

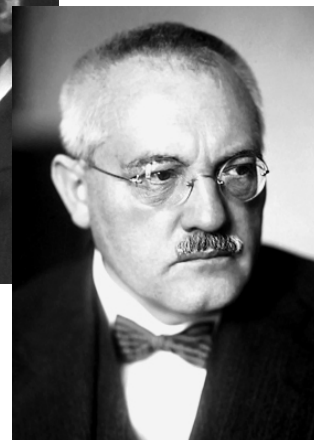
Sustainability Profile

Ammonia (NH₃)

Industrial Production of Ammonia

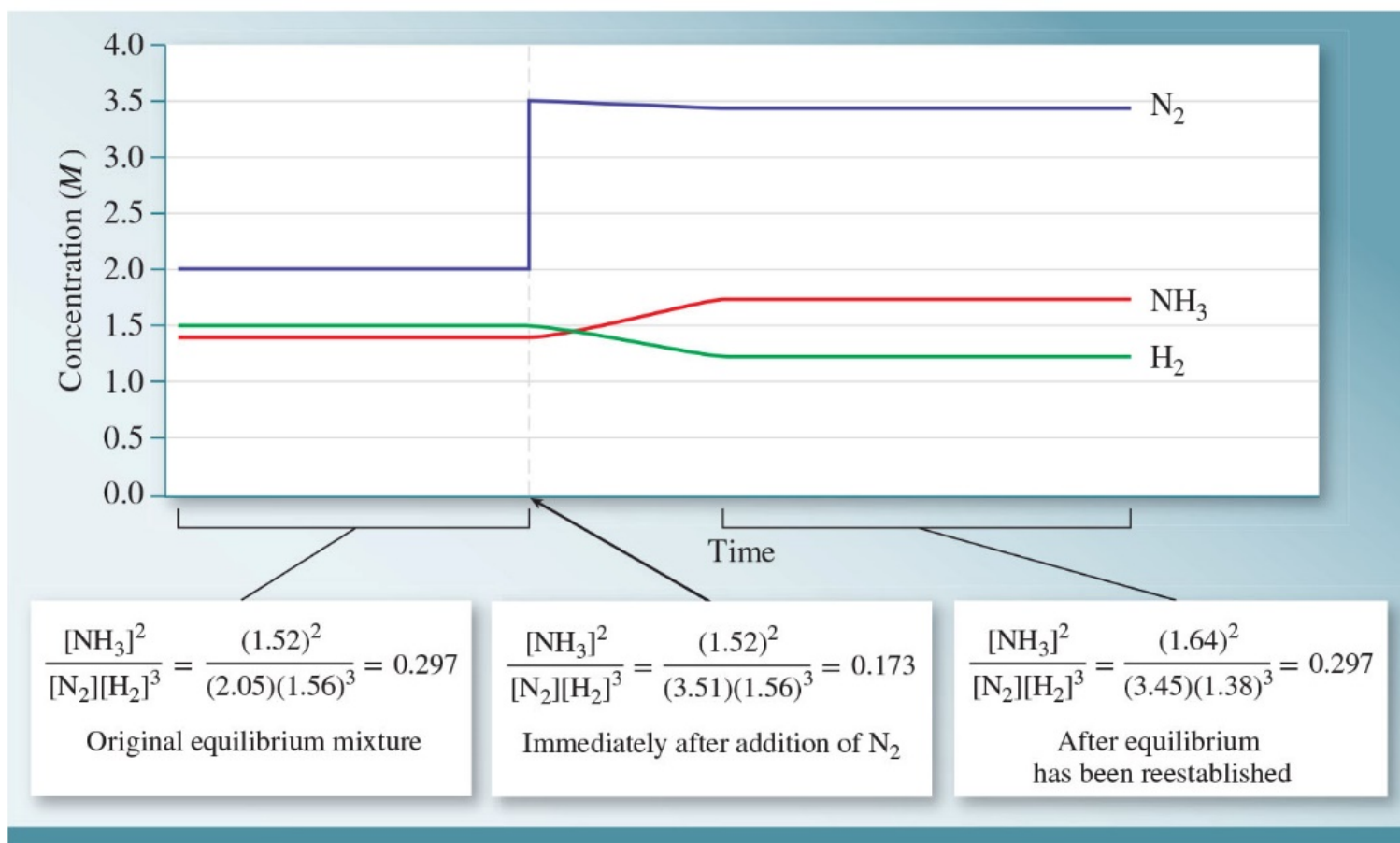


- Industrial process is known as the Haber-Bosch process
- Named after early 20th century German chemists Fritz Haber and Carl Bosch
- 1919 Nobel prize for Haber—1931 for Bosch
- An early application of Le Chatelier's Principle
