

# Innovations in Ammonia

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*US DOE, Hydrogen & Fuel Cell Technical Advisory Committee  
Washington, DC, December 12, 2018*

# Ammonia: Hydrogen at Scale

2017 Production (metric tons)	Ammonia	Hydrogen (17.8 %wt NH <sub>3</sub> )
USA	12.8 million	2.3 million
World	183 million	32.6 million

Hydrogen is captive:

- SMR / POX process; gas, coal, etc feedstock

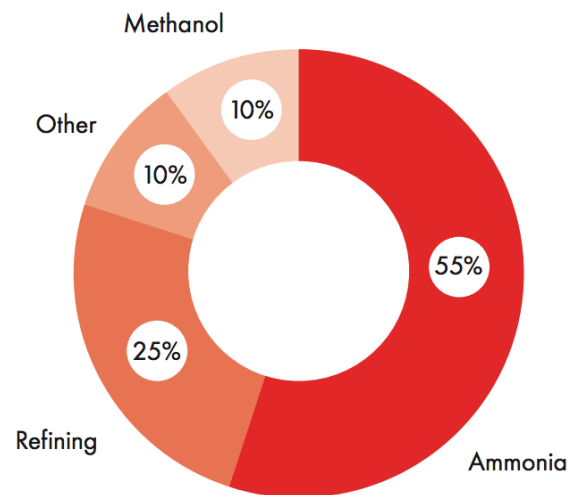
Ammonia is mostly captive:

- Urea, nitric acid, AN, UAN, etc

Mature markets:

- 80% fertilizer, ~2% CAGR, <10% traded (16-17 million merchant tons)

19 GLOBAL USAGE OF HYDROGEN

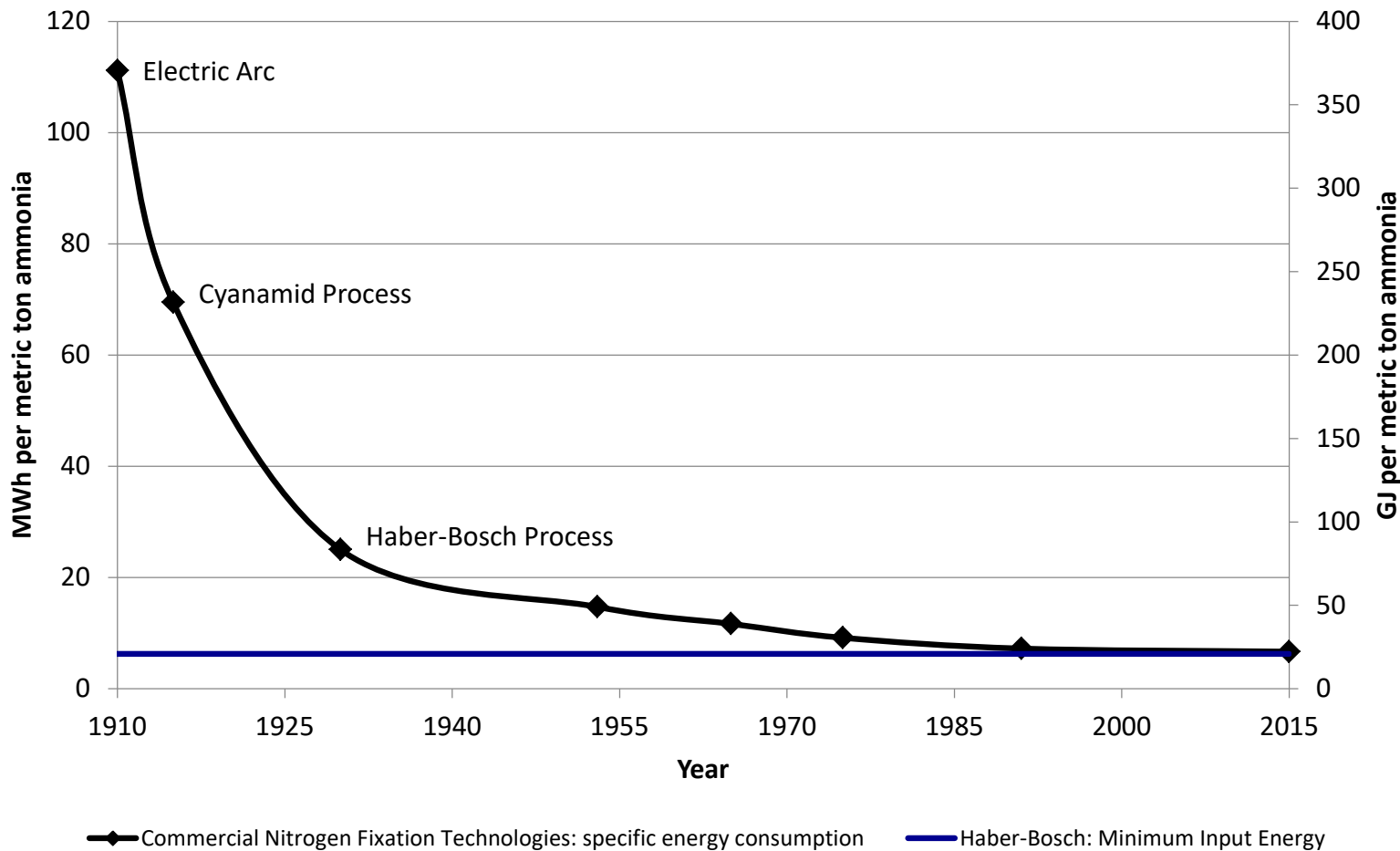


# Innovations in Ammonia

- 1) History of Innovation: **Energy Efficiency**
- 2) Future of Innovation: **Carbon Efficiency**
- 3) Low-carbon Ammonia: **Available Today**
- 4) Carbon-free Ammonia: **Electrolysis + Haber-Bosch Pilot Plants**
- 5) Green Ammonia Markets: **Hydrogen Carrier Technologies**

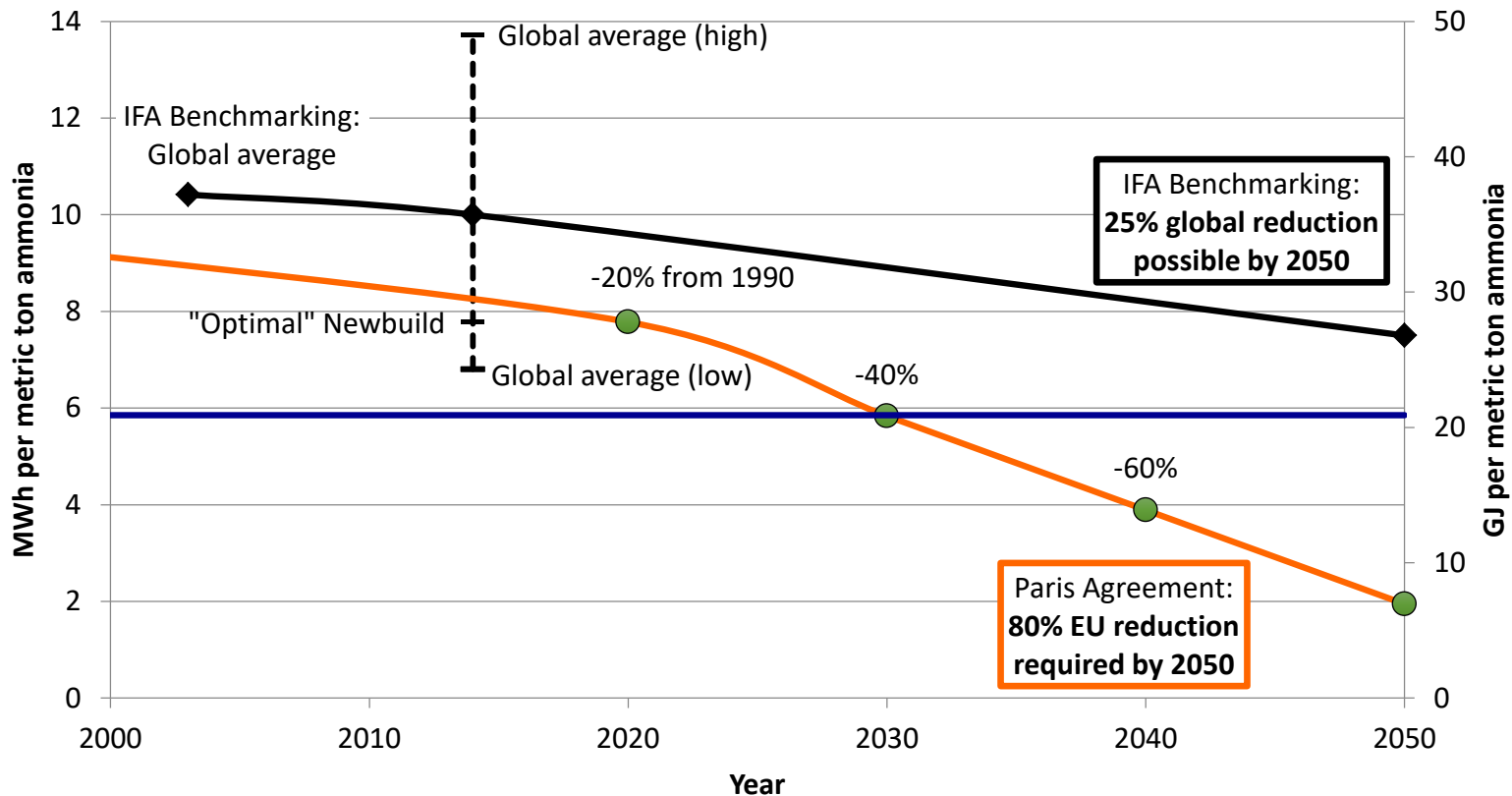
# Ammonia Synthesis (Nitrogen Fixation): Energy Efficiency, 1910-2015

Various sources / AmmoniaIndustry.com, November 2018



# Ammonia Synthesis: Energy Efficiency, 2000-2050

IFA Benchmarks / AmmoniaIndustry.com, November 2018

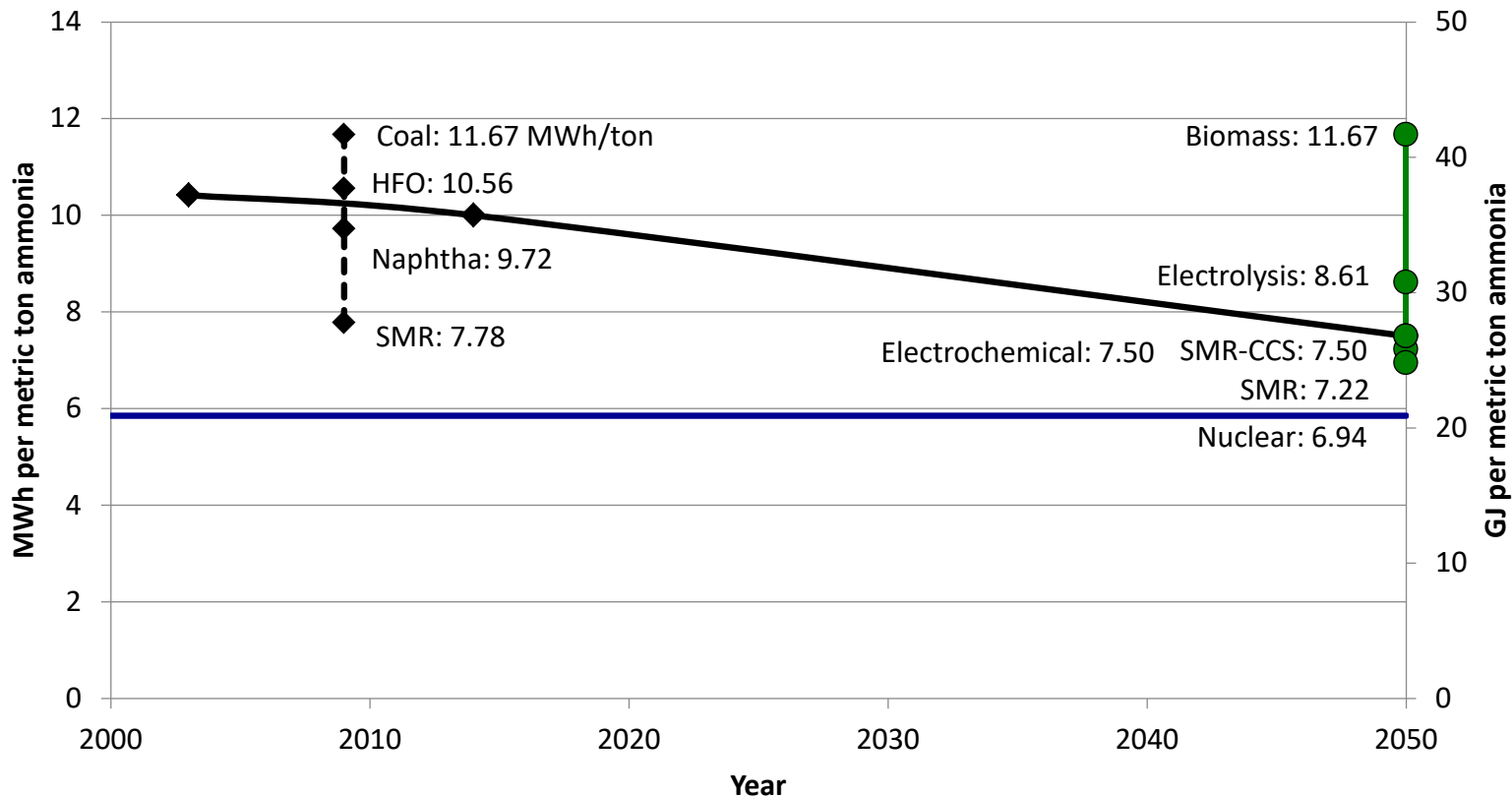


◆ IFA Benchmarking: Global Average  
— Haber-Bosch: Minimum Input Energy

● Paris Agreement: EU Emission Reduction Targets

# Ammonia Synthesis: Best Available Technologies, 2000-2050

IFA Benchmarks / CEFIC / AmmoniaIndustry.com, November 2018



—◆— IFA Benchmarking: Global Average

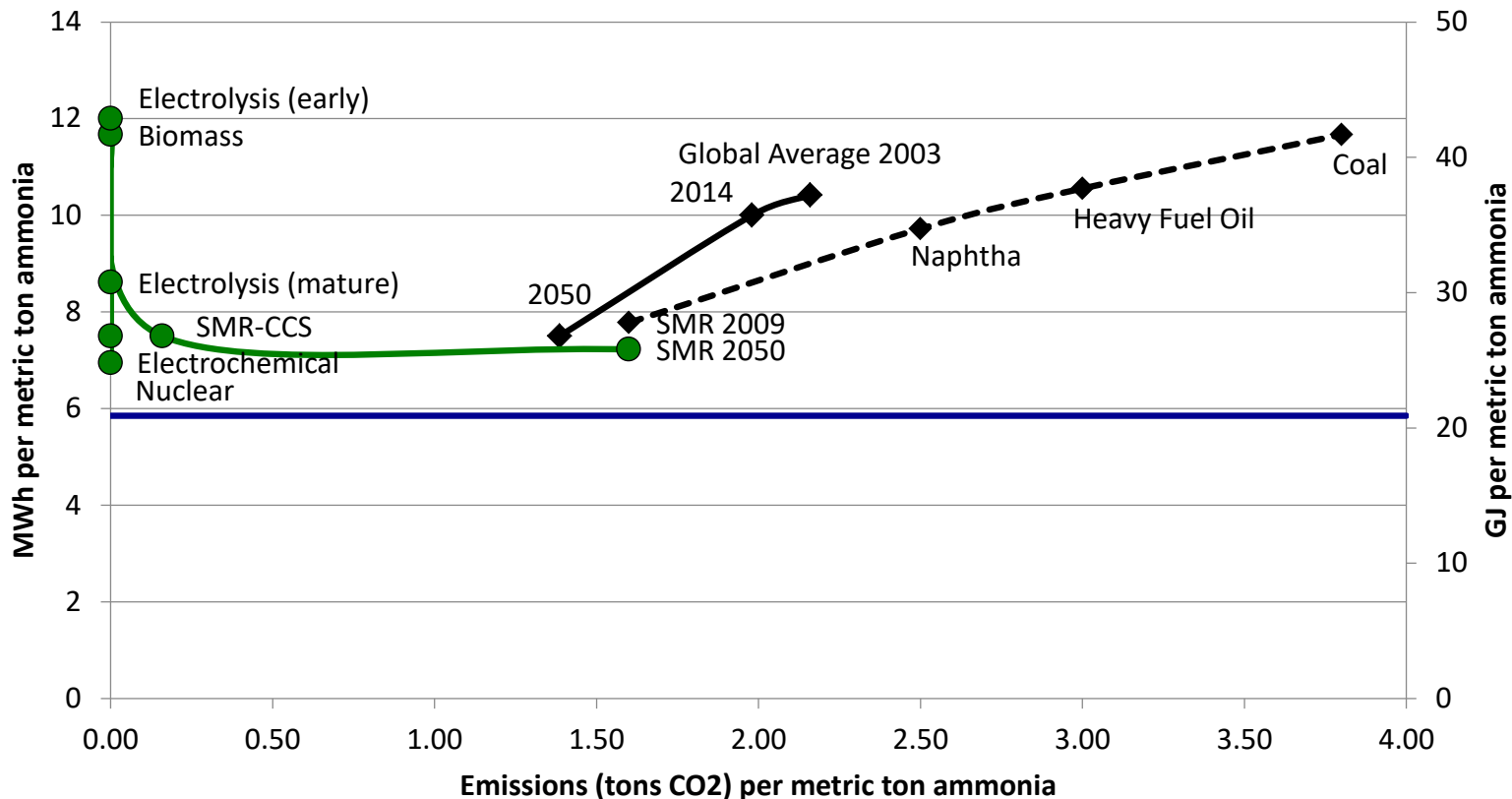
—●— CEFIC: Energy Roadmap 2050

-◆- IFA Benchmarking: 2009 Best Available Technology (BAT)

— Haber-Bosch: Minimum Input Energy

# Ammonia Synthesis: Carbon Efficiency, 2000-2050

IFA Benchmarking / CEFIC / AmmoniaIndustry.com, November 2018



—◆— IFA Benchmarking: Global Average

—◆— IFA Benchmarking: 2009 Best Available Technology (BAT)

—●— CEFIC: Energy Roadmap 2050

— Haber-Bosch: Minimum Input Energy

# Low-carbon Haber-Bosch: Available Today

Showa Denko (Kawasaki, Japan)

- Plastic gasification since 2003
- Ammonia capacity 175 tons per day
- 65% hydrogen feedstock from recycled plastic

Premium for low-carbon technology in Japan

- Ecoann™ ammonia sold as deNOx product

*“Approved and rated high as ‘eco-friendly goods for procurement’ by major electric power companies.”*





# Low-carbon Haber-Bosch: Available Today

Nutrien (Joffre, Canada)

- Byproduct hydrogen feedstock since 1987
- Ammonia capacity 1,350 tons per day
- 25% reduction in carbon footprint v SMR

Premium for low-carbon technology in Canada

- Alberta carbon tax hits both fuel and feedstock

*Joffre plant generates carbon credits that offset emission cost of other plants in Nutrien's fleet*



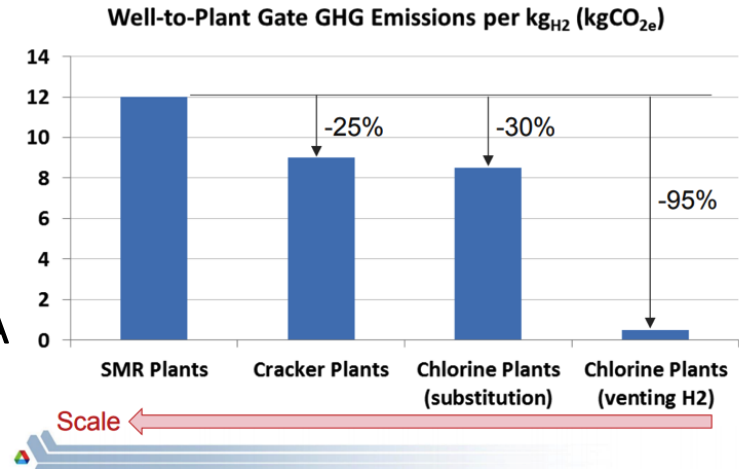
# Low-carbon Haber-Bosch: Available Today

Yara / BASF, Freeport, TX

- Byproduct hydrogen feedstock since 2018
- Ammonia capacity 2,200 tons per day
- 25% reduction in carbon footprint v SMR

No premium for low-carbon technology in USA

## Low GHG emissions of byproduct hydrogen



# Green Ammonia: Back to the future

Yara (Norsk Hydro), Glomfjord, Norway

- Hydropower ammonia, 1953 – 1991
- The world's biggest electrolyzers:  
2 x 135 MW units; 30,000 Nm<sup>3</sup> per hour
- 100% carbon free

Closed because no market advantage,  
not competitive v SMR.

But now, in 2018 ...  
electrolyzer costs down, efficiency up; and  
renewable power input prices dropping



# Green Ammonia: Electrolyzer Pilot Plants

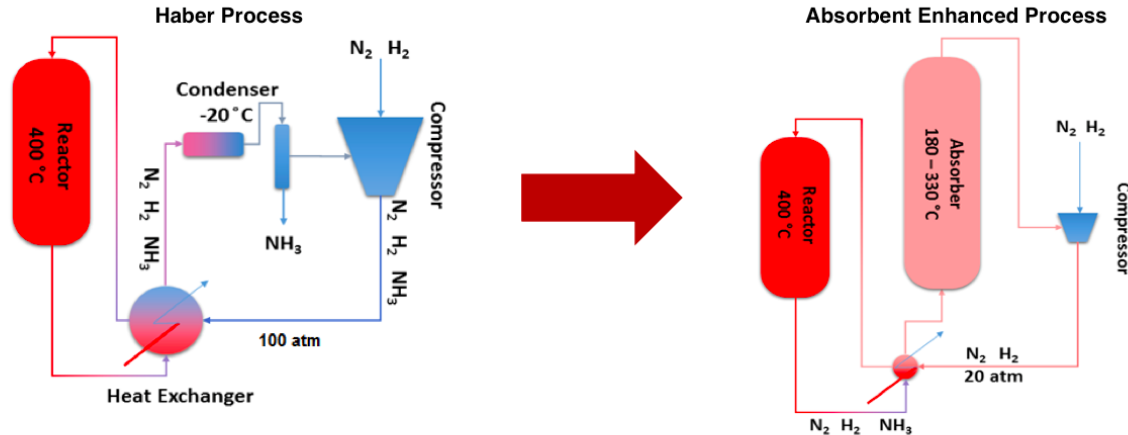
- **University of Minnesota:** Morris, MN, US
- Operational since 2013
- R&D innovation:  
**Scaling down Haber-Bosch to match wind**



# Green Ammonia: Electrolyzer Pilot Plants

## Lowering Capital Cost: Absorbent Enhanced Synthesis

- Absorption instead of condensation<sup>1</sup>
- Lower pressure and less heat exchange (temperature difference)
- Lower capital cost than conventional process, especially at small scale<sup>2</sup>



[1] Malmali et al, *Ind. Eng. Chem. Res.*, 2016, 55, 33, 8922-8932.

[2] Palys et al, *Processes*, 2018, 6, 7, 91.

# Green Ammonia: Electrolyzer Pilot Plants

- **FREA:** Fukushima, Japan
- Operational since April 2018
- R&D innovation:  
**Catalyst development optimized for low-pressure electrolytic hydrogen**





# Green Ammonia: Electrolyzer Pilot Plants

- **Siemens:** Oxford, UK
- Operational since June 2018
- R&D innovation:  
**Business Models: ancillary grid services (DSM), energy storage, electrofuel production**



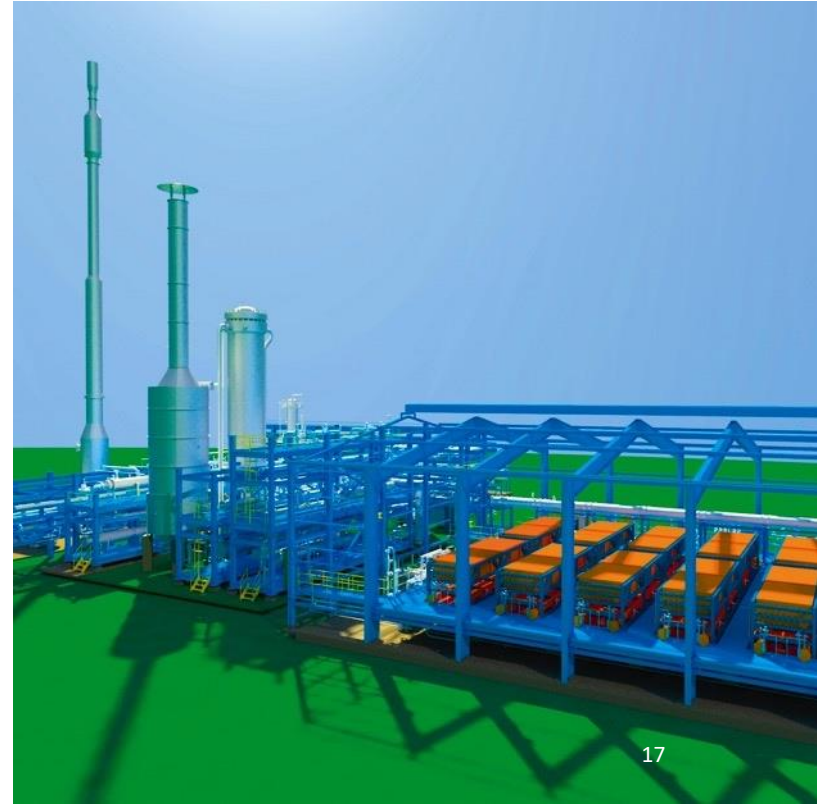
# Green Ammonia: Electrolyzer Pilot Plants

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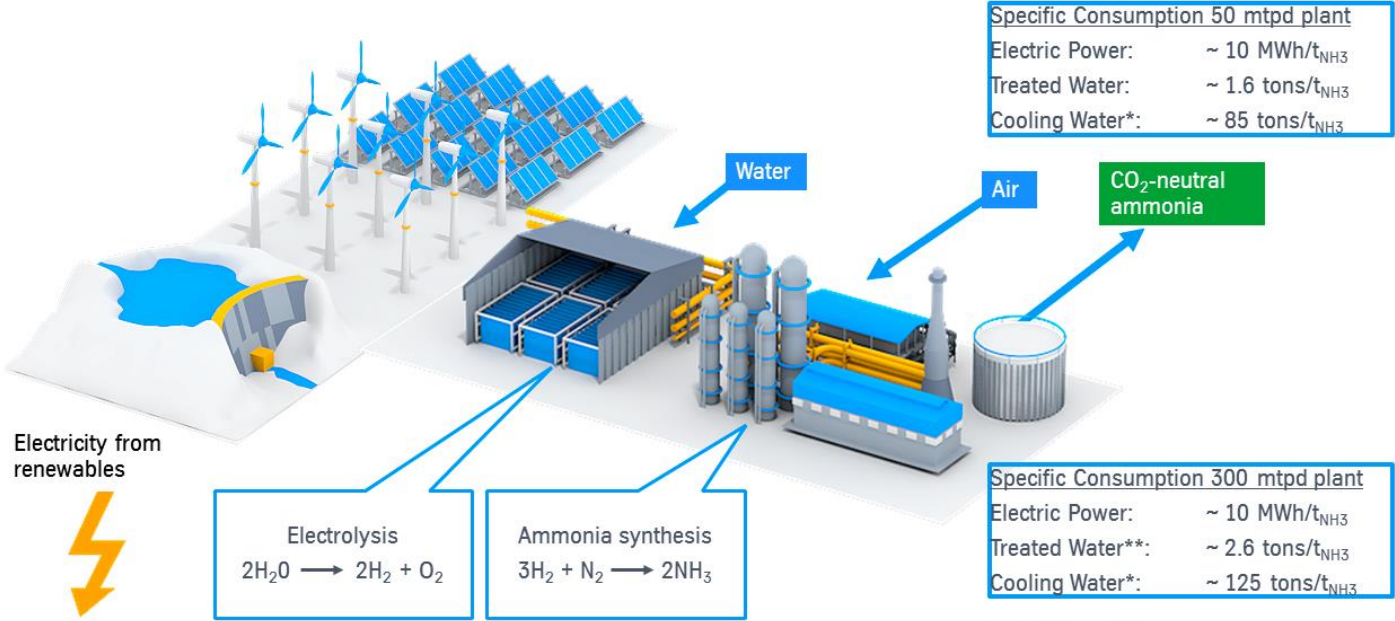
# Green Ammonia: Electrolyzer Pilot Plants

- **ThyssenKrupp:** Port Lincoln, Australia
- Announced 2018 for 2020 start
- R&D innovation:  
**Market development for ammonia exports as renewable energy commodity**



# Green Ammonia: Electrolyzer Pilot Plants

Introducing renewable ammonia by thyssenkrupp



\*CW loop flowrate  
 \*\* incl. steam generation



# Green Ammonia: Electrolyzer Pilot Plants



# Green Ammonia: Electrolyzer Pilot Plants

- **Haldor Topsoe:** Denmark
- Announced 2018 for 2025 start
- R&D innovations:  
**Solid oxide electrolyzer,  
SMR-ammonia plant revamp**

## Green Ammonia by SOEC

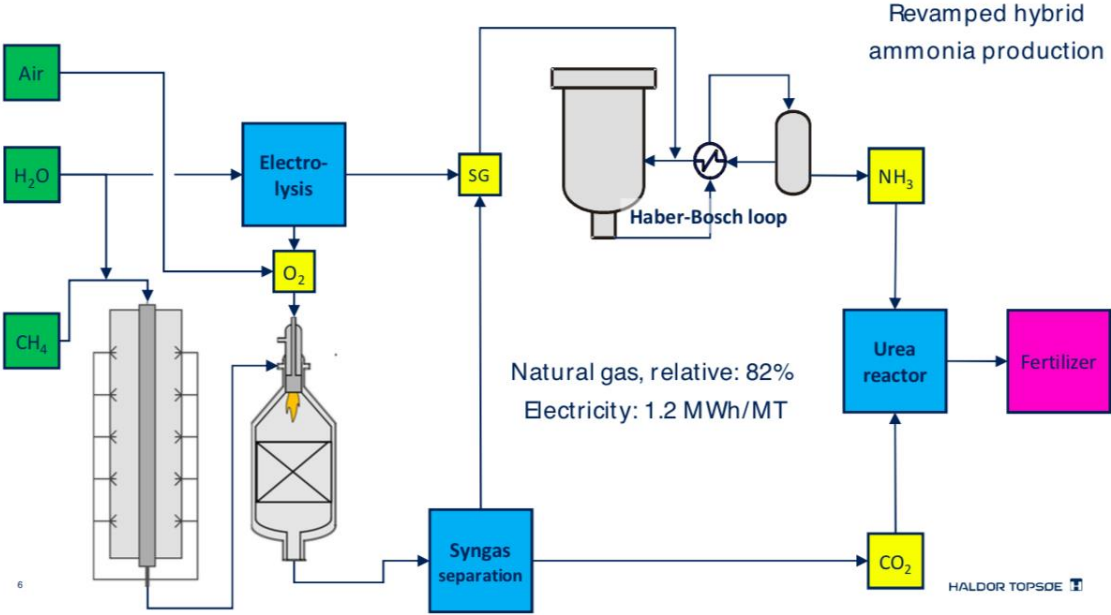
Synergy between SOEC and Synthesis



- Ammonia synthesis waste heat for steam production.
- SOEC more efficient than present electrolysis. Internal waste heat used to split water.
- SOEC is steam electrolysis. **This is new and more efficient!**

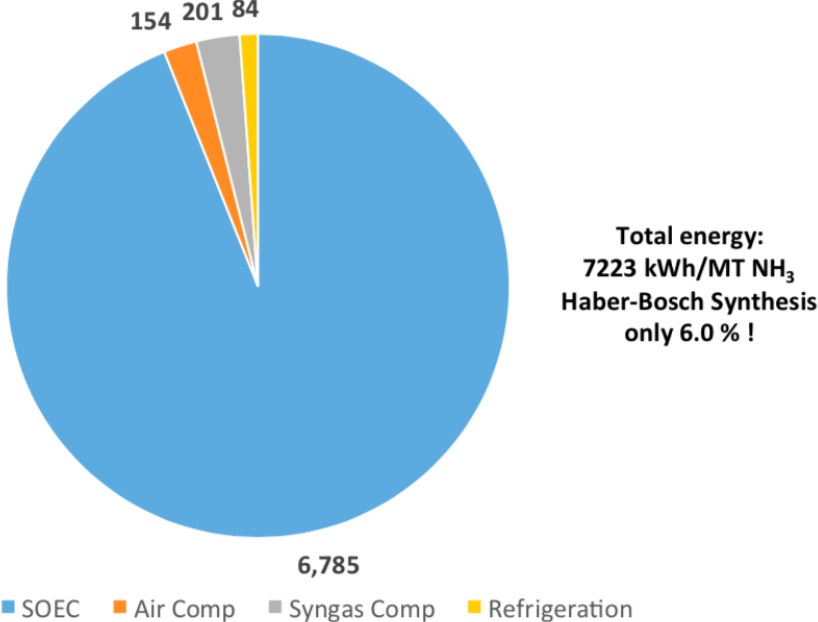
(presented by John B. Hansen in AIChE 2017)

# Green Ammonia: Electrolyzer Pilot Plants



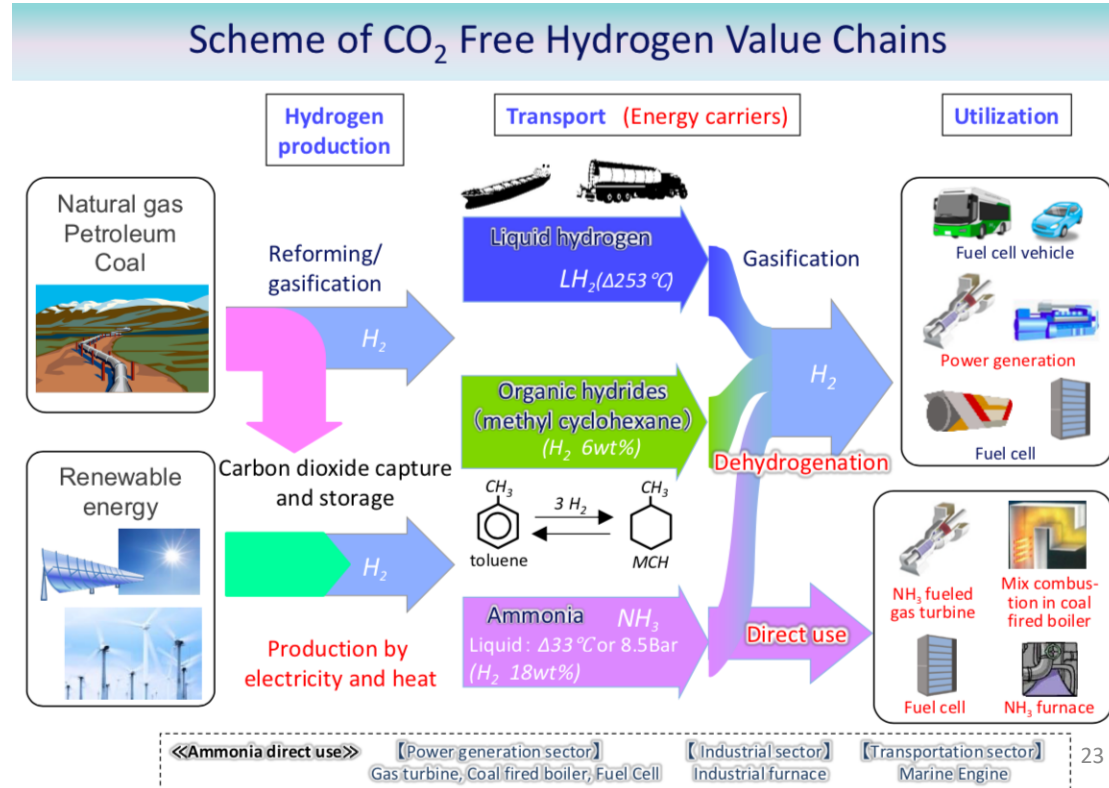
# Green Ammonia: Electrolyzer Pilot Plants

Breakdown of power consumption in kWh per MT ammonia



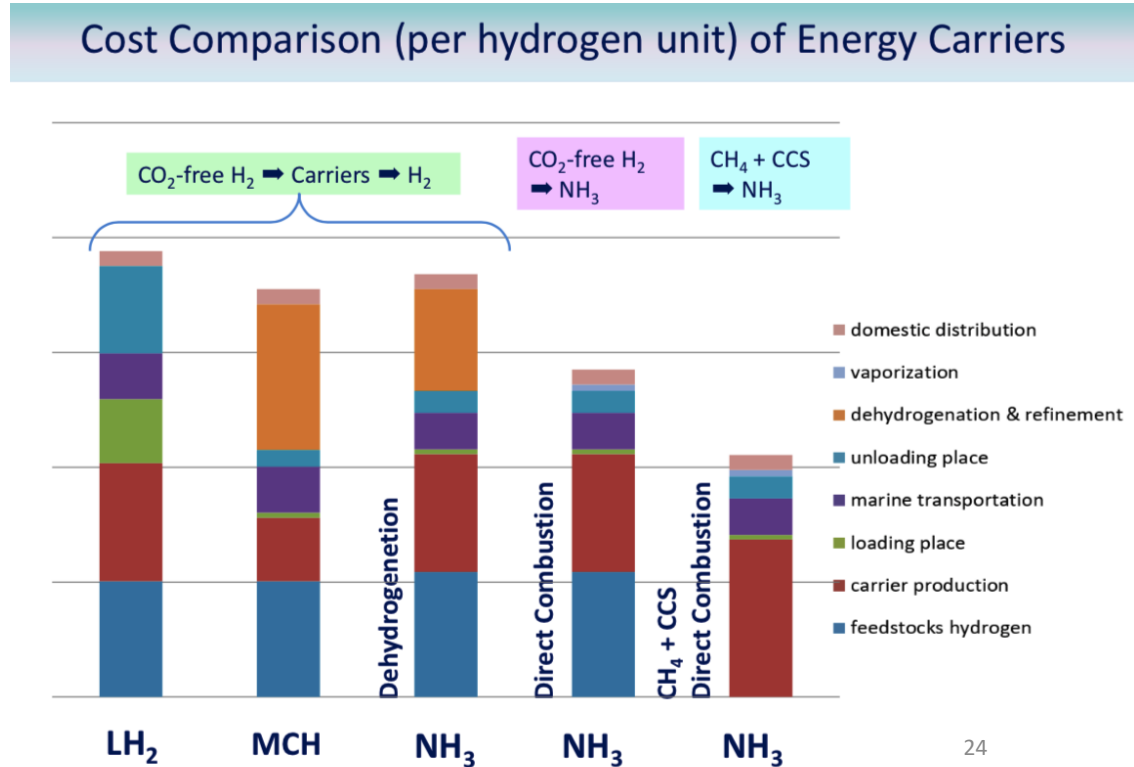
# Japan: SIP “Energy Carriers”

