Innovations in Ammonia

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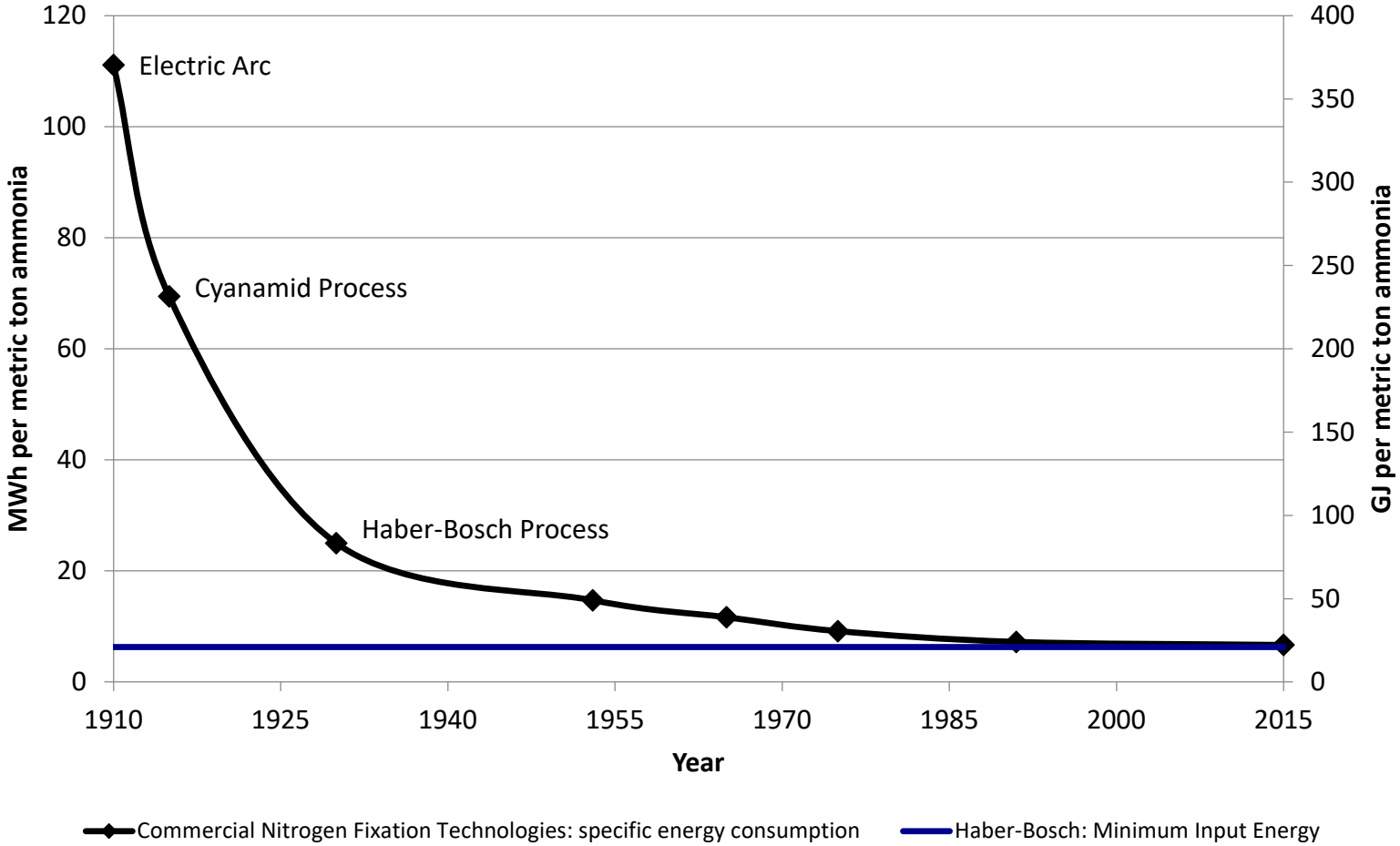
Innovations in Ammonia

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

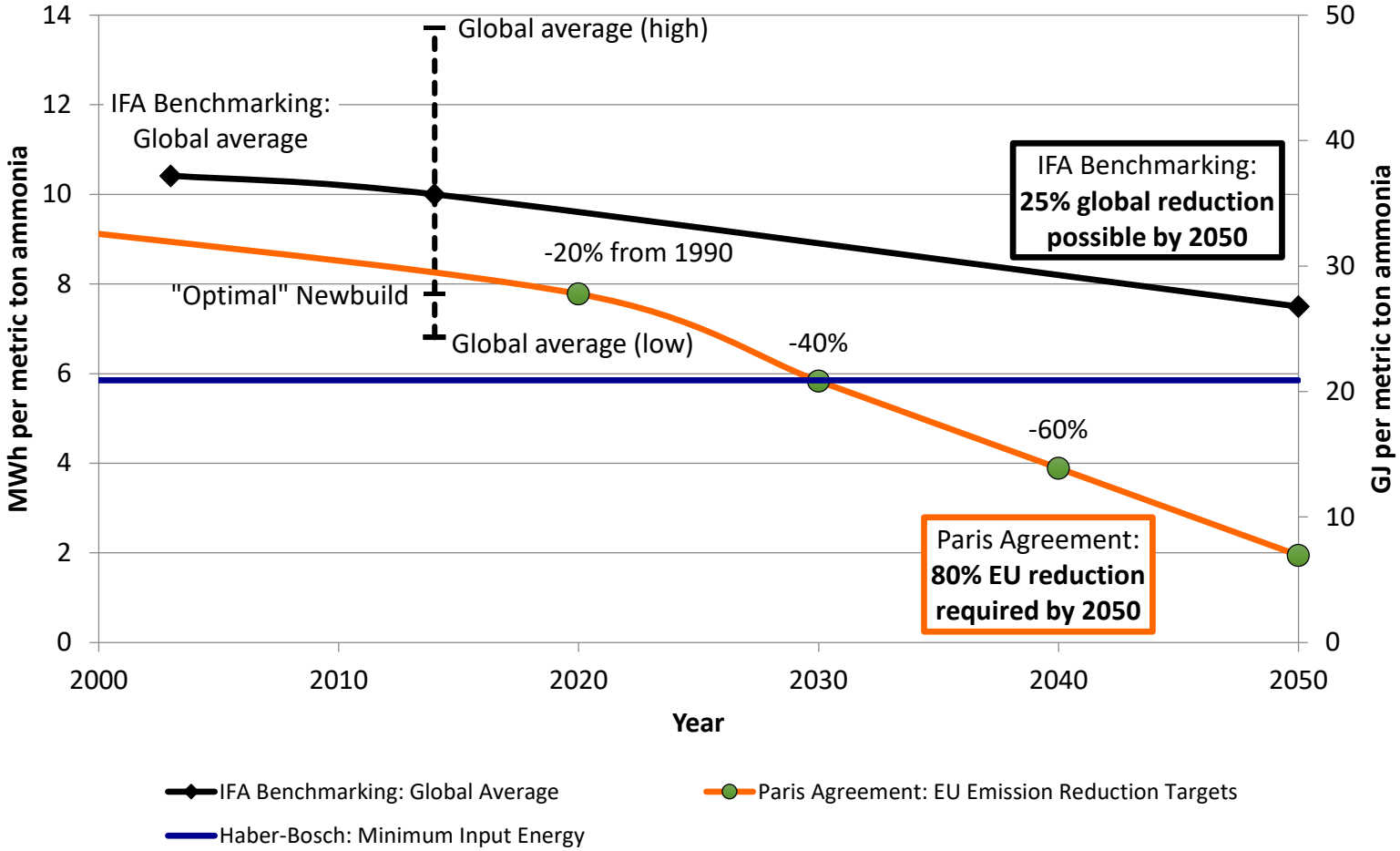
Ammonia Synthesis (Nitrogen Fixation): Energy Efficiency, 1910-2015

Various sources / AmmoniaIndustry.com, November 2018



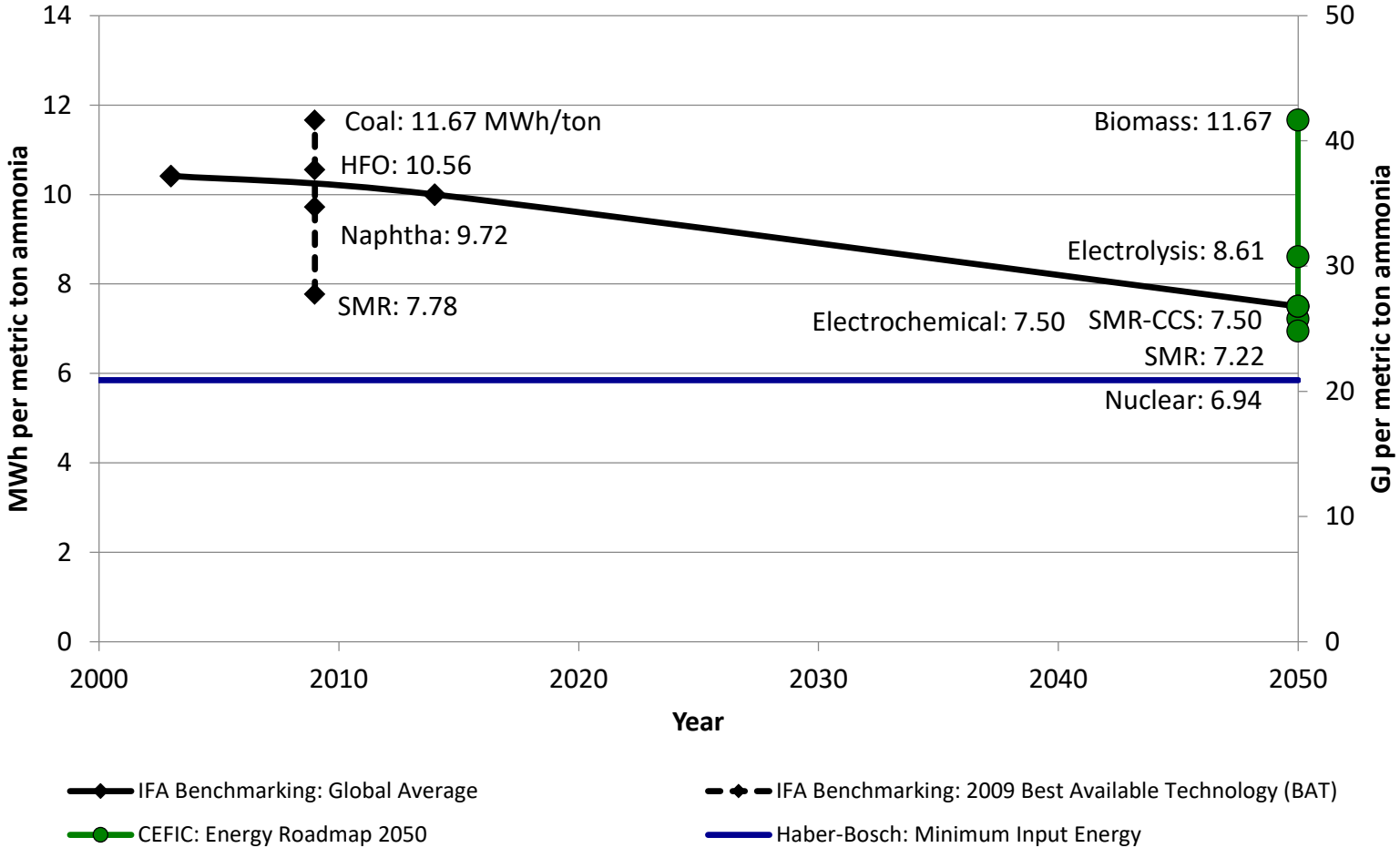
Ammonia Synthesis: Energy Efficiency, 2000-2050

