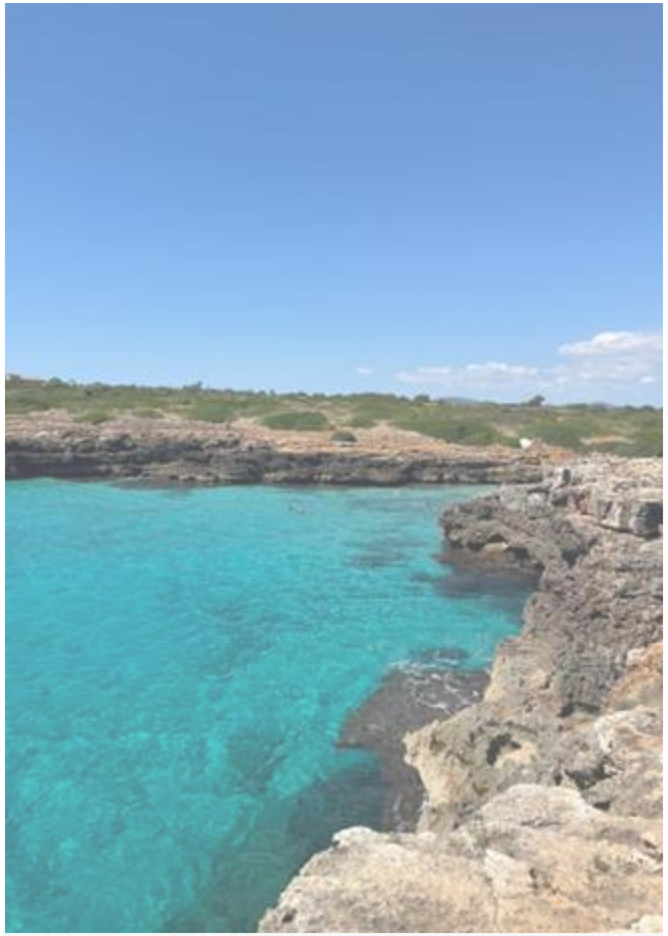
The microbial component of ecosystem processes



École Polytechnique Fédérale de Lausanne (EPFL)

Lecturer: Dr. Ferran Romero
Coordinator: Prof. Dr. Ianina Altshuler

The microbial component of ecosystem processes

1. **Introduction to (microbial) metabolism**

2. **Ecosystem processes**
    i. Carbon
    ii. Nitrogen
    iii. Sulphur
    iv. Other elements

3. **Take-home messages**

Introduction to metabolism

Metabolism **is the sum of all chemical reactions that occur within a living organism to sustain life.**

Introduction to metabolism

***Metabolism* is the sum of all chemical reactions that occur within a living organism to sustain life.**

Catabolism reactions break down molecules to <u>release</u> energy

Anabolism reactions build up molecules using simpler ones, <u>requires</u> energy

Introduction to metabolism

Energy	Electron donor	Carbon source
Breaking down chemical compounds Chemotrophs	Organic Organotrophs	Organic Heterotrophs
Sunlight Phototrophs	Inorganic Lithotrophs	Inorganic Autotrophs

Introduction to metabolism

Energy

Breaking down chemical compounds
Chemotrophs

Electron donor

Organic
Organotrophs

Carbon source

Organic
Heterotrophs

Chemoorganoheterotrophs

Introduction to metabolism

Energy source	Electron donor	Carbon source	Name
Breaking chemical bonds *Chemo-*	Organic *-organo-*	Organic *-hetero*	CHEMOORGANOHETEROTROPH

Humans are chemoorganoheterotrophs because **we obtain energy breaking down chemical bonds. Electrons move from organic compounds to oxygen**, and **we build our own structures using the C released from organic molecules**.

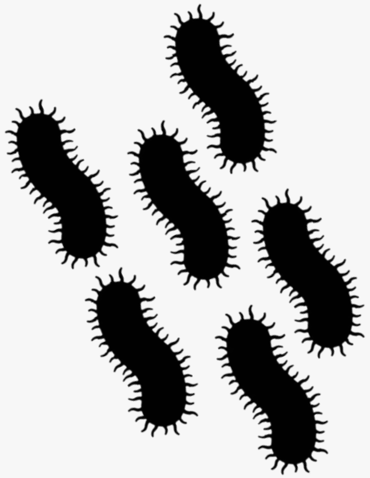
Introduction to metabolism

Energy source	Electron donor	Carbon source	Name
Sunlight *Photo-*	Inorganic *-litho-*	CO_2 *-auto*	PHOTOLITHOAUTOTROPH

Plants are photolithoautotrophs because **they obtain energy from the sun. Electrons move from H_2O to NADP+**, and **they build their structures using the C released from CO_2**.

Introduction to metabolism

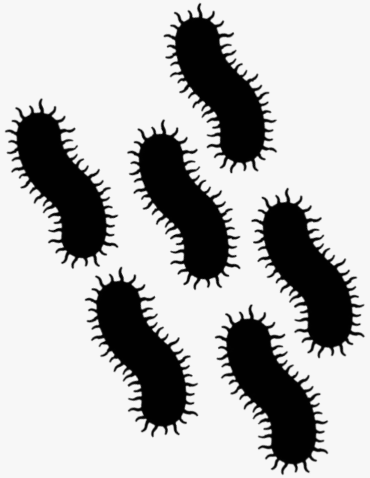
What about microorganisms?



Introduction to metabolism

Energy source	Electron donor	Carbon source	Name
Sunlight *Photo-*	Organic *-organo-*	Organic *-hetero*	PHOTOORGANOHETEROTROPH
		CO_2 *-auto*	PHOTOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	PHOTOLITHOHETEROTROPH
		CO_2 *-auto*	PHOTOLITHOAUTOTROPH
Breaking chemical bonds *Chemo-*	Organic *-organo-*	Organic *-hetero*	CHEMOORGANOHETEROTROPH
		CO_2 *-auto*	CHEMOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	CHEMOLITHOHETEROTROPH
		CO_2 *-auto*	CHEMOLITHOAUTOTROPH

Microbes do everything ☺



Introduction to metabolism

Energy source	Electron donor	Carbon source	Name
Sunlight *Photo-*	Inorganic *-litho-*	CO_2 *-auto*	**PHOTOLITHOAUTOTROPH**

Cyanobacteria and algae are, like plants,

photolithoautotrophs because

… they obtain energy from the sun

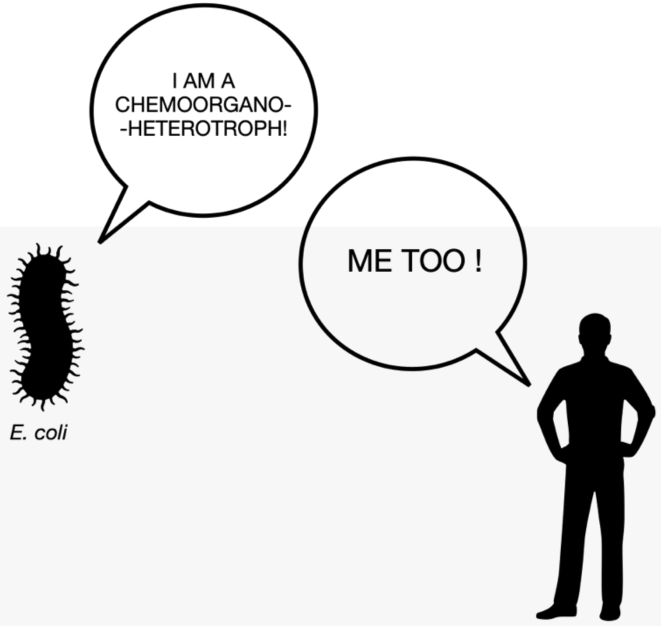
… electrons move from H_2O to NADP+

… they build their structures using the C released from CO_2

Department of Env. quality. Oklahoma city

Introduction to metabolism

Energy source	Electron donor	Carbon source	Name
Breaking chemical bonds *Chemo-*	Organic *-organo-*	Organic *-hetero*	CHEMOORGANOHETEROTROPH



***Escherichia coli* is,** like humans**, a chemoorganoheterotroph** because:

… it obtains energy breaking down chemical bonds

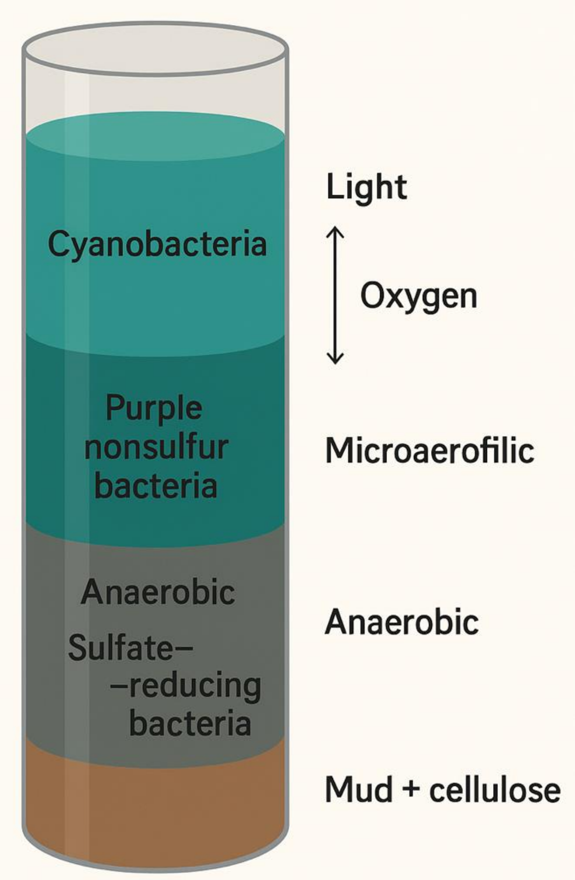
… electrons move from organic compounds to oxygen

… it builds their own structures using the C released from organic molecules.

Introduction to metabolism

Energy source	Electron donor	Carbon source	Name
Sunlight *Photo-*	Organic *-organo-*	Organic *-hetero*	PHOTOORGANOHETEROTROPH
		CO_2 *-auto*	PHOTOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	PHOTOLITHOHETEROTROPH
		CO_2 *-auto*	PHOTOLITHOAUTOTROPH
Breaking chemical bonds *Chemo-*	Organic *-organo-*	Organic *-hetero*	CHEMOORGANOHETEROTROPH
		CO_2 *-auto*	CHEMOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	CHEMOLITHOHETEROTROPH
		CO_2 *-auto*	CHEMOLITHOAUTOTROPH

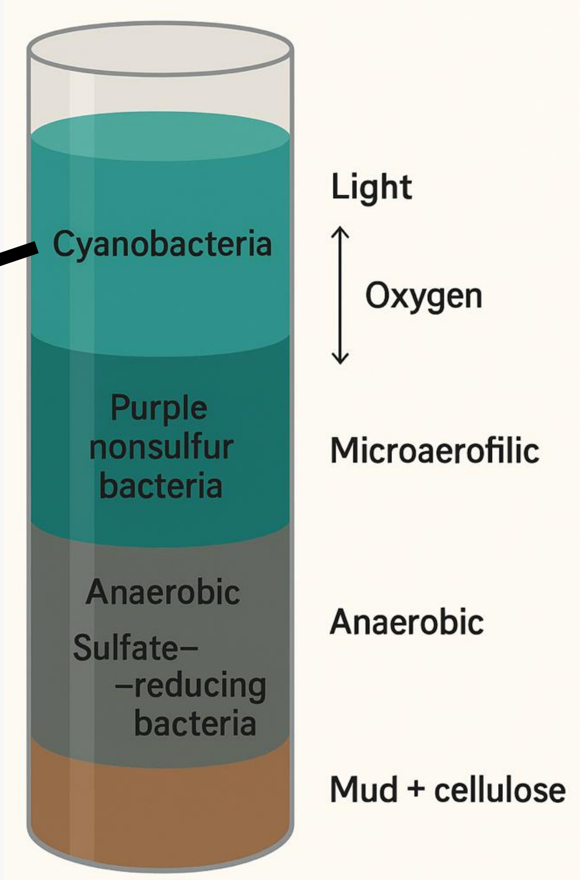
The Winogradsky column



Introduction to metabolism

Energy source	Electron donor	Carbon source	Name
Sunlight *Photo-*	Organic *-organo-*	Organic *-hetero*	PHOTOORGANOHETEROTROPH
		CO_2 *-auto*	PHOTOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	PHOTOLITHOHETEROTROPH
		CO_2 *-auto*	PHOTOLITHOAUTOTROPH
Breaking chemical bonds *Chemo-*	Organic *-organo-*	Organic *-hetero*	CHEMOORGANOHETEROTROPH
		CO_2 *-auto*	CHEMOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	CHEMOLITHOHETEROTROPH
		CO_2 *-auto*	CHEMOLITHOAUTOTROPH

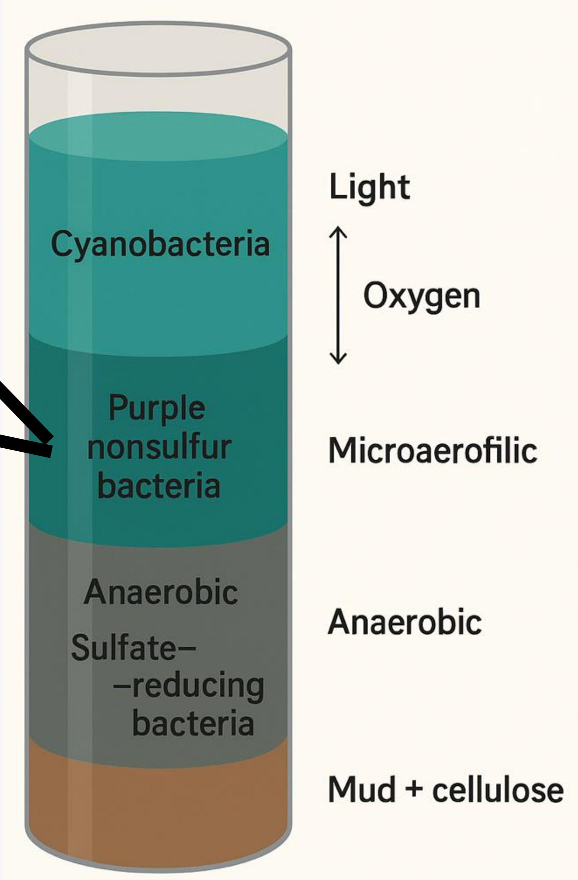
The Winogradsky column



Introduction to metabolism

Energy source	Electron donor	Carbon source	Name
Sunlight *Photo-*	Organic *-organo-*	Organic *-hetero*	PHOTOORGANOHETEROTROPH
		CO_2 *-auto*	PHOTOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	PHOTOLITHOHETEROTROPH
		CO_2 *-auto*	PHOTOLITHOAUTOTROPH
Breaking chemical bonds *Chemo-*	Organic *-organo-*	Organic *-hetero*	CHEMOORGANOHETEROTROPH
		CO_2 *-auto*	CHEMOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	CHEMOLITHOHETEROTROPH
		CO_2 *-auto*	CHEMOLITHOAUTOTROPH

