Nuclear-based ammonia production

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AMMONIA ENERGY ASSOCIATION

Ammonia Energy Association

- A global industry association that advocates for the responsible use of ammonia (NH_3) in a sustainable energy economy

- **Supply**: decarbonize ammonia production
- **Demand**: adopt ammonia in energy markets

- **Members**: global and cross-sectoral

AMMONIA ENERGY
ASSOCIATION

Ammonia Energy Association

MEMBER LIST — February 2022

* indicates representation on Board of Directors

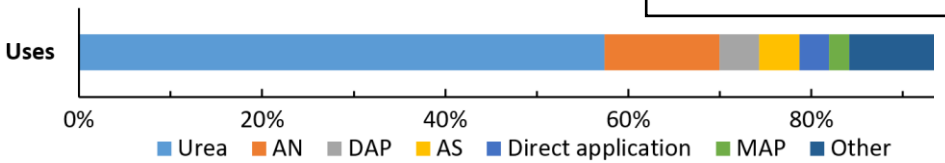
PLATINUM: bp, CF Industries*, CWP Global, Denbury, The Hydrogen Utility*, InterContinental Energy*, KBR*, LSB Industries, Mitsui & Co., Monolith Materials, Nutrien*, OCI*, Starfire Energy*, Yara*. **GOLD**: Acron, AFC Energy, Airgas, Aker Clean Hydrogen, Asian Renewable Energy Hub, Casale*, Enaex, Engie, Equinor, Fortescue Future Industries, FuelPositive, Haldor Topsøe*, Hamilton Locke, Hydrofuel, Marnco, Mitsubishi Heavy Industries, Origin Energy*, Proton Ventures*, Ridley Terminals, Syzygy Plasmonics, thyssenkrupp Industrial Solutions*, Trammo, Tri-State Generation & Transmission. **SILVER**: AES Gener, Air Products, Ammonigy, AmmPower, Amogy, Argus Media, BASF, Black & Veatch, Bureau Veritas, Burns & McDonnell, Casa dos Ventos, Consorcio Eólico, CRU Group, CS Combustion Solutions, Cummins, EIFER, Enterprize Energy, Fertiberia, GenCell Energy, GTI, Gunvor Group*, H2Site, Horisont Energi, HyFuels Holdings, IHI Americas, inodú, Intecsa Industrial, Johnson Matthey, Koch Fertilizer, Linde, Lotte Fine Chemical, Maersk*, Mercuria, MineARC Systems, Mitsui OSK Lines, Nel Hydrogen*, OGS Global, Organics Group, Pacific Green Technologies, SagaPure*, Schoeller-Bleckmann Nitec, Shell, Sperre Industri, Stamicarbon, Thorium Energy Alliance*, TotalEnergies*, Tsubame BHB, Wonik Materials, Woodside Energy. **MEMBERS**: Advanced Ionics, Advanced Thermal Devices, AHMON, Air Liquide, Airthium, Apex Clean Energy, Ark Energy, Arizona Public Service, Arranged, AustriaEnergy, Axetris, BLG, Brittany Ferries, C-Job Naval Architects, Carbon-Neutral Consulting*, CHZ Technology, Cozairo, Cura IT, Danaos Shipping, Duiker Combustion Engineers, Energy Estate, Eneus Energy, ESNA, Exmar, Gaztransport & Technigaz, George Propane Inc., GESCA, Greenfield Nitrogen, Idemitsu Kosan, Incitec Pivot, