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Ammonia - the Green Energy Carrier of the Future

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Molecular Energy Vectors

- Transition to renewable energy such as wind and sun:
  - Chemical energy vectors needed to store and transport energy.
- **Ammonia** (NH_3): Carbon-free energy vector
  - Hydrogen-based[1]
  - Almost twice the energy density of liquid hydrogen; toxic, but not explosive.
- Existing infrastructure and experience.

[1] Olje- og energidepartementet og Klima- og miljødepartementet. Regjeringens hydrogenstrategi, 2020.

Why Ammonia?

- May fuel combustion engines, and be converted to electricity and H_2.
- In particular:
  - Shipping fuel, storage and transport of energy, e.g. to Svalbard.[1]

Supply-ship Viking Energy. (Photo: Eidesvik Offshore)

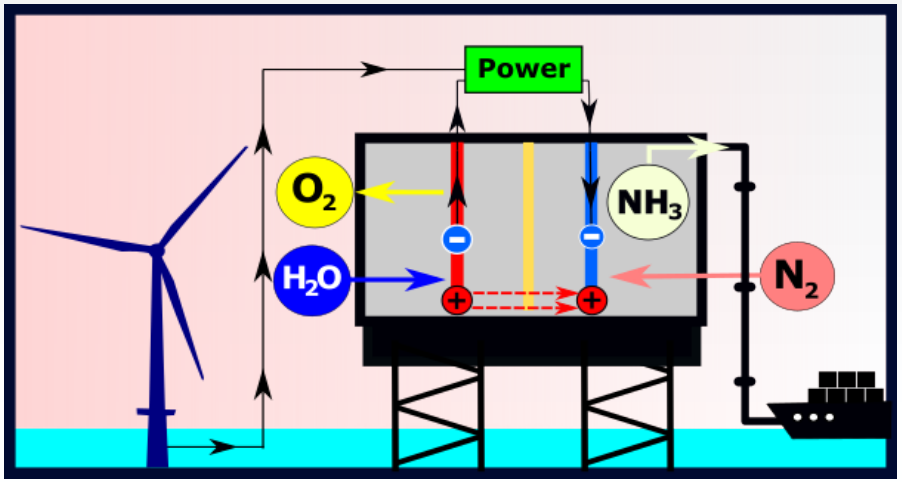
[1]Zero Emission Distribution at Sea (ZEEDS). Memo to members of the Norwegian Parliament, 12.01.20.

TU Energi 06.08.2020

HYDROGEN FRA HAVVIND

Vil lage hydrogen eller ammoniakk på Norges nye havvind-felt

Regjeringen åpnet nylig Sørlige Nordsjø for flytende havvind. Greenstat og Universitetet i Bergen mener energien kan brukes i flytende form.