- An exothermic reaction ($\Delta H = -91.8 \text{ kJ/mol}$) so high temperature favors reactants
- High pressure favors NH_3 production (more moles of gas in reactants than products)
- Condensation converts $\text{NH}_3(\text{g})$ to $\text{NH}_3(\text{l})$ removes product and favors further product formation



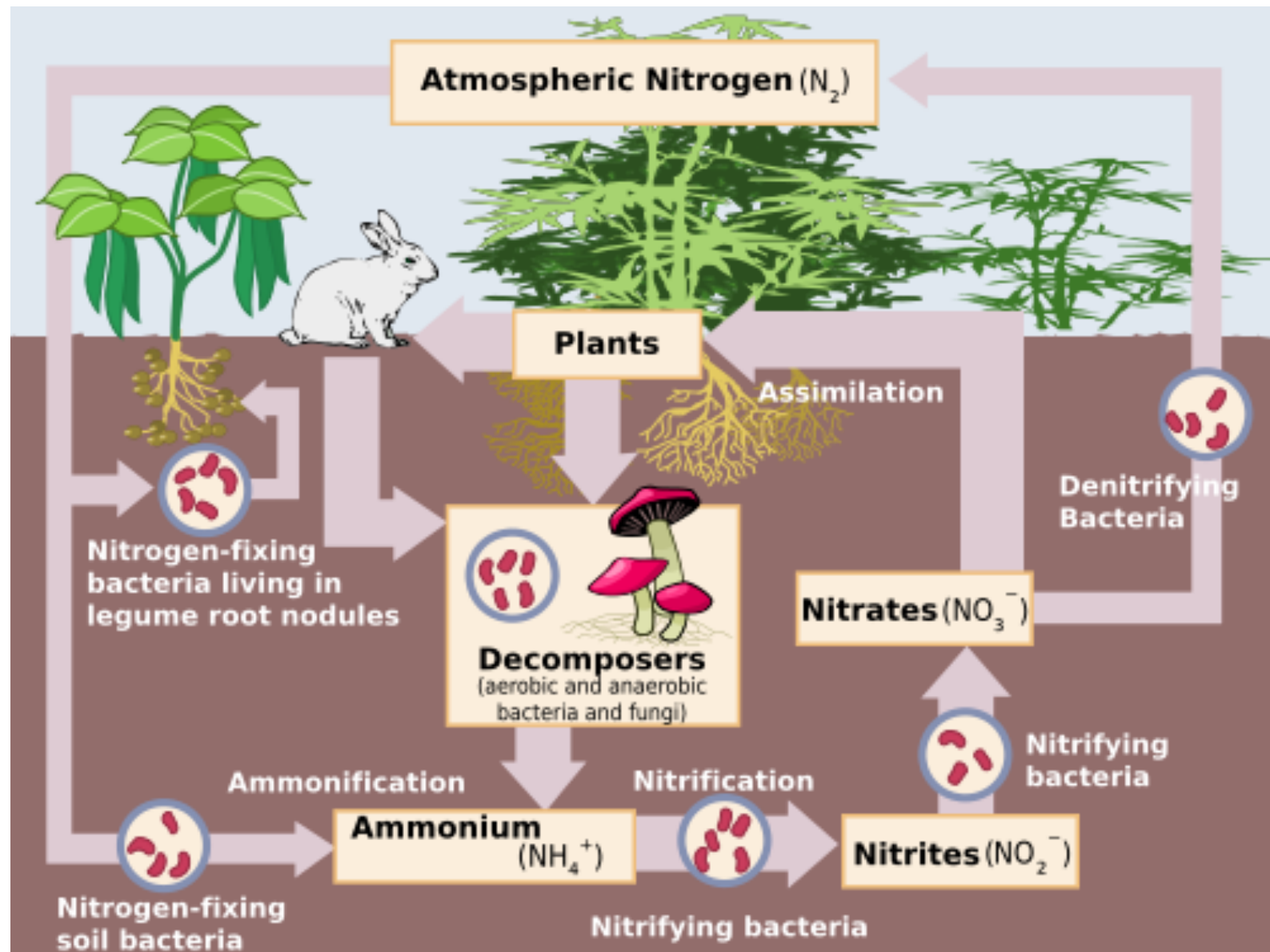
LeChatelier's Principle and NH₃ Synthesis