IFA Benchmarks / AmmoniaIndustry.com, November 2018



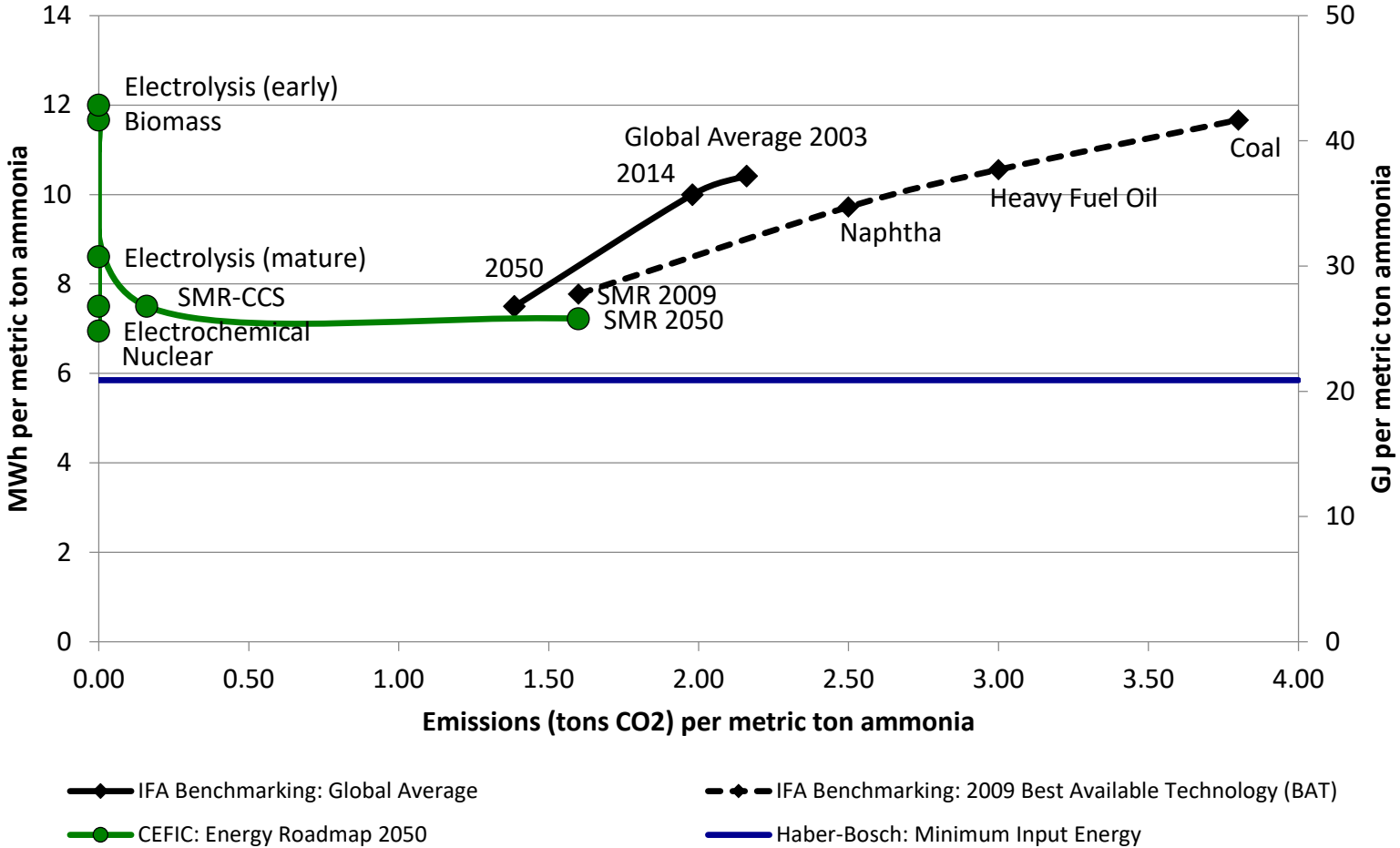
Ammonia Synthesis: Best Available Technologies, 2000-2050

IFA Benchmarks / CEFIC / AmmoniaIndustry.com, November 2018



Ammonia Synthesis: Carbon Efficiency, 2000-2050

IFA Benchmarking / CEFIC / AmmoniaIndustry.com, November 2018



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
- Ecoann™ ammonia sold as premium 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
- Alberta carbon tax hits both fuel and feedstock

Credits generated by the Joffre plant can offset emission costs of other plants in the Alberta fleet

(on the subject of carbon taxes)

- 10/25/2018: On one hand …
- CEO of US ammonia producer, during Q3 2018 earnings call, responds to question about perhaps expanding ammonia capacity in Canada:
- *“The Trudeau government and some of their carbon backstop legislation … they're doing things that are really anti-business and make it very difficult for us to want to spend money in that particular area.”*

(on the subject of carbon taxes)

- 10/25/2018: On the other hand …
- PM Justin Trudeau of Canada meets a Dutch trade delegation, and receives a knitted ammonia molecule mascot, ‘Monia,’ from Jacco Mooijer of Proton Ventures, renewable ammonia plant engineers, in the presence of visiting PM Mark Rutte of the Netherlands.
  Photo credit: Adam Scotti

Green Ammonia: Back to the future

- Yara (Norsk Hydro), Glomfjord, Norway
- Carbon-free ammonia, 1953 – 1991
- The world's biggest electrolyzers: two 135 MW units, generating hydrogen feedstock at 30,000 Nm^3 per hour
- No market advantage for "green"-ness, eventually not competitive v SMR

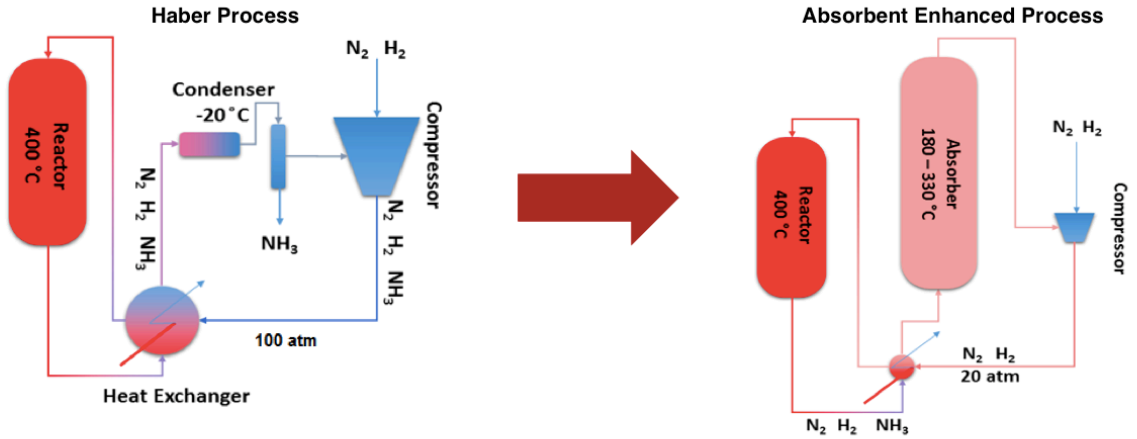
Green Ammonia: Electrolyzer Pilot Plants