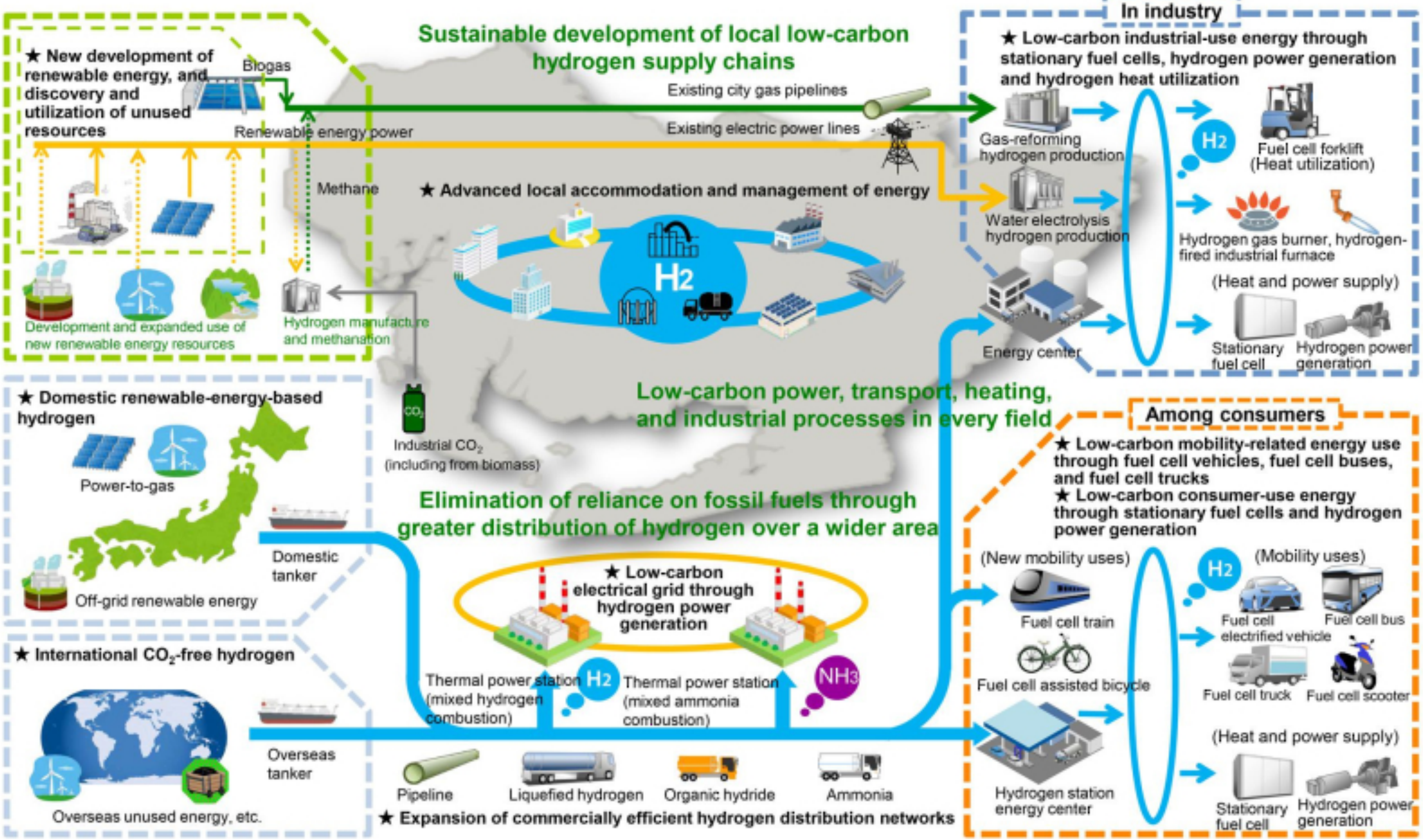
Aichi Low-carbon Hydrogen Supply Chain 2030 Vision

Principles

- As a manufacturing prefecture, lead Japan in realizing a hydrogen-based society
- Achieve use of low-carbon hydrogen and build relationships through cooperation among industry, academia, and government
- Establish a renewable energy-based CO_2-free hydrogen supply system
- Verify and communicate the social significance of hydrogen energy

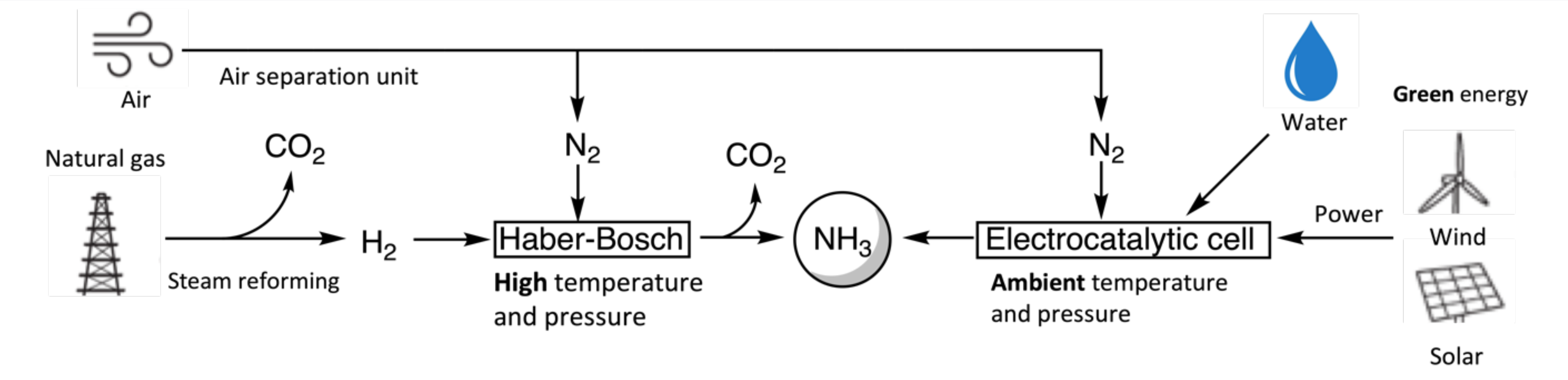
Initiatives

- Developing and expansion a renewable energy-based, low-carbon hydrogen supply chain using existing infrastructure
- Using low-carbon industrial and civilian energy by adopting stationary fuel cells and hydrogen power generation
- Developing supply chains that use domestic and international low-carbon hydrogen
- Communicate both in Japan and abroad the outcomes of Aichi initiatives to promote expanded use of CO_2-free hydrogen