- Gov’t-Industry-Academia R&D, launched 2015
- Ammonia demonstrations:
  - Green ammonia synthesis
  - Ammonia SOFC
  - Ammonia turbine
  - Ammonia furnace
  - Ammonia co-combustion (coal power, cement)
  - Ammonia cracking / purification on-site, for hydrogen stations (PEM FC)
  - Ammonia safety, regulations, & public acceptance issues



# Japan: SIP “Energy Carriers”

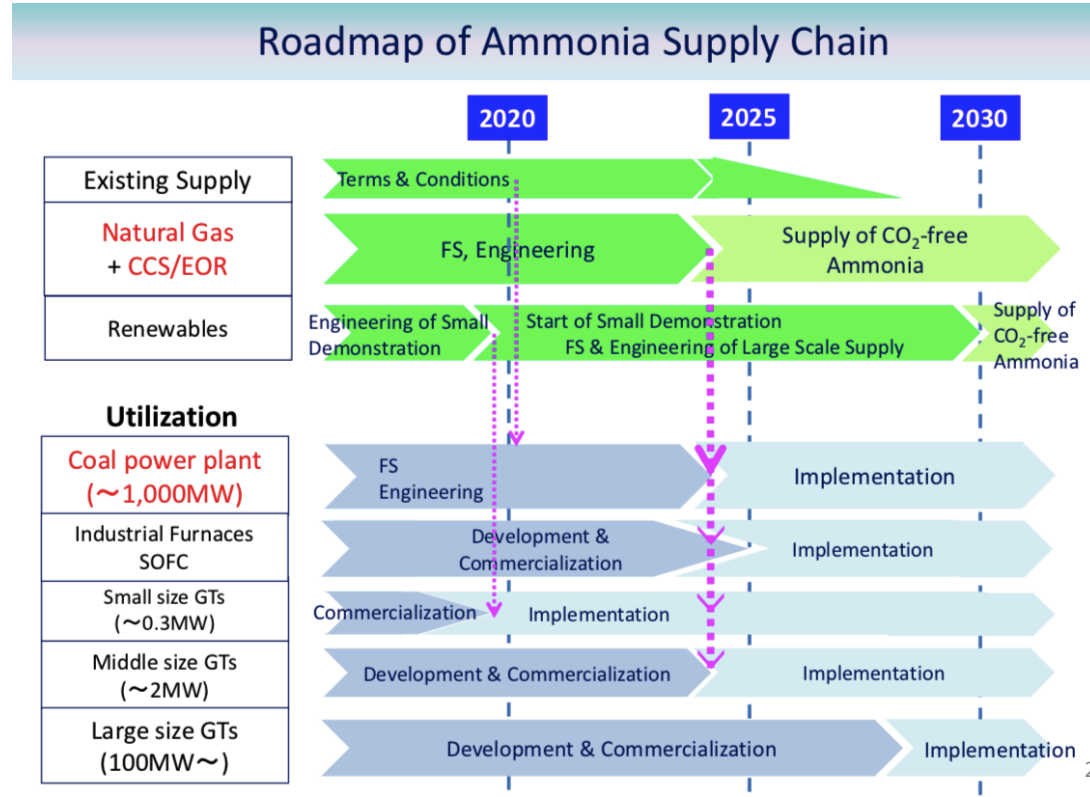
- Cheaper to import and dehydrogenate ammonia than to import hydrogen
- Economics improve if using ammonia as direct fuel
- Economics improve using conventional process with sequestration (CH<sub>4</sub>+CCS) as bridge technology





# Japan: SIP “Energy Carriers”

- Demonstration projects already operational
- Imports of CO<sub>2</sub>-free ammonia planned to begin in 2024 (CH<sub>4</sub>+CCS)
- Imports of CO<sub>2</sub>-free ammonia planned to begin in 2030 (renewables)
- Signed into law by PM Abe, Hydrogen Basic Strategy, December 2017



# Green Ammonia: Market Transformations

- Nitrogen Commodity → Hydrogen Commodity
- Homogenous Commodity → Heterogeneous Commodity  
*Price Premium = Local Function[Carbon Footprint]*
- Green Ammonia (Energy Markets) → Green Ammonia (Ag Markets)  
*Low-Carbon Leakage: supply creates demand*

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Questions?

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