- **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[1]
- Lower pressure and less heat exchange (temperature difference)
- Lower capital cost than conventional process, especially at small scale[2]



[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

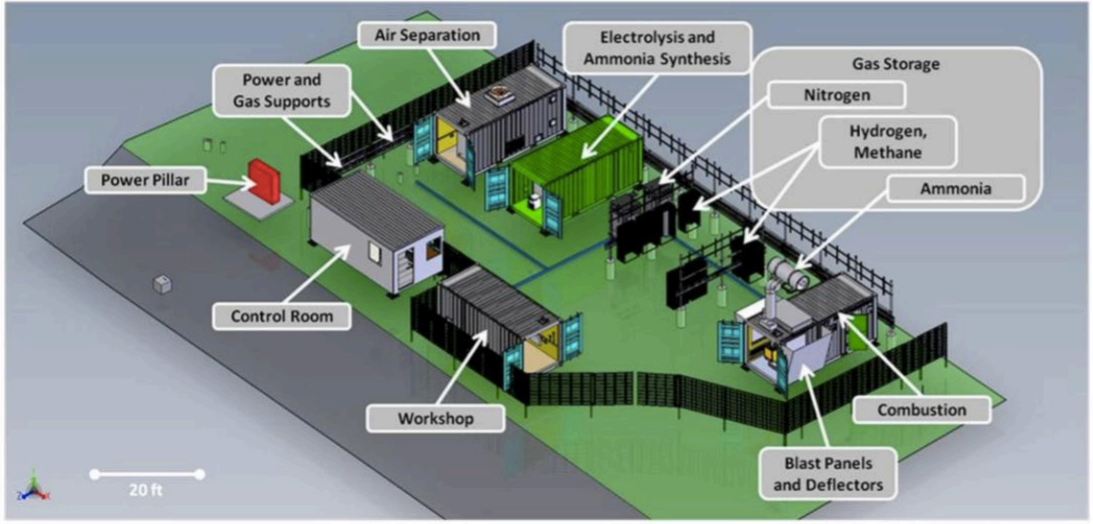
Green Ammonia: Electrolyzer Pilot Plants

- **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

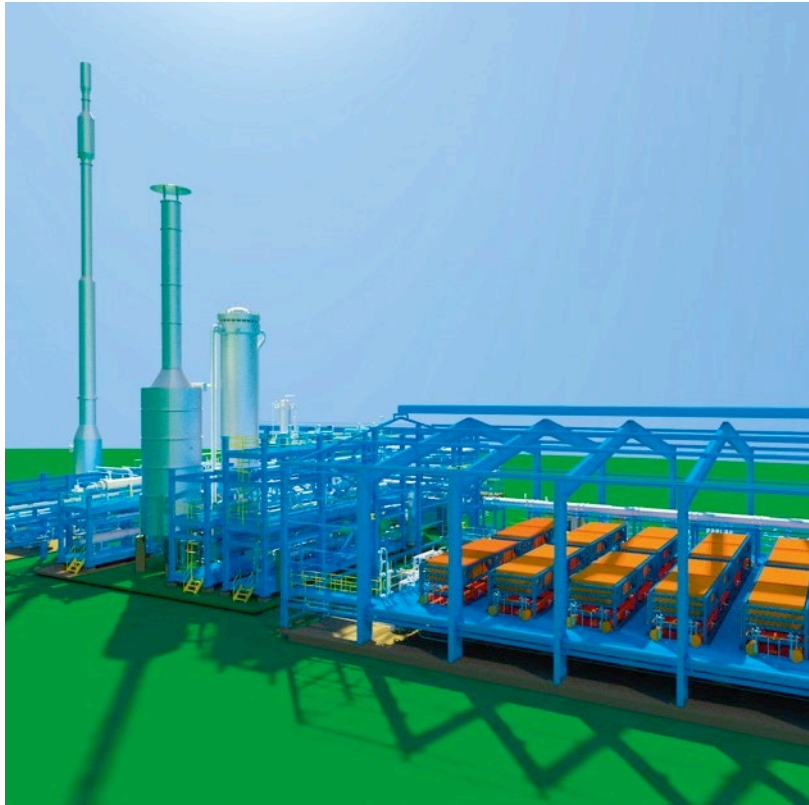
The Green Ammonia Demonstrator will show the complete cycle of renewable power, storage as ammonia, and conversion back to electricity

SIEMENS



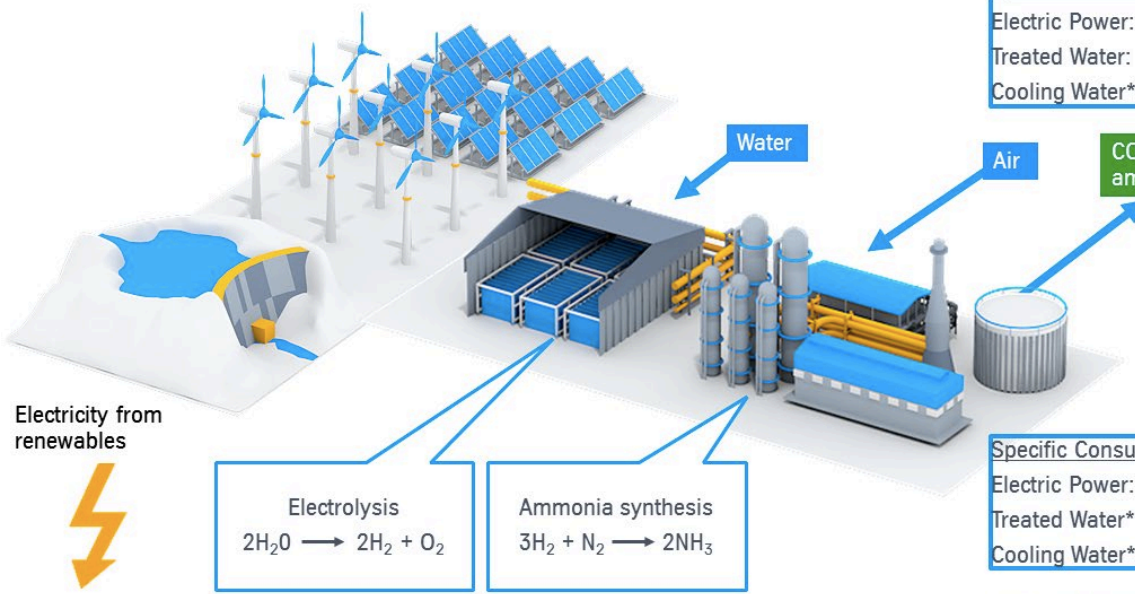
Green Ammonia: Electrolyzer Pilot Plants