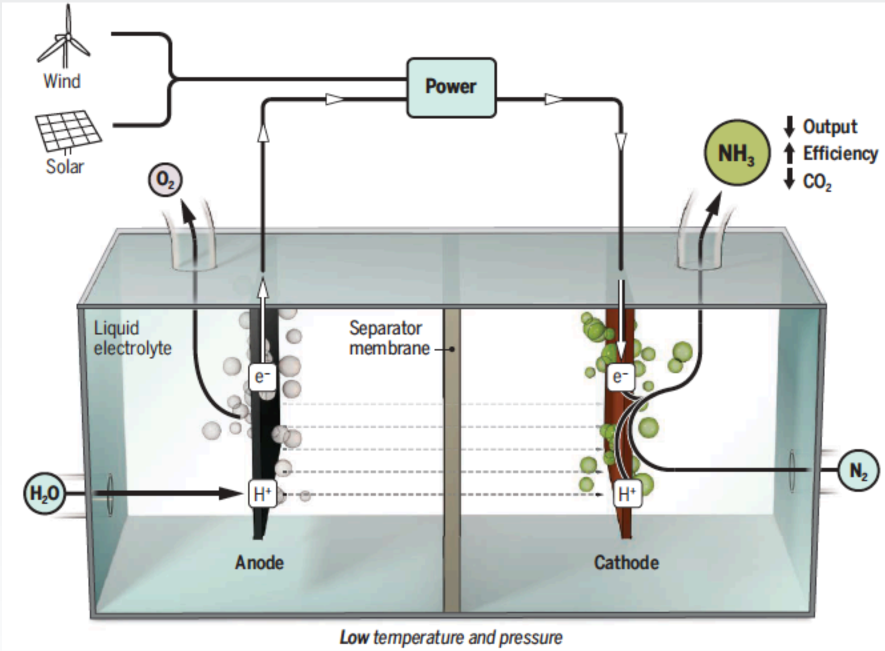
Challenge: The Haber-Bosch Process

- 400–500°C, 150–250 atm.
- Using H_2 from fossil resources as starting material.
- 1% of world energy consumption, 3% of CO_2 emissions.



Alternative: Electrocatalysis

- A major scientific goal.[1]
- With emission tax of NOK 2000 / ton CO_2:[2]
  - Competitive already at 60% energy efficiency.
- What is needed to reach this?
  - CATALYSTS



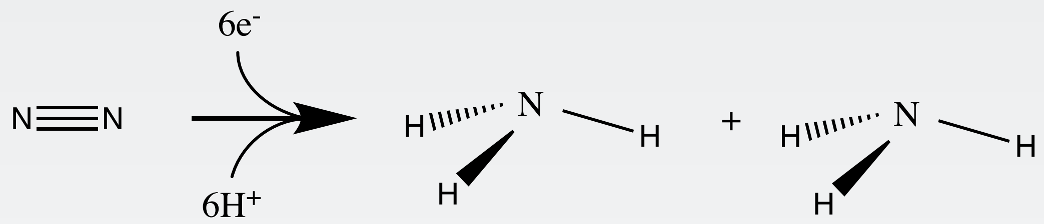
Graphic from: Service, R. F. *Science*, **2018**, 361, 120.

[1] Martín, A. J. et al. *Chem* **2019**, *5*, 263.

[2] Norway's Climate Action Plan for 2021 – 2030. "Det Kongelege Klima- og Miljødepartement, Meld. St. 13 (2020–2021)". https://www.regjeringen.no/no/dokumenter/meld.-st.-13-20202021/id2827405/

