Nitrogenase; Nitrogen Fixation vs Haber-Bosch Process

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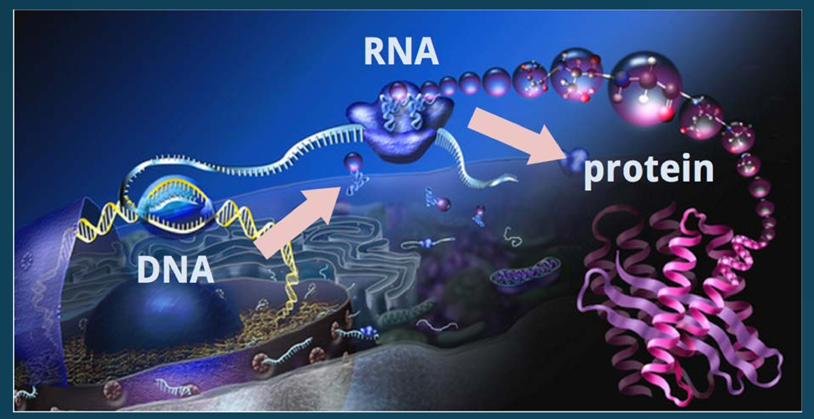
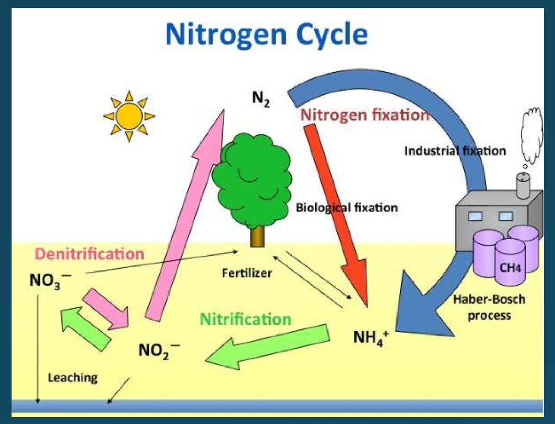
Abstract

Overview: The Nitrogen Cycle is a chemical cycle which recycles nitrogen into usable forms, such as ammonium, nitrates, and nitrites. Nitrogen and nitrogen compounds are important because they make up our atmosphere as well as our earthly environments. Nitrogen can be recycled into ammonium naturally via nitrogen fixing bacteria, or synthetically using the Haber-Bosch process. Nitrogen fixation in bacteria follows the reaction $N_2 + 8H^+ + 8e^- \rightarrow 2NH_3 + H_2$ and is powered by the hydrolysis of 16 ATP equivalents. The Haber-Bosch process follows the reaction scheme of $N_2 + 3H_2 \rightarrow 2NH_3$ and is powered by using high pressures, temperatures, and catalysts. Using the Haber-Bosch process an optimum yield of 97% ammonium can be obtained. These reactions both use diatomic nitrogen as well as hydrogen, but differ in their final products as bacterial nitrogen fixation releases hydrogen gas as a byproduct. Bacteria in the soil use nitrogen to create energy to grow and reproduce as well as to introduce nitrogen for use by other species. The Haber-Bosch process produces ammonium which can be used for a range of activities such as the production of fertilizers, or even explosives.