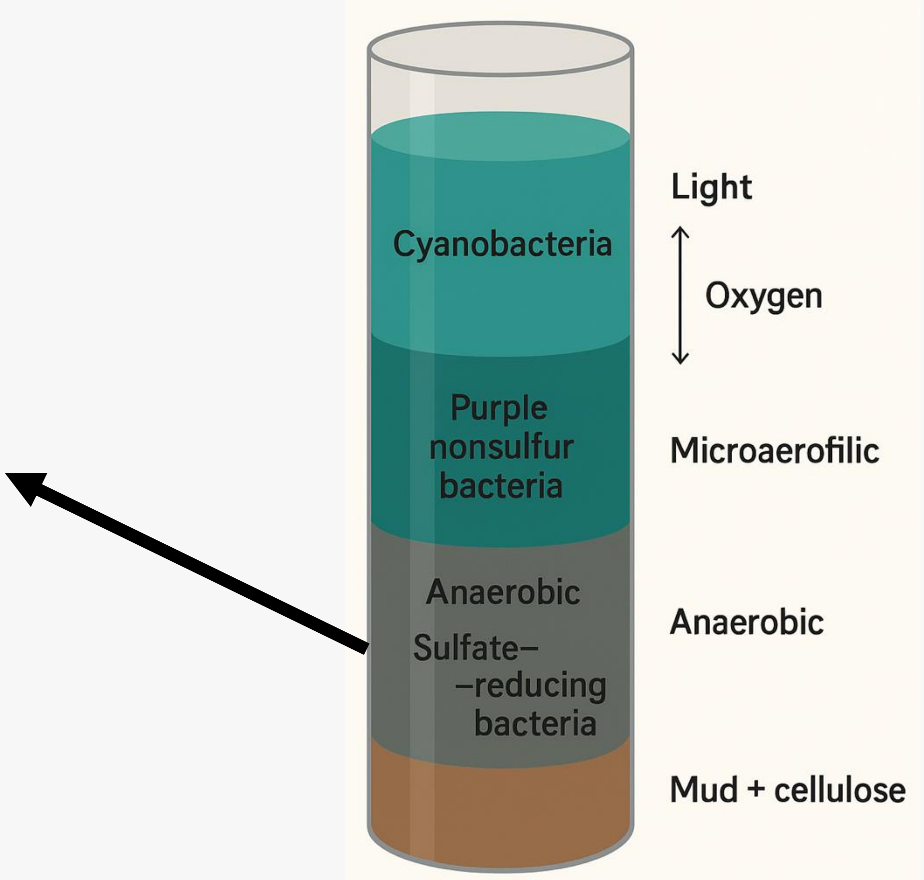
The Winogradsky column



Introduction to metabolism

Energy source	Electron donor	Carbon source	Name
Sunlight *Photo-*	Organic *-organo-*	Organic *-hetero*	PHOTOORGANOHETEROTROPH
		CO_2 *-auto*	PHOTOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	PHOTOLITHOHETEROTROPH
		CO_2 *-auto*	PHOTOLITHOAUTOTROPH
Breaking chemical bonds *Chemo-*	Organic *-organo-*	Organic *-hetero*	CHEMOORGANOHETEROTROPH
		CO_2 *-auto*	CHEMOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	CHEMOLITHOHETEROTROPH
		CO_2 *-auto*	CHEMOLITHOAUTOTROPH

The Winogradsky column



Introduction to metabolism

Energy source	Electron donor	Carbon source	Name
Sunlight *Photo-*	Organic *-organo-*	Organic *-hetero*	PHOTOORGANOHETEROTROPH
		CO_2 *-auto*	PHOTOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	PHOTOLITHOHETEROTROPH
		CO_2 *-auto*	PHOTOLITHOAUTOTROPH
Breaking chemical bonds *Chemo-*	Organic *-organo-*	Organic *-hetero*	CHEMOORGANOHETEROTROPH
		CO_2 *-auto*	CHEMOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	CHEMOLITHOHETEROTROPH
		CO_2 *-auto*	CHEMOLITHOAUTOTROPH

Why are microorganisms so metabolically diverse?

Introduction to metabolism

Energy source	Electron donor	Carbon source	Name
Sunlight *Photo-*	Organic *-organo-*	Organic *-hetero*	PHOTOORGANOHETEROTROPH
		CO_2 *-auto*	PHOTOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	PHOTOLITHOHETEROTROPH
		CO_2 *-auto*	PHOTOLITHOAUTOTROPH
Breaking chemical bonds *Chemo-*	Organic *-organo-*	Organic *-hetero*	CHEMOORGANOHETEROTROPH
		CO_2 *-auto*	CHEMOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	CHEMOLITHOHETEROTROPH
		CO_2 *-auto*	CHEMOLITHOAUTOTROPH

Why are microorganisms so metabolically diverse?

Microorganisms have evolved during **3500 million years.**

Humans have evolved during **0,3 million years**

The microbial component of ecosystem processes

1. Introduction to (microbial) metabolism

2. **Ecosystem processes**
    i. Carbon
    ii. Nitrogen
    iii. Sulphur
    iv. Other elements

3. Take-home messages

Ecosystem processes

- Any flow of energy or matter that sustains an ecosystem and all the living organisms within.

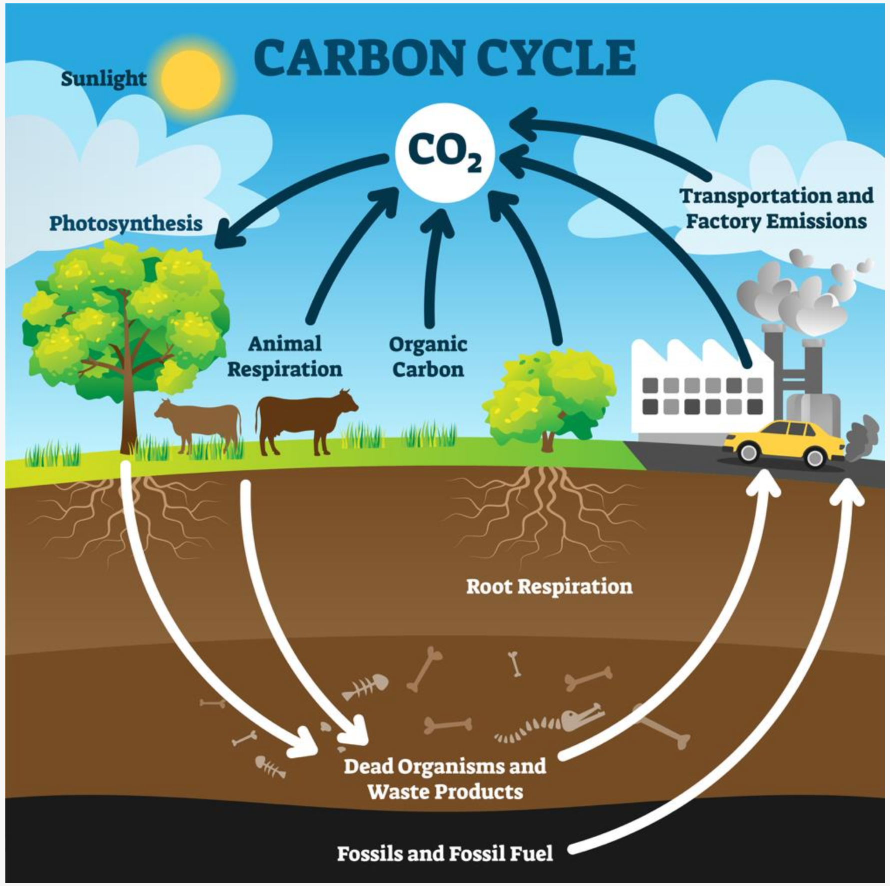
Ecosystem processes

- Microorganisms are the backbone of all ecosystems.
  - Microbial processes are critical to maintain a balanced ecosystem by facilitating nutrient cycling.
  - Many ecosystems function without macroorganisms, but none do without microorganisms.
- Microorganisms play a critical role in energy transformations and biogeochemical processes that result in the recycling of elements.
  - Biogeochemical cycles (incl. nutrient cycles) are the cyclic transformation of chemicals between their chemical forms. Often via *redox* reactions.

Ecosystem processes

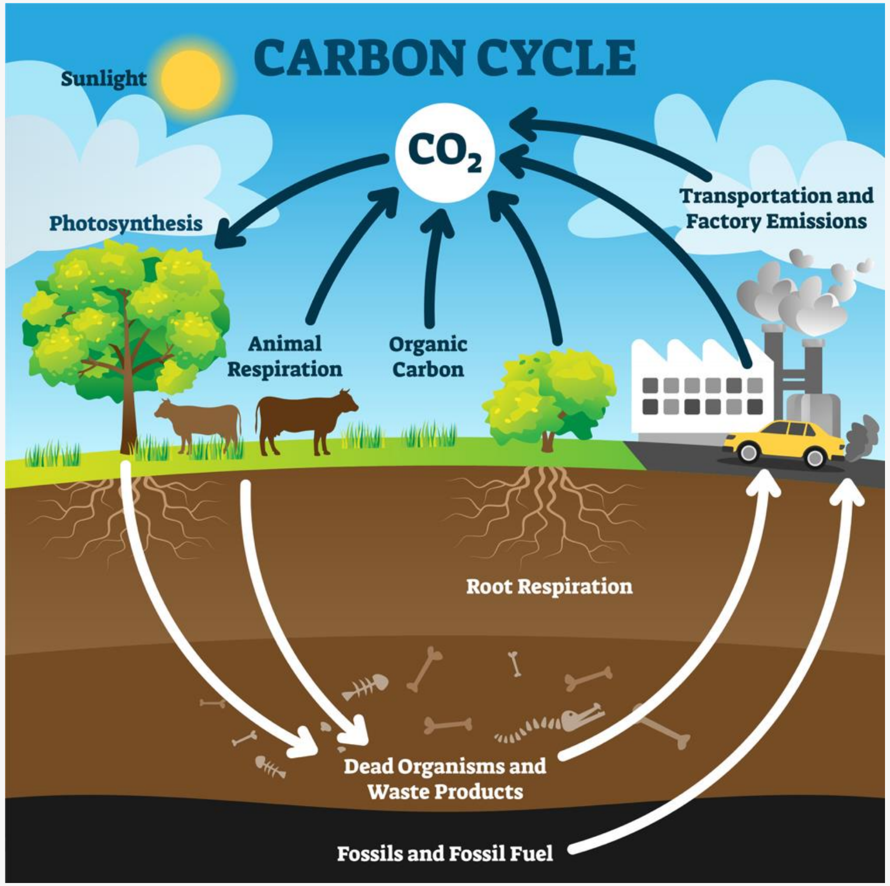
- **Sinks** are anything that absorbs more than emits any given nutrient.
- **Sources** are anything that emits more than absorbs any given nutrient.

Ecosystem processes: The carbon cycle



In the atmosphere, carbon exists mainly as **carbon dioxide** (CO2)

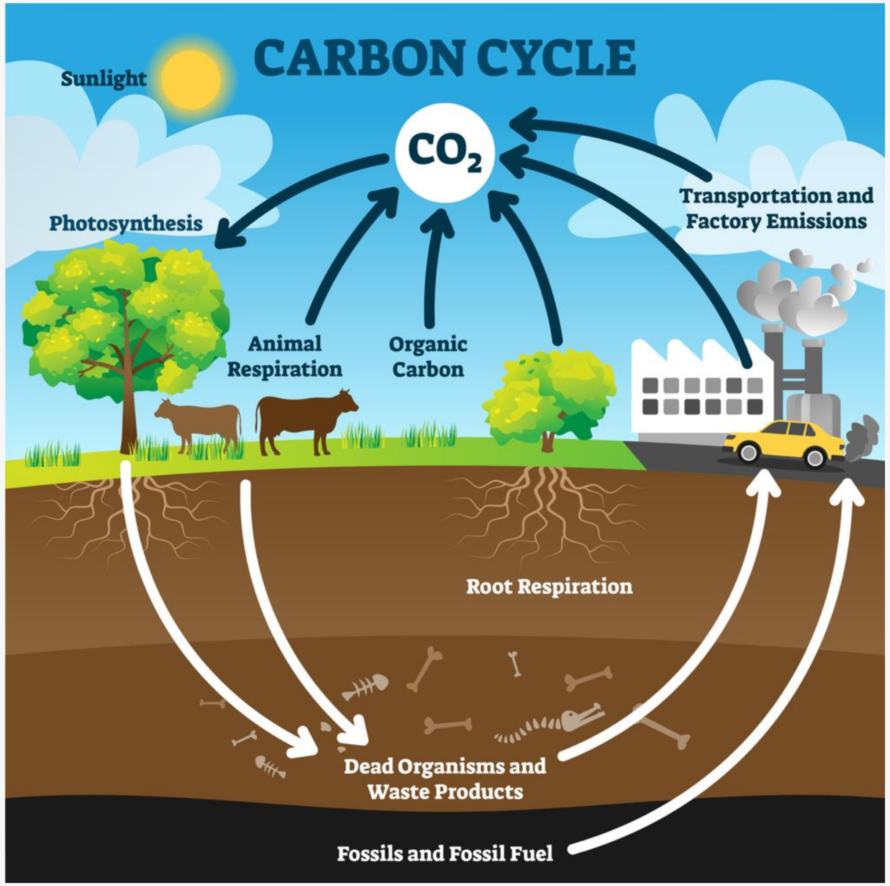
Ecosystem processes: The carbon cycle



In the atmosphere, carbon exists mainly as **carbon dioxide** (CO2)

CO2 is incorporated into organic matter through the action of **autotrophs**. In terrestrial ecosystems, most of these are *photolithoautotrophs* (= they use sunlight for energy, and the electron donor is inorganic – H2O).

Ecosystem processes: The carbon cycle



In the atmosphere, carbon exists mainly as **carbon dioxide** (CO2)

CO2 is incorporated into organic matter through the action of **autotrophs**. In terrestrial ecosystems, most of these are *photolithoautotrophs* (= they use sunlight for energy, and the electron donor is inorganic – H2O).

Heterotrophs (mostly *chemoorganoheterotrophs*) eat plants and release CO2 back to the atmosphere.

When organisms die, microbial **decomposers** break their components down, releasing CO2 back to the atmosphere and returning some carbon to the soil

Some carbon is stored in fossil fuels and sedimentary rocks.

Ecosystem processes: The carbon cycle

Major Carbon Reservoirs on Earth

Reservoir	Percent of Total[a]
Rocks and sediments	99.5[b]
Oceans	0.05
Methane hydrates	0.014
Fossil fuels	0.006
Terrestrial biosphere	0.003
Aquatic biosphere	0.000002

[a] Total carbon, 76×10^{15} tons
[b] 80% inorganic

In the atmosphere, carbon exists mainly as **carbon dioxide** (CO2)

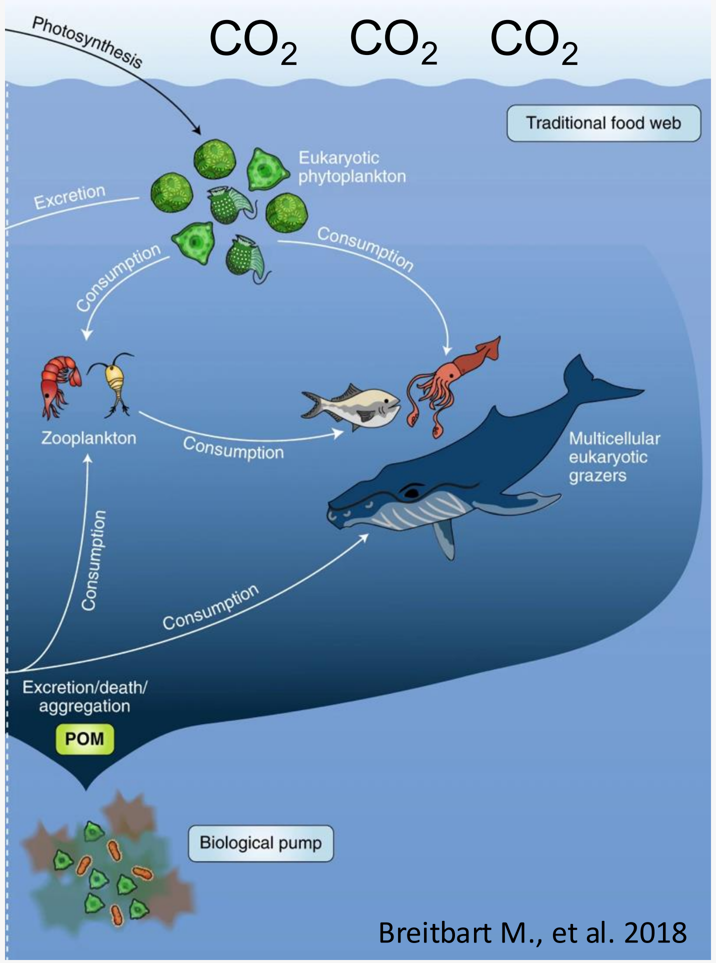
CO2 is incorporated into organic matter through the action of **autotrophs**. In terrestrial ecosystems, most of these are *photolithoautotrophs* (= they use sunlight for energy, and the electron donor is inorganic – H2O).

Heterotrophs (mostly *chemoorganoheterotrophs*) eat plants and release CO2 back to the atmosphere.

When organisms die, microbial **decomposers** break their components down, releasing CO2 back to the atmosphere and returning some carbon to the soil

Some carbon is stored in fossil fuels and sedimentary rocks.