N_2 Fixation: Challenge

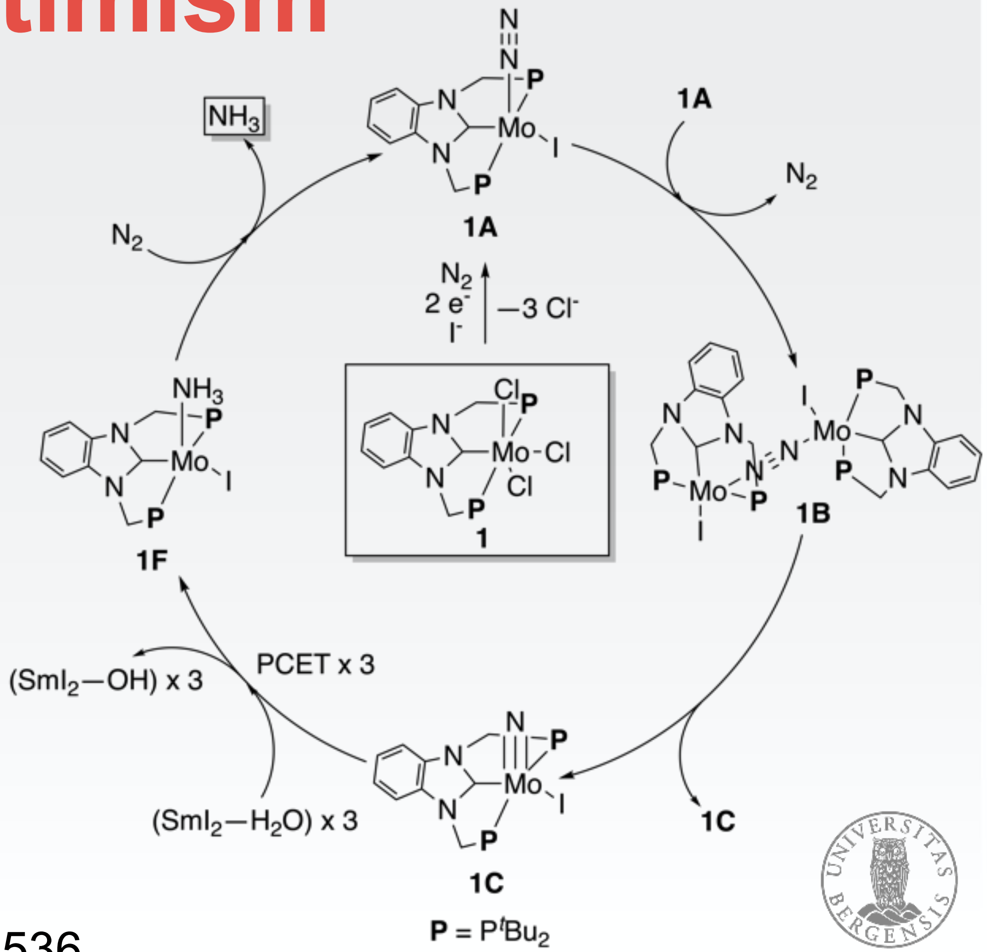
- Partly rupture N–N bond before N–H bonds form:
  - N–N bond: 945 kJ/mole
  - N–H bond: 389 kJ/mole



- Haber-Bosch activation: >200 kJ/mole
- Reason for optimism:
  - Nitrogenase bacterial enzyme activation: ca. 60 kJ/mole. Nature’s catalysts, based on molybdenum.

More Reasons for Optimism

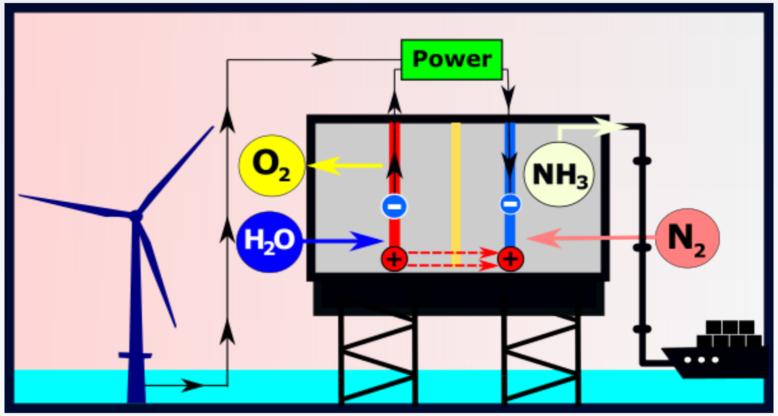
- Nitrogenase-like activities in Mo-catalyzed N_2 fixation.[1]
- Challenges:
  - Chemical reductant must be replaced by current.
  - Catalyst stability must be increased.



[1]Ashida, Y. et al. *Nature* **2019**, *568*, 536.

UiB: Safe & Benign Ammonia Production

- Catalysts & electrolysis
  - KI: Kristine Spildo, Vidar R. Jensen, Erwan Le Roux, and others.
- Safety
  - IFT: Trygve Skjold
- Long-term: From offshore wind:
  - BOW



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