- **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



Specific Consumption 50 mtpd plant	
Electric Power:	~ 10 MWh/t_{NH3}
Treated Water:	~ 1.6 $tons/t_{NH3}$
Cooling Water*:	~ 85 $tons/t_{NH3}$

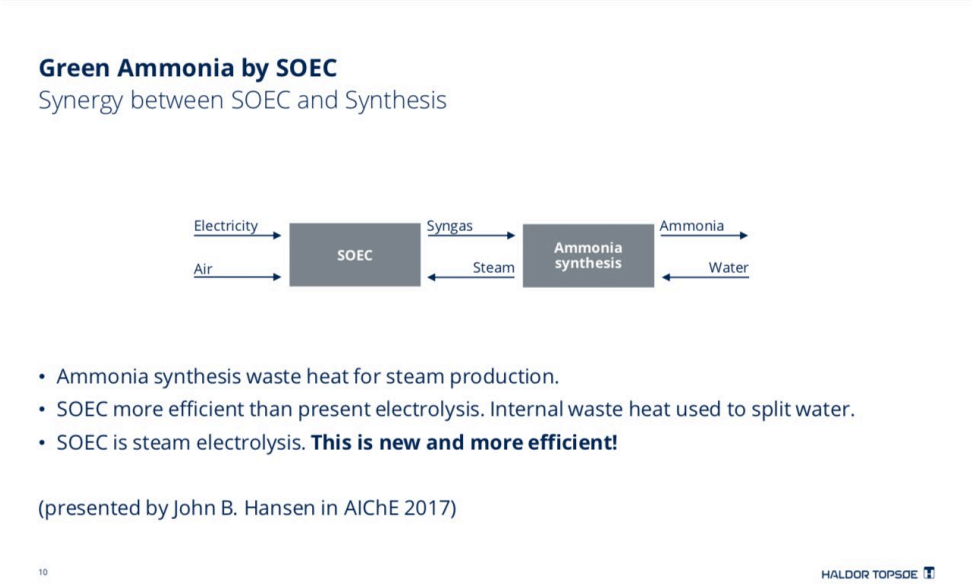
Specific Consumption 300 mtpd plant	
Electric Power:	~ 10 MWh/t_{NH3}
Treated Water**:	~ 2.6 $tons/t_{NH3}$
Cooling Water*:	~ 125 $tons/t_{NH3}$

*CW loop flowrate
** incl. steam generation

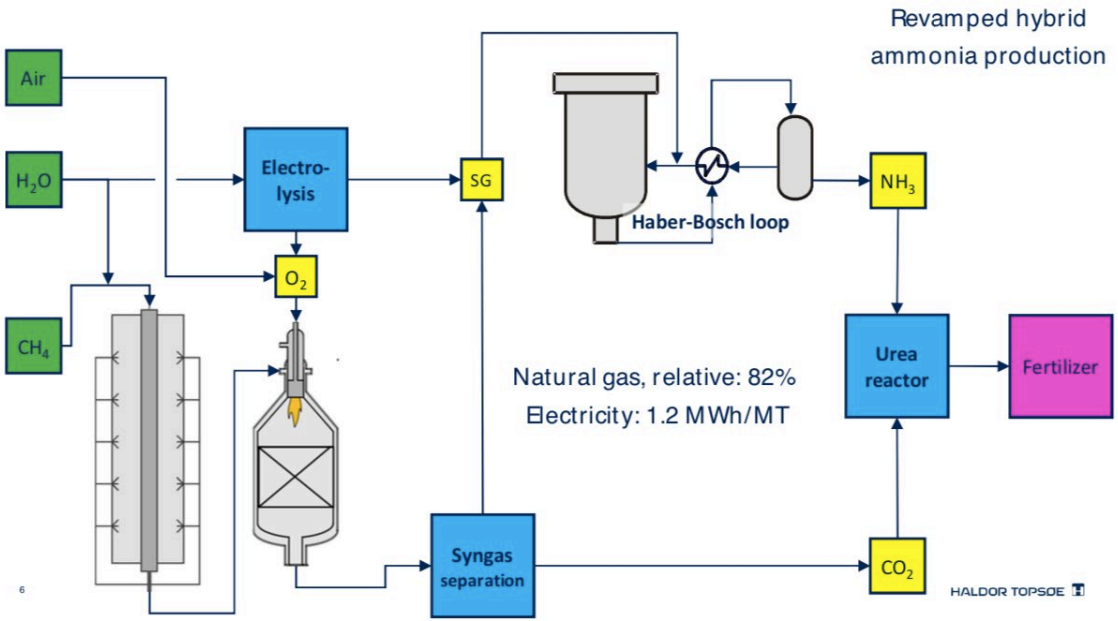
Green Ammonia: Electrolyzer Pilot Plants

Green Ammonia: Electrolyzer Pilot Plants

- **Haldor Topsoe**: Denmark
- Announced 2018 for 2025 start
- R&D innovation:
  Staged electrification of industry, SMR-ammonia plant revamp