Copyright © McGraw-Hill Education. All rights reserved. No reproduction or distribution without the prior written consent of McGraw-Hill Education.



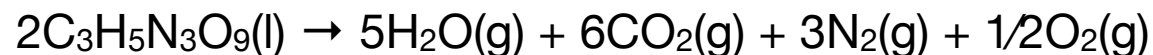
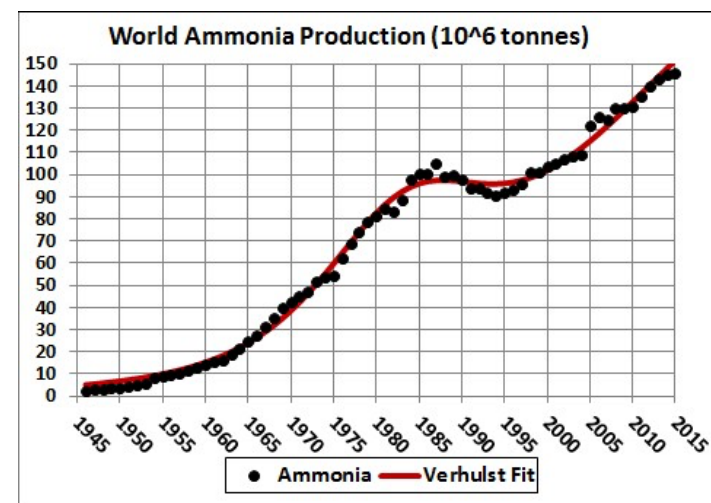
Naturally Occurring Nitrogen Fixation

- Nitrogen is abundant as $\text{N}_2(\text{g})$ in the earth's atmosphere (78%)
- N_2 has a strong triple bond not easily broken $:\text{N}\equiv\text{N}:$
- Nitrogen is accessible to organisms as a nutrient only when it is “fixed”, i.e. converted to nitrates (NO_3^-), nitrites (NO_2^-), ammonium (NH_4^+) compounds, and ammonia (NH_3)
- Lightning causes $\text{N}_2(\text{g})$ and $\text{O}_2(\text{g})$ to form $\text{NO}(\text{g})$ which eventually forms nitrates (NO_3^-) and nitrites (NO_2^-)
- Nitrogen can also be fixed by bacteria and archaeobacteria in soils; nitrogen fixing bacteria are associated with the roots of legumes