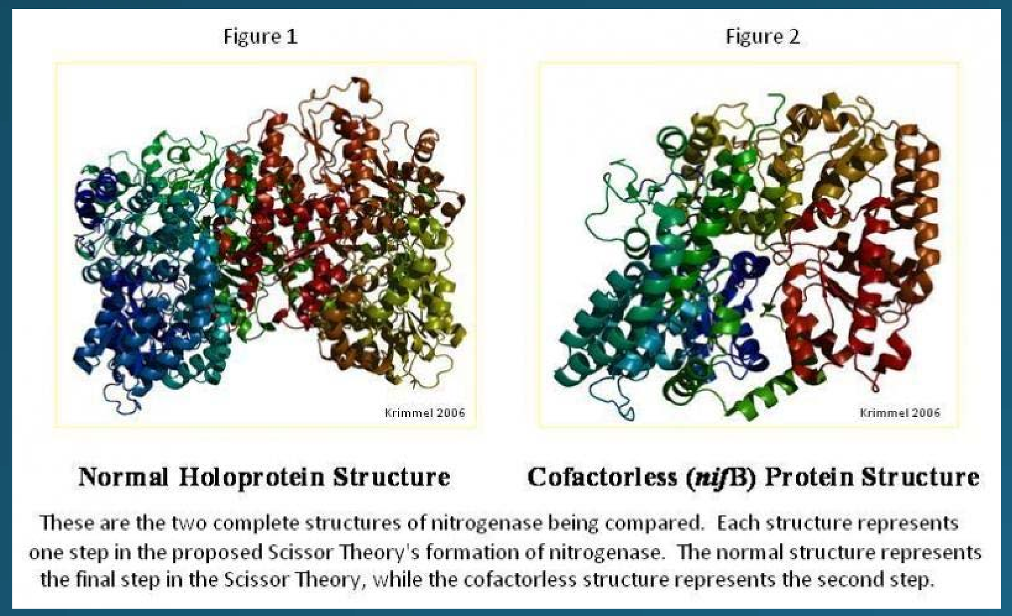
Nitrogen Fixation in Bacteria

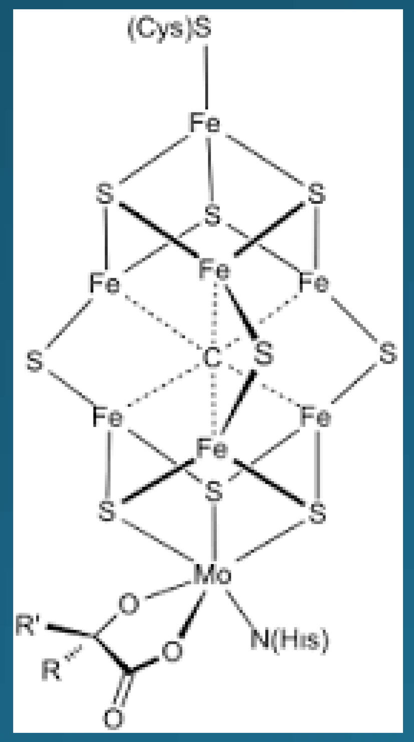
- Process by which nitrogen gas is converted into ammonia.
- Nitrogen is required to biosynthesize basic building blocks of plants, animals, and other life forms





- The most common nitrogen fixing bacteria are cyanobacteria
- Biological nitrogen fixation is done by metalloenzymes called nitrogenases
- The nitrogenase reaction is coupled to 16 equivalents of ATP and is accompanied by co-formation of one molecule of H_2
- Nitrogen fixation is an anaerobic process with many nitrogen fixing organisms existing in only anaerobic conditions
- Nitrogenase complex consists of two proteins- Homodimeric Fe protein and a heterotetrameric MoFe protein
- H2, CO, and CS2 function as inhibitors of nitrogenase