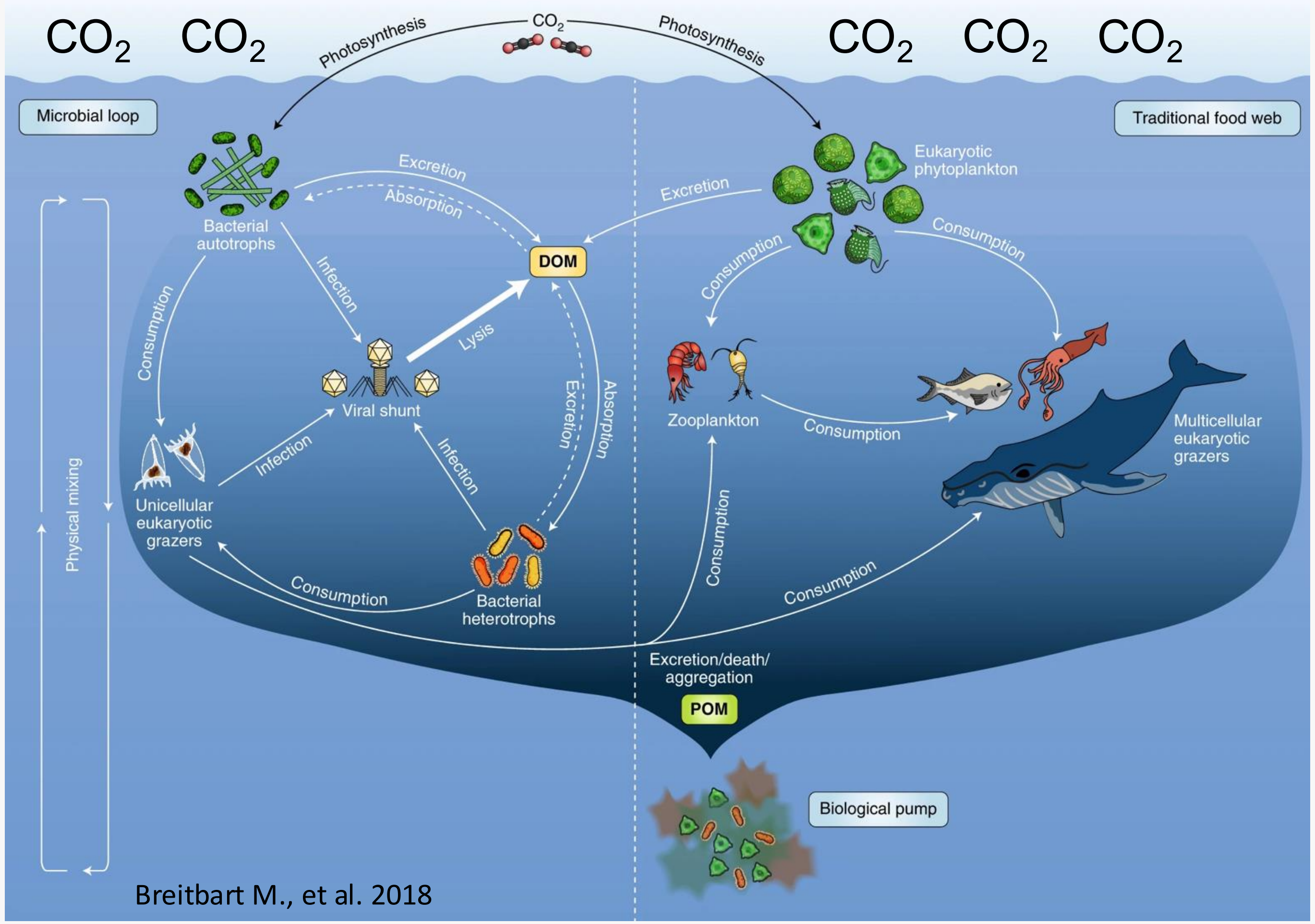
Ecosystem processes: The carbon cycle



Breitbart M., et al. 2018

In the ocean, the main **photolithoautotrophs** are not plants, but microorganisms.

Ecosystem processes: The carbon cycle



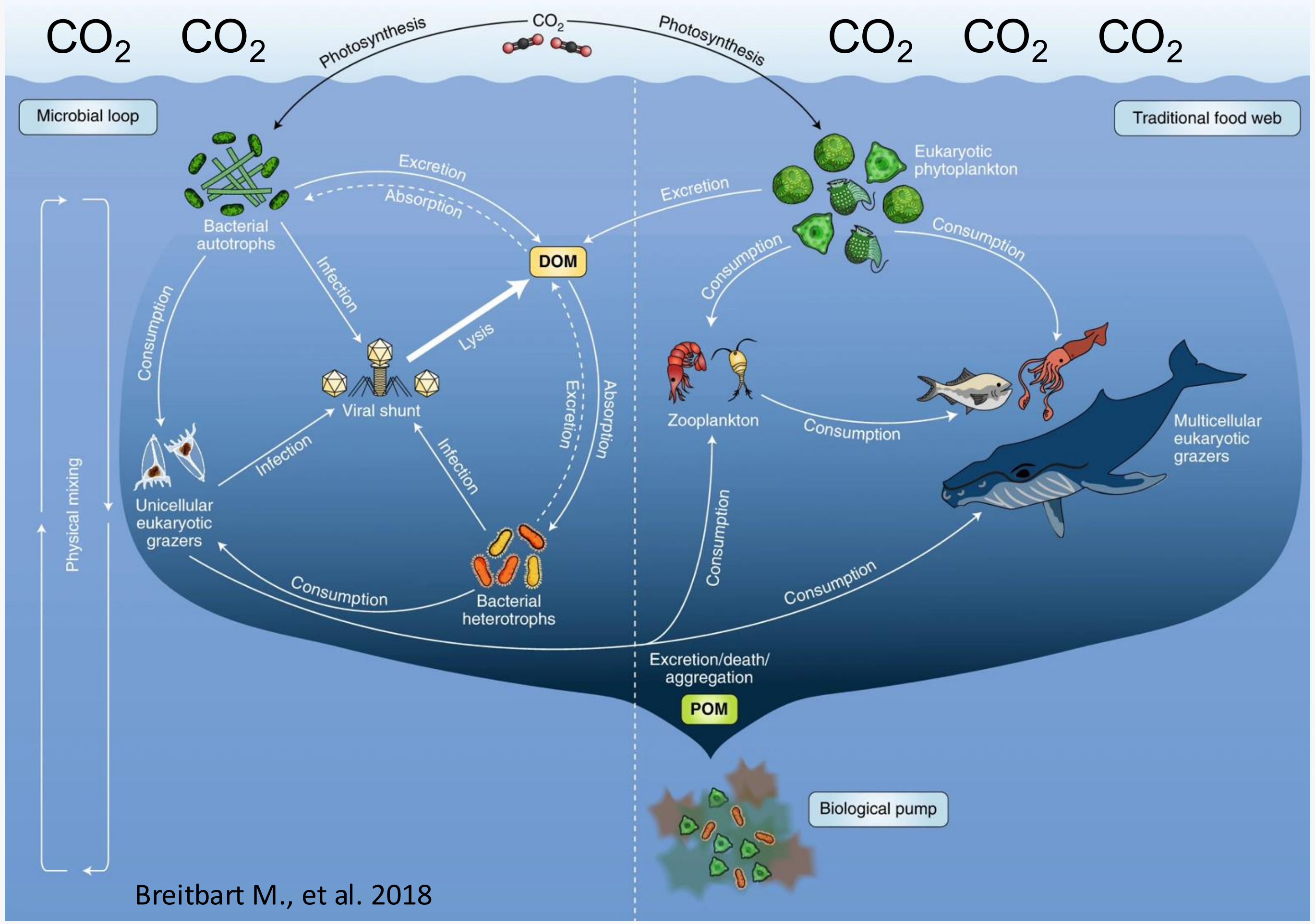
Breitbart M., et al. 2018

In the ocean, the main **photolithoautotrophs** are not plants, but microorganisms.

A major source of dissolved organic matter (DOM, <0.7 µm) in the ocean is released after viral infection of bacteria and other microorganisms.

This DOM is important since it constitutes the C source for a wide variety of aquatic heterotrophs.

Ecosystem processes: The carbon cycle



Breitbart M., et al. 2018

In the ocean, carbon is incorporated into biomolecules in the surface by **photolithoautotrophs**. Carbon is then transferred through the food web and sinks to the deep ocean as particulate organic matter (POM, >0.7 µm) when organisms die or excrete. Since most of this POM will remain in the deep ocean for millennia, the ocean actively removes C from the atmosphere and stores it in the deep ocean layers.

Therefore, the ocean has a natural carbon-sequestration mechanism = THE BIOLOGICAL PUMP.

Ecosystem processes: The carbon cycle

Methane (CH_4)

Ecosystem processes:
The carbon cycle

Methane (CH_4)

CH_4 is the most reduced form of carbon,and a powerful greenhouse gas (x28 CO_2).

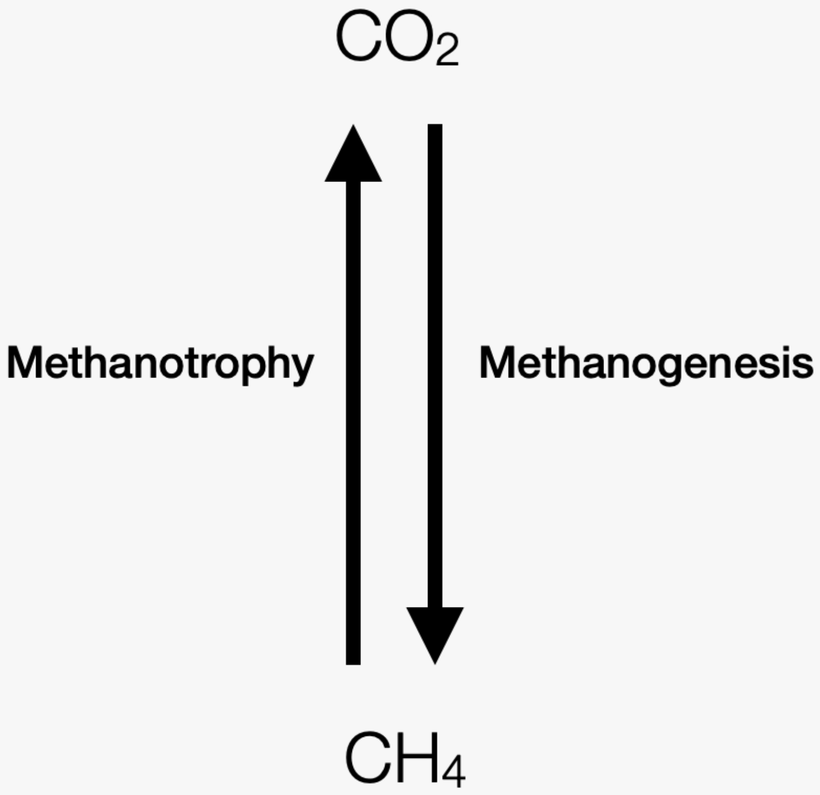
Produced and consumed by microorganisms, so the control over CH_4 is biologic.

Ecosystem processes: The carbon cycle

Methane (CH_4)

CH_4 is the most reduced form of carbon,and a powerful greenhouse gas (x28 CO_2).

Produced and consumed by microorganisms, so the control over CH_4 is biologic.

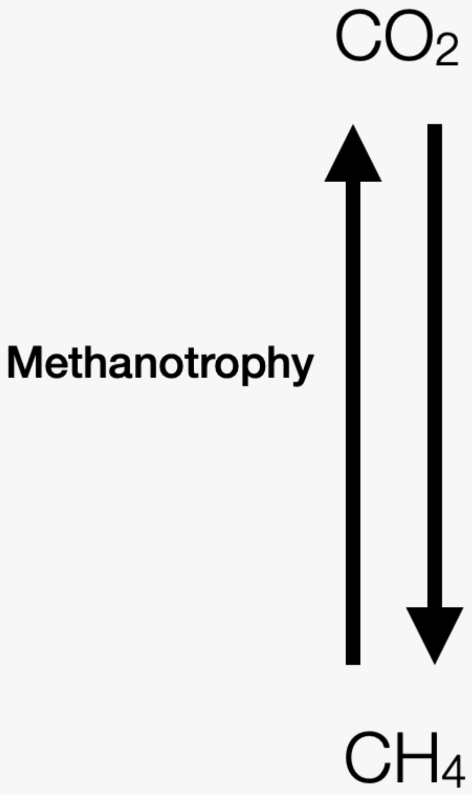


Ecosystem processes: The carbon cycle

Methane (CH_4)

CH_4 is the most reduced form of carbon,and a powerful greenhouse gas (x28 CO_2).

Produced and consumed by microorganisms, so the control over CH_4 is biologic.



Methanogenesis

Performed by a group of microorganisms called Archaea.

Archaea obtain energy following the breakdown of chemical linkages: Chemo-

Electron donor is H_2 or acetate.
-litho- / -organo-

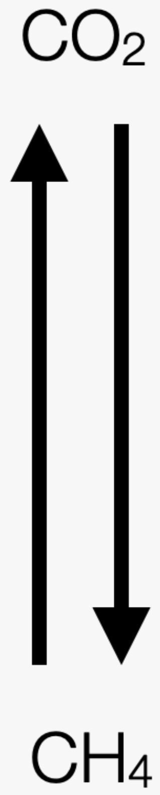
Carbon source is (often) CO_2
-auto

Ecosystem processes: The carbon cycle

Methane (CH_4)

CH_4 is the most reduced form of carbon,and a powerful greenhouse gas (x28 CO_2).

Produced and consumed by microorganisms, so the control over CH_4 is biologic.



Methanotrophy

Performed by diverse microorganisms called methanotrophs.