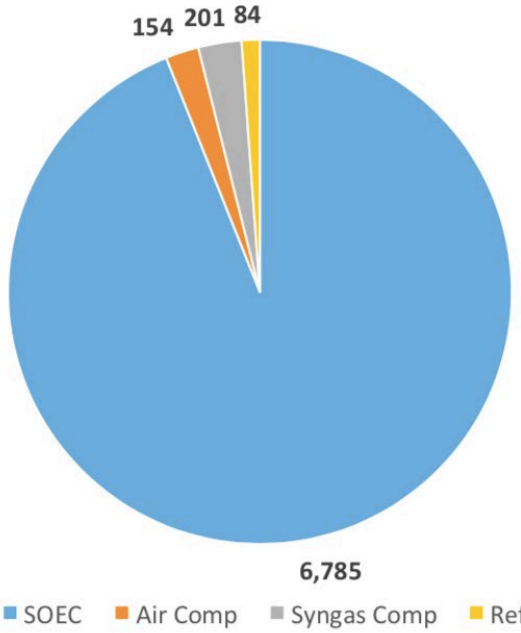


Green Ammonia: Electrolyzer Pilot Plants



Green Ammonia: Electrolyzer Pilot Plants

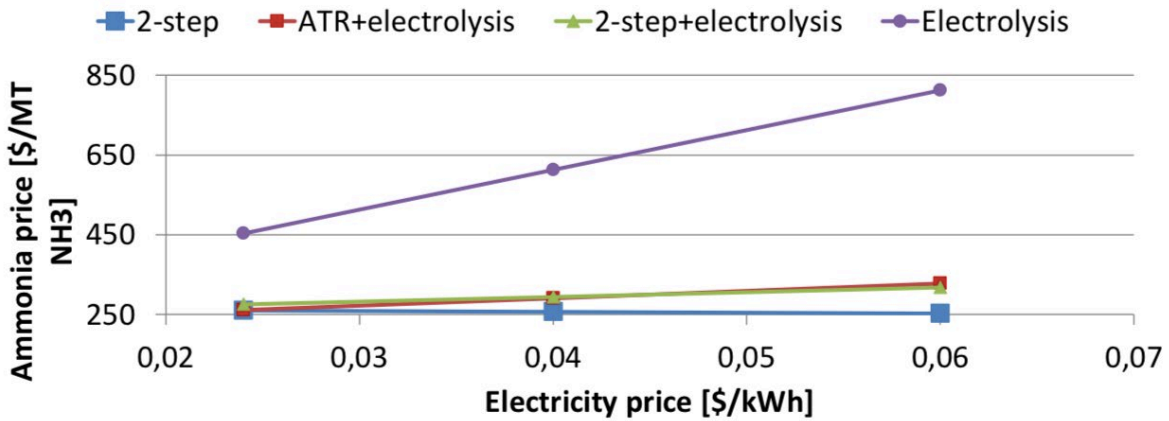
Breakdown of power consumption in kWh per MT ammonia



Total energy:
7223 kWh/MT NH_3
Haber-Bosch Synthesis
only 6.0 % !

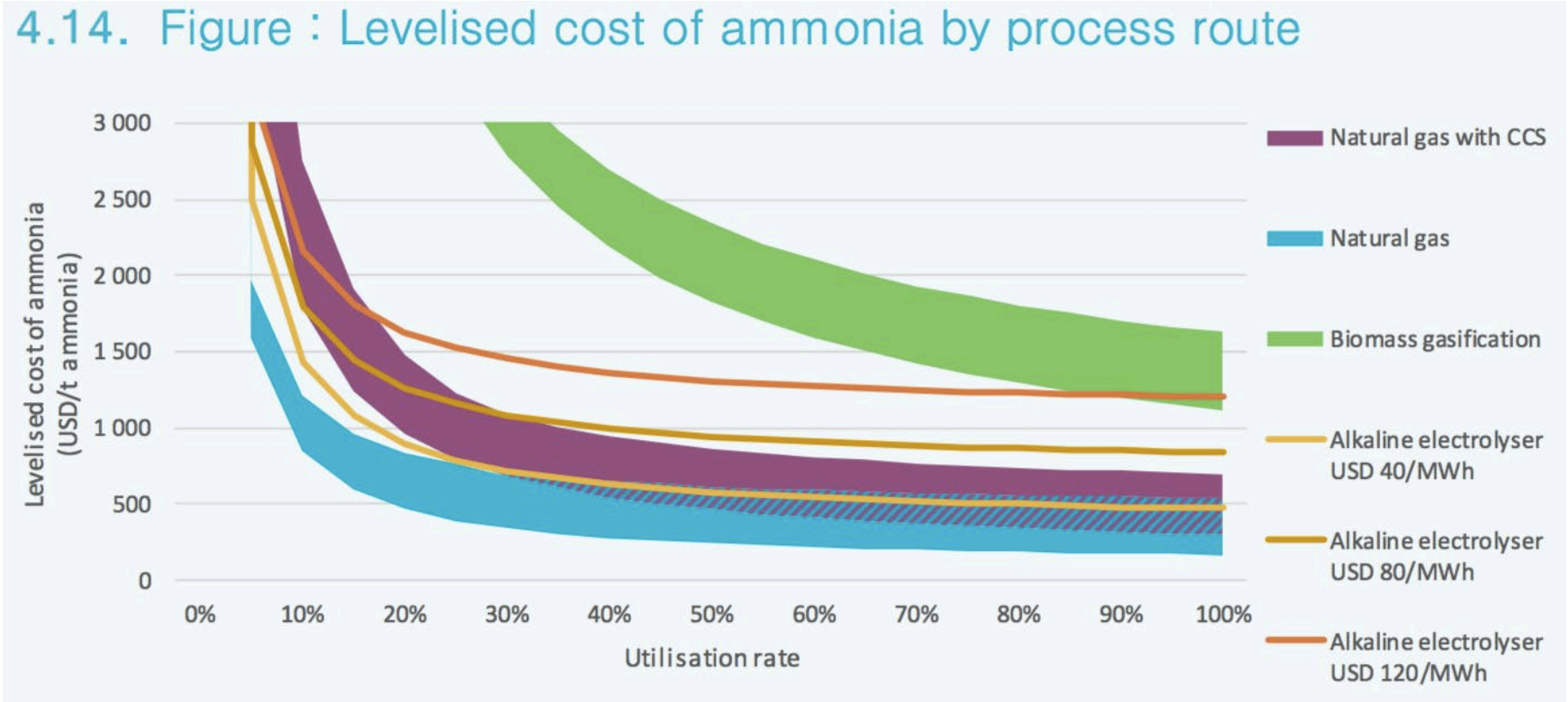
Green Ammonia: Electrolyzer Pilot Plants

