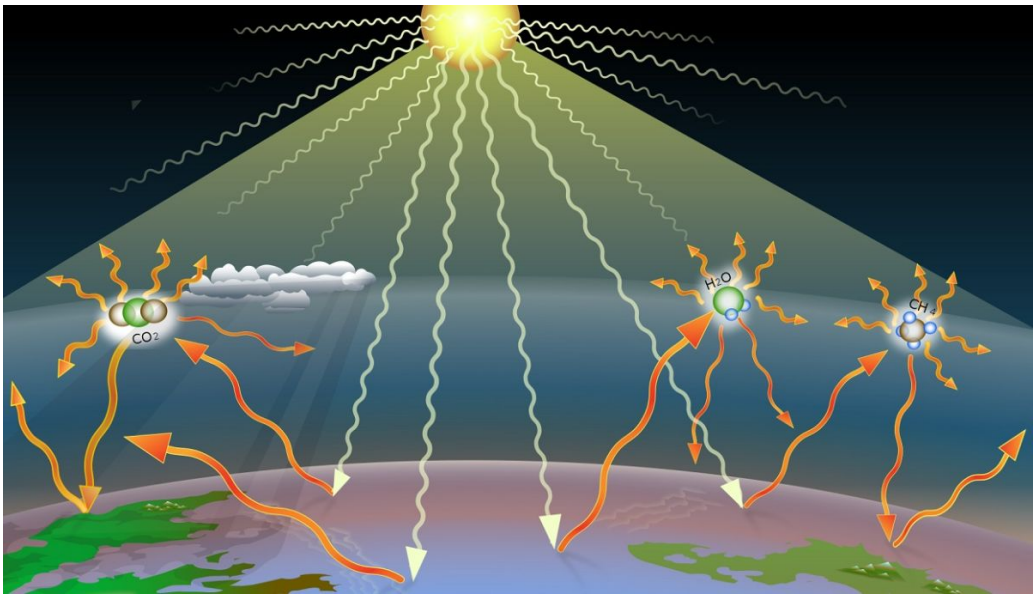
8.2 Greenhouse gases (GHGs)

GHGs are gases which reflects UVs, impeding them to exit from the ozone and therefore dissipate their heat in it.



8.2.1 Sources

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8.2.2 Reactions

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8.2.3 Effect

...

8.2.4 Fate

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8.3 Particulate matter (PM)

PM is made by microscopic particles which can depositate inside the respiratory system of animals and create health problems, such as asthma or cardiovascular issues.

8.3.1 Sources

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8.3.2 Reactions

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8.3.3 Effect

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8.3.4 Fate

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8.4 Persistent organic pollutants (POPs)

POPs are chemicals which have a very long degradation time. They are called “forever chemicals”.

8.4.1 Halogenated organic compounds (HOCs)

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8.4.2 Per- and Polyfluoroalkyl substances (PFASs)

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8.4.3 Both categories

- Reactions:
- Effect:
- Fate:

8.5 Chlorofluorocarbons (CFCs)

CFCs are gases ...

8.5.1 Sources

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8.5.2 Reactions

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8.5.3 Effect

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8.5.4 Fate

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8.6 Polycyclic aromatic hydrocarbons (PAHs)

PAHs are gases created by incompleted combustions, such as tobacco smoke or grilled food.

8.6.1 Sources

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8.6.2 Reactions

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8.6.3 Effect

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8.6.4 Fate

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8.7 Volatile organic compounds (VOCs)

VOCs are gases with a low molecular weight which can evaporate at room temperature.

8.7.1 Sources

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8.7.2 Reactions

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8.7.3 Effect

...

8.7.4 Fate

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8.8 Environmentally persistent pharmaceutical pollutants (EPPPs)

EPPPs are pharmaceutical chemicals with a complex structure, which gives to molecules a big stability and a slow biodegradability.

8.8.1 Sources

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8.8.2 Reactions

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8.8.3 Effect

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8.8.4 Fate

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8.9 Plastics

Plactics are chemicals made by long chains of carbon...

8.9.1 Sources

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8.9.2 Reactions

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8.9.3 Effect

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8.9.4 Fate

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