Methanotrophs obtain energy following the breakdown of CH_4: Chemo-

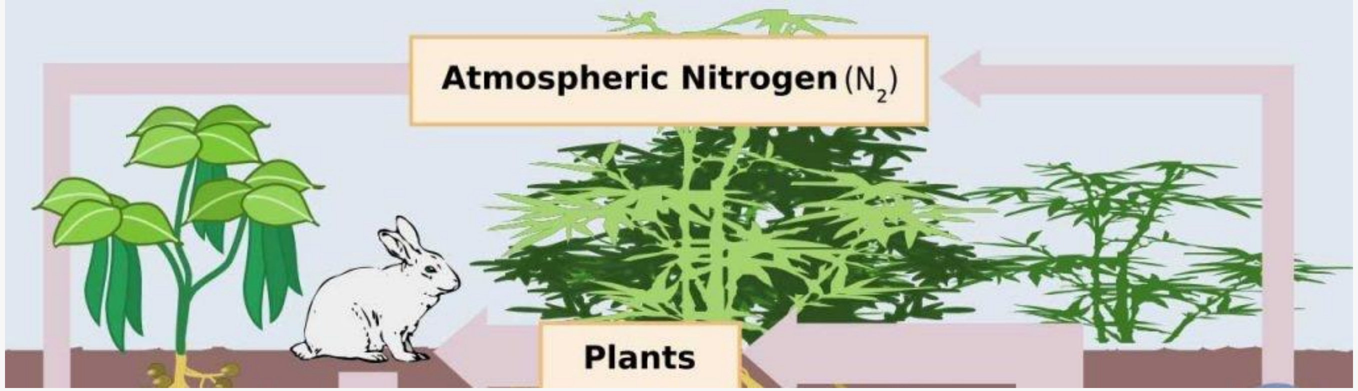
Electron donor is CH_4. -organo-

Carbon source is CH_4 -hetero

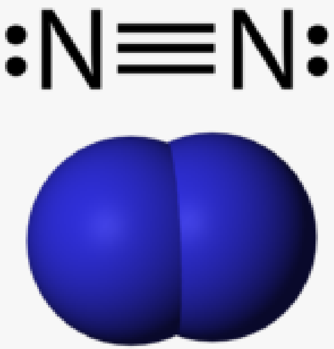
Methanogenesis

Ecosystem processes: The nitrogen cycle

Ecosystem processes: The nitrogen cycle

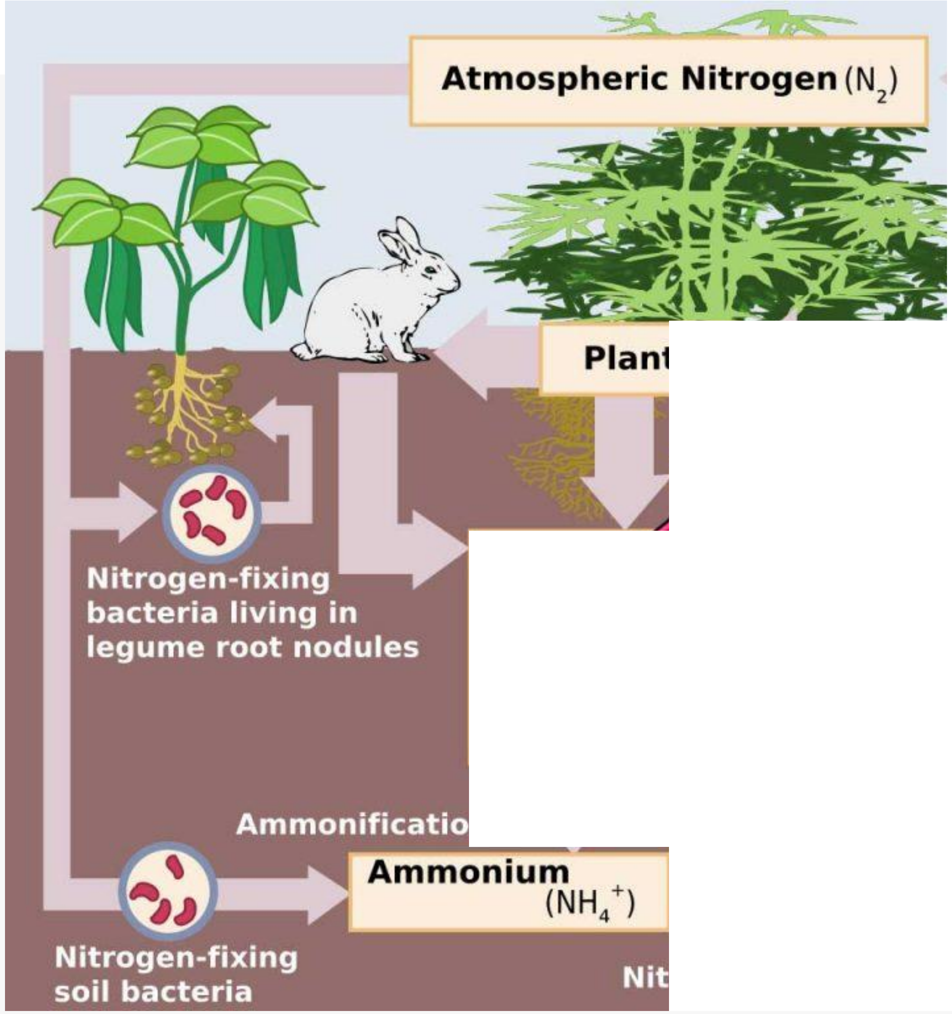


In the atmosphere, **nitrogen exists as N_2 (≈78%)**. This is a highly unavailable form of nitrogen (it cannot be used to build aminoacids or DNA)



Ref: Uni. of California Museum of Paleontology

Ecosystem processes: The nitrogen cycle

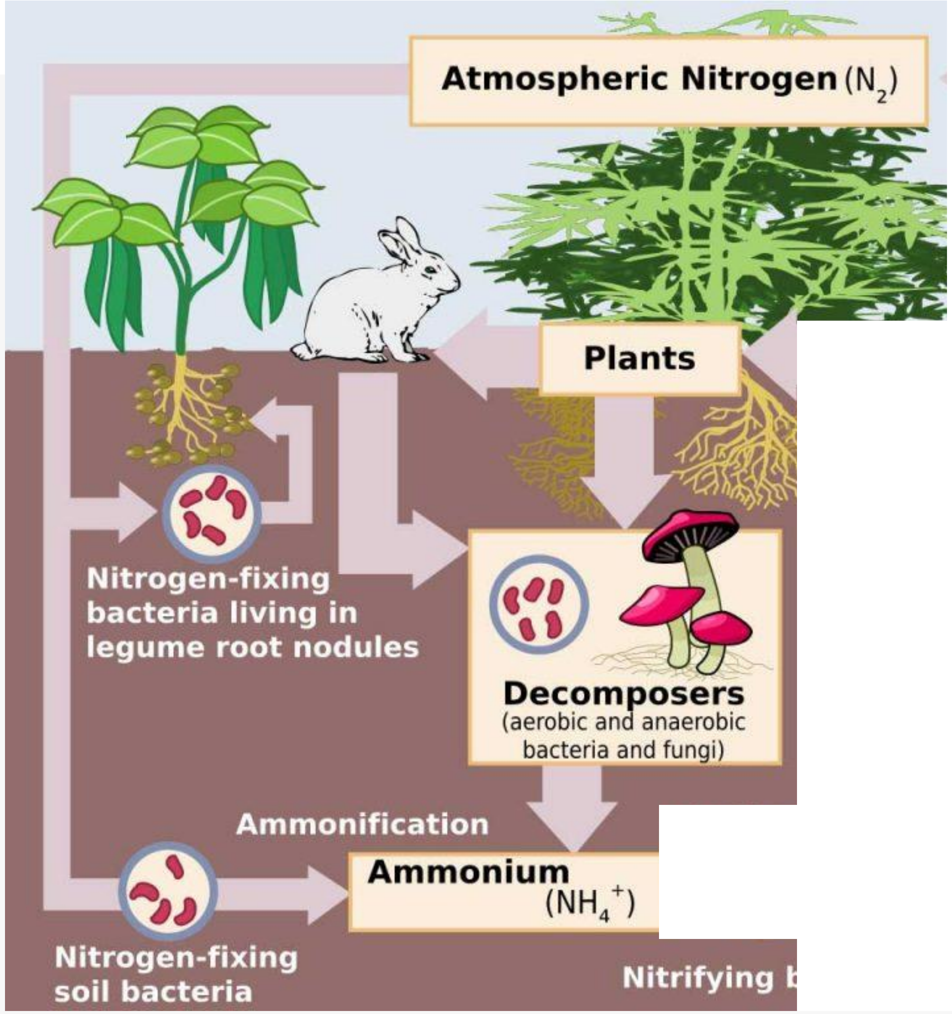


In the atmosphere, **nitrogen exists as N_2 (≈78%)**. This is a highly unavailable form of nitrogen (it cannot be used to build aminoacids or DNA)

Nitrogen-fixing bacteria convert N_2 into NH_4^+, a form of nitrogen that living organisms can use to build aminoacids and DNA.

Ref: Uni. of California Museum of Paleontology

Ecosystem processes: The nitrogen cycle



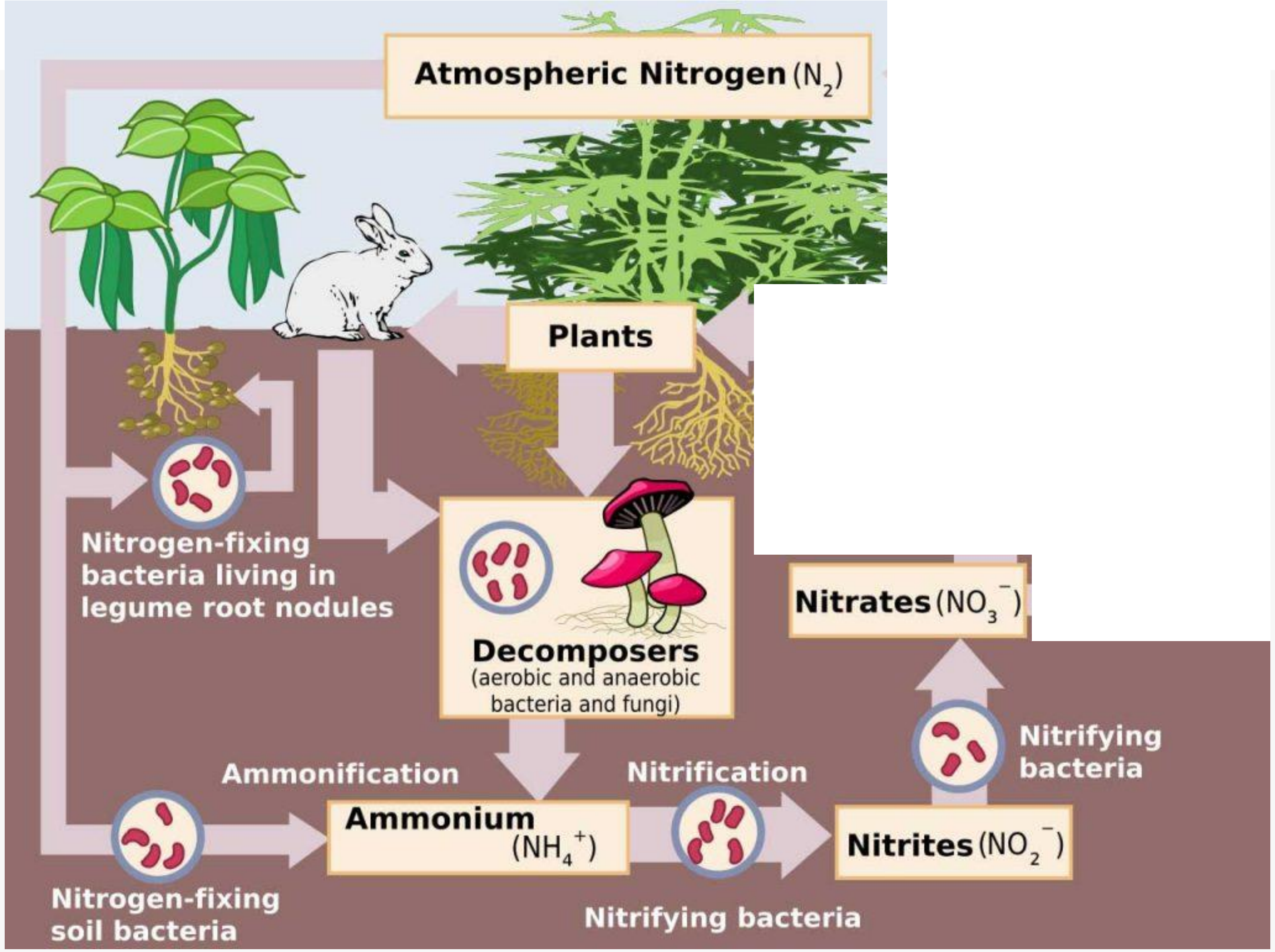
Ref: Uni. of California Museum of Paleontology

In the atmosphere, **nitrogen exists as N_2 (≈78%)**. This is a highly unavailable form of nitrogen (it cannot be used to build aminoacids or DNA)

Nitrogen-fixing bacteria convert N_2 into NH_4^+, a form of nitrogen that living organisms can use to build aminoacids and DNA.

Decomposers (mainly *chemo- organo-heterotrophic* bacteria and fungi) also contribute to the pool of NH_4^+