Ammonia production price – all inclusive



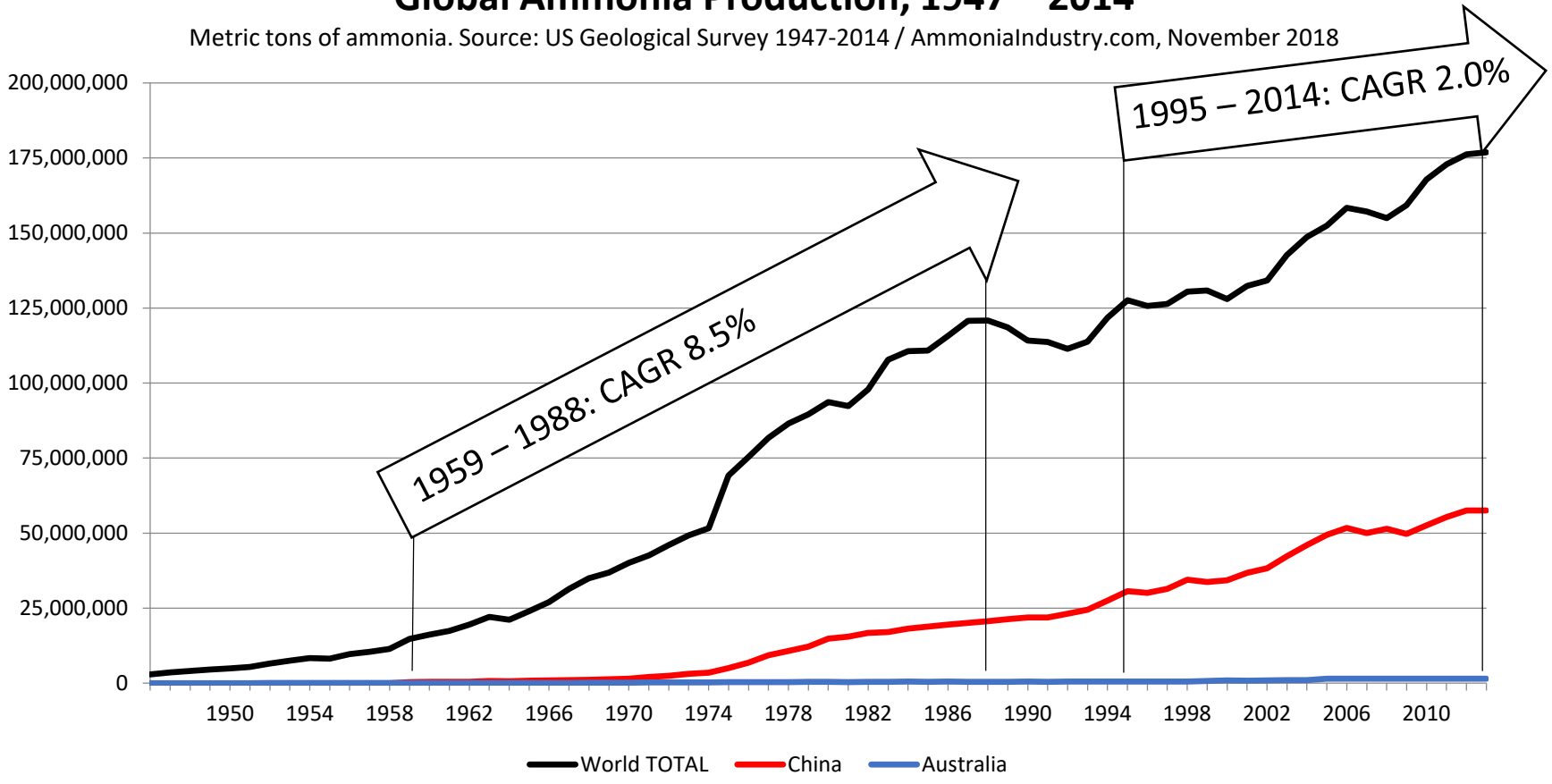
NG = 6 $/MMBTU

International Energy Agency: Economics



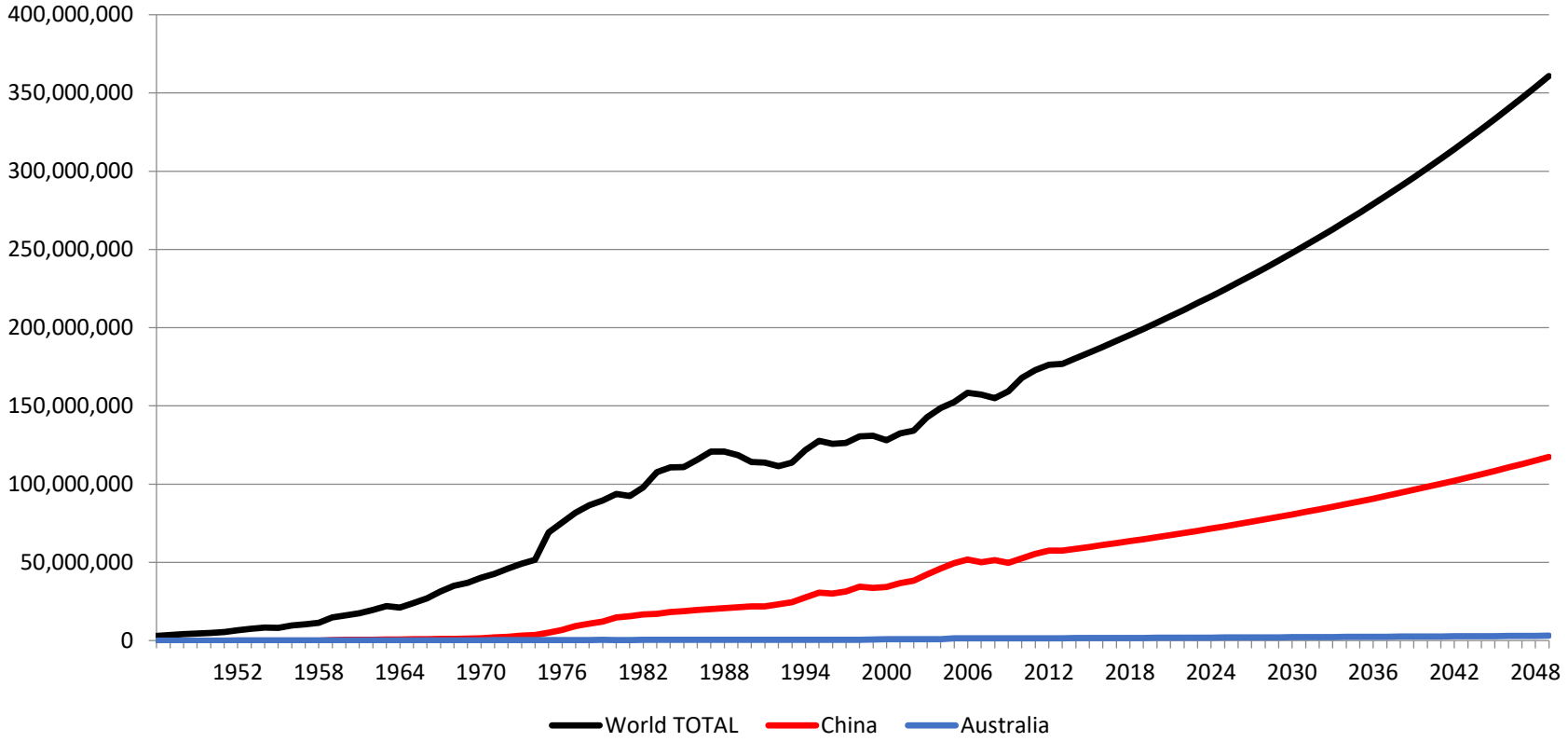
Global Ammonia Production, 1947 – 2014

Metric tons of ammonia. Source: US Geological Survey 1947-2014 / AmmoniaIndustry.com, November 2018



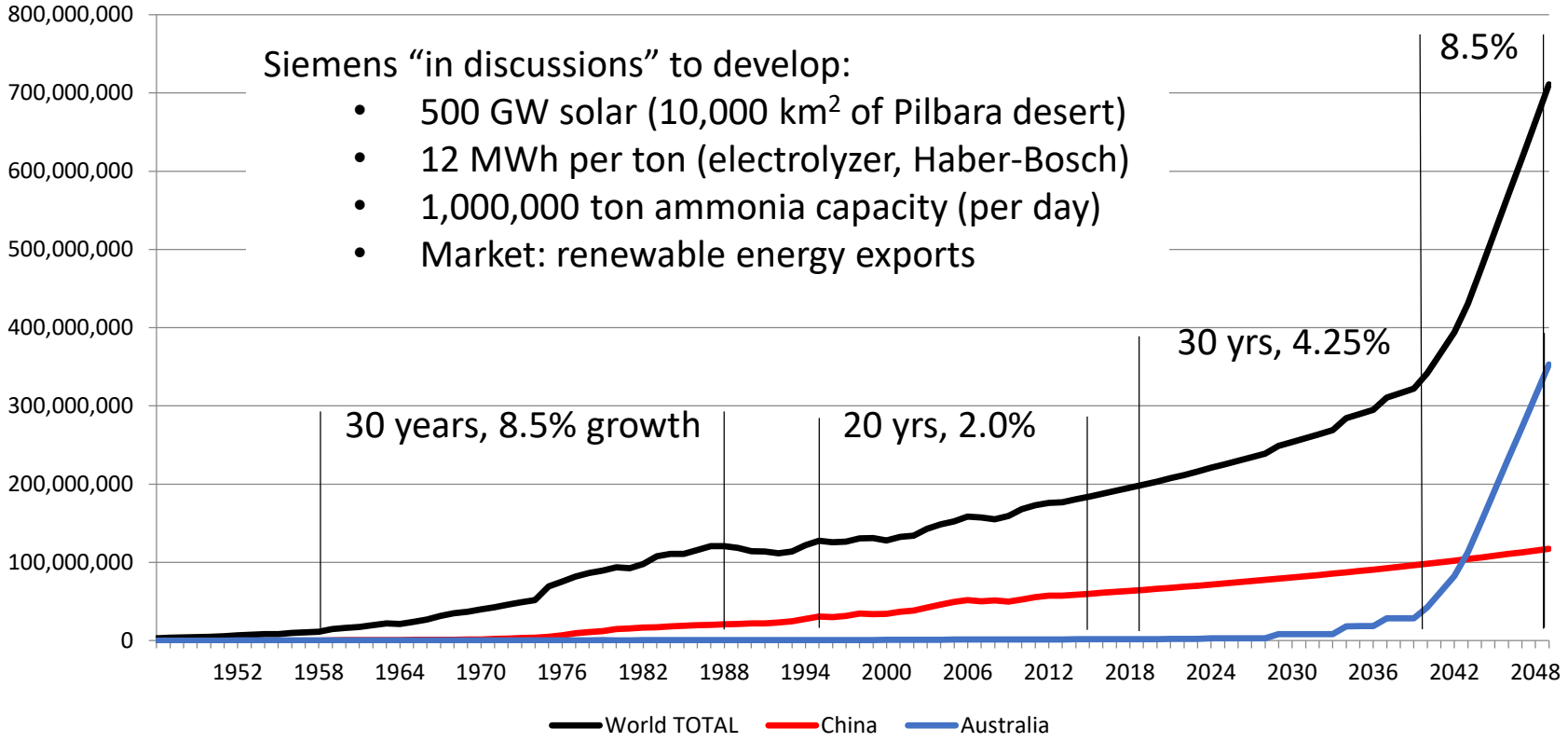
Global Ammonia Production, Scenario to 2050 @ 2% growth

Metric tons of ammonia. Source: US Geological Survey, 1947-2014 / AmmoniaIndustry.com, November 2018



Global Ammonia Production, Scenario to 2050 @ export strength

Metric tons of ammonia. Source: US Geological Survey, 1947-2014 / AmmoniaIndustry.com, November 2018



The Green Ammonia Market

- 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

- Thank you

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