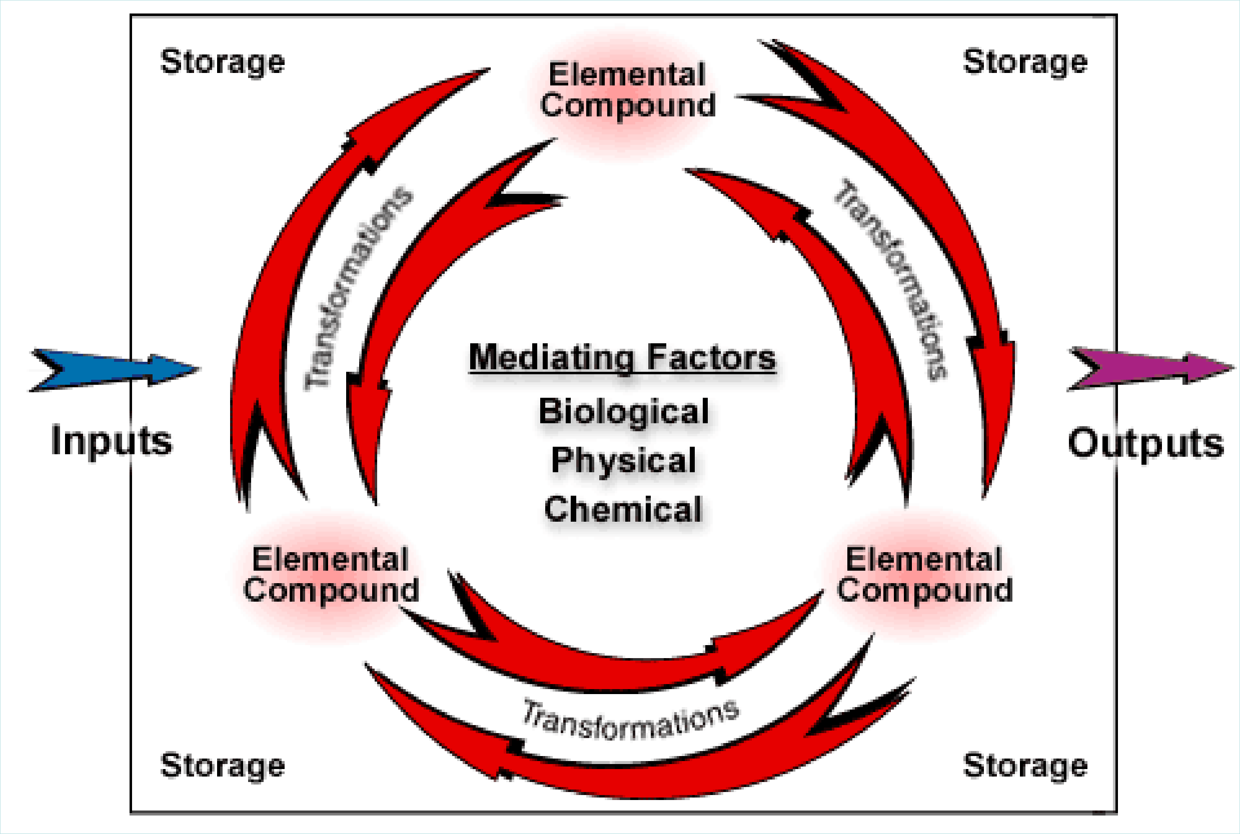
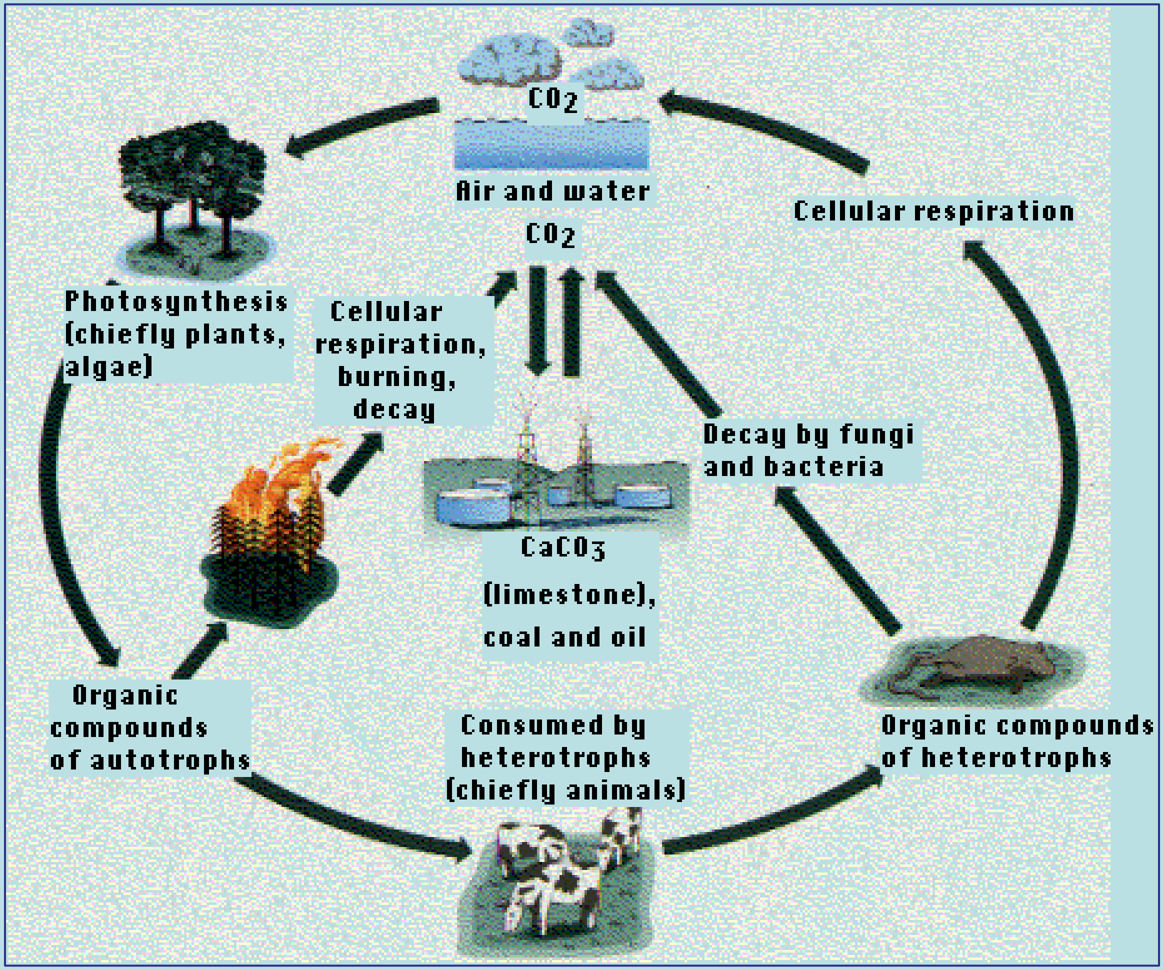
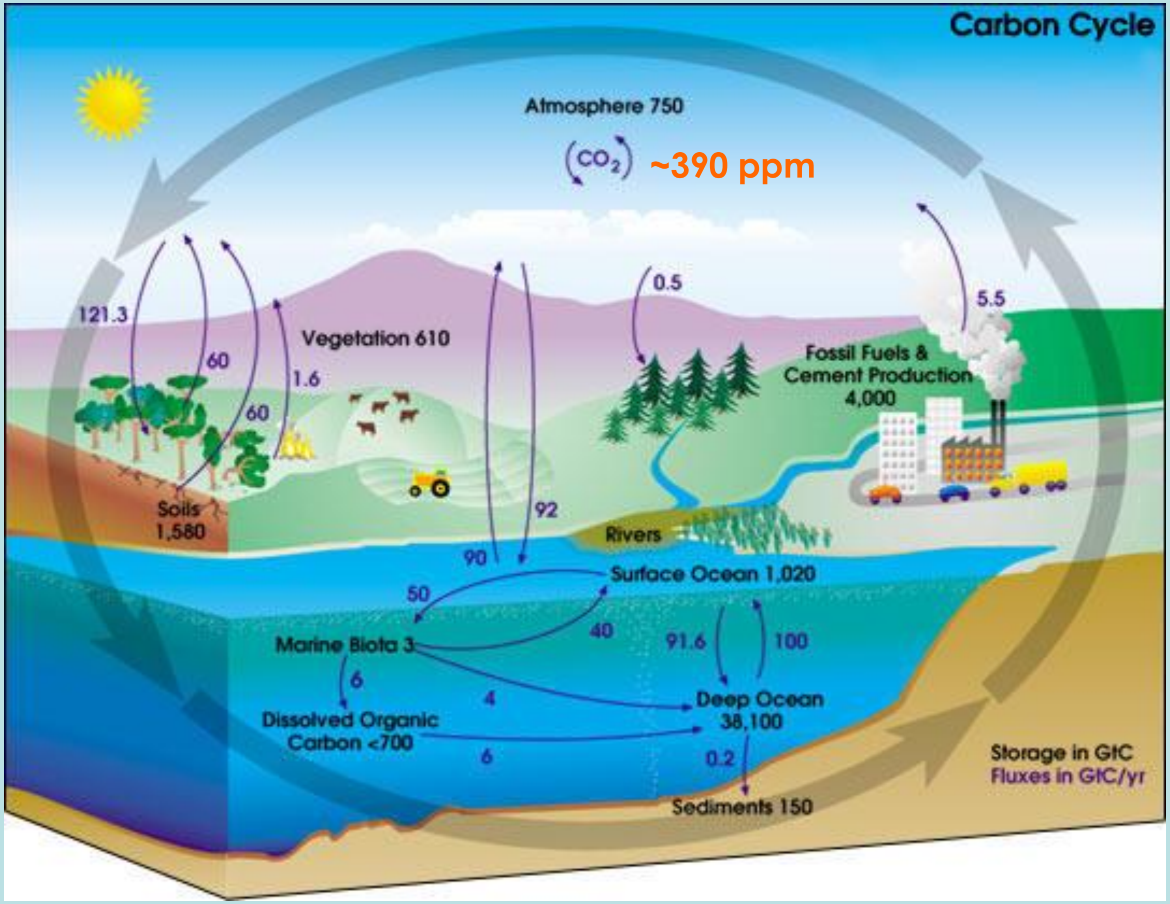
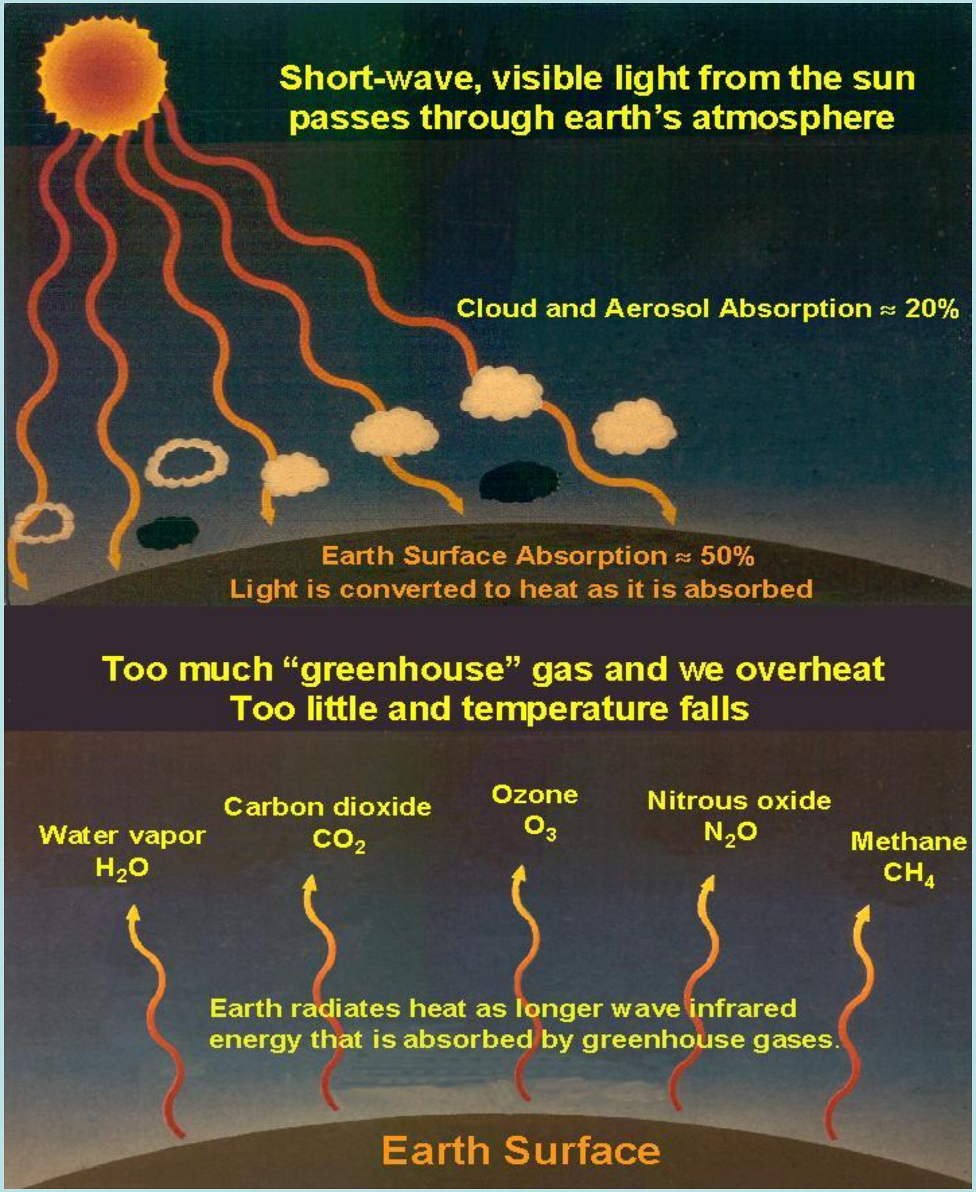


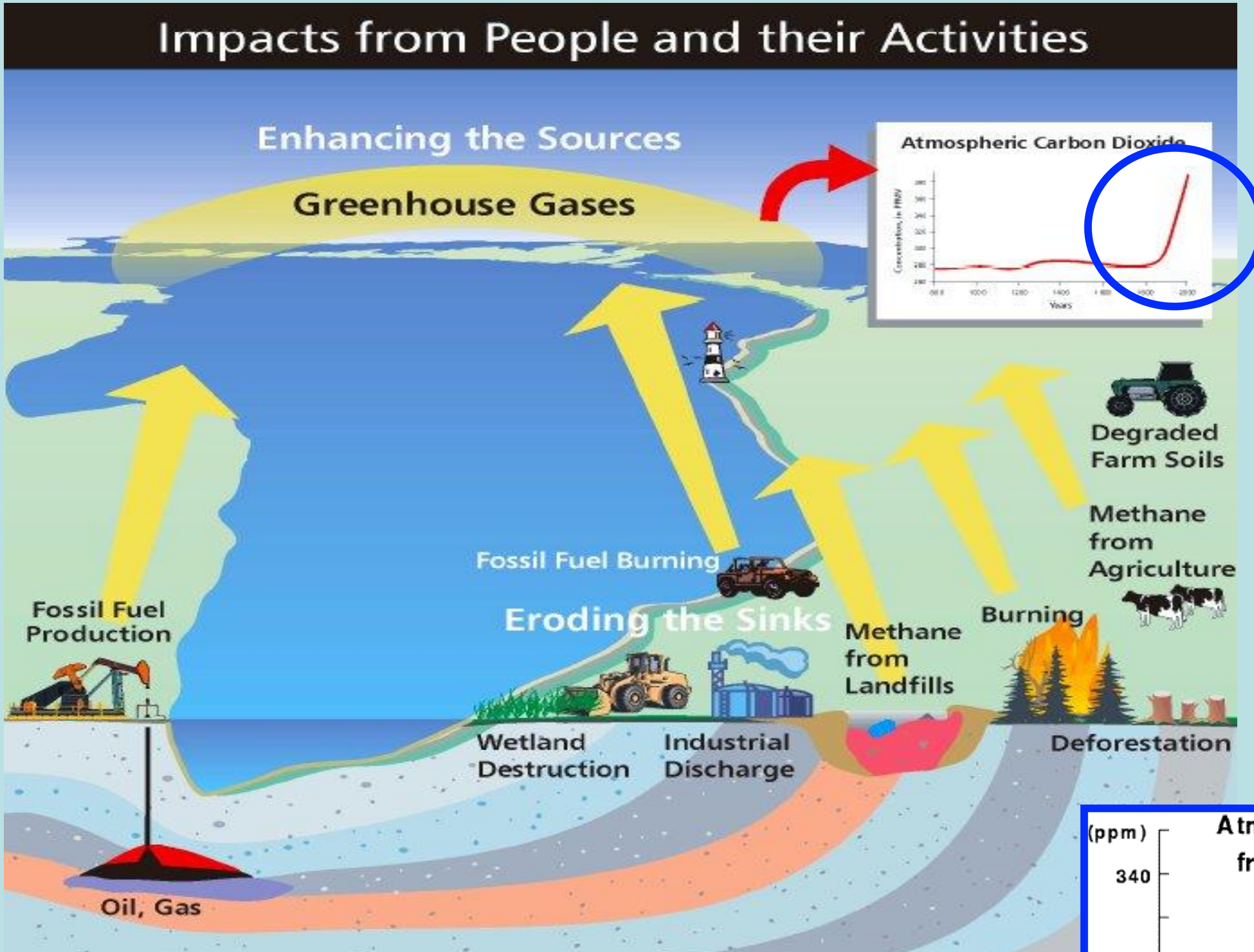
The concept of biogeochemical cycles is a concept that recognizes the dynamism of multiple, complex processes that **move, transform** and **store** chemicals in the **geosphere**, **atmosphere**, **hydrosphere**, and **biosphere**. The term biogeochemical cycles expresses the interactions among the organic **(*bio-*)** and inorganic **(*geo-*)** worlds, and focuses on the chemistry **(*chemical-*)**, and movement **(*cycles*)** of chemical elements and compounds.