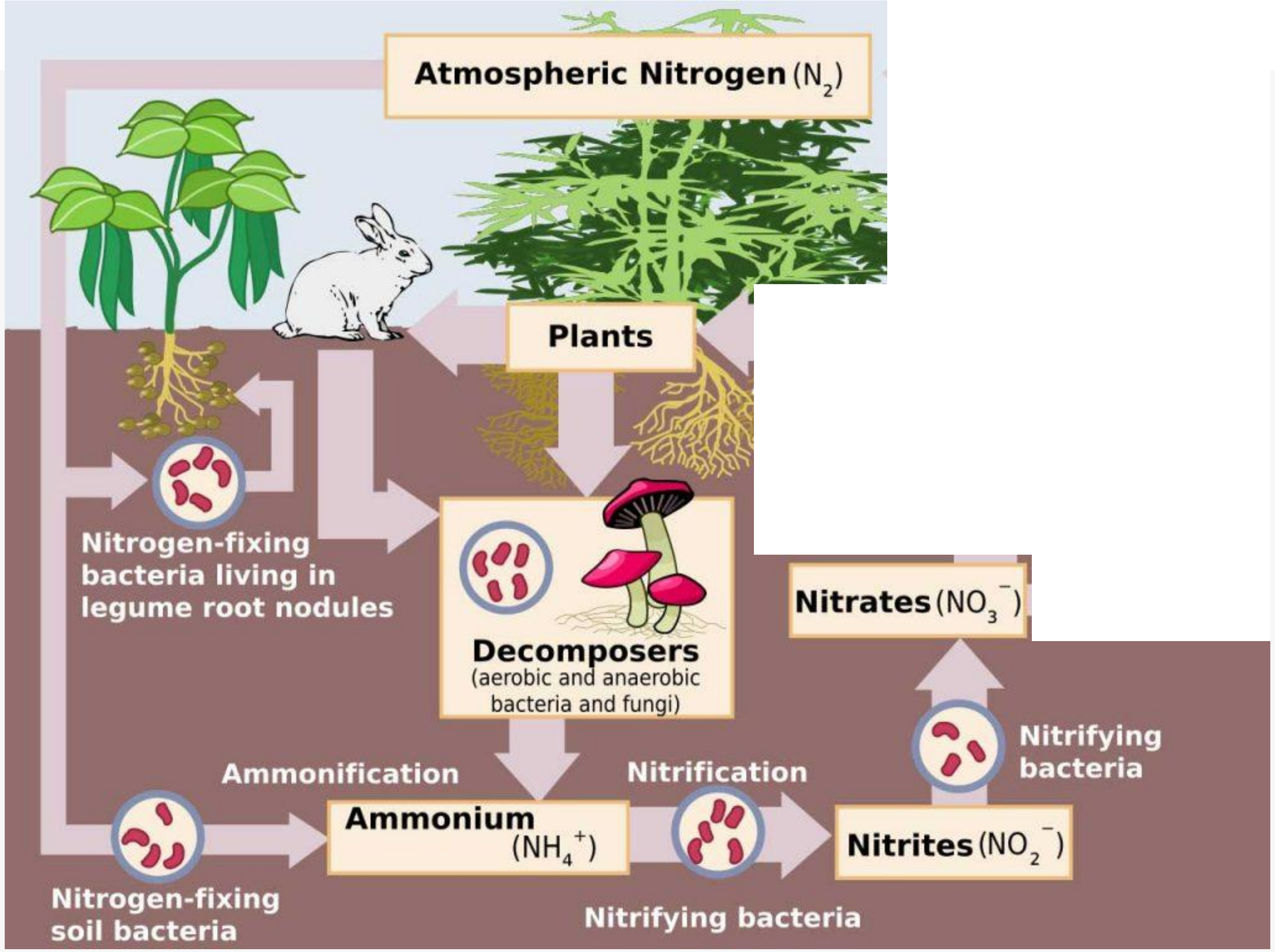
Ecosystem processes: The nitrogen cycle



Nitrifying bacteria oxidize NH_4^+ into NO_3^-

Ref: Uni. of California Museum of Paleontology

Ecosystem processes:
The nitrogen cycle



Ref: Uni. of California Museum of Paleontology

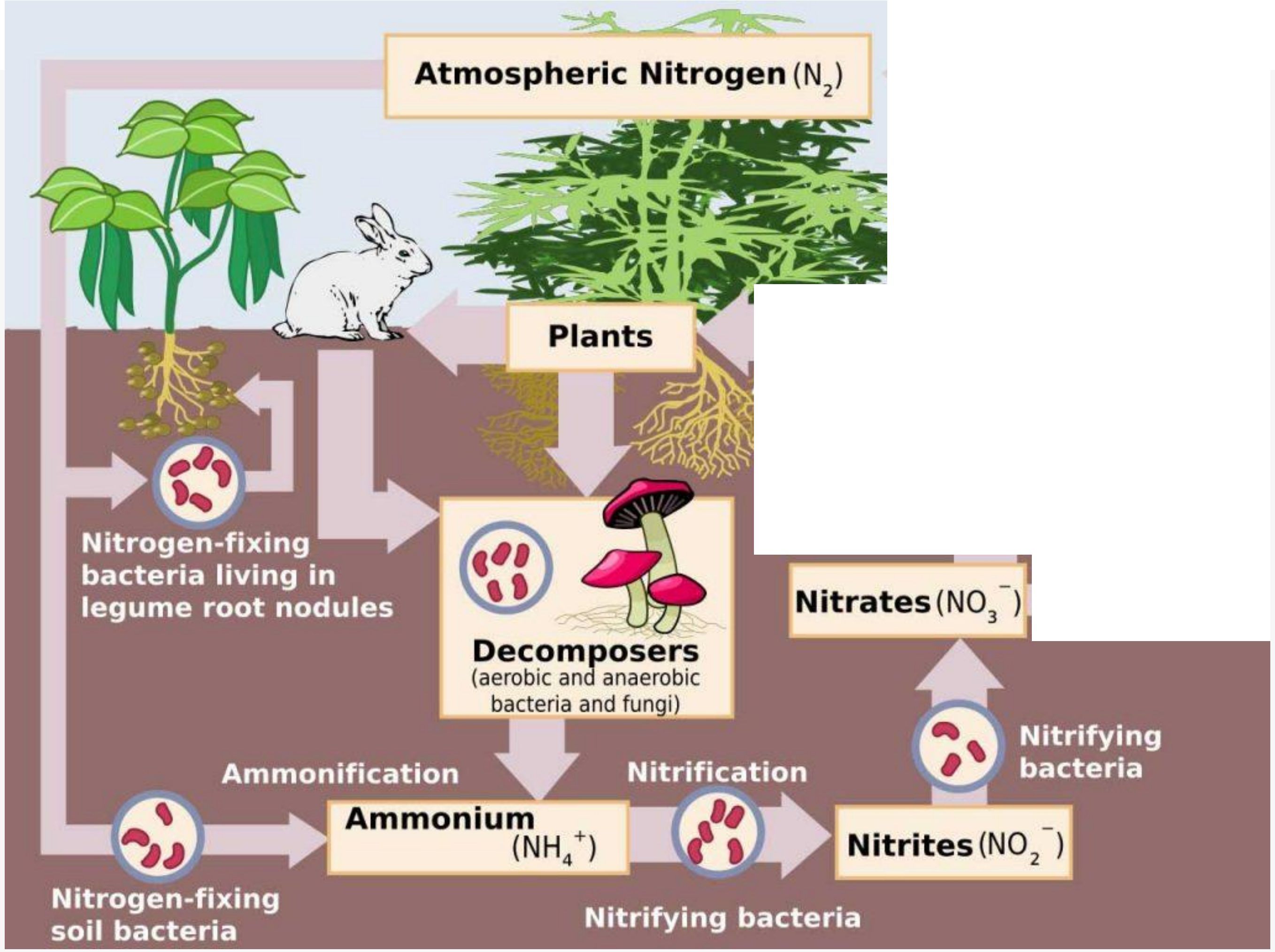
Nitrifying bacteria oxidize NH_4^+ into NO_3^-

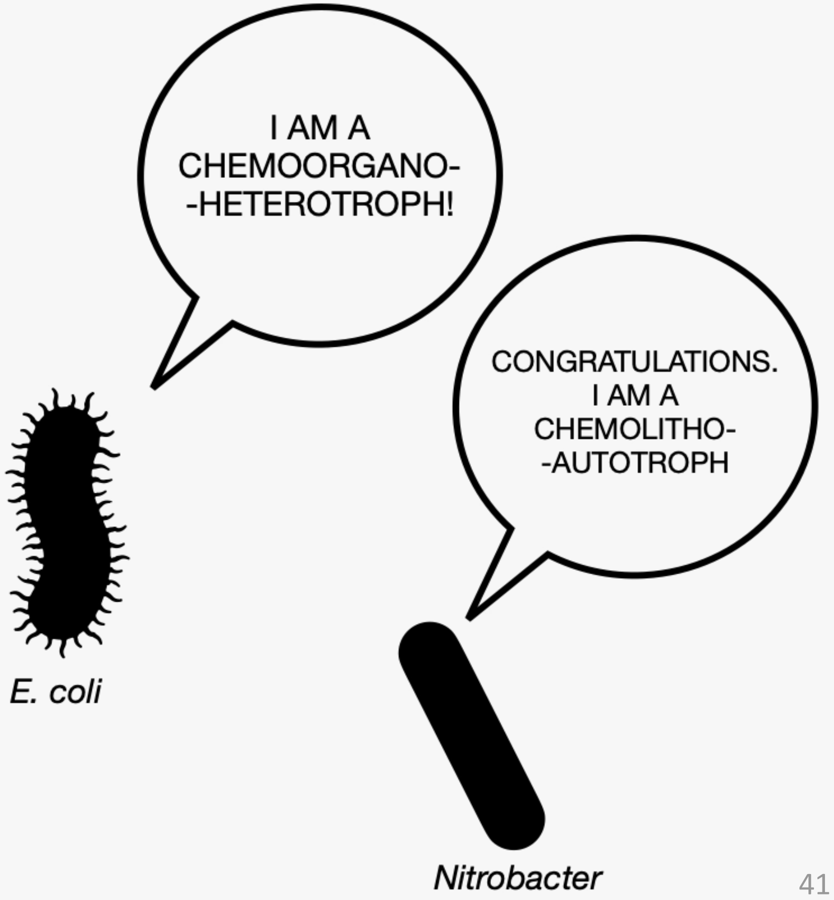
Obtain <u>energy from chemical reactions</u> (not from sun) = *chemo-*
oxidation of NH_4^+ or NO_2^-

Their respiratory chains start with an electron obtained from an <u>inorganic</u> compound = *-litho-*
NH_4^+ or NO_2^-

They build their biomolecules using C from <u>inorganic</u> sources (CO_2) = *-auto*

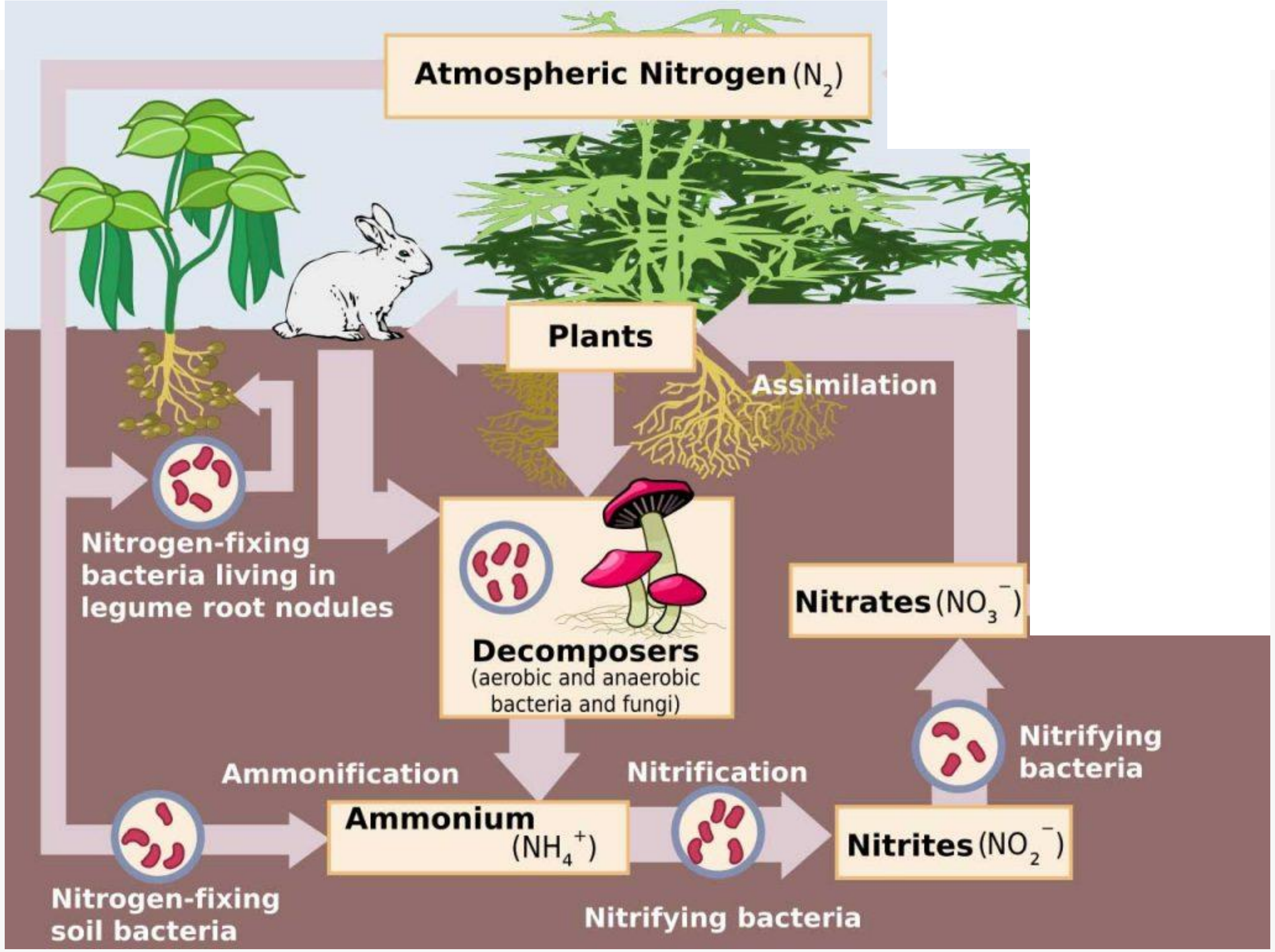
Ecosystem processes: The nitrogen cycle





Ref: Uni. of California Museum of Paleontology

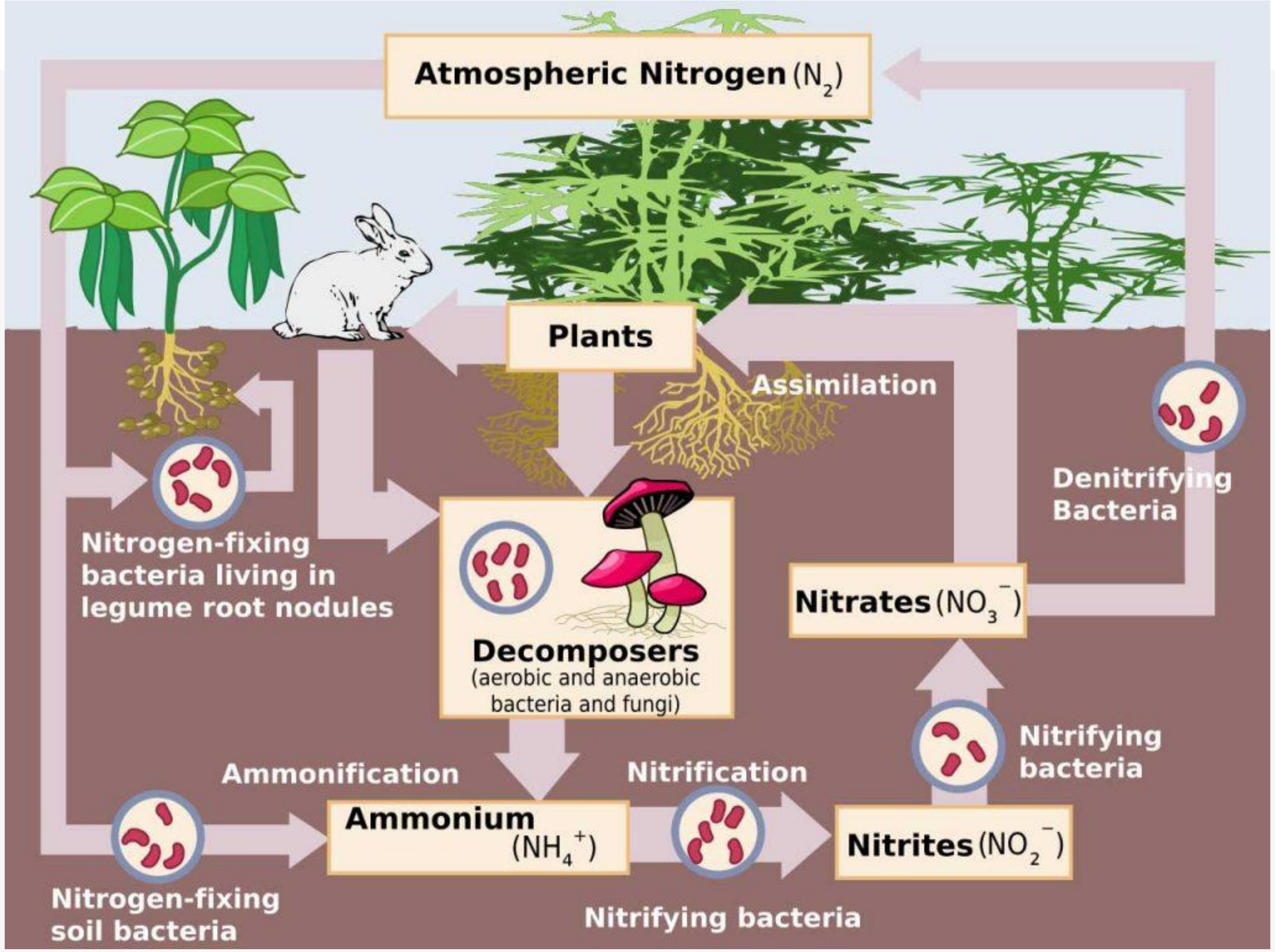
Ecosystem processes: The nitrogen cycle



Ref: Uni. of California Museum of Paleontology

The end-product of nitrifying bacteria is nitrate (NO_3^-), which is **used by plants**.

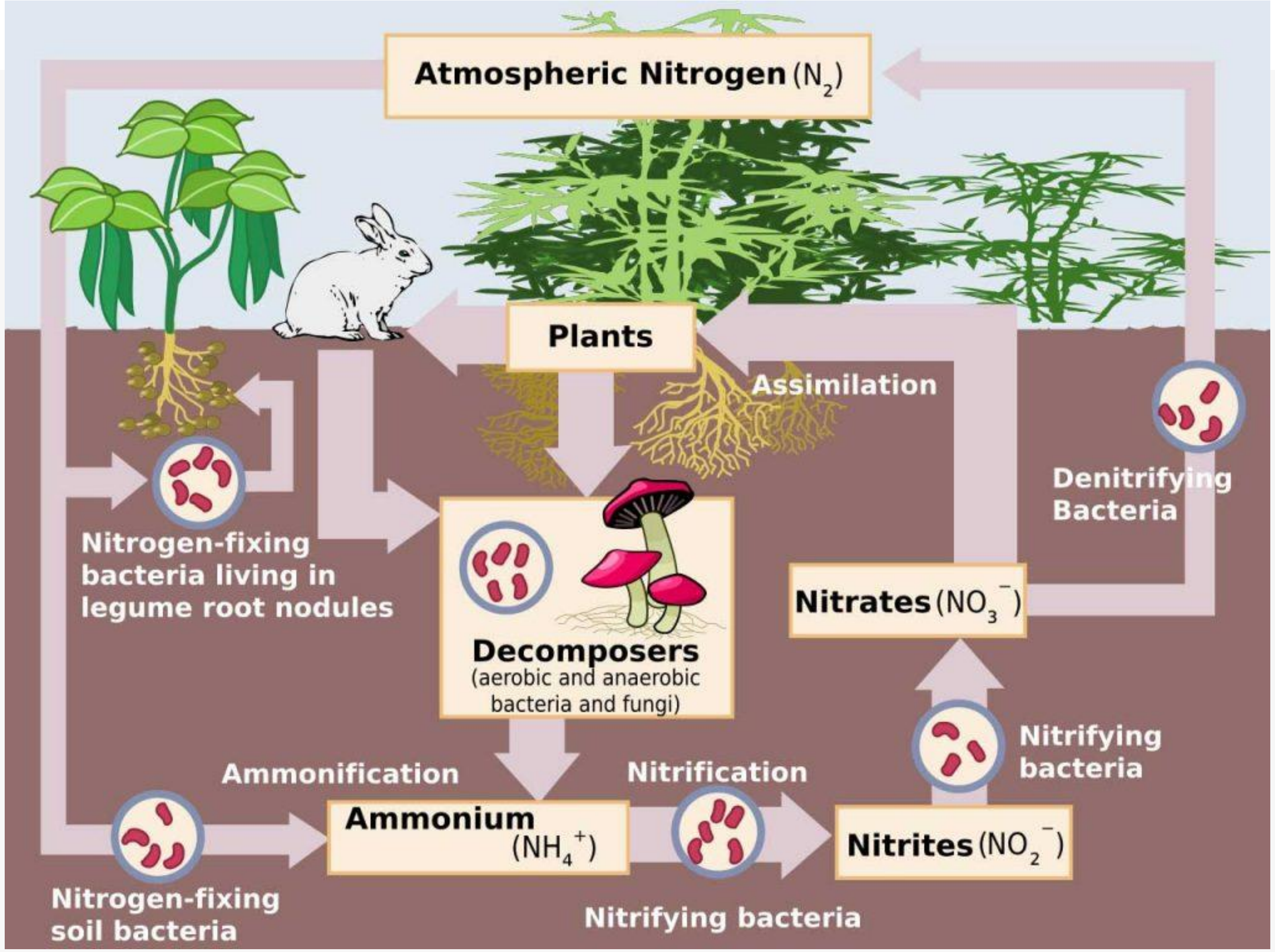
Ecosystem processes: The nitrogen cycle



Denitrifying bacteria are capable of releasing N_2 back into the atmosphere after nitrate respiration. They move electrons in their respiratory chains from organic compounds (-*organo*-) until nitrate (humans move electrons from organic compounds to O_2)