Haber–Bosch Nitrogen Fixation

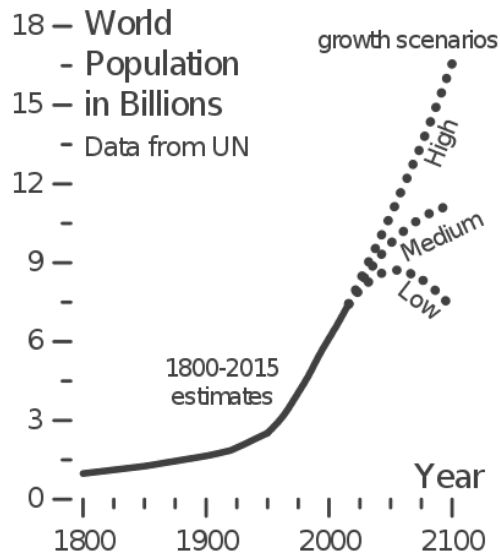
- Today 175 million tonnes of NH_3 are produced
- About half of the nitrogen found in living systems is fixed by this method
- The main use is as nitrogen containing fertilizers: ammonia, nitrates, urea
- The second main use of ammonia is in the production of explosives. Nitric acid produced from ammonia is used to add nitrate groups to organic compounds to make TNT and nitroglycerin (dynamite). This was Haber's interest during World War 1.



$\Delta H = -1414 \text{ kJ/mol}$ (highly exothermic) and produces 7.25 moles of gas per mole

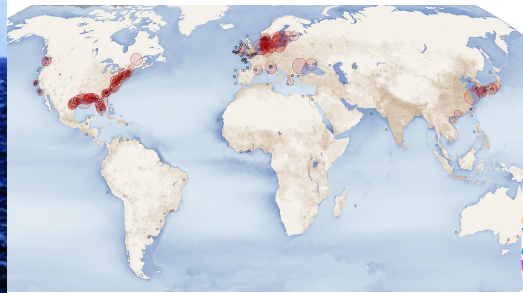
Ammonia and World Population

- Late 19th century scientist feared that the available fixed nitrogen from bat and seabird guano and salt peter (KNO_3) mineral deposits would run out and agriculture could not support the growing human population, then under 2 billion

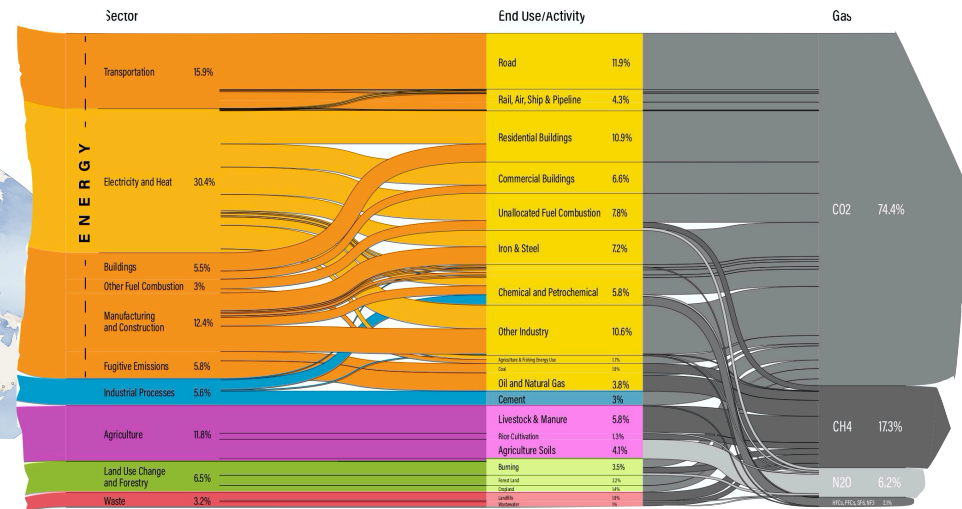


- Today we're nearly 8 billion in number largely due to increased food production through the "green revolution", a combination of higher yield crops, pesticides, and fertilizers produced via the Haber-Bosch process.

Nitrogen Pollution



World Greenhouse Gas Emissions in 2016
Total: 49.4 GtCO₂e



Source: Greenhouse gas emissions - Climate Watch. Available at: <https://www.climatewatchdata.com>

WORLD RESOURCES INSTITUTE

- Excess fertilizer runs off fields and into waterways and ultimately into the ocean causing algal blooms and oxygen depleted regions
- These are known as **dead zones**
- Nitrogen compounds are also converted to N₂O (nitrous oxide) which is a greenhouse gas 300x more potent than CO₂
- N₂O is responsible for around 6% of greenhouse gas emissions in CO₂-equivalents