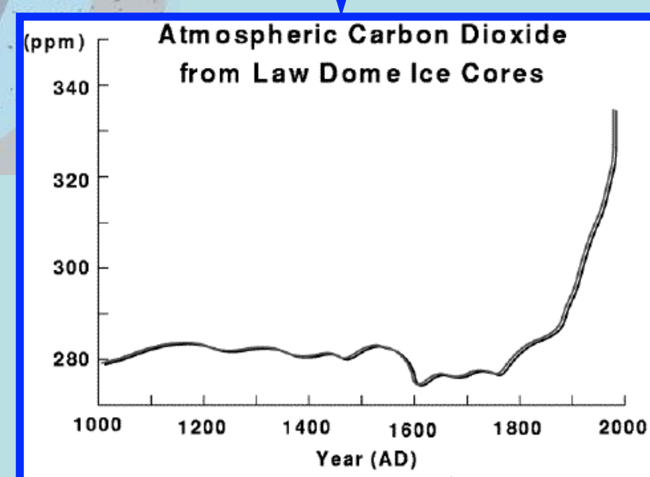
IL CICLO DEL CARBONIO



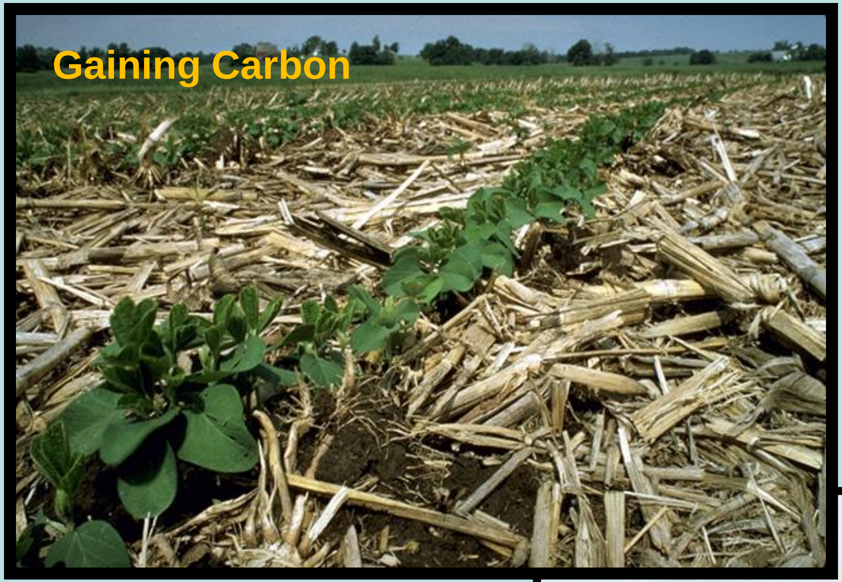

Carbon Cycle
Atmosphere 750
CO2
~390 ppm
121.3
60
60
1.6
Vegetation 610
Soils 1,580
90
92
0.5
5.5
Fossil Fuels & Cement Production 4,000
Rivers
Surface Ocean 1,020
50
40
Marine Biota 3
91.6
100
6
4
Deep Ocean 38,100
Dissolved Organic Carbon <700
6
0.2
Sediments 150
Storage in GtC
Fluxes in GtC/yr


Short-wave, visible light from the sun passes through earth's atmosphere
Cloud and Aerosol Absorption ≈ 20%
Earth Surface Absorption ≈ 50%
Light is converted to heat as it is absorbed
Too much "greenhouse" gas and we overheat
Too little and temperature falls
Water vapor H_2O
Carbon dioxide CO_2
Ozone O_3
Nitrous oxide N_2O
Methane CH_4
Earth radiates heat as longer wave infrared energy that is absorbed by greenhouse gases.
Earth Surface


Impacts from People and their Activities
Enhancing the Sources
Greenhouse Gases
Atmospheric Carbon Dioxide
Years
Fossil Fuel Burning
Eroding the Sinks
Fossil Fuel Production
Degraded Farm Soils
Methane from Agriculture
Burning
Methane from Landfills
Wetland Destruction
Industrial Discharge
Deforestation
Oil, Gas

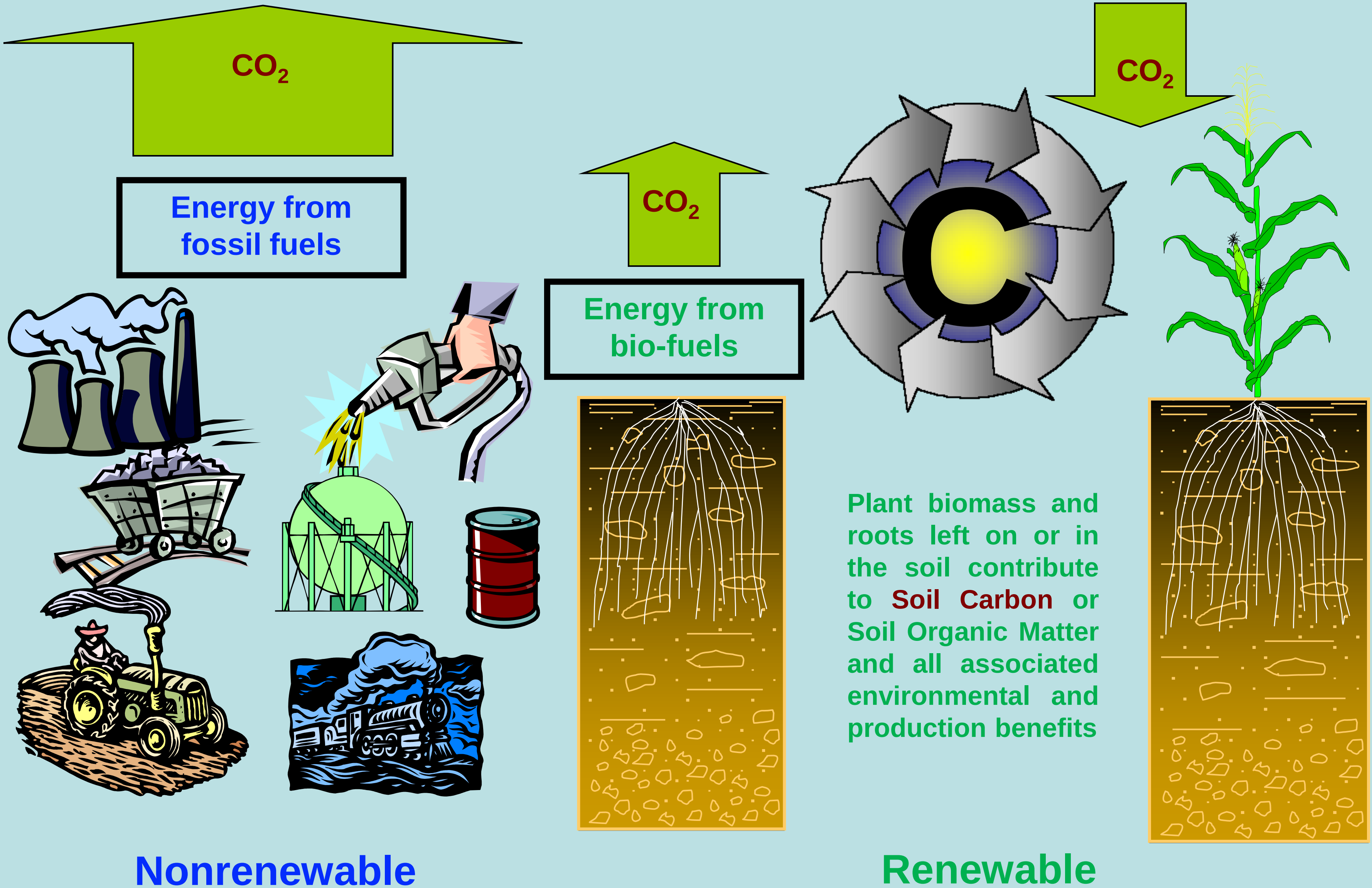

Atmospheric Carbon Dioxide
from Law Dome Ice Cores
(ppm)
340
320
300
280
1000
1200
1400
1600
1800
2000
Year (AD)

Soil Carbon: it easy comes, it easy goes!



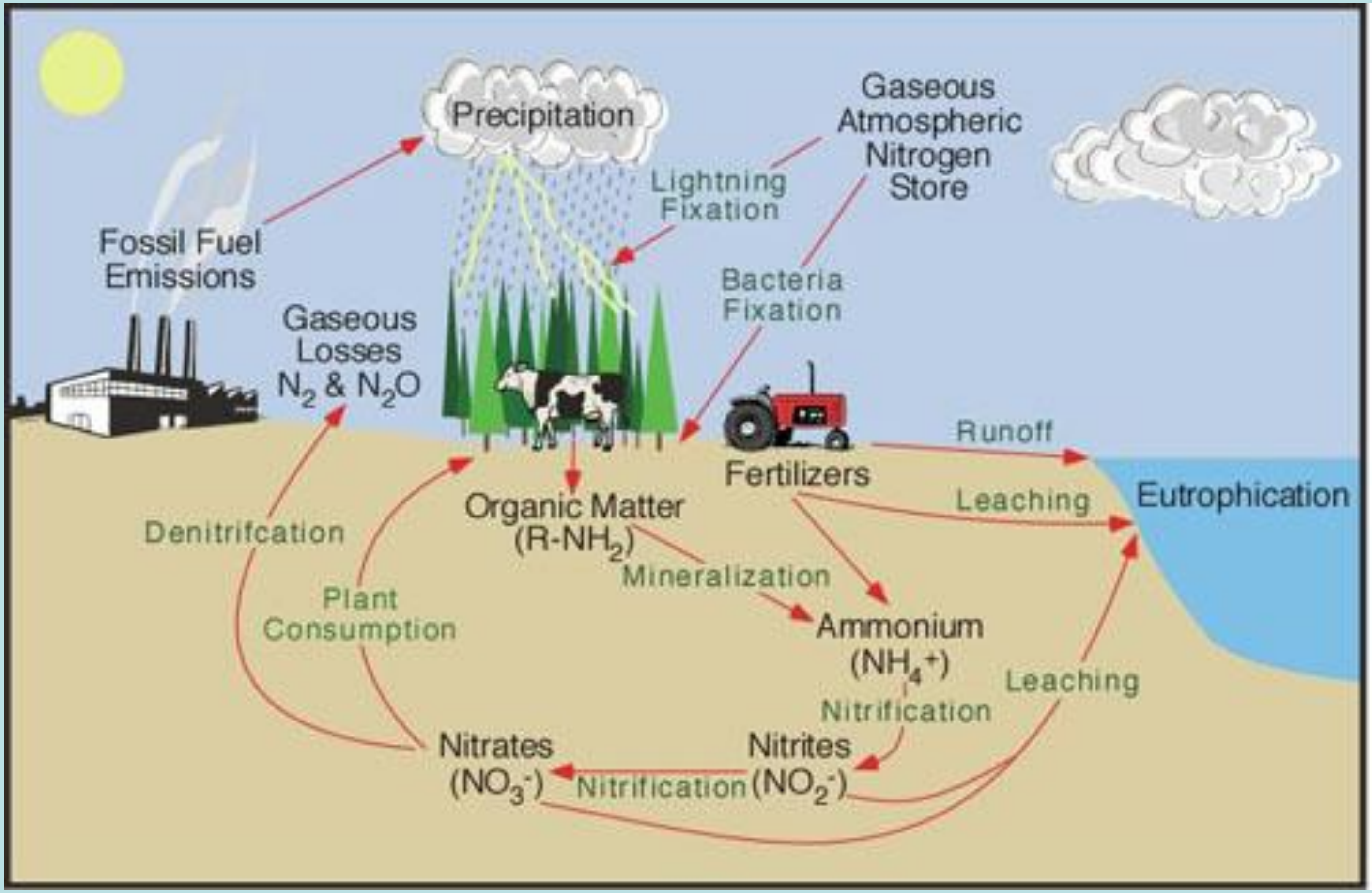
Better residue management and/or less tillage can result in net carbon sequestration

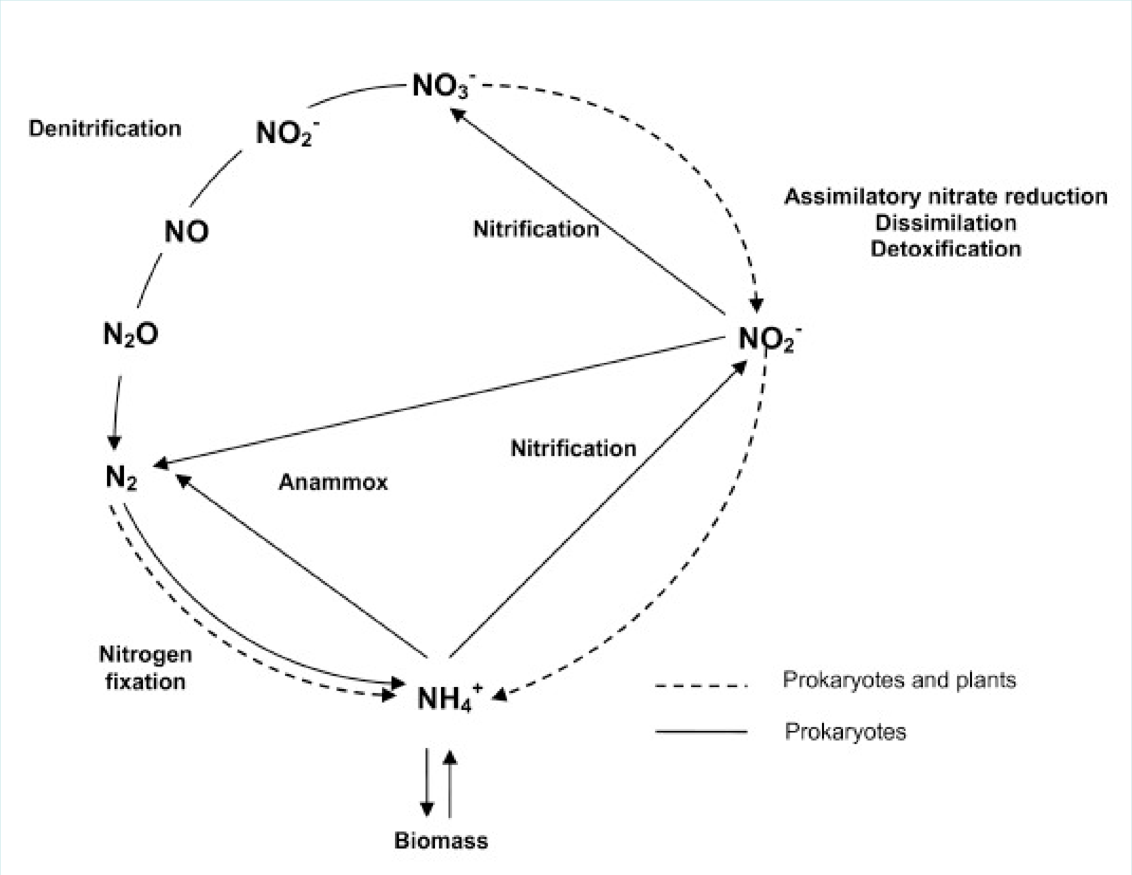
Improved soil tillage and short-rotation cropping intensity can make carbon easy to go



CO_2
Energy from fossil fuels
CO_2
Energy from bio-fuels
C
CO_2
Plant biomass and roots left on or in the soil contribute to Soil Carbon or Soil Organic Matter and all associated environmental and production benefits
Nonrenewable
Renewable

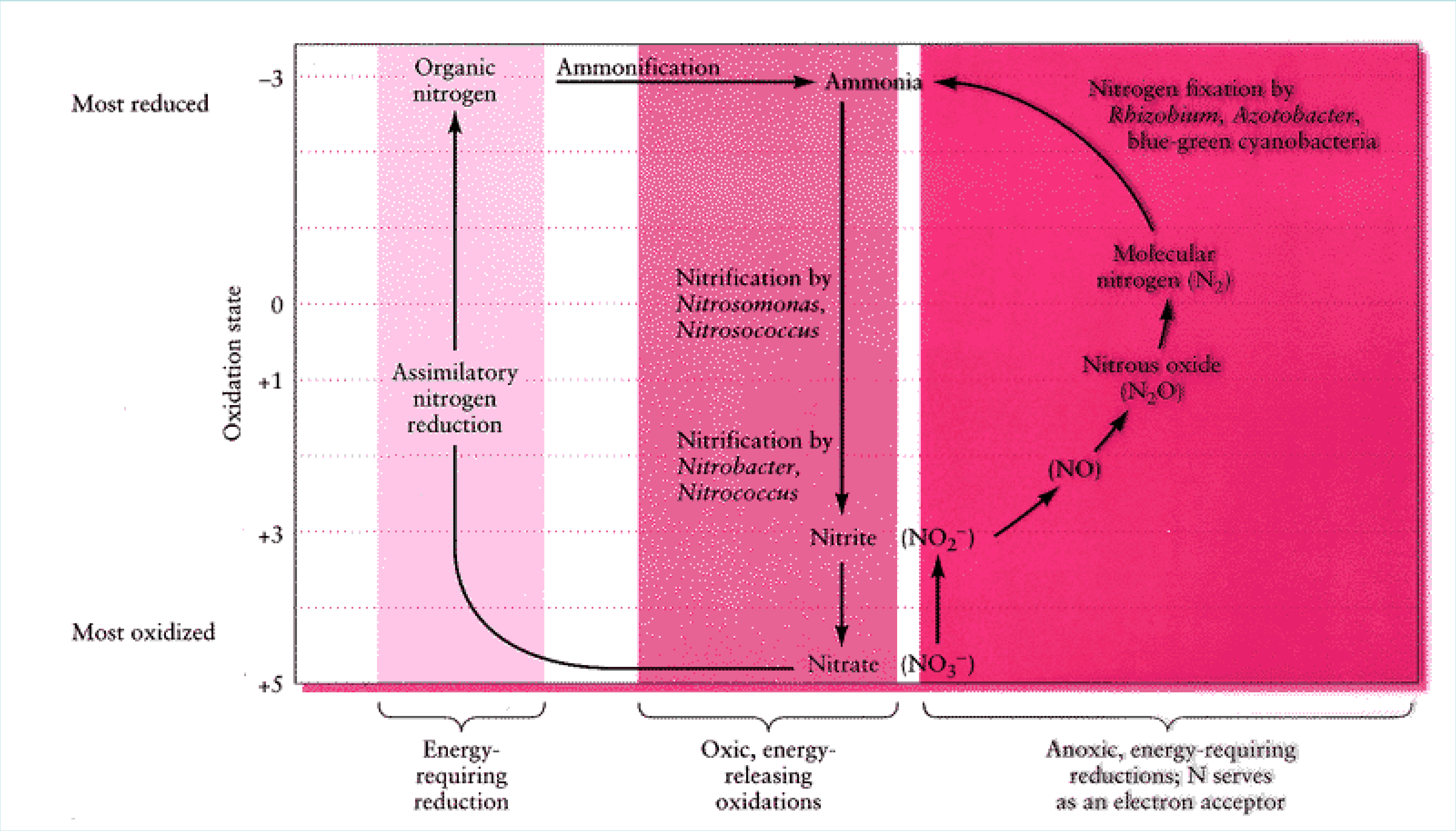
The Nitrogen Cycle



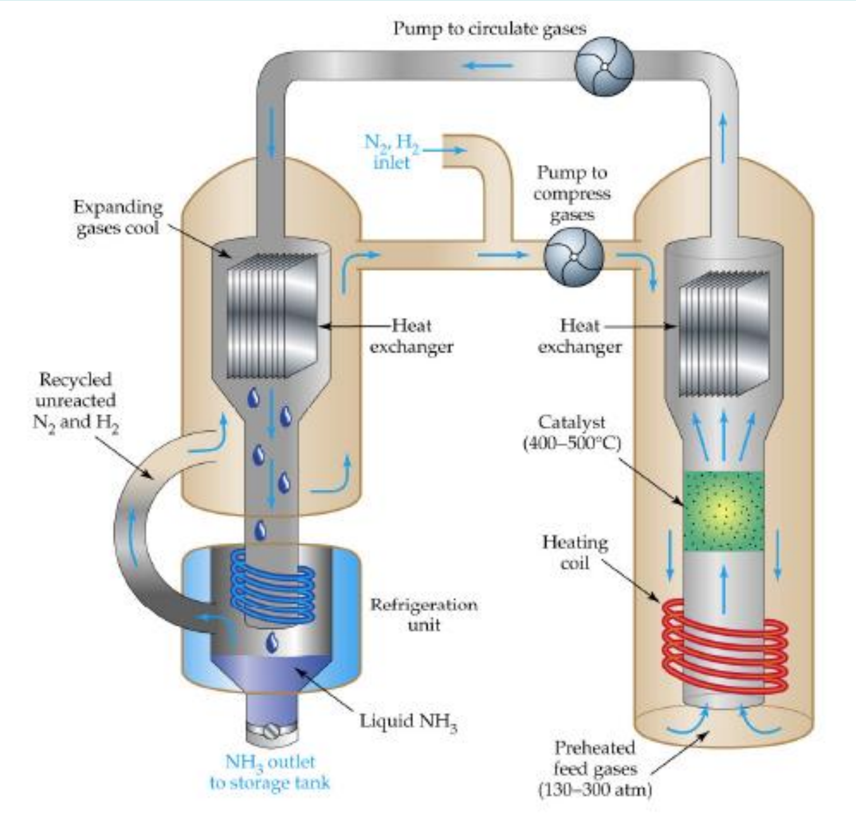


N-cycle scheme. NO_3^- is used as nitrogen source for growth under aerobic conditions using an assimilatory NO_3^- reductase, while it acts as an electron acceptor to eliminate excess of reductant power through dissimilatory NO_3^- reduction. *Dissimilatory NO_3^- reduction*, *NO_3^- respiration* or *denitrification* are often used equivalently in the literature. However, *dissimilatory pathway* makes reference to non-assimilatory reactions that are not directly coupled to generation of proton-motive force. In some *Enterobacteriaceae*, NO_2^- is reduced to NH_4^+ which is then excreted; this process is known as *NO_3^-/NO_2^- ammonification*. Specialised organisms are able to oxidize either NH_4^+ or NO_2^- by using a pathway called *nitrification*, while other organisms such as some planctomycetes oxidize NH_4^+ and utilize NO_2^- as respiratory electron acceptor in a pathway named *anammox*. Finally, *(di)nitrogen fixation* allows several bacteria and archaea to reduce N_2 to NH_4^+ to provide N-requirements.

IL CICLO DELL'AZOTO



500ºC, 450 bar, catalysts



Haber-Bosch process for industrial N_2 reduction

Esempi di microorganismi azotofissatori

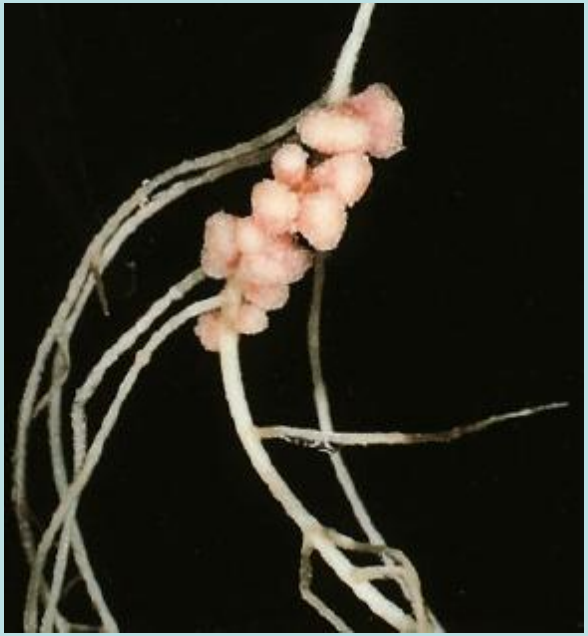
Fissazione simbiontica dell'azoto

Pianta ospite	Genere di procariota diazotrofo
Piante leguminose: *Parasponia*	*Azorhizobium, Bradyrhizobium, Photorhizobium, Rhizobium, Sinorhizobium*
Piante actinorriziche; ontano (albero), *Ceanothus* (cespuglio), *Casuarina* (albero), *Datisca* (cespuglio)	*Frankia*
Gunnera	*Nostoc*
Azolla (felce d'acqua)	*Anabaena*

Fissazione non simbiontica dell'azoto

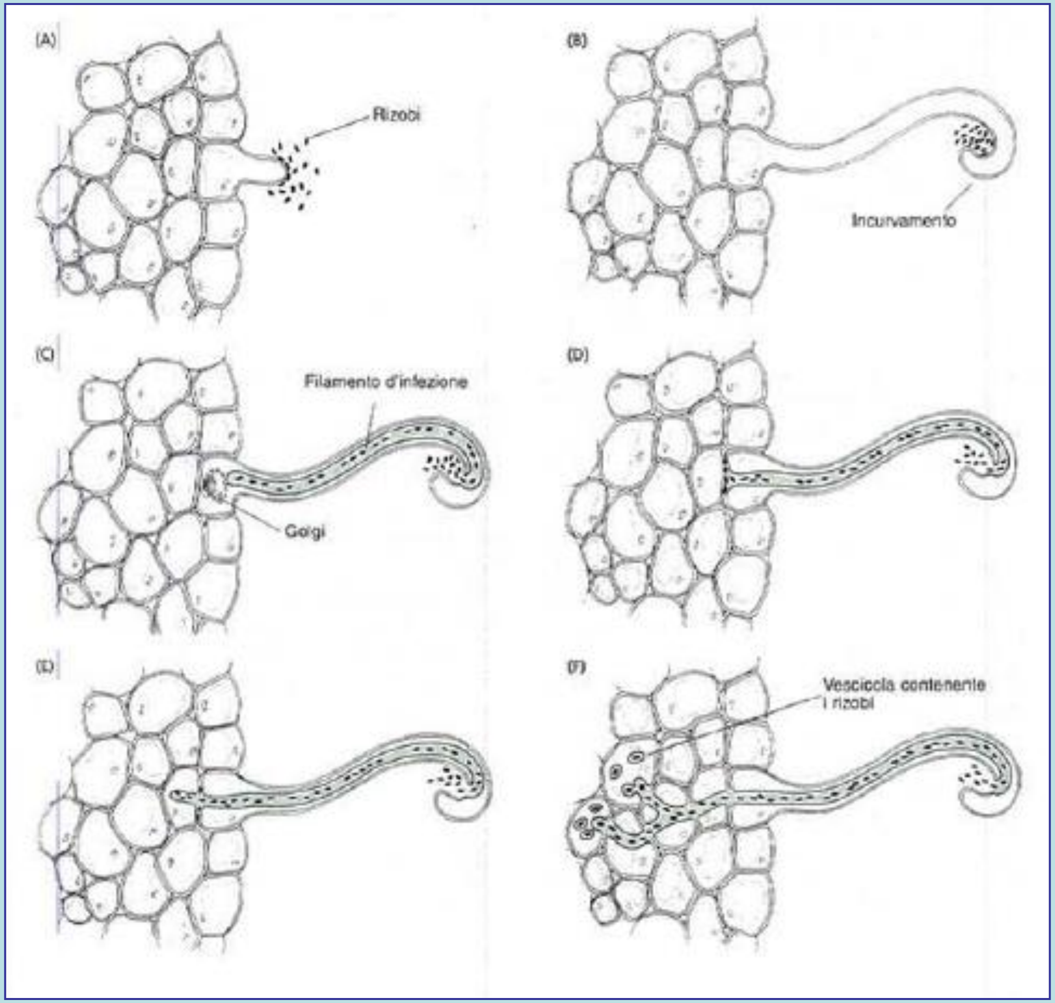
Tipo di batterio	Genere di procariota diazotrofo
Cianobatteri (alghe verdazzurre)	*Anabaena, Calothrix, Gloeotheca, Nostoc*
Altri batteri	
Aerobici	*Azotobacter, Azospirillum, Beijerinckia, Derxia*
Facoltativi	*Bacillus, Klebsiella*
Anaerobici	
Non fotosintetici	*Clostridium, Methanococcus* (Archebatterio)
Fotosintetici	*Chromatium, Rhodospirillum*

$$N_2 + 8\ H^+ + 8\ e^- + 16\ ATP = 2\ NH_3 + H_2 + 16\ ADP + 16\ Pii$$

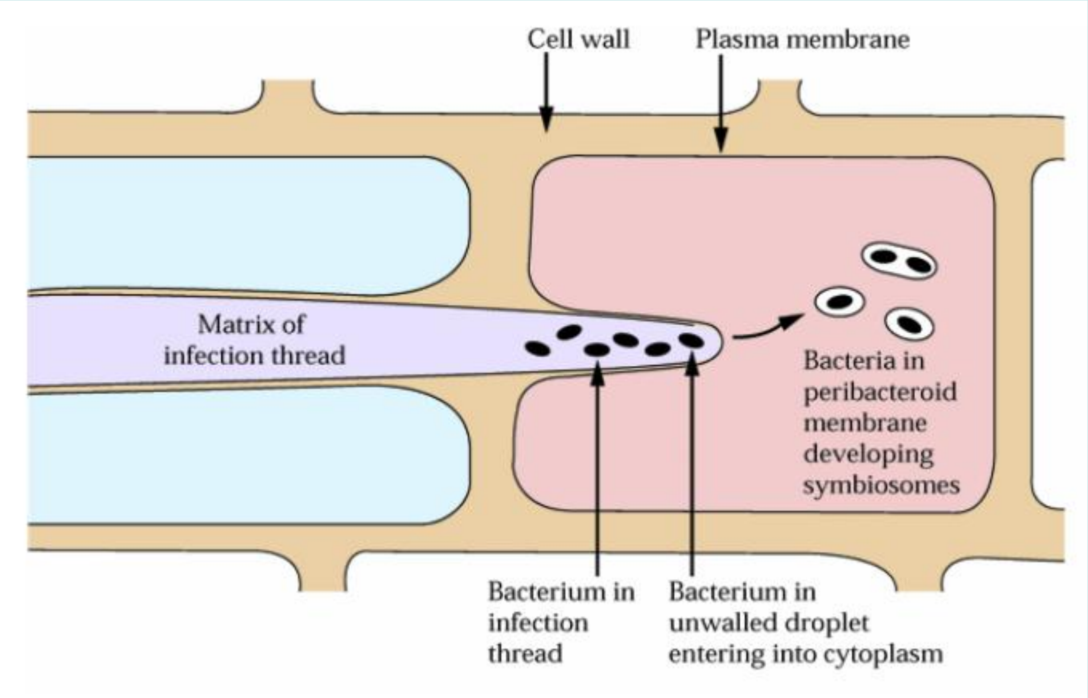


Clover root nodules at higher magnification, showing two partly crushed nodules (arrowheads) with pink-coloured contents. This color is caused by the presence of the pigment leghaemoglobin a unique metabolite of this type of symbiosis. Leghaemoglobin is found only in the nodules and is not produced by either the bacterium or the plant when grown alone.