Ref: Uni. of California Museum of Paleontology

Ecosystem processes: The nitrogen cycle



Sometimes, denitrification ends up in N_2O instead of N_2 (this is the case if oxygen is available). This is of much concern since **N_2O is a potent greenhouse gas (x300 CO_2)**

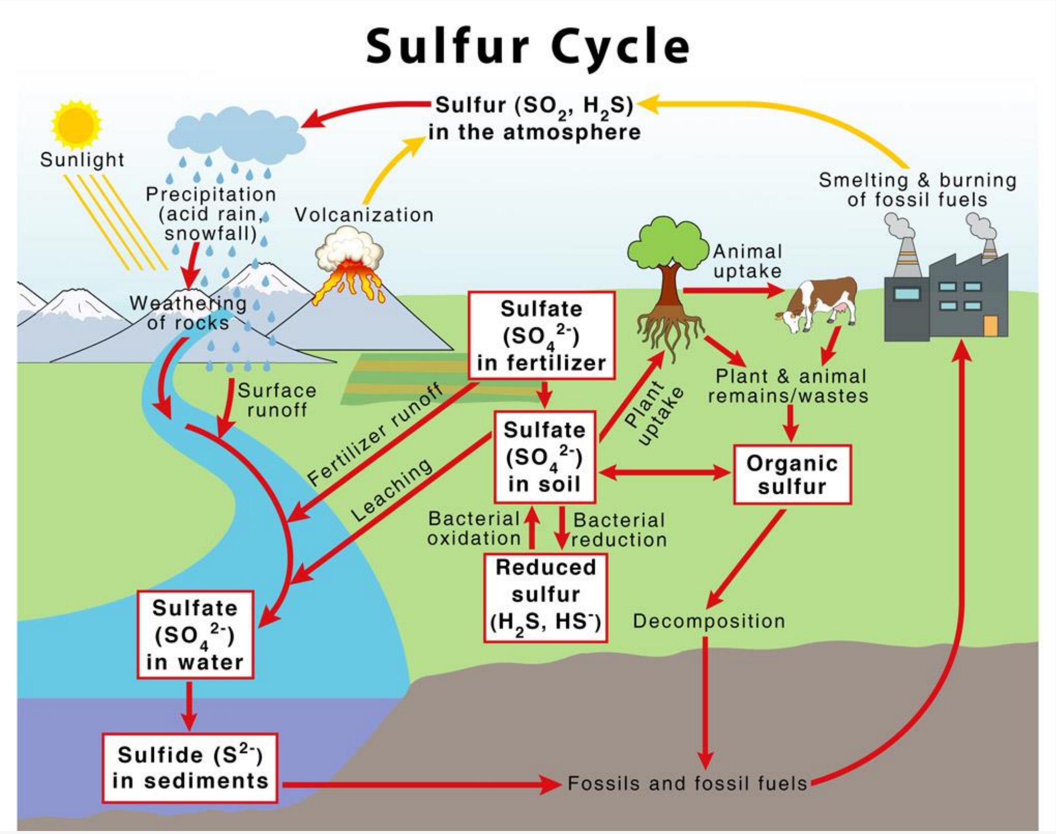
This is concerning in soils that are heavily fertilized with ammonium and nitrate!

Main source of N_2O = Agriculture.

Ref: Uni. of California Museum of Paleontology

Ecosystem processes: The sulphur cycle

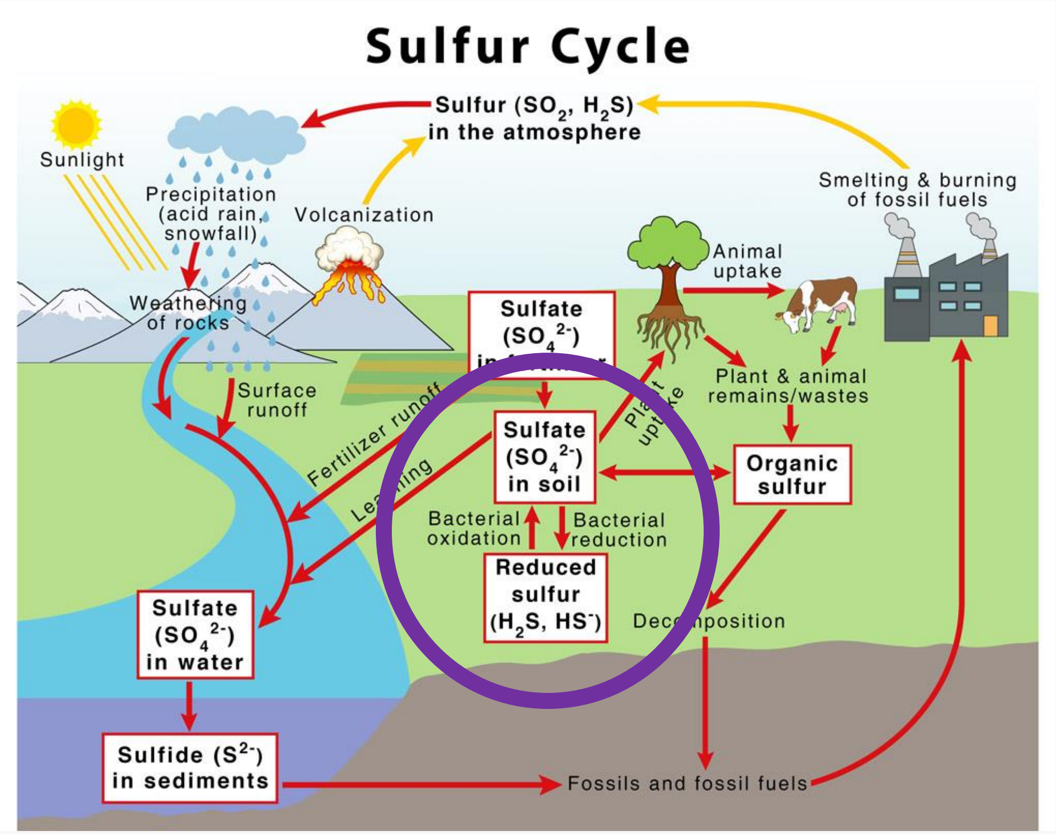
Ecosystem processes: The sulphur cycle



In the atmosphere, **sulphur mainly exists as SO_2, H_2S**. Sulphur sources are humans and volcanoes.

In the soil, the main source of sulphur is sulphate (SO_4^{2-}). Sulfur comes from weathering of rocks and atmospheric deposition … and from fertilizers!

Ecosystem processes: The sulphur cycle

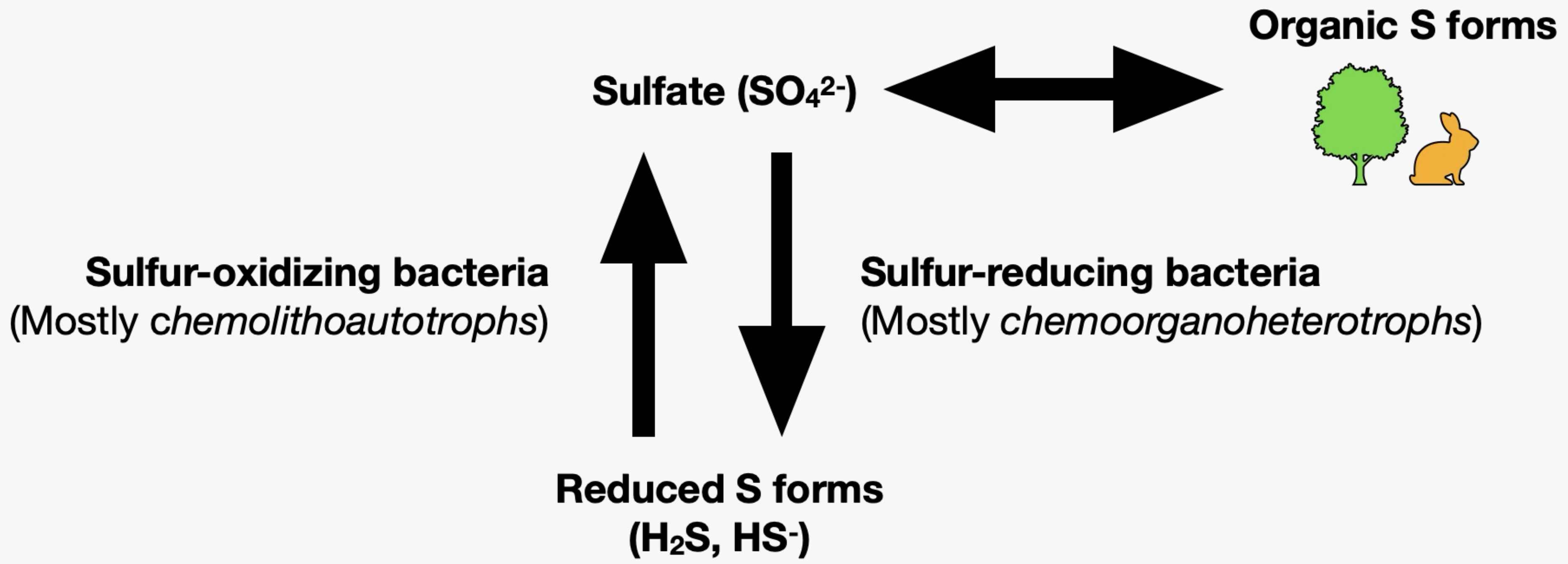


In the atmosphere, **sulphur mainly exists as SO_2, H_2S**. Sulphur sources are humans and volcanoes.

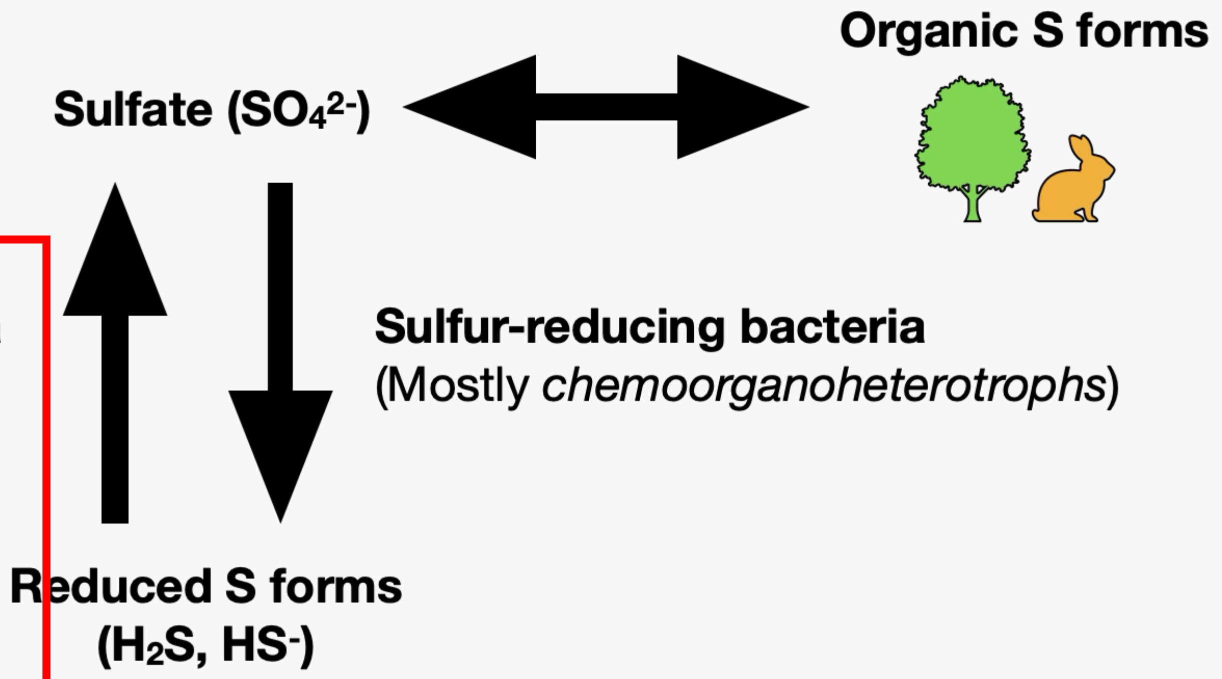
In the soil, the main source of sulphur is sulphate (SO_4^{2-}). Sulfur comes from weathering of rocks and atmospheric deposition … and from fertilizers!

Bacteria contribute to the oxidation and reduction of sulphur in the soil! This is important since only the oxidized form is used by plants.

Ecosystem processes: The sulphur cycle



Ecosystem processes: The sulphur cycle

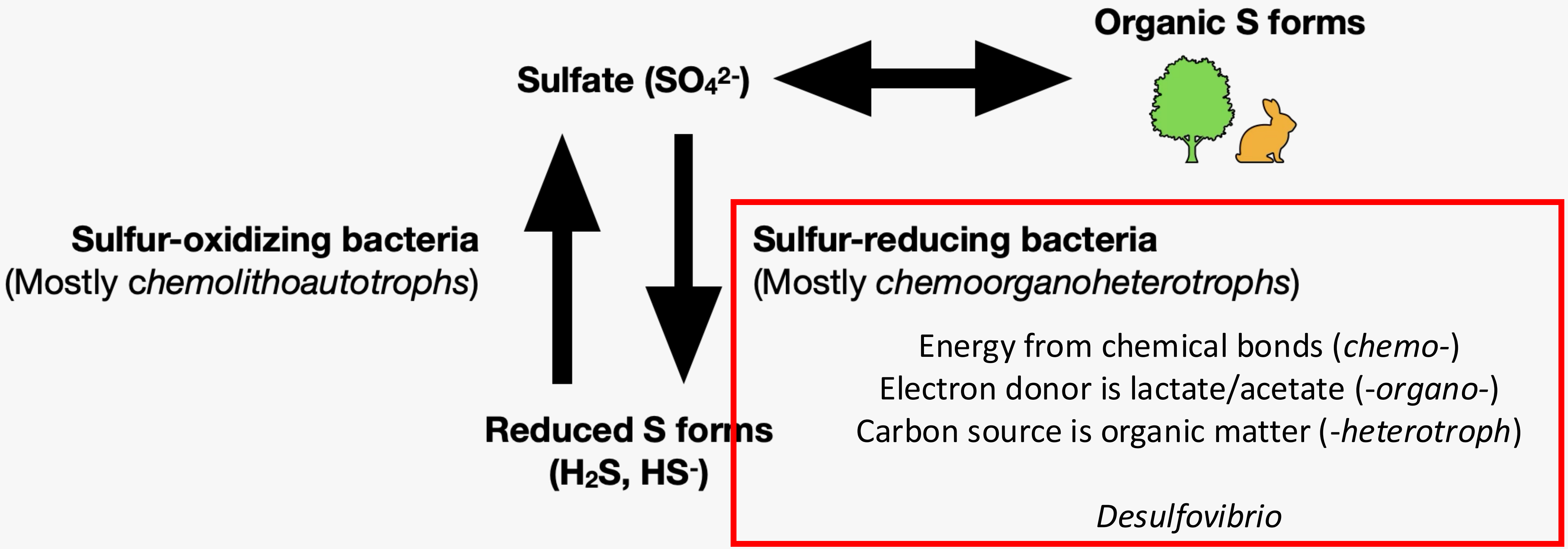


Sulfur-oxidizing bacteria
(Mostly *chemolithoautotrophs*)

Energy from chemical bonds (*chemo*-)
Electron donor is H_2S (-*litho*-)
Carbon source is CO_2 (-*autotroph*)

Thiobacillus

Ecosystem processes: The sulphur cycle



Ecosystem processes: The cycling of other elements

Ecosystem processes:
The cycling of other elements

Iron (Fe), Manganese (Mn)

Key components of many proteins, crucial for many biological processes including respiration, photosynthesis, and nitrogen fixation.