Comparison of Processes

Haber-Bosch Reaction

$$N_2 + 3H_2 \rightarrow 2NH_3 \quad (\Delta H = -92.4\ kJ \cdot mol^{-1})$$

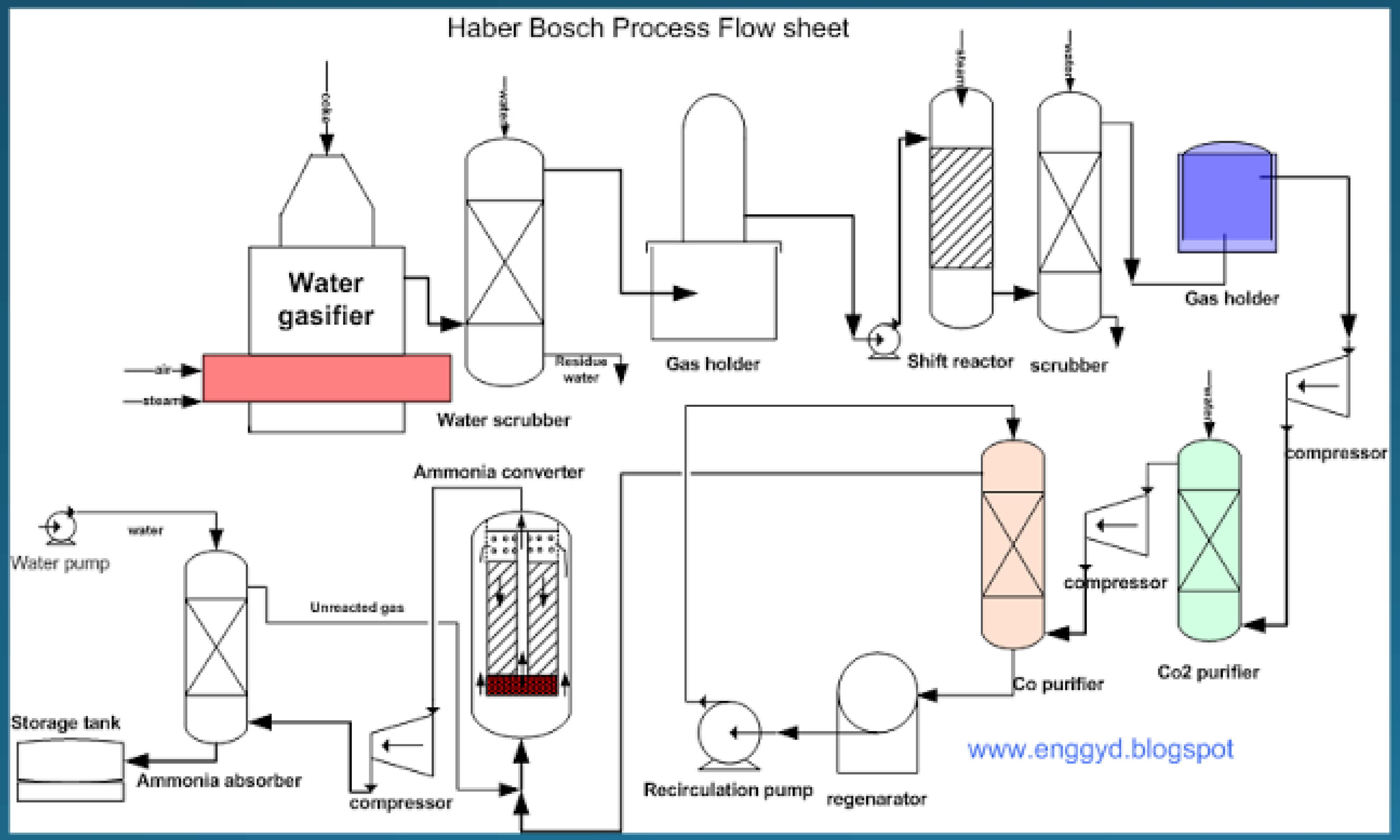
Nitrogen Fixation Reaction

$$N_2 + 8H^+ + 8e^- \longrightarrow 2NH_3 + H_2$$

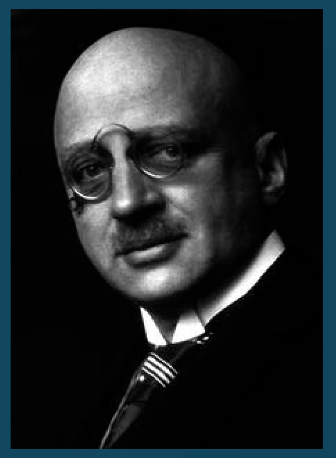
Equilibrium modifications

- Pressure- increased pressure
- Temperature-low temperature favored
- Concentration-remove product as it is formed
- Catalyst- Iron catalyst is used

Equipment required for Haber-Bosch process

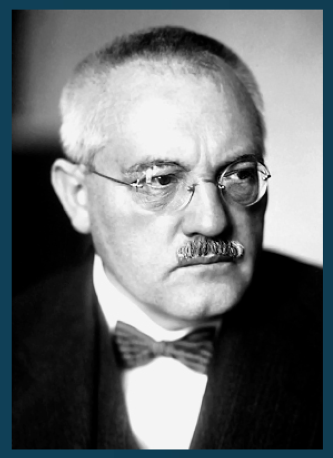


Haber-Bosch Process



Fritz Haber

- Discovered by Fritz Haber, process scaled up by Carl Bosch
- Response to Germany's need for ammonia for explosive during WWI
- Prolonged WWI when Germany was able to produce fertilizer and explosives



Carl Bosch

$$N_2 + 3H_2 \rightarrow 2NH_3 \quad (\Delta H = -92.4\ kJ \cdot mol^{-1})$$

- Nitrogen from air and hydrogen from natural gas
- Process repeated with so that overall conversion is around 97%
- Temperature at 400-450°C
- Pressure at 200 atm
- Remove ammonia as it is produced to increase production of products
- Uses an iron catalyst, which is not used up during reaction

Uses for Ammonia

- Ammonia used to make NH_4NO_3, which is used in fertilizers
- 88% of ammonia is used to make fertilizers
- Ammonia is oxidized to NO_2 and NO_3 for use in explosives
- Used in household cleaners, microorganism cultures, and pesticides
- Ammonia is used in the textile industry for dyes

Environmental Impacts

- Ammonia is toxic, but humans and animals can incorporate it into their bodies through the urea cycle
- Excess fertilizer applied to fields can runoff into water supplies
- Top soil is eroded, causing more pests and increasing the need for pesticides

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