Formazione di batteroidi da parte di *Rhizobium* in radici di leguminose



Formazione del batteroide nella simbiosi *Rhizobium*/leguminose



Nitrogenasi

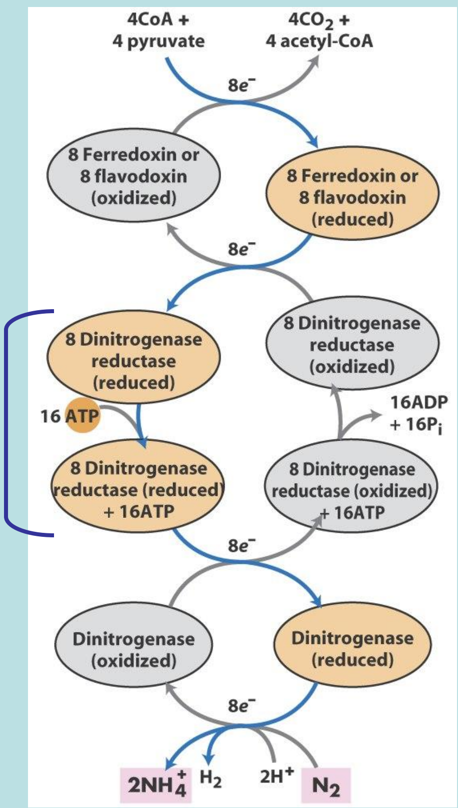
Enzima a due componenti

- 1 → Dinitrogenasi
- 2 → Dinitrogenasi reduttasi

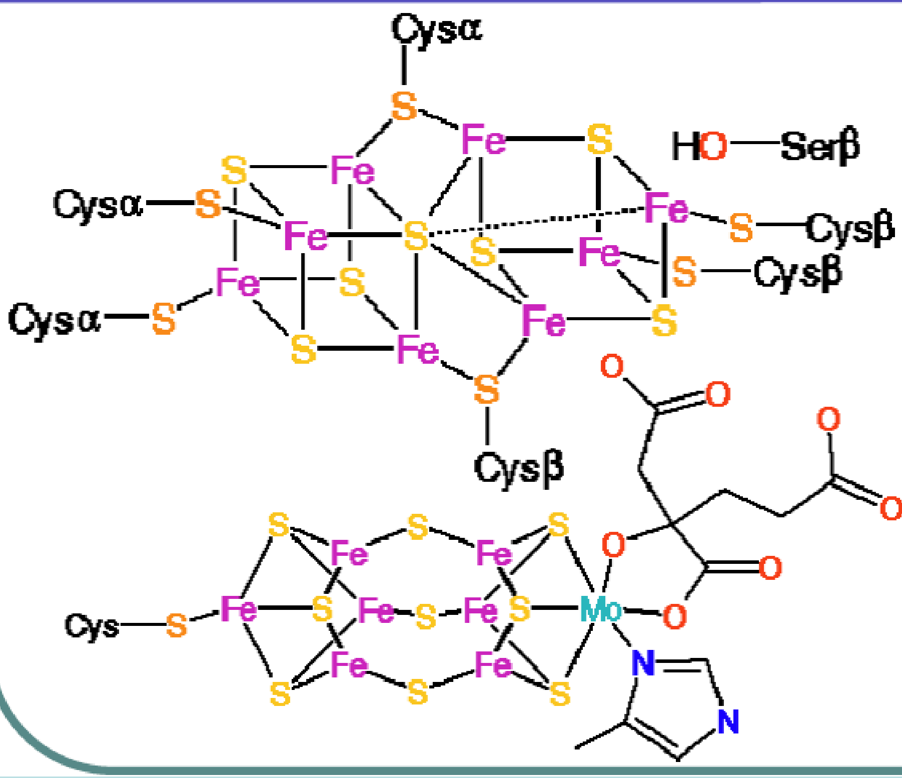
Dinitrogenasi: contiene il sito attivo, proteina Mo-Fe

Dinitrogenasi reduttasi: E’ sensibile all’O_2.

Nitrogenase-enzyme Complex

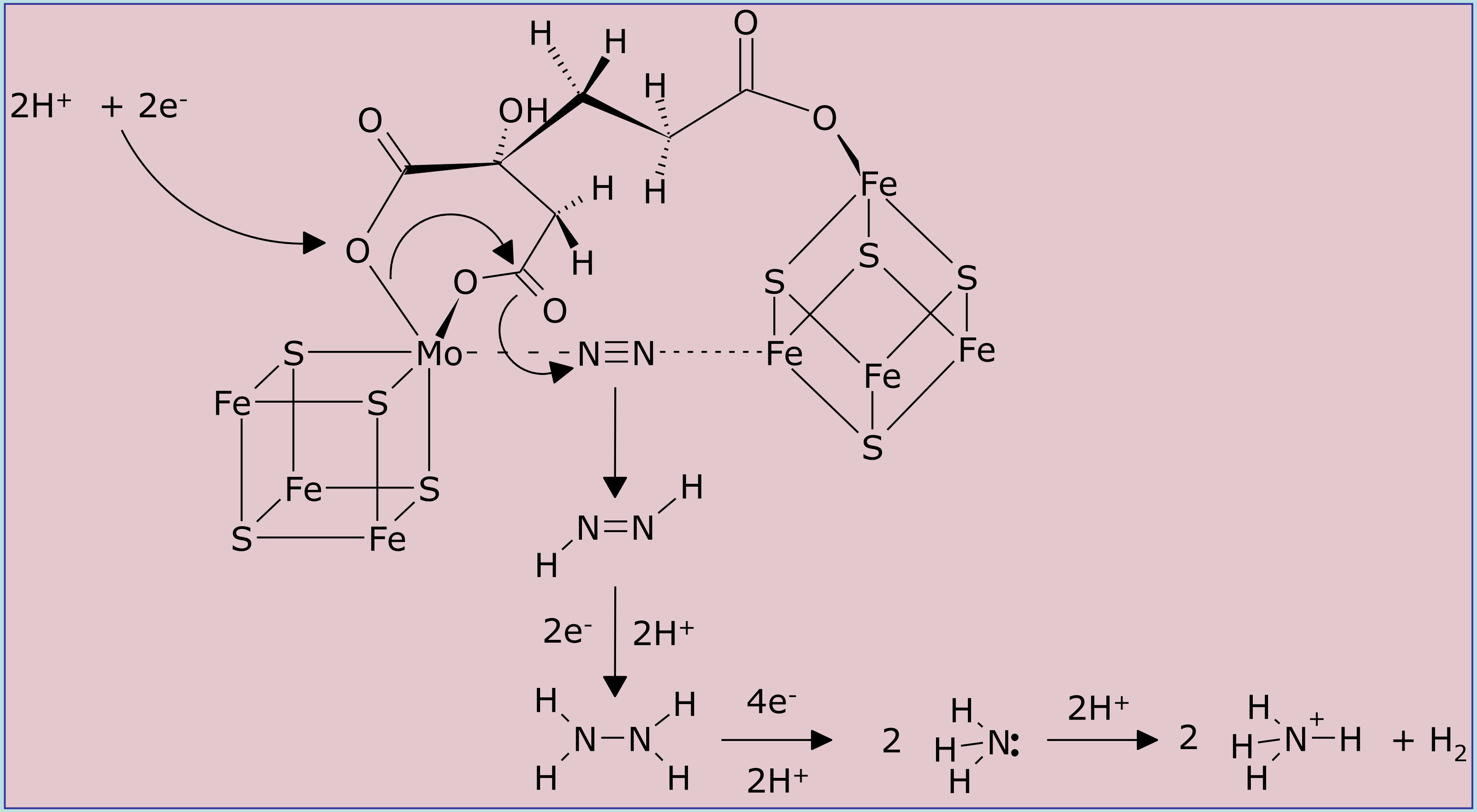


Nitrogenase

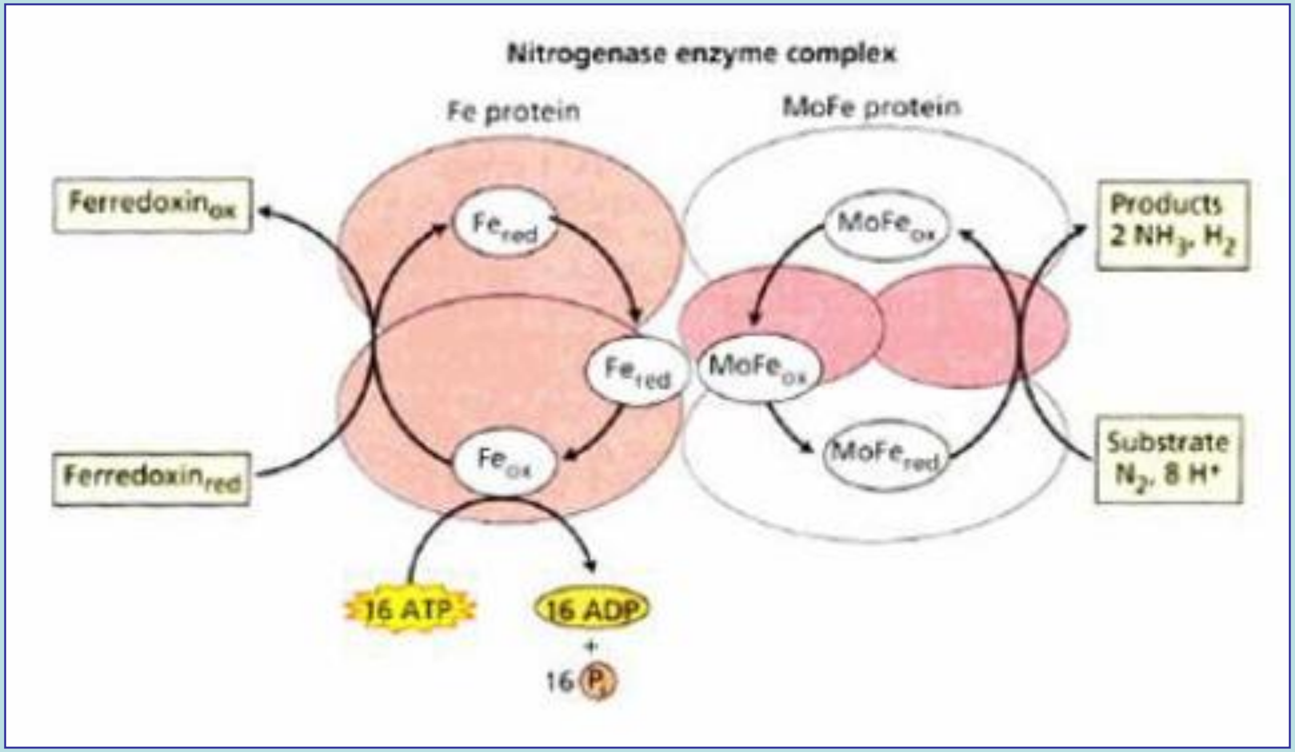


P-cluster

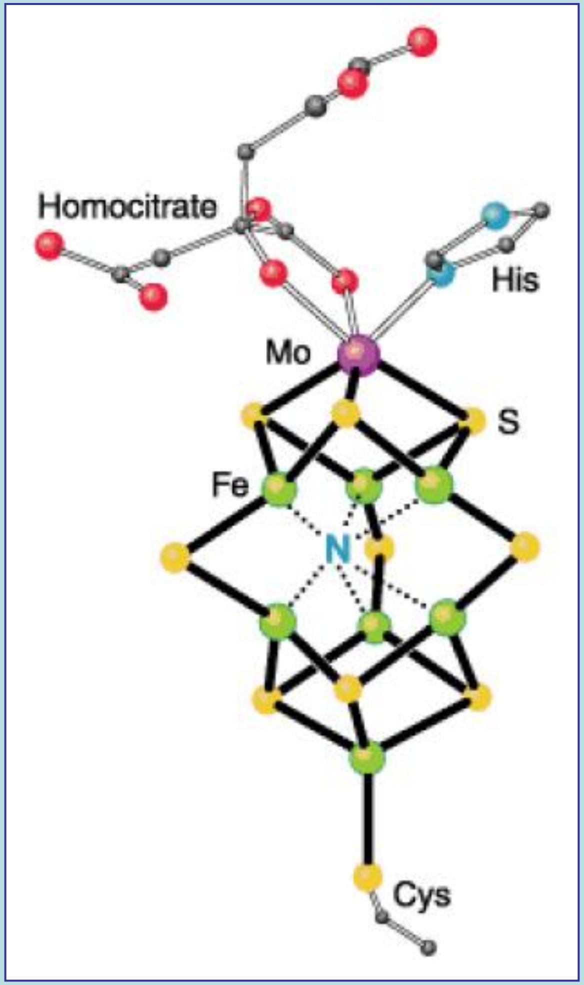
FeMo- Cofactor of nitrogenase



2H+ + 2e-
O
OH
H
H
H
O
O
Fe
H
H
O
H
O
O
S
S
S
Mo
N≡N
Fe
Fe
Fe
S
Fe
S
Fe
S
Fe
S
S
Fe
S
H
N=N
H
2e-
2H+
H
H
N—N
H
H
4e-
2H+
2
H
H—N:
H
2H+
2
H
H—N—H
H
+
+ H2


Nitrogenase enzyme complex
Fe protein
MoFe protein
Ferredoxin$_{ox}$
Ferredoxin$_{red}$
Fe$_{red}$
Fe$_{red}$
Fe$_{ox}$
MoFe$_{ox}$
MoFe$_{ox}$
MoFe$_{red}$
Products
2 NH$_3$, H$_2$
Substrate
N$_2$, 8 H$^+$
16 ATP
16 ADP
+
16 P$_i$

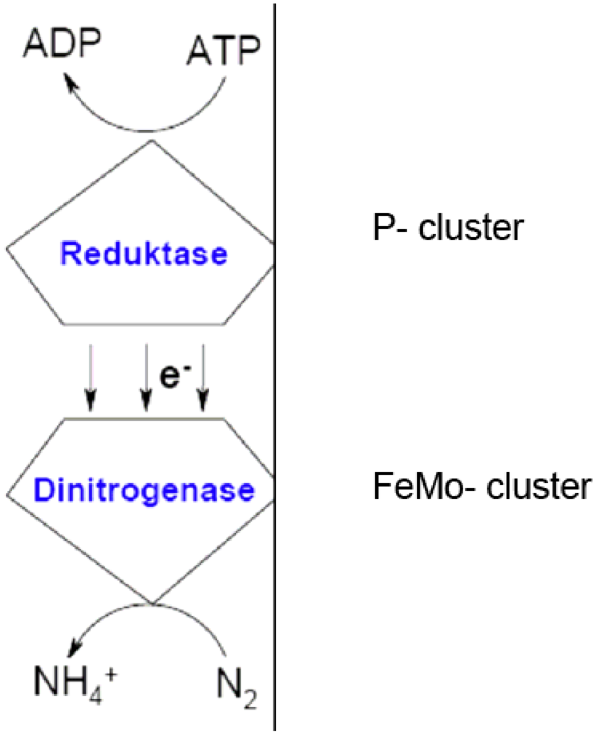
Struttura del co-fattore ferro-molibdeno presente nella nitrogenasi

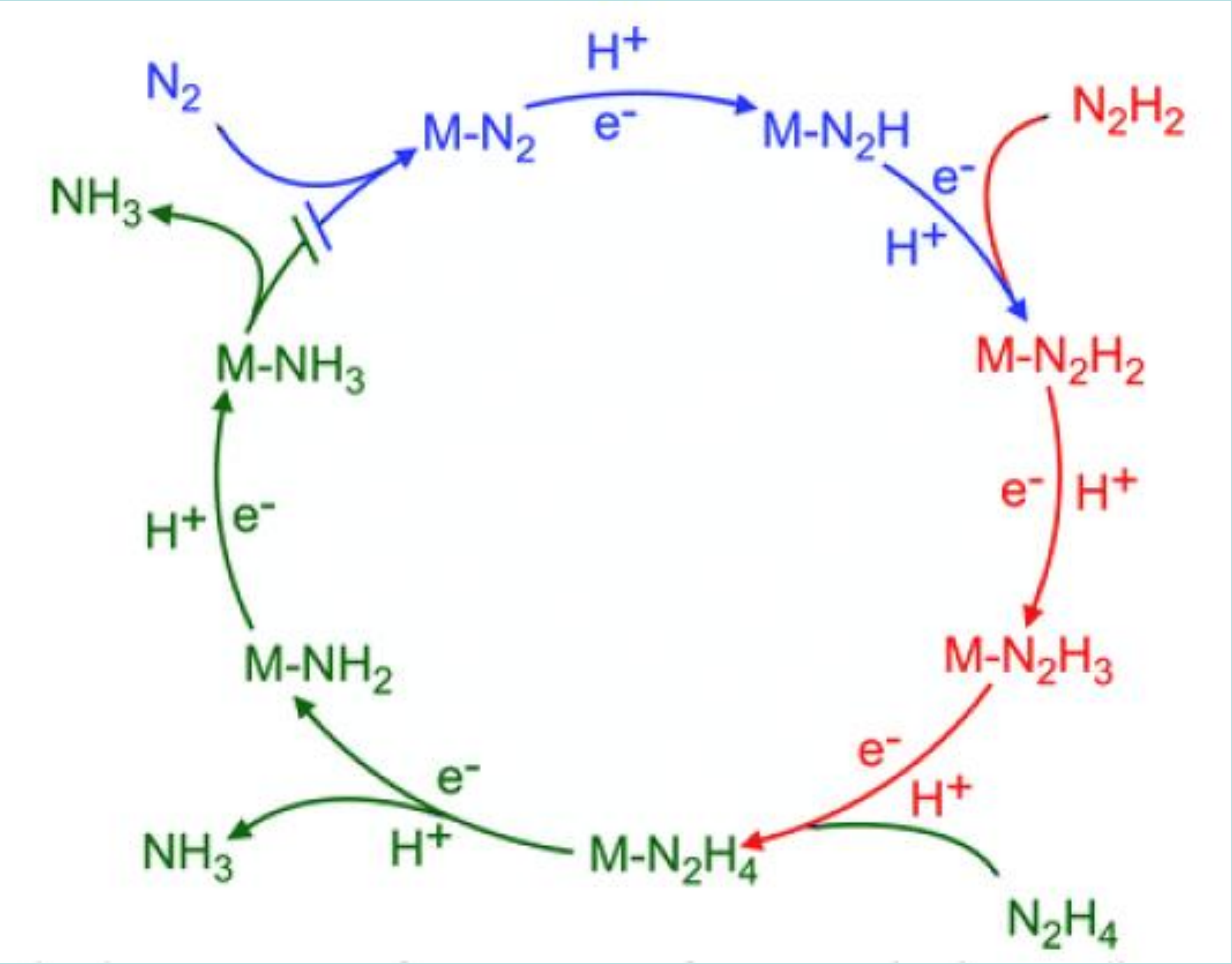


Charge and energy transfer

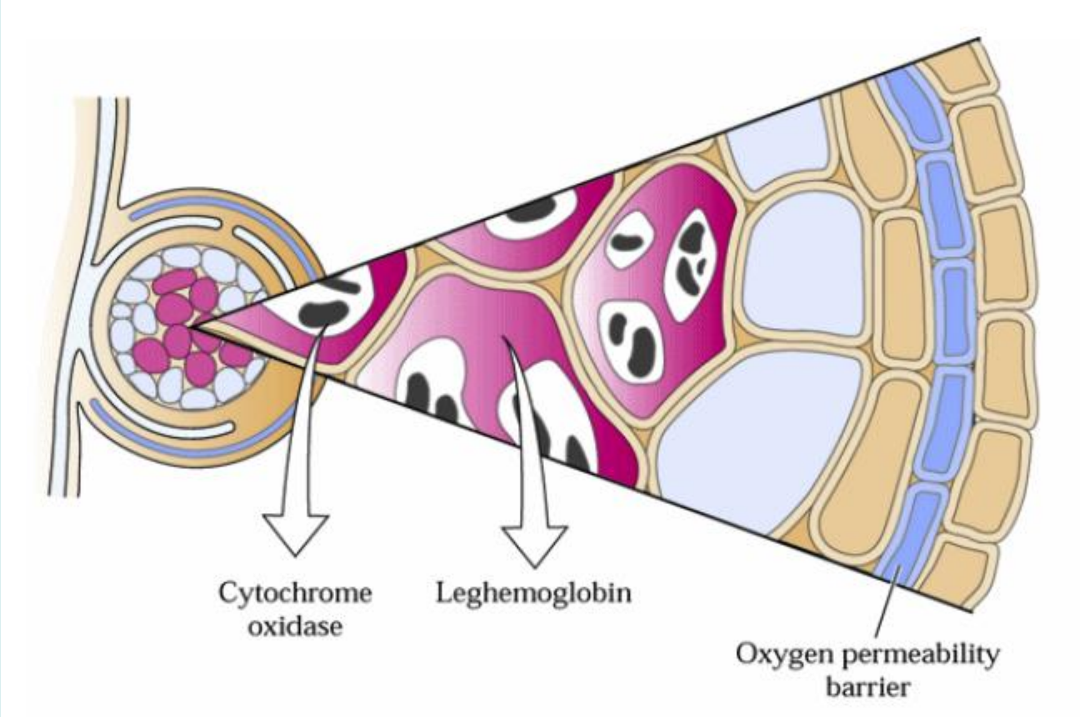
The dinitrogenase reductase is activated with ATP

The Fe-Mo cluster accepts charges and H^+ ions

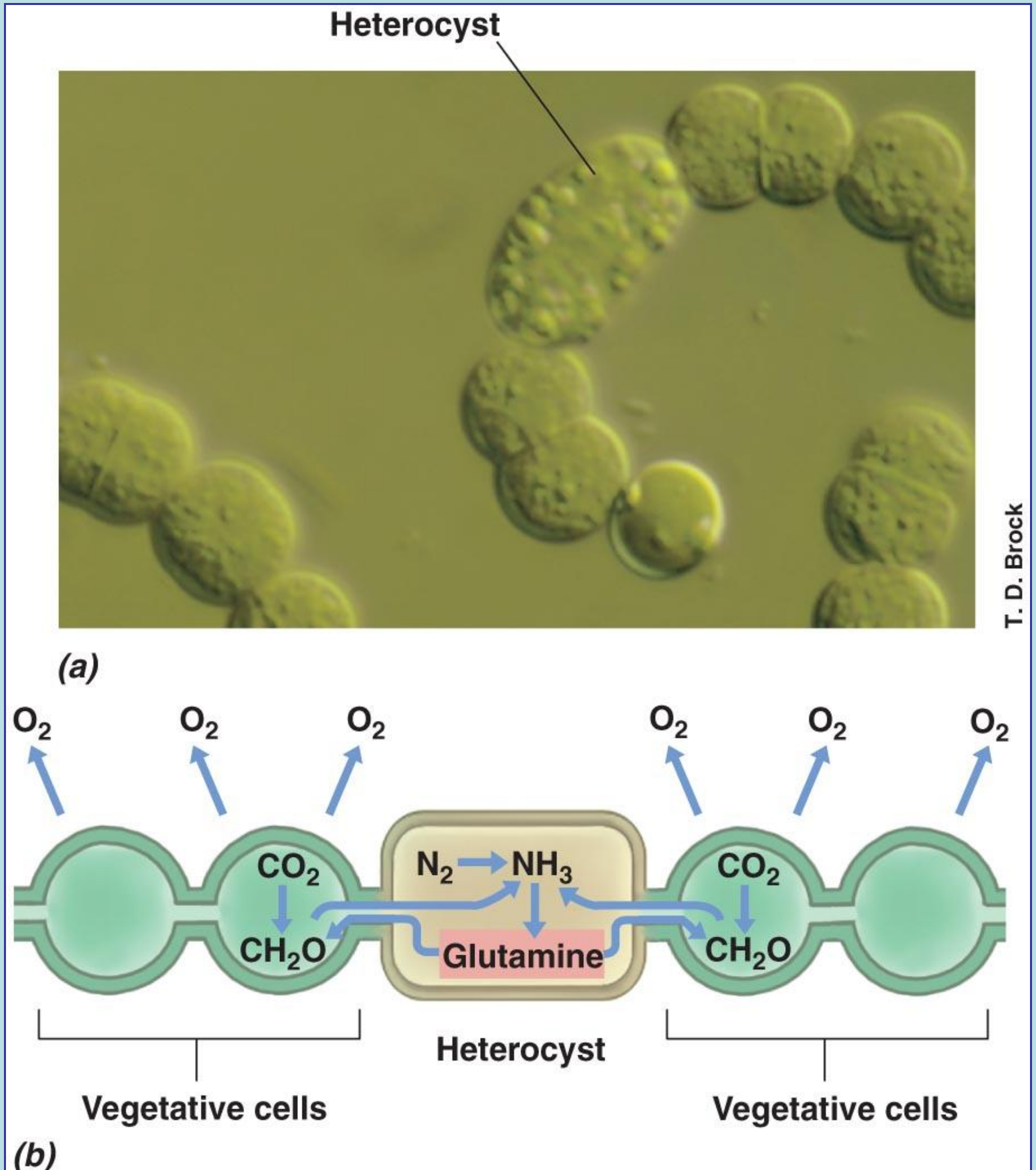


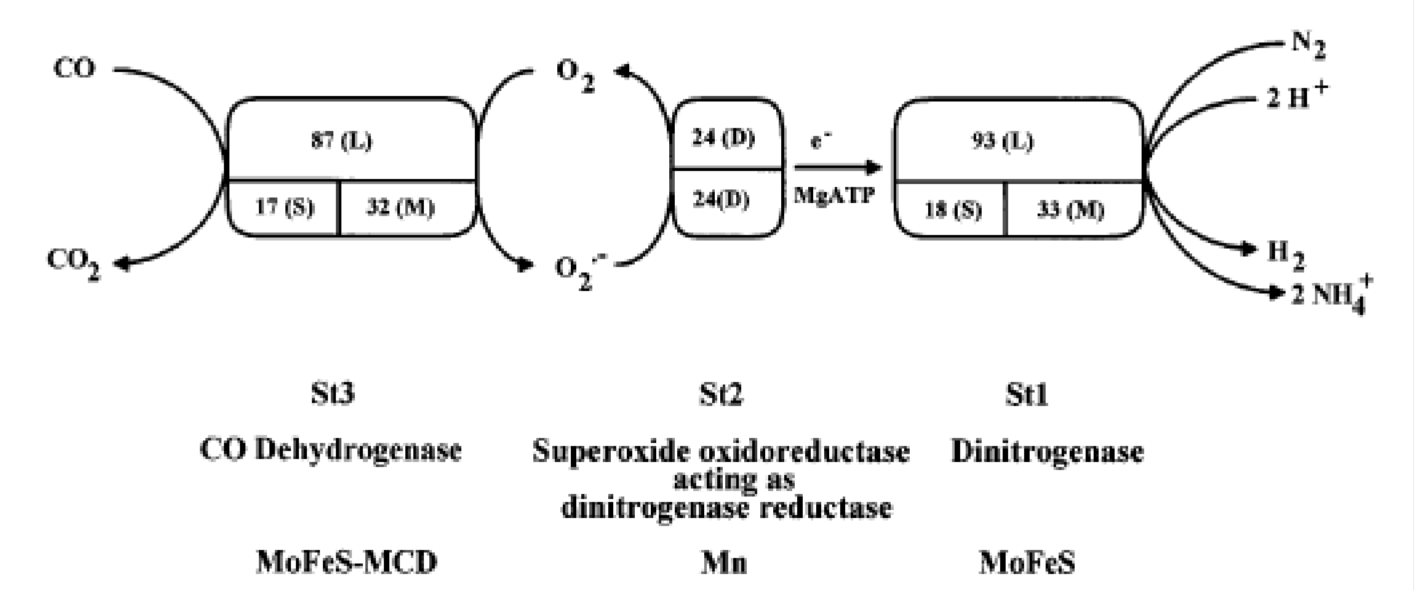

N2
M-N2
H+
e-
M-N2H
N2H2
e-
H+
M-N2H2
e- H+
M-N2H3
e-
H+
M-N2H4
N2H4
e-
H+
NH3
M-NH2
H+ e-
M-NH3
NH3

Difesa della nitrogenasi dall'effetto tossico dell'O_2 a livello del nodulo

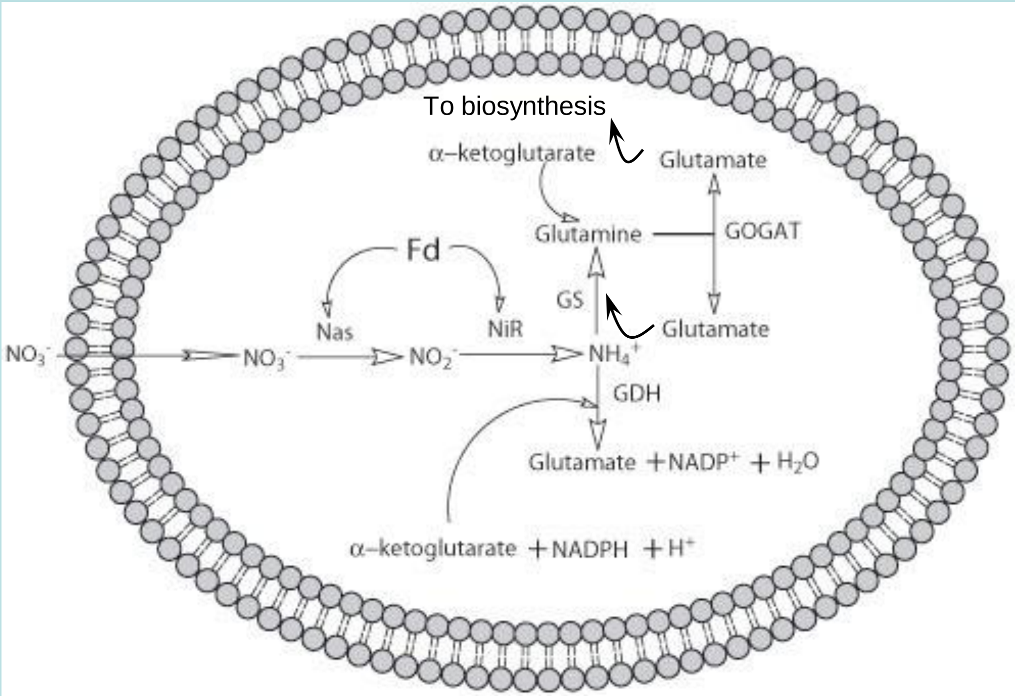


FISSAZIONE BIOLOGICA DELL'AZOTO





Reactions of nitrogen fixation in *Streptomyces thermoautotrophicus*



GDH

NH_3 + 2-oxoglutarate + NADPH + H^+ <---> glutamate + $NADP^+$

GS-GOGAT

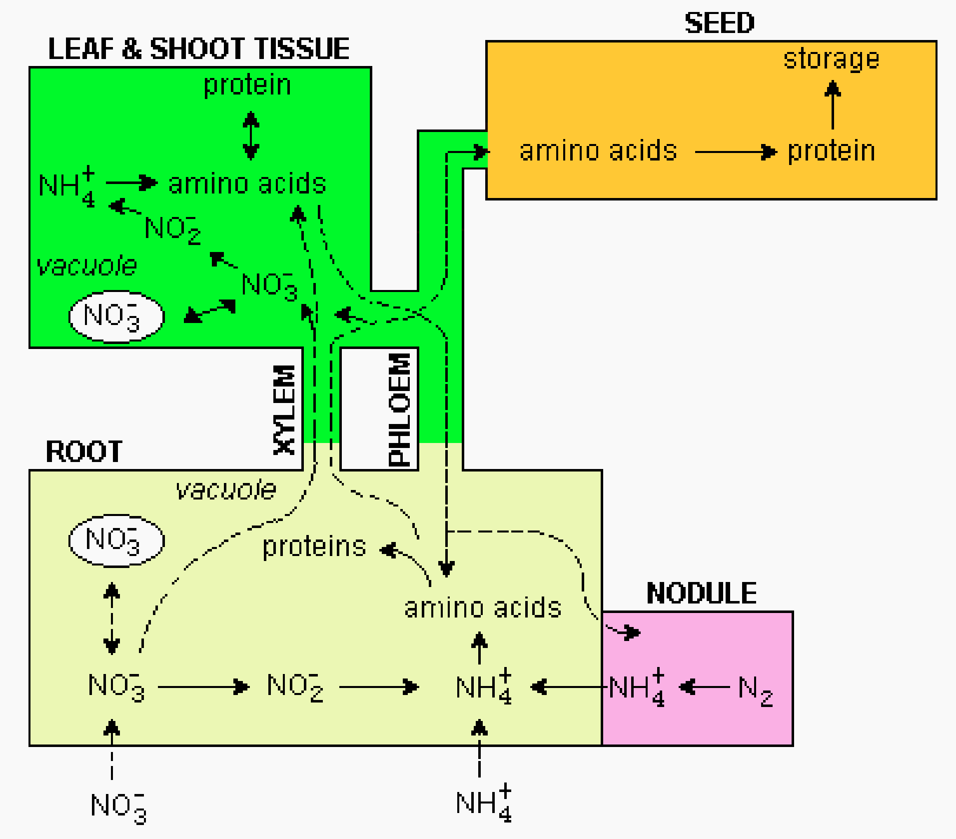
NH_3 + glutamate + ATP ---> glutamine + ADP + Pi