Ecosystem processes:
The cycling of other elements

Iron (Fe), Manganese (Mn)

Key components of many proteins, crucial for many biological processes including respiration, photosynthesis, and nitrogen fixation.

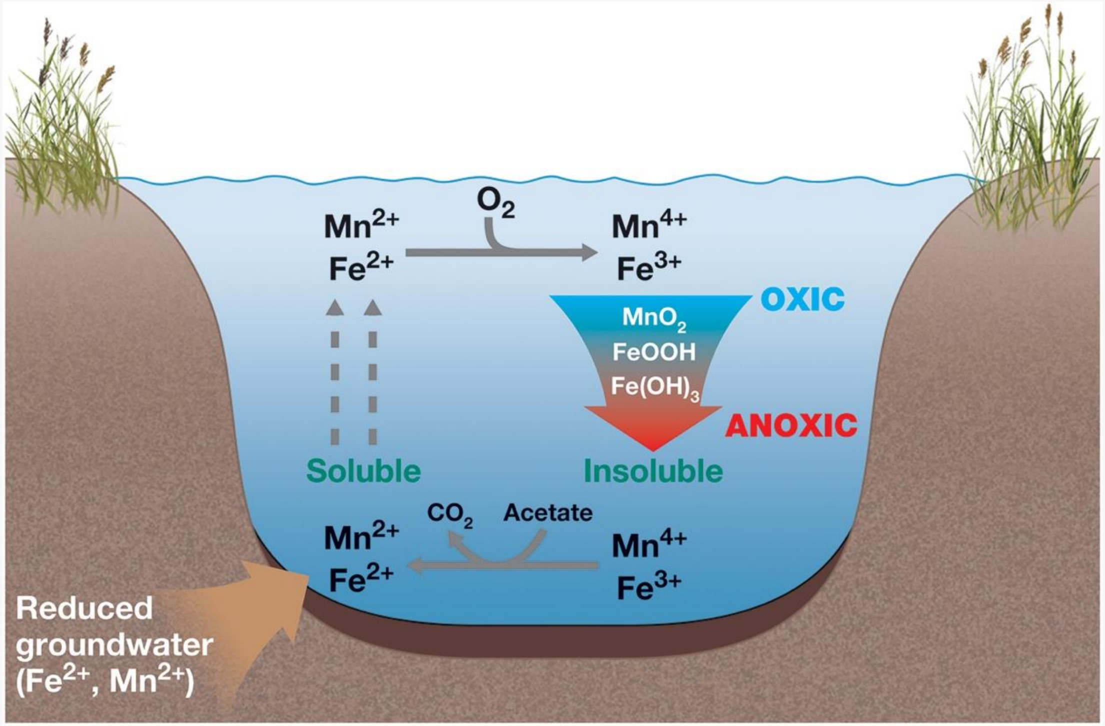
The cycling of these micronutrients consists on biochemical transformations of their oxidized (Fe^{3+} and Mn^{4+}) and reduced (Fe^{2+} and Mn^{2+}) forms.

Ecosystem processes:
The cycling of other elements

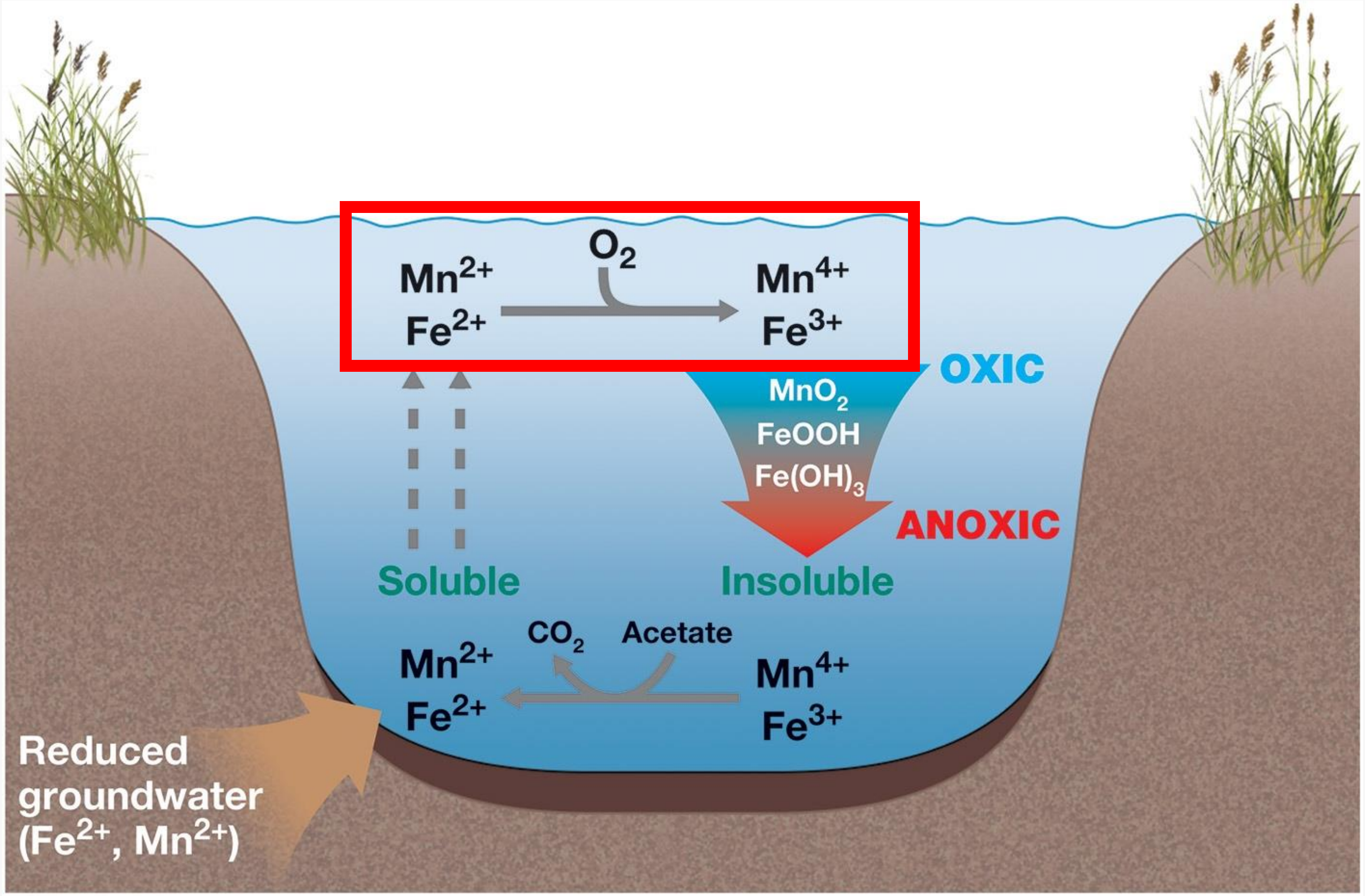
Iron (Fe), Manganese (Mn)

Key components of many proteins, crucial for many biological processes including respiration, photosynthesis, and nitrogen fixation.

The cycling of these micronutrients consists on biochemical transformations of their oxidized (Fe^{3+} and Mn^{4+}) and reduced (Fe^{2+} and Mn^{2+}) forms.



Ecosystem processes:
The cycling of other elements



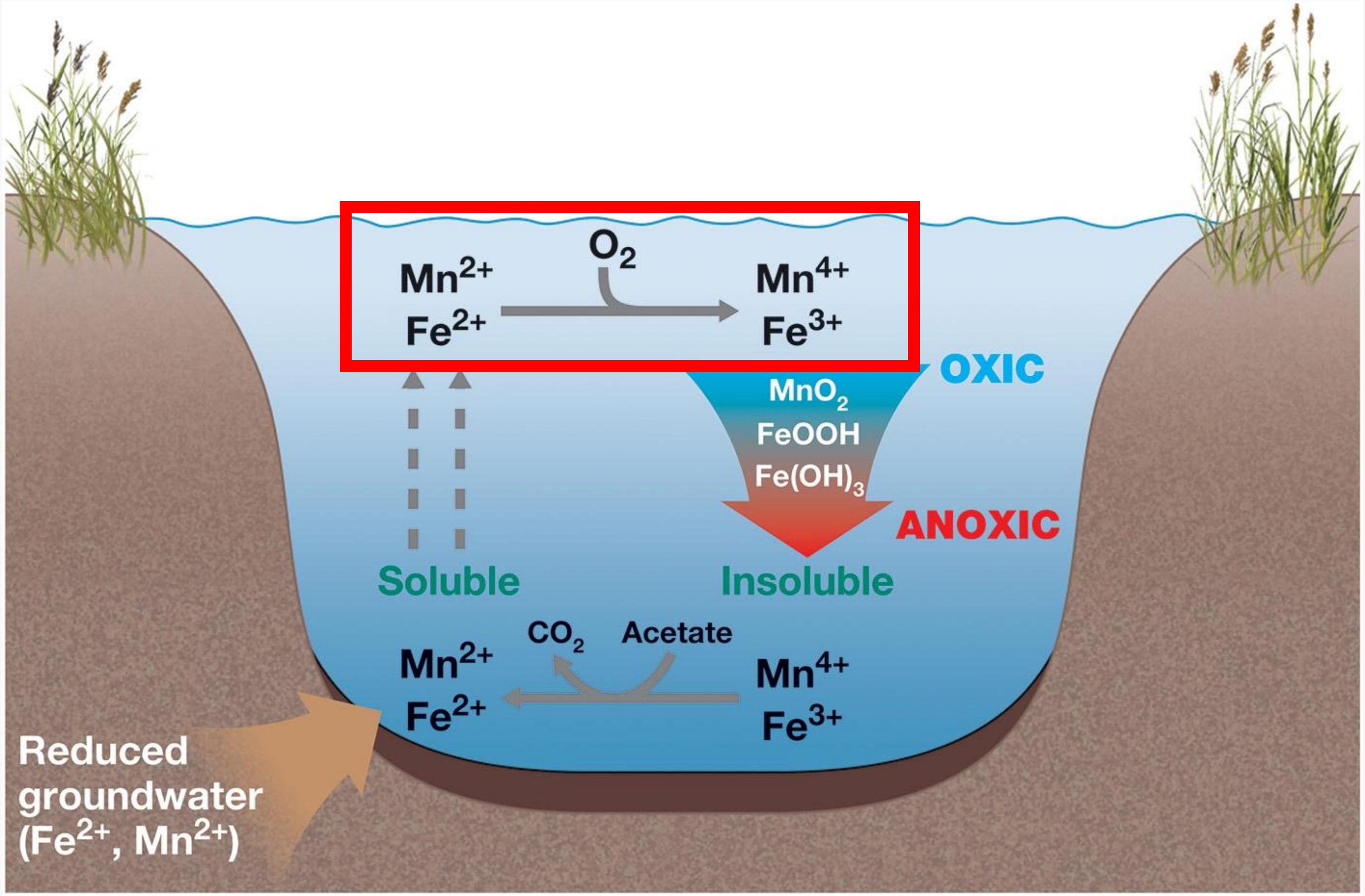
Oxidation of reduced forms (Mn^{2+} and Fe^{2+}) is performed by **iron-oxidizing bacteria** (like *Acidithiobacillus ferrooxidans*)

They obtain energy from iron oxidation
Chemo-

Electron donor is a reduced form of iron (Fe^{2+})
-litho-

They build their biomolecules using CO_2
-auto

Ecosystem processes:
The cycling of other elements



Oxidation of reduced forms (Mn^{2+} and Fe^{2+}) is performed by **iron-oxidizing bacteria** (like *Acidithiobacillus ferrooxidans*)

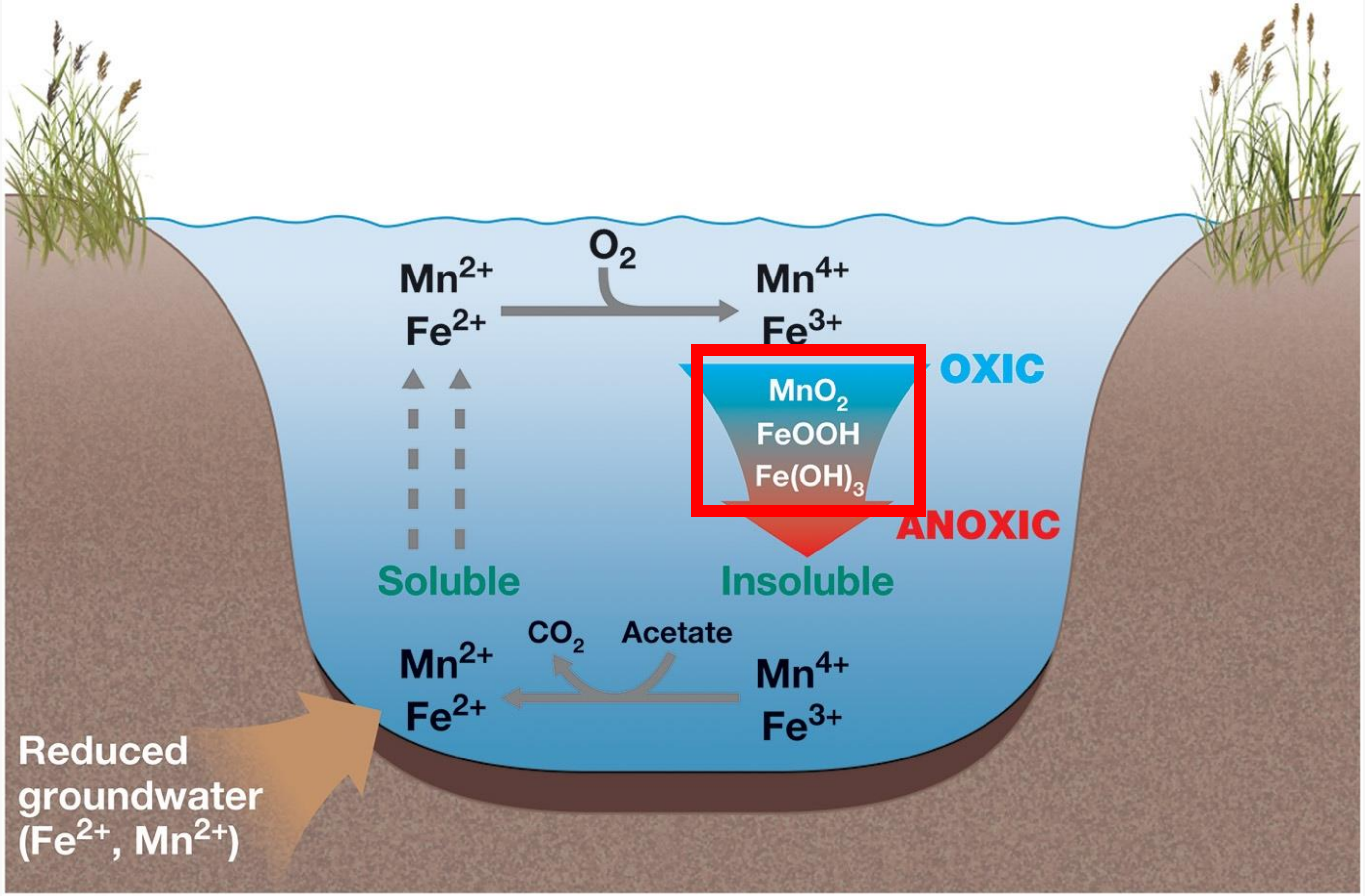
They obtain energy from iron oxidation
Chemo-

Electron donor is a reduced form of iron (Fe^{2+})
-litho-

They build their biomolecules using CO_2
-auto

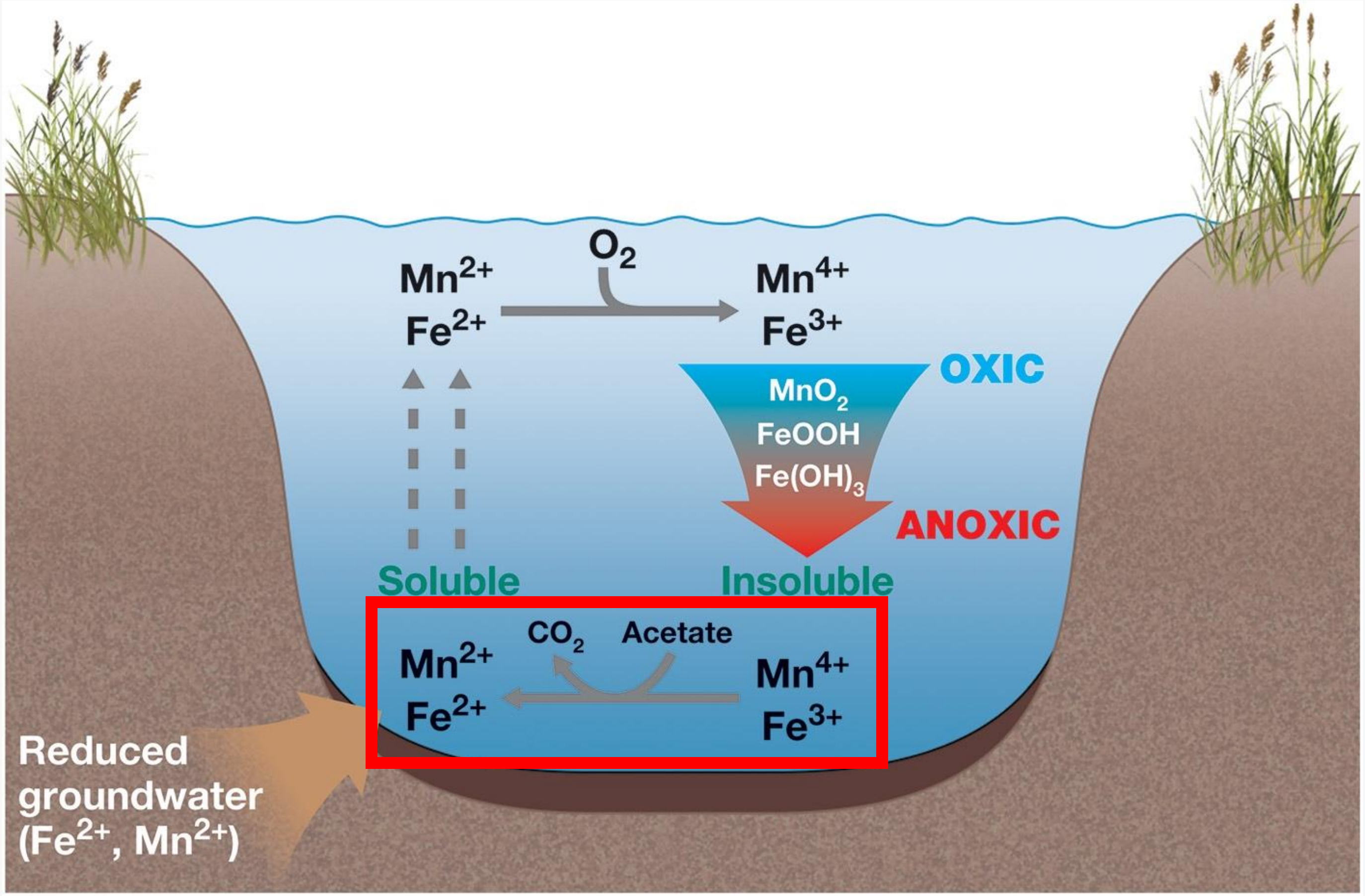
Chemolithoautotrophs

Ecosystem processes:
The cycling of other elements



Río Tinto, Huelva, Spain

Ecosystem processes:
The cycling of other elements



Reduction of oxidized forms (Mn^{4+} and Fe^{3+}) is performed by **iron-reducing bacteria** (*Geobacter*)

They obtain energy from iron reduction
Chemo-

Electron donor is acetate
-organo-

They build their biomolecules using acetate
-hetero

Chemoorganoheterotroph

Ecosystem processes:
The cycling of other elements

Energy source	Electron donor	Carbon source	Name
Sunlight *Photo-*	Organic *-organo-*	Organic *-hetero*	PHOTOORGANOHETEROTROPH
		CO_2 *-auto*	PHOTOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	PHOTOLITHOHETEROTROPH
		CO_2 *-auto*	PHOTOLITHOAUTOTROPH
Breaking chemical bonds *Chemo-*	Organic *-organo-*	Organic *-hetero*	CHEMOORGANOHETEROTROPH
		CO_2 *-auto*	CHEMOORGANOAUTOTROPH
	Inorganic *-litho-*	Organic *-hetero*	CHEMOLITHOHETEROTROPH
		CO_2 *-auto*	CHEMOLITHOAUTOTROPH

Ecosystem processes:
The cycling of other elements

Energy source	Electron donor	Carbon source	Name	
Breaking chemical bonds *Chemo-*	Organic *-organo-*	Organic *-hetero*	CHEMOORGANOHETEROTROPH	**iron-reducing bacteria** (*Geobacter*)
	Inorganic *-litho-*	CO_2 *-auto*	CHEMOLITHOAUTOTROPH	**iron-oxidizing bacteria** (*Acidithiobacillus ferrooxidans*)

Ecosystem processes:
The cycling of other elements

Mercury (Hg)

Elemental mercury (Hg^0) is highly volatile and can move long distances in the atmosphere

Inorganic mercury/ oxidized form (Hg^{2+}) is found in soils, sediments, and water

Organic mercury (CH_3Hg^+) is highly toxic and bioaccumulates in living tissues

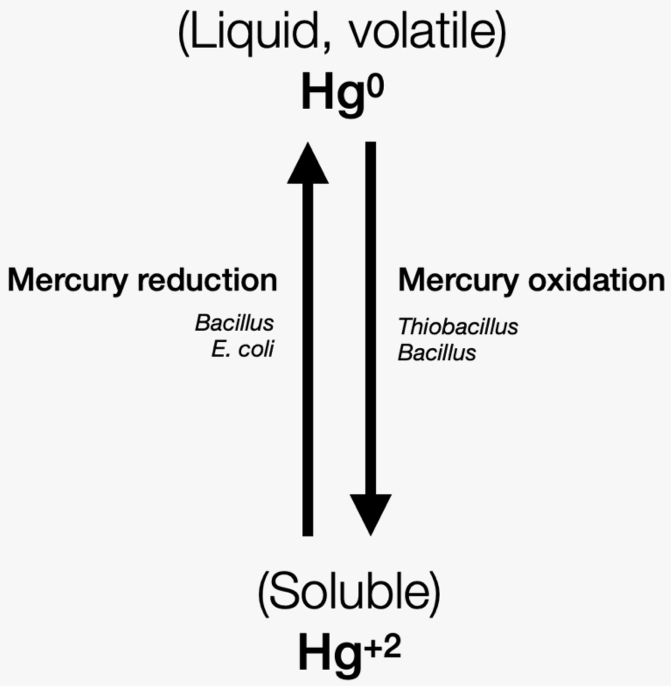
Ecosystem processes: The cycling of other elements

Mercury (Hg)

Elemental mercury (Hg^0) is highly volatile and can move long distances in the atmosphere

Inorganic mercury/ oxidized form (Hg^{2+}) is found in soils, sediments, and water

Organic mercury (CH_3Hg^+) is highly toxic and bioaccumulates in living tissues



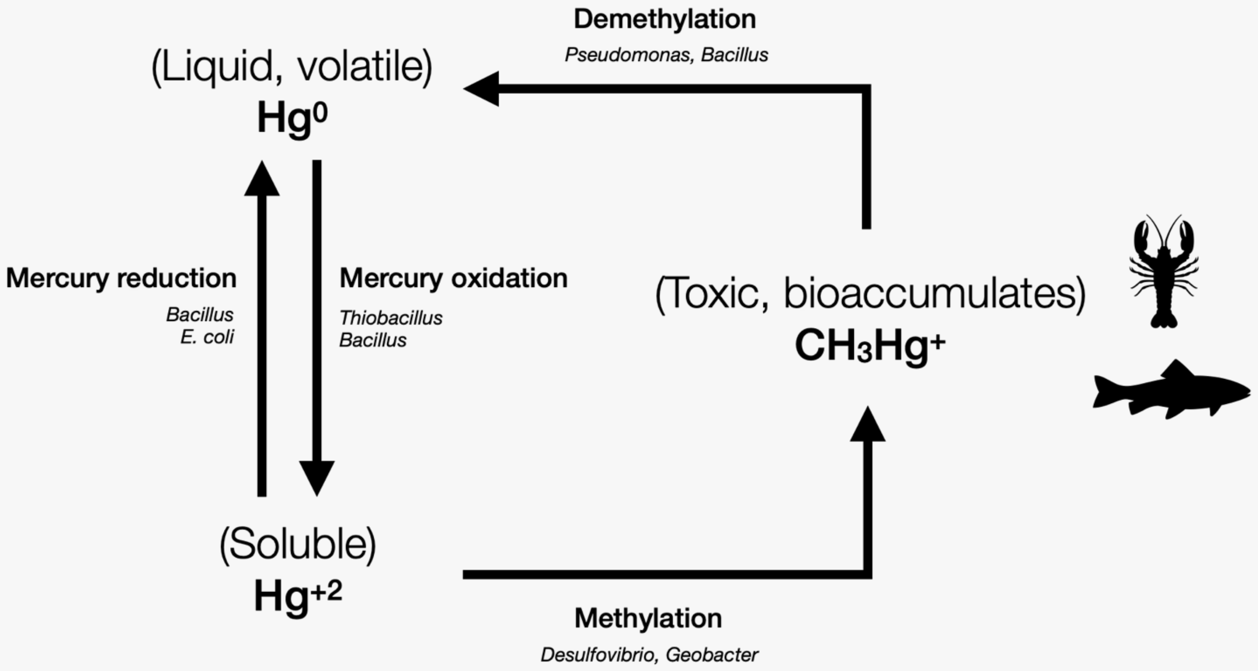
Ecosystem processes:
The cycling of other elements

Mercury (Hg)

Elemental mercury (Hg^0) is highly volatile and can move long distances in the atmosphere

Inorganic mercury/ oxidized form (Hg^{2+}) is found in soils, sediments, and water

Organic mercury (CH_3Hg^+) is highly toxic and bioaccumulates in living tissues



Ecosystem processes:
The cycling of other elements

Phosphorus (P) and Calcium (Ca)

Phosphorous cycle

Organic and inorganic phosphates (PO_4^{2-}).
Phosphorus is a typical limiting nutrient that limits the growth of aquatic photosynthetic autotrophs.
Alternate forms, such as phosphite (PO_3^{-3}) and hypophosphite ($H_2PO_2^{-}$), rapidly cycle through aquatic ecosystems.

Calcium cycle

Reservoirs are rocks and oceans.
Marine phototrophic microorganisms, such as ***foraminifera*,** use Ca^{2+} to form exoskeleton.

Take-home messages

Microorganisms (particularly bacteria) are **metabolically very complex**. They show diverse energetic strategies (chemo- vs. photo-), oxidize a wide variety of compouns (-organo- vs -litho-), and obtain carbon from different sources (-hetero vs -auto).

Take-home messages

Microorganisms (particularly bacteria) are **metabolically very complex**. They show diverse energetic strategies (chemo- vs. photo-), oxidize a wide variety of compouns (-organo- vs -litho-), and obtain carbon from different sources (-hetero vs -auto).

The cycling of elements in nature highly depends on the **biochemical transformations** carried out by microbes.

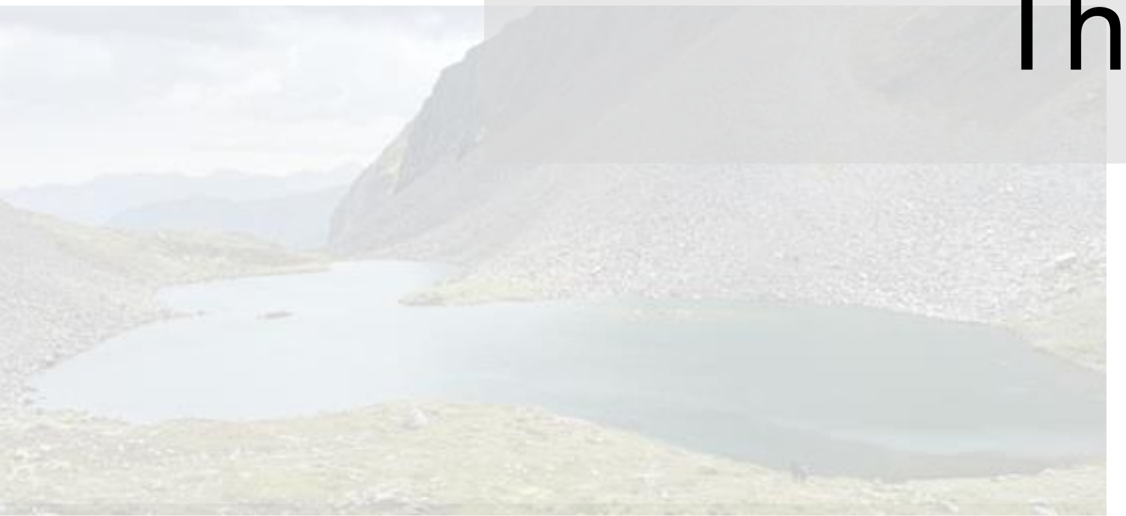
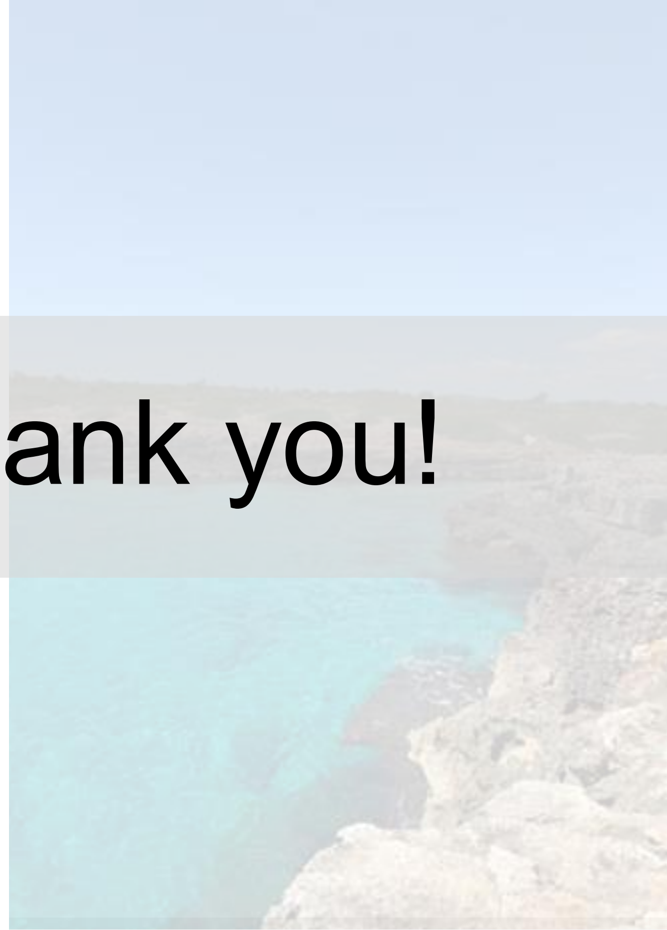
Take-home messages

Microorganisms (particularly bacteria) are **metabolically very complex**. They show diverse energetic strategies (chemo- vs. photo-), oxidize a wide variety of compouns (-organo- vs -litho-), and obtain carbon from different sources (-hetero vs -auto).

The cycling of elements in nature highly depends on the **biochemical transformations** carried out by microbes.

> Microbes **decompose organic matter** into forms that can be used by multicellular organisms (plants), **perform CO_2 and N_2 fixation**, release **greenhouse gases** into the atmosphere, and control the **toxicity of some metals**.

The microbial component of ecosystem processes

Thank you!

École Polytechnique Fédérale
de Lausanne (EPFL)

Lecturer: Dr. Ferran Romero
Coordinator: Prof. Dr. Ianina Altshuler