

Establishing a Global Market for Ammonia Energy

Panel discussion

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Panel introduction



Ashwani Dudeja — President & Director, Green Hydrogen and Ammonia, ACME Group

- 29+ years of Marketing and Business Development experience in the energy sector across Asia and Europe

Patrick Molloy — Manager, Climate Aligned Industries, RMI

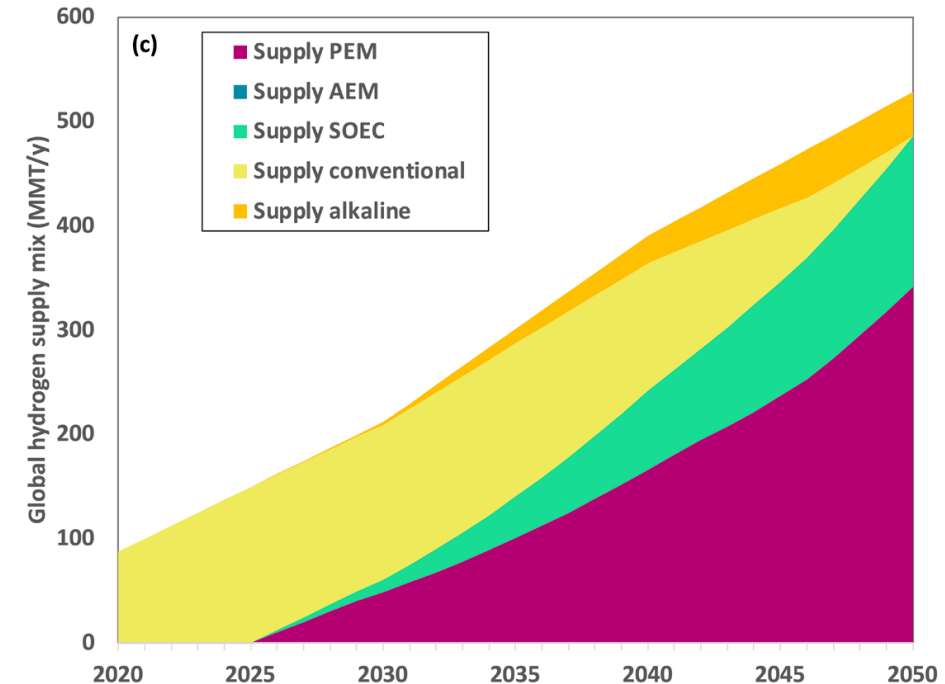
- leads research on hydrogen adoption in the shipping and fertilizer sectors, coordinates work on H₂ hub

Hans Vrijenhoef — Chair, Proton Ventures

- a champion to green ammonia with 40 year experience in management, engineering, production, and R&D

Clean ammonia and clean hydrogen

- **Hydrogen is a critical part of decarbonization**
 - Energy storage to stabilize high VRE grid
 - Hard to decarbonize industries (steel, cement, heating)
 - Heavy duty transportation
 - Energy security
- **Clean ammonia closely bound to clean hydrogen**
 - H₂ – the main feedstock for ammonia synthesis
 - NH₃ – the best hydrogen carrier
- **Projections for clean hydrogen demand by 2050 is within the range of 500 – 800 MMTY [1 – 5]**



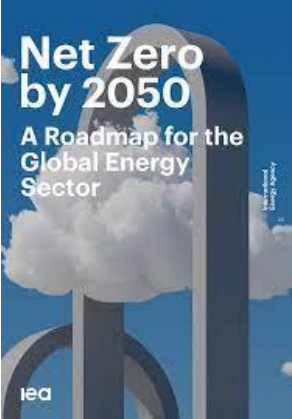
1. <https://www.energy-transitions.org/clean-electrification-and-hydrogen-can-deliver-net-zero/>
2. <https://www.iea.org/reports/net-zero-by-2050>
3. <https://www.investmentbank.barclays.com/our-insights/the-hydrogen-economy-fuelling-the-fight-against-climate-change.html>
4. <https://www.strategyand.pwc.com/m1/en/reports/2020/the-dawn-of-green-hydrogen/the-dawn-of-green-hydrogen.pdf>
5. BloombergNEF, New Energy Outlook NEO2021, July 2021 report
6. Water Electrolyzers and Fuel Cells Supply Chain, DOE Response to Executive Order 14017, “America’s Supply Chains”, 2022

How much renewables needed to scale green hydrogen?

500 million tonnes of green hydrogen would require

- a global electrolyser capacity of 5566 GW (18,500x of today)
- ~22,500TWh of electricity - >30% of today supply (71,164TWh)

<https://www.iea.org/reports/net-zero-by-2050>



Electricity generation for green hydrogen



x 7,500

1.55 GW Alta Wind Energy Centre, CA

or



x 20,000

580 MW Solar Star, CA

Hydrogen production



x 133,000

Air Liquide 20MW facility in Quebec, Canada

or



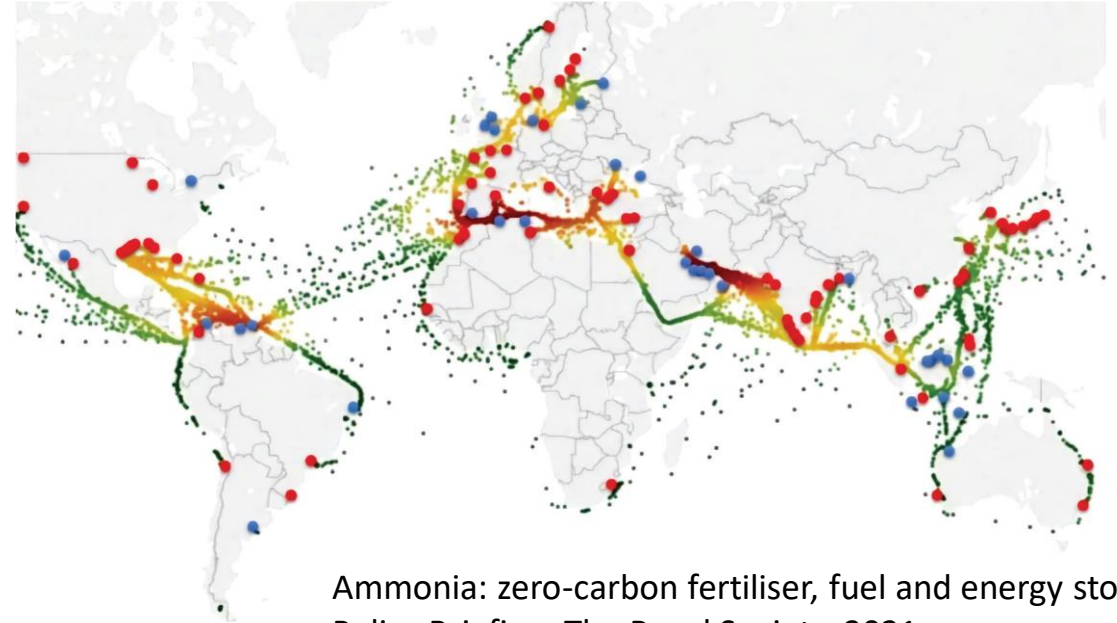
x 19,500

Nel Hydrogen 135 MW plant in Glomfjord, Norway

Current ammonia global market

- Currently ammonia is used mostly for fertilizers (85%) and chemicals
- Practically all ammonia produced from fossil fuels (natural gas and coal)
- About 185 million metric tons (~1,000,000 GWh) produced annually
- Market size was \$71.2B in 2019 and expected to grow at a CAGR of 5.59%
- Only 10% of global production is traded (mostly by ships)
- There are about 40 liquid ammonia carriers (~200 ships are capable) and 120 harbor terminals worldwide
- U.S. currently produces 14 MMTY at 32 plants

Ammonia shipping infrastructure, including a heat map of liquid ammonia carriers and existing ammonia port facilities (2017)



Ammonia: zero-carbon fertiliser, fuel and energy store
Policy Briefing, The Royal Society, 2021

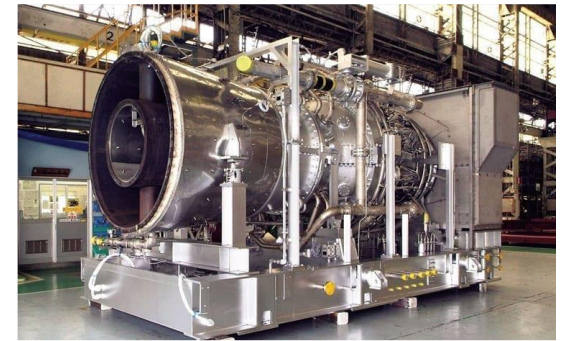


Ammonia as energy vector

- Truly zero-carbon fuel
- Energy dense in liquid form (4.3 kWh/L, 5.25 kWh/kg)
- Can be stored indefinitely as liquid at 10 bar or -33°C
- Excellent hydrogen carrier (17,75% hydrogen, 121 kg H/m³
- cleanly generates hydrogen at 450 C
- Well developed infrastructure
- Excellent safety record
- Can be utilized directly by multiple ways (fuel cells, turbines, ICEs, burners)

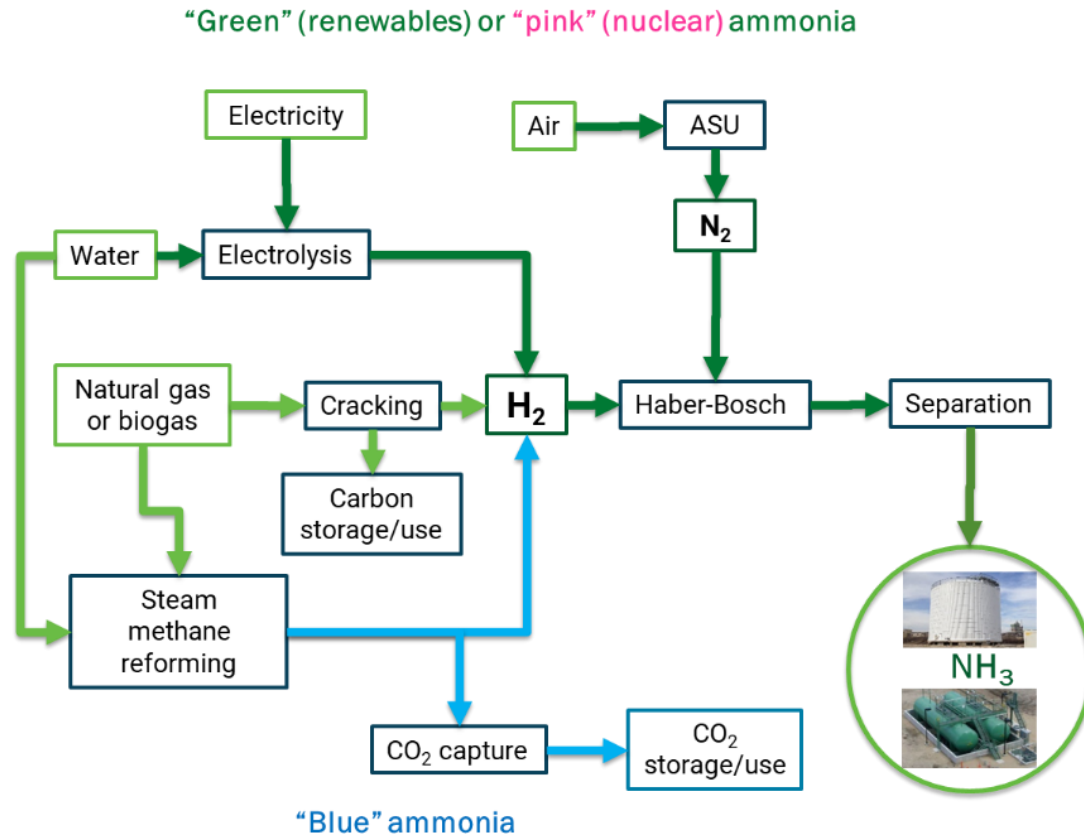


Wartsila 4 stroke engine fueled by NH₃, 2020
<https://www.swzmaritime.nl/news/2020/06/30/marine-engine-to-be-tested-running-onammonia/?gdpr=deny>



Mitsubishi Power 40-MW class ammonia gas turbine, 2021
<https://www.powermag.com/mitsubishi-power-developing-100ammonia-capable-gas-turbine/>

Clean ammonia rainbow



Carbon intensity does NOT defined by color

- Green ammonia projected to beat blue ammonia by 2040
- Turquoise ammonia may be attractive if the market for carbon byproduct will be realized
- Pink ammonia (via SOEC hydrogen) may grow with introduction of modular reactors

Demand for clean ammonia

- About 85% of announced clean hydrogen projects worldwide include its shipping in the form of ammonia
- Market for green ammonia expected to grow from \$63 million to \$5.48 billion with CAGR of 74.78% [1]
- Global ammonia projected demand in 2050 will increase from 460 MMTY by IEA (maritime fuel 44%) [2] to 688 Mt by IRENA (maritime fuel 29%, hydrogen carrier 18%) [3]
- If ammonia is used as a predominant maritime fuel, it will triple the current production
- Transition to an ammonia-based farm ecosystem may double the current production

1. <https://www.precedenceresearch.com/green-ammonia-market#:~:text=The%20green%20ammonia%20market%20size,yet%20in%20the%20planning%20stages>
2. <https://www.iea.org/reports/ammonia-technology-roadmap/executive-summary>
3. <https://www.irena.org/publications/2022/May/Innovation-Outlook-Renewable-Ammonia>



How to transform ammonia fertilizer market into global ammonia energy market?

- Substantially increase generation of VRE
- Develop more efficient ammonia synthesis technologies working with VRE
- Multiply existing infrastructure (terminals, ships, pipelines)
- Build supply chain to support the production of electrolyzers and green ammonia
- Invest in ammonia-to-energy technologies (H₂ production, electricity and heat generation)
- Ensure long-term off-take contracts
- Adopt internationally recognized clean ammonia certification
- Develop national policies supporting transition to clean ammonia

Questions for discussion

- How ammonia may serve as a key driver for energy transition?
- How world clean energy needs will drive ammonia market growth?
- How related are ammonia and hydrogen markets?
- How technology development can affect the market growth?
- How to balance supply and demand?
- How existing ammonia trade can help in setting ammonia energy trade?
- What global infrastructure development needed to support the market growth?
- How local attributes may affect the market?
- What is the role of governments in creation of global ammonia energy market?
- How certification can reduce barriers for global clean ammonia trade?
- How geopolitics may affect the ammonia rainbow and market development?