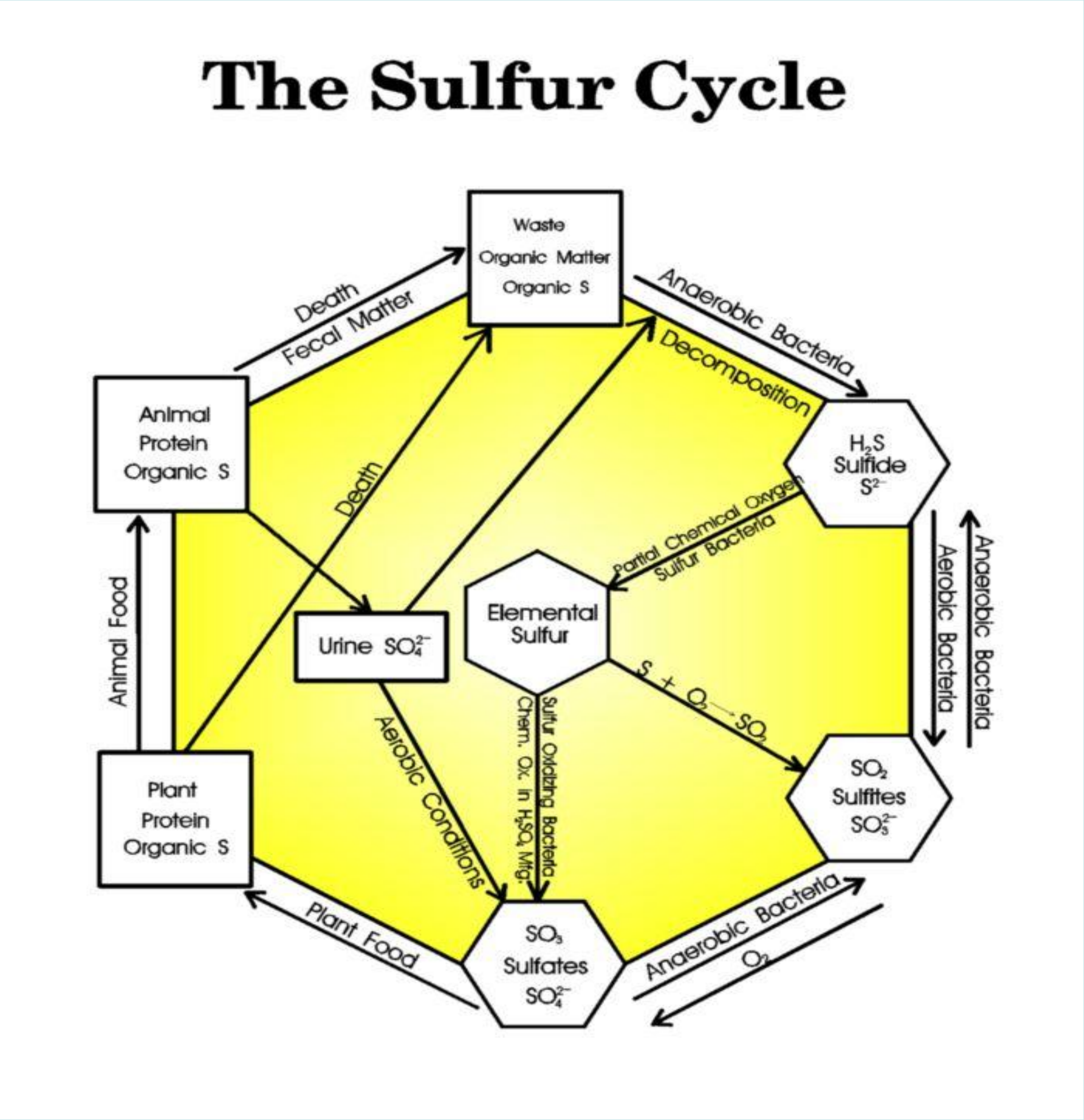
glutamine + 2-oxoglutarate + NADPH + H+ ---> 2 glutamate + $NADP^+$

Both the GDH and GS-GOGAT pathways produce 1 mole of glutamate from 1 mole each of NH_3, 2-oxoglutarate and NADPH. But note that the GS-GOGAT pathway is energetically more costly than the GDH pathway, consuming 1 ATP.

The GS/GOGAT Pathway - nitrogen assimilation in bacteria. Nas: assimilatory nitrate reductase; NiR: assimilatory nitrite reductase; Fd: Ferredoxin; GDH: glutamate dehydrogenase; GS: glutamine synthetase; GOGAT: glutamate synthase (glutamate/oxoglutarate amino-transferase).

For many years, it was thought that bacteria and higher plants assimilate ammonia into glutamate via the GDH pathway, as in certain fungi and yeasts. However, in bacteria it became clear in 1970 that an alternative pathway of ammonia assimilation involving glutamine synthetase (GS) and an NADPH-dependent glutamine/2-oxoglutarate amidotransferase (GOGAT) or glutamate synthase, must be operating when ammonia is present in the growth medium at low levels (Tempest et al, 1970). Thus, N-starvation leads to derepression and activation of GS (with a high affinity for NH_3) and derepression of GOGAT, and repression of GDH (with a relatively low affinity for NH_3) (Tempest et al, 1970). High ammonia availability leads to repression and deactivation of GS and induction of GDH (Tempest et al, 1970).

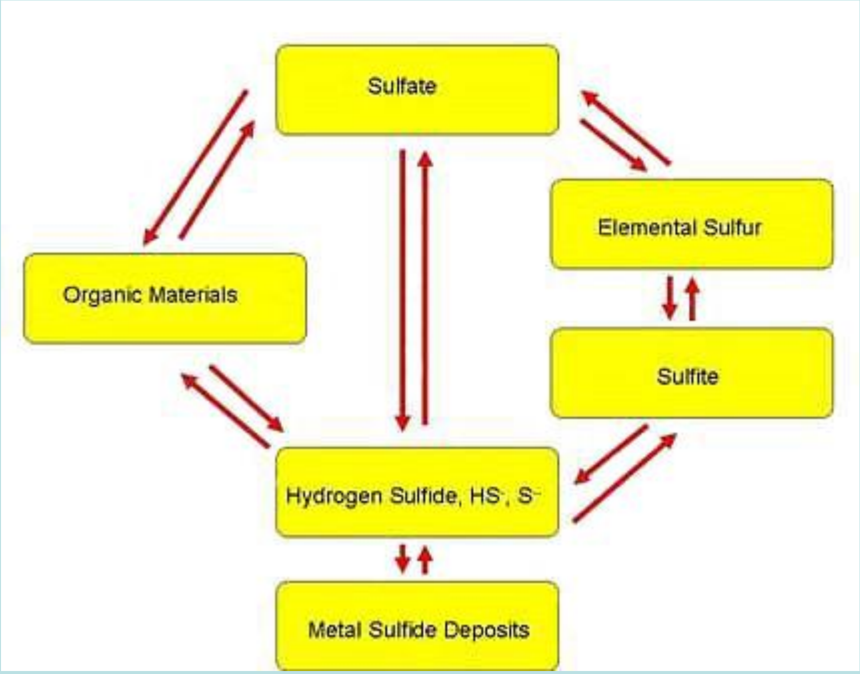

SEED
storage
amino acids
protein
LEAF & SHOOT TISSUE
protein
NH_4^+
amino acids
NO_2^-
vacuole
NO_3^-
NO_3^-
XYLEM
PHLOEM
ROOT
vacuole
NO_3^-
proteins
amino acids
NODULE
NO_3^-
NO_2^-
NH_4^+
NH_4^+
N_2
NO_3^-
NH_4^+

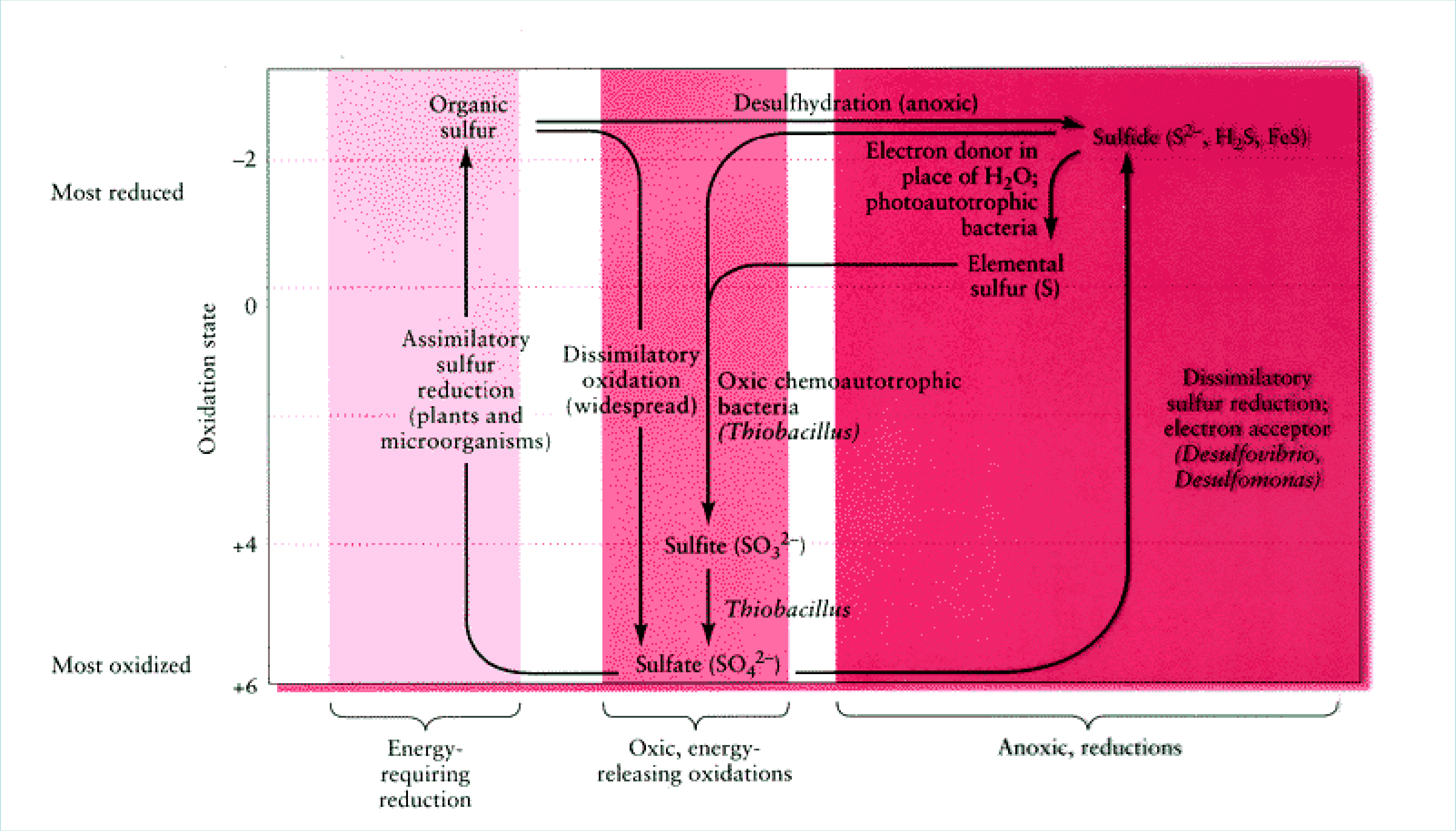

The Sulfur Cycle
Waste
Organic Matter
Organic S
Anaerobic Bacteria
Decomposition
Death
Fecal Matter
Animal
Protein
Organic S
Death
H$_2$S
Sulfide
S^{2-}
Partial Chemical Oxygen
Sulfur Bacteria
Elemental
Sulfur
Urine SO$_4^{2-}$
Animal Food
Aerobic Bacteria
Anaerobic Bacteria
S + O$_2$ → SO$_2$
Aerobic Conditions
Sulfur Oxidizing Bacteria
Chem. Ox. in H$_2$SO$_4$ Mfg.
Plant
Protein
Organic S
SO$_2$
Sulfites
SO$_3^{2-}$
Plant Food
SO$_3$
Sulfates
SO$_4^{2-}$
Anaerobic Bacteria
O$_2$

Some major steps in the sulfur cycle include:

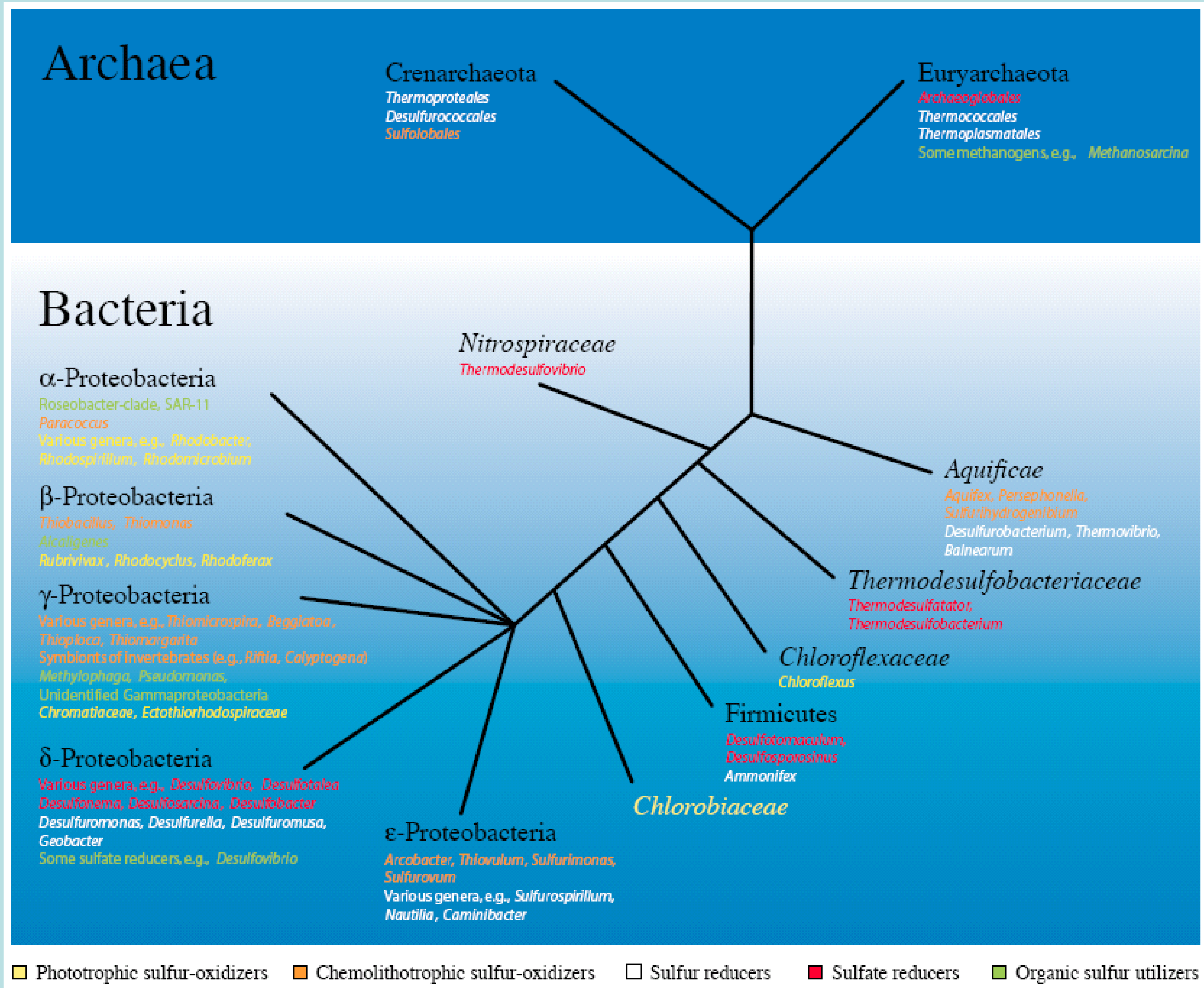
Assimilative reduction of sulfate ($SO_4^=$) into -SH groups in proteins.
Release of SH^- to form H_2S during excretion, decomposition, and desulfurylation.
Oxidation of H_2S by **chemolithotrophs** to form sulfur (S^o) and sulfate ($SO_4^=$)
Dissimilative reduction of sulfate ($SO_4^=$) by anaerobic respiration of sulfate-reducing bacteria.
Anaerobic oxidation of H_2S and S by **anoxygenic phototrophic bacteria** (purple and green bacteria) .

The sulfur cycle includes more steps than are shown here. Sulfur compounds undergo some interconversions due to chemical and geologic processes. In addition, a number of organic sulfur compounds (e.g. dimethyl sulfide, DMS) accumulate in significant amounts, especially in marine environments.



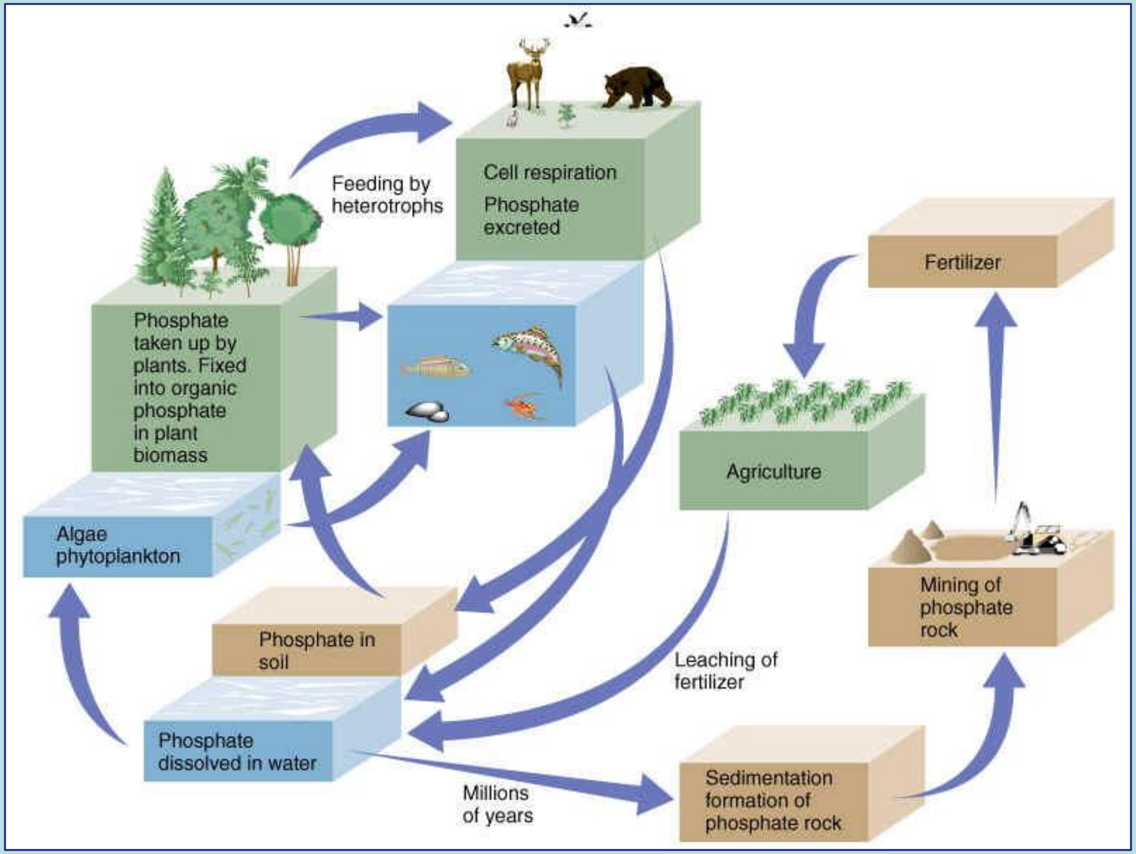


Organic sulfur
Desulfhydration (anoxic)
Sulfide (S^{2-}, H_2S, FeS)
Electron donor in place of H_2O; photoautotrophic bacteria
Elemental sulfur (S)
Most reduced
Most oxidized
Oxidation state
−2
0
+4
+6
Assimilatory sulfur reduction (plants and microorganisms)
Dissimilatory oxidation (widespread)
Oxic chemoautotrophic bacteria (*Thiobacillus*)
Dissimilatory sulfur reduction; electron acceptor (*Desulfovibrio*, *Desulfomonas*)
Sulfite (SO_3^{2-})
Thiobacillus
Sulfate (SO_4^{2-})
Energy-requiring reduction
Oxic, energy-releasing oxidations
Anoxic, reductions

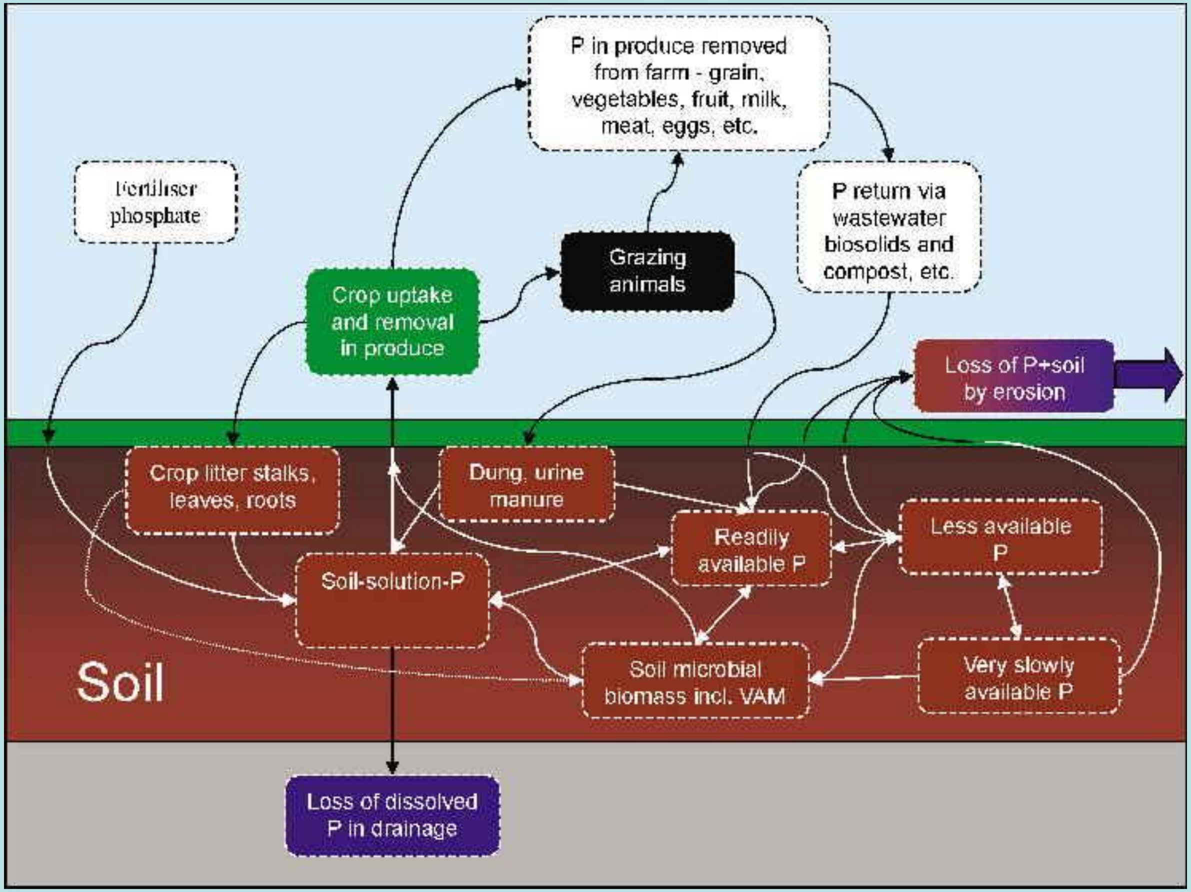


Schematic phylogenetic tree depicting the distribution of different types of sulfur-metabolizing microorganisms among major phylogenetic lineages. All forms of sulfur metabolism can be found within the proteobacteria, whereas as other lineages are more restricted in their physiological repertoire.

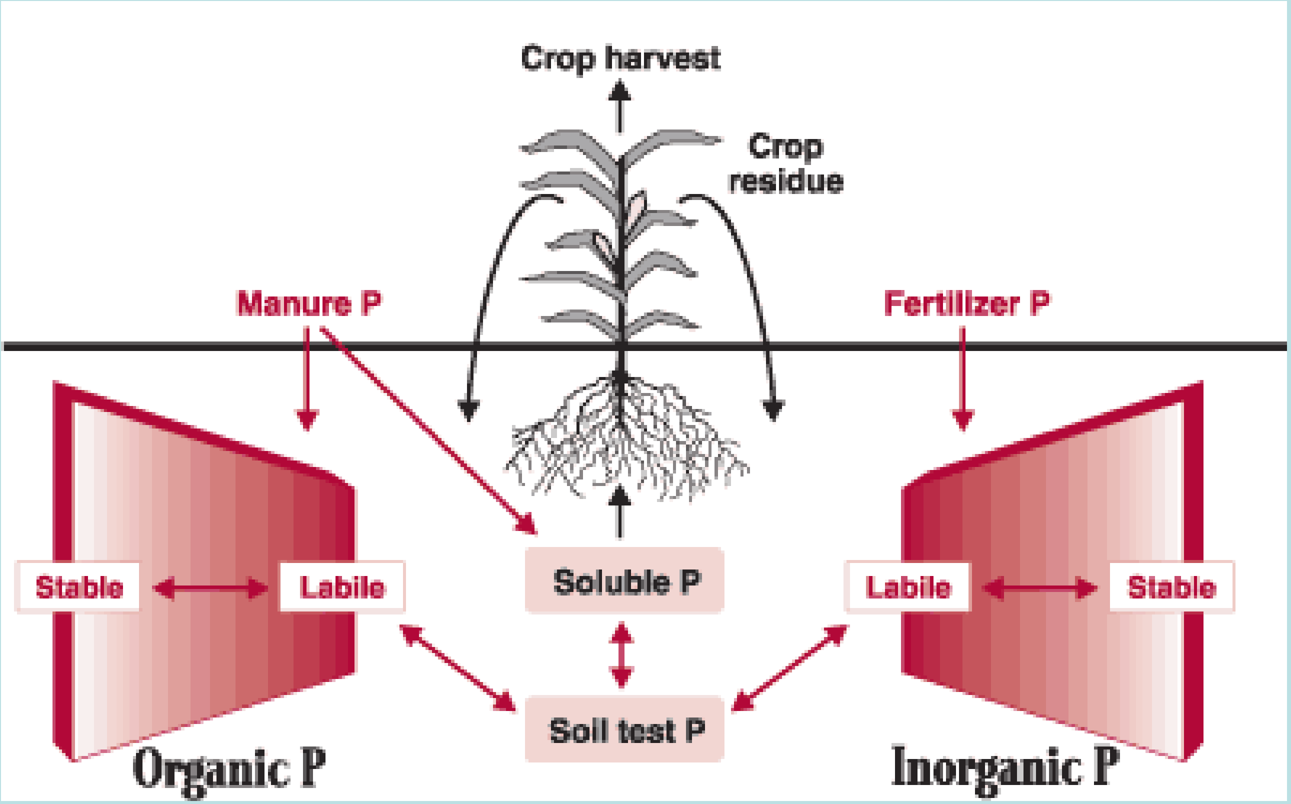
THE GLOBAL PHOSPHORUS CYCLE



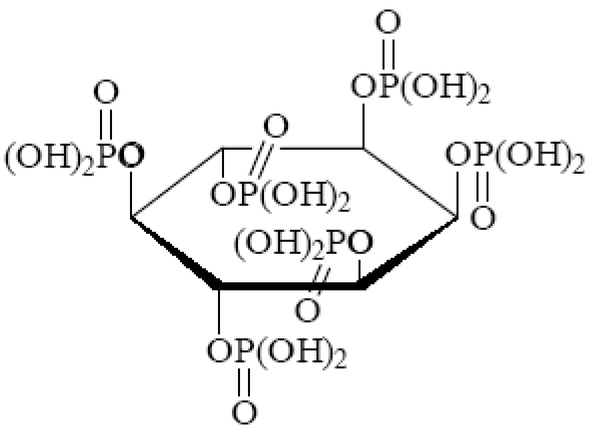
PHOSPHORUS CYCLING MECHANISMS IN SOIL



PHOSPHORUS SOLUBILIZATION/IMMOBILIZATION IN SOIL

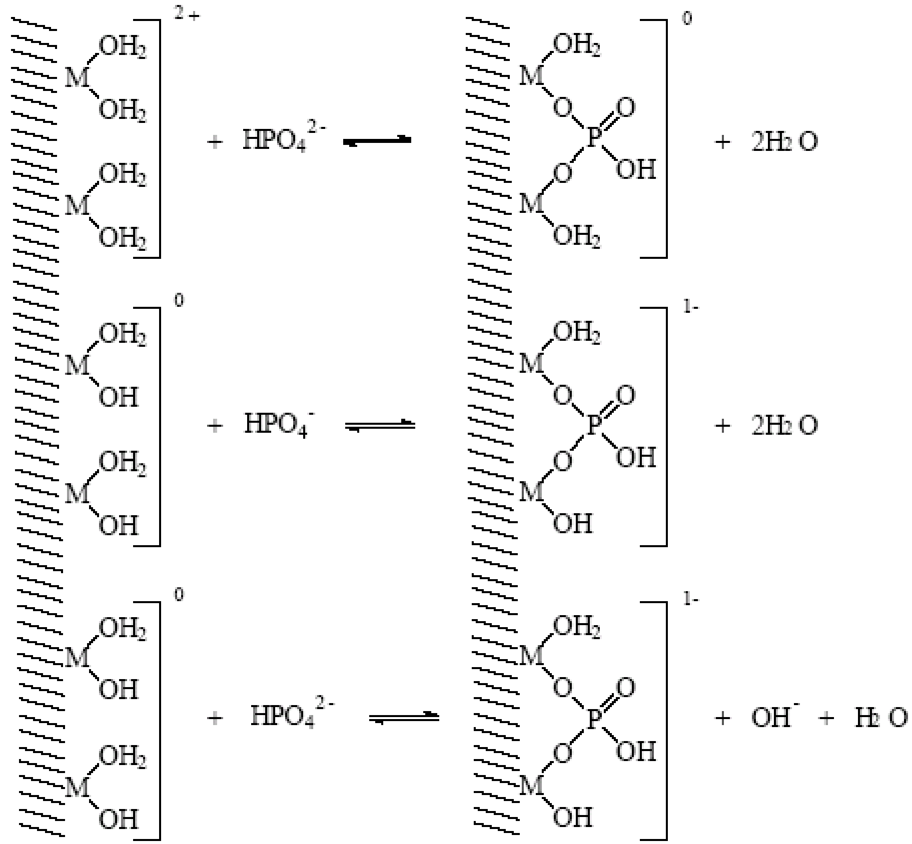


Organic phosphate compound mostly occurring in soil



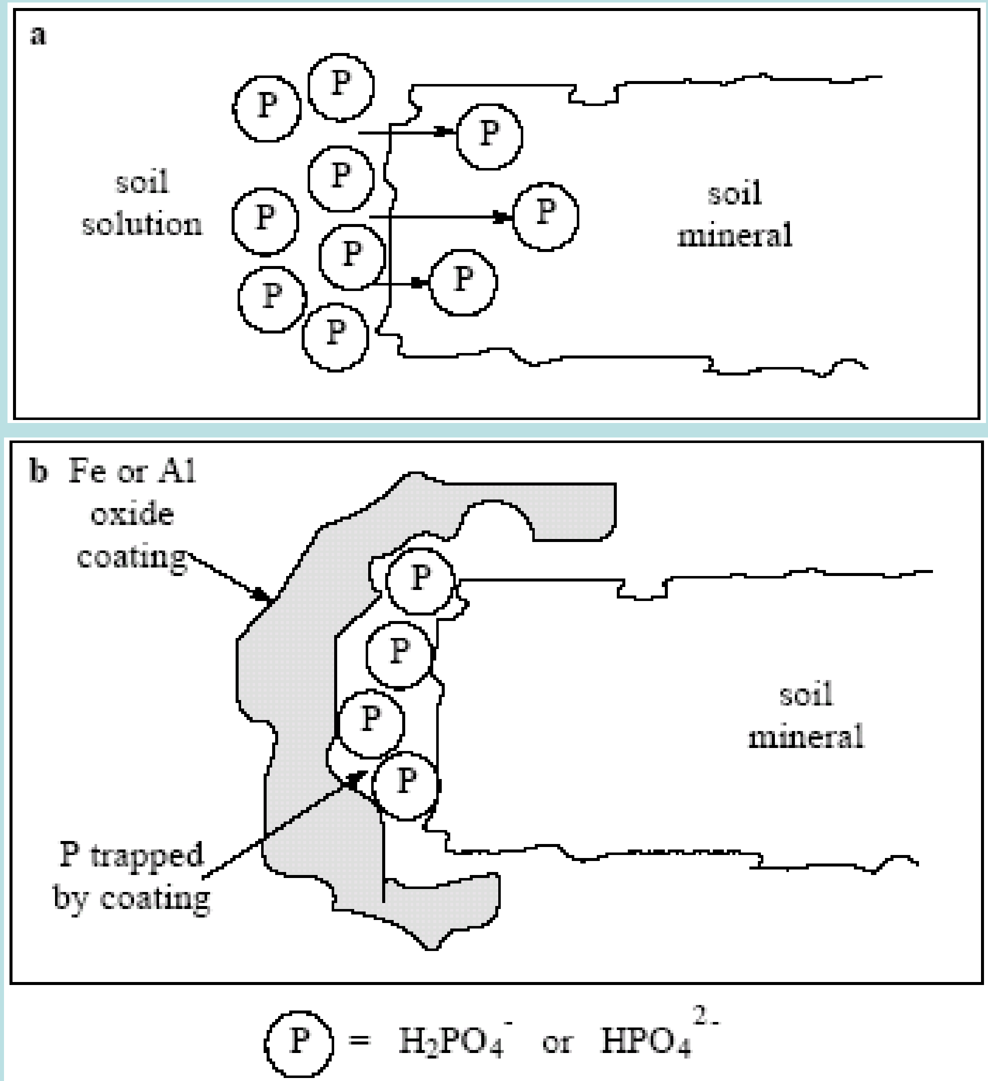
Inositol hexaphosphate

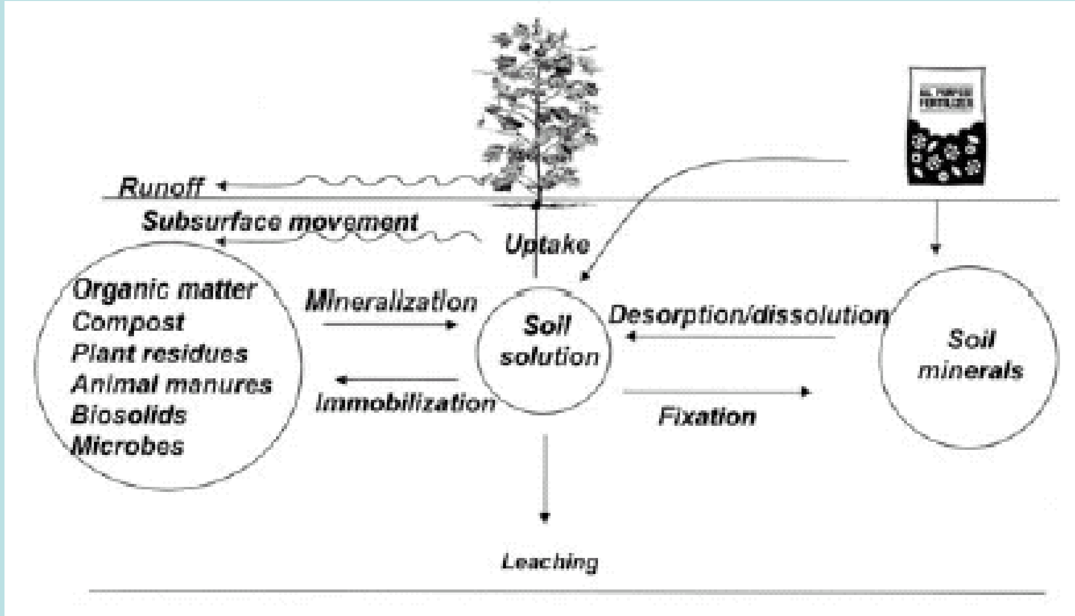
Examples of phosphate adsorption mechanisms

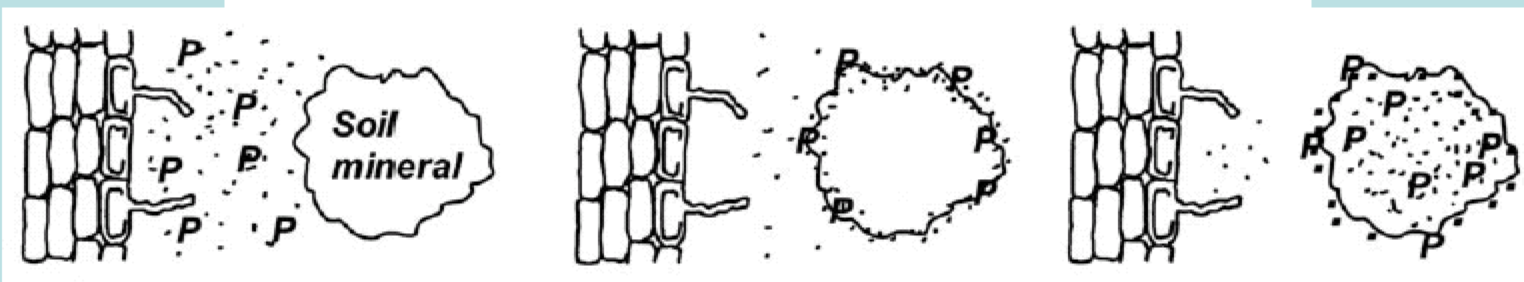


M = Al or Fe

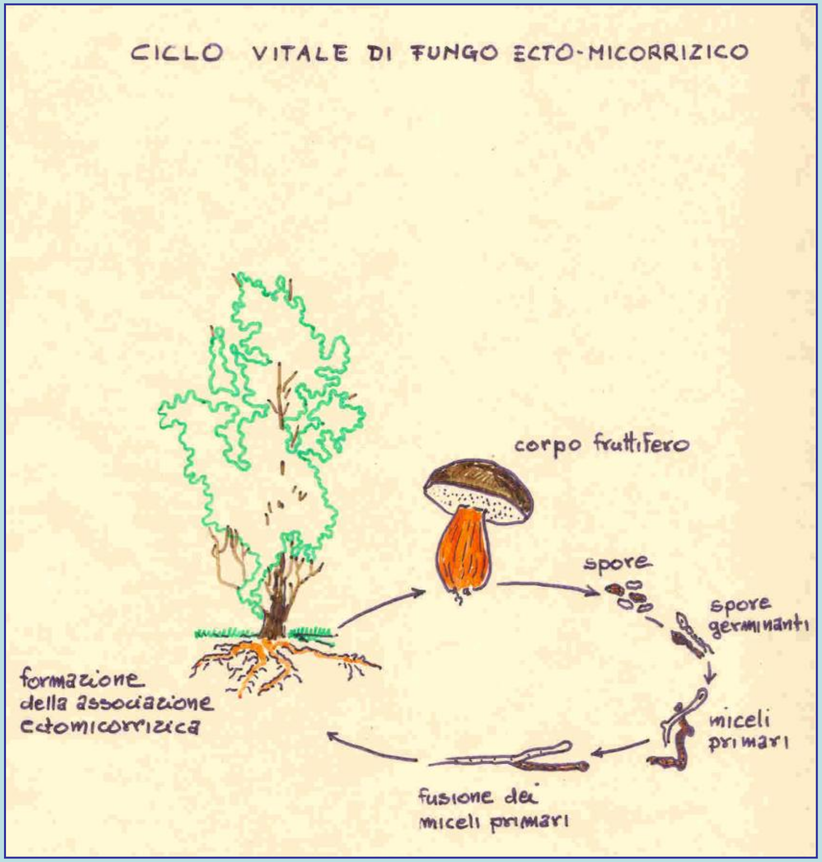
(a) The absorption of adsorbed P into soil minerals and (b) the subsequent occlusion of adsorbed P

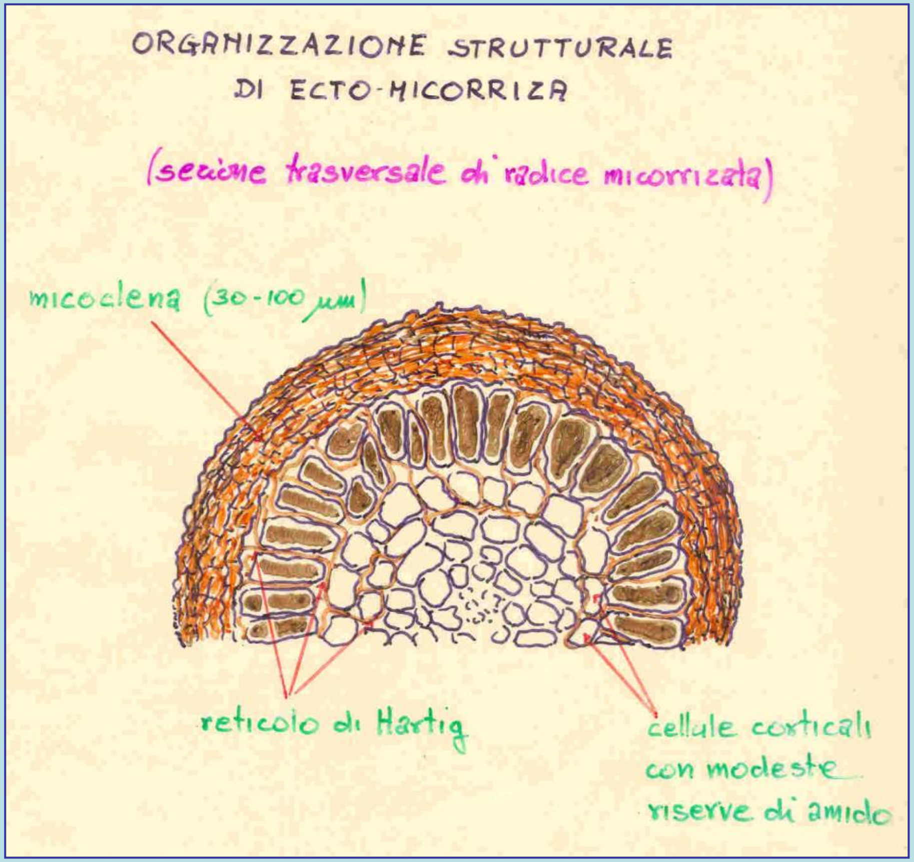




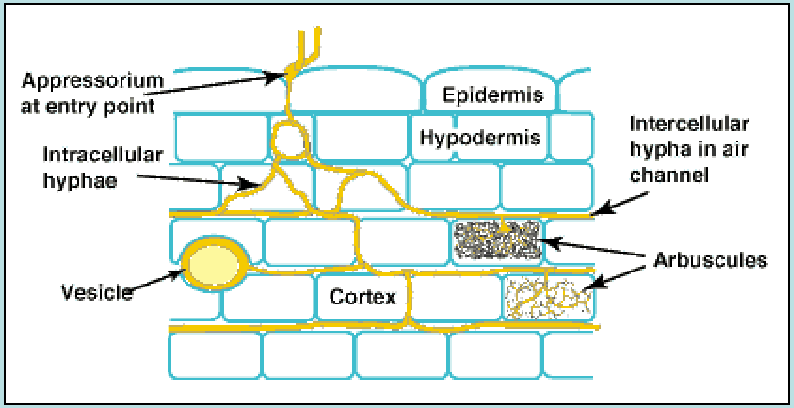


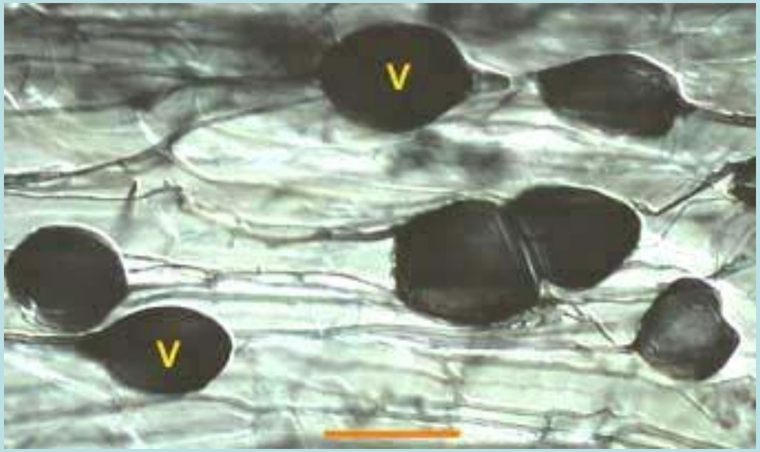
How phosphorus (phosphates) are tied up by soil minerals. A) A large percentage of the P is available for root uptake immediately after fertilization application. B) P in solution binds rapidly to the surface of soil minerals. Roots may still use this P. C) Eventually, most of the bound P becomes part of the structure of the mineral, with its plant availability being significantly reduced.


CICLO VITALE DI FUNGO ECTO-MICORRIZICO
corpo fruttifero
spore
spore germinanti
miceli primari
fusione dei miceli primari
formazione della associazione ectomicorrizica

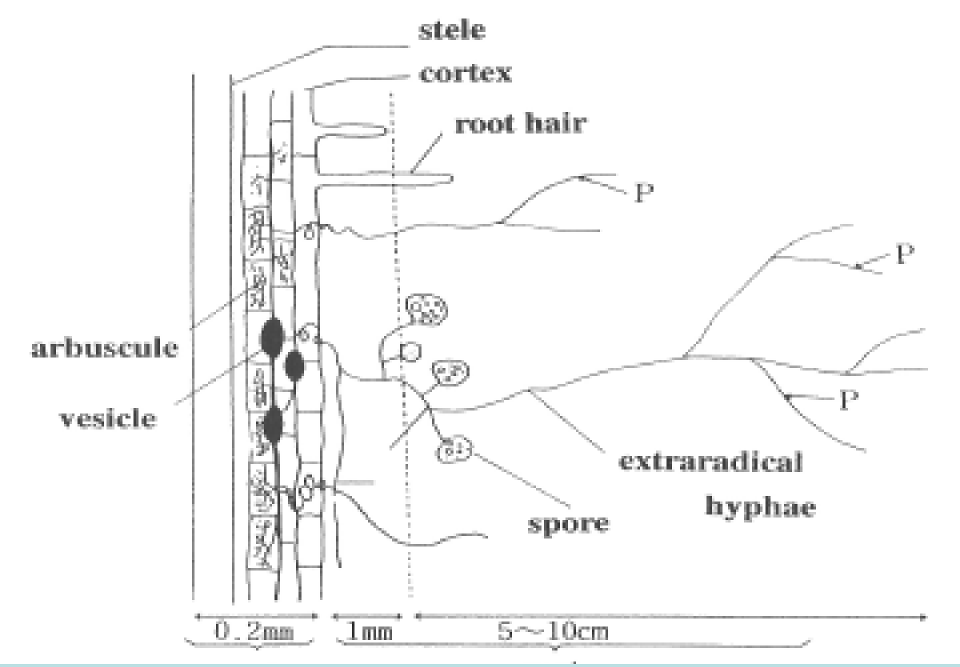

ORGANIZZAZIONE STRUTTURALE
DI ECTO-MICORRIZA
(sezione trasversale di radice micorrizata)
micoclena (30-100 µm)
reticolo di Hartig
cellule corticali
con modeste
riserve di amido

LE MICORRIZE VESCICOLARI-ARBUSCOLARI (VA Mycorrhiza)





Rappresentazione schematica della colonizzazione di una radice da parte in un fungo micorrizzico VA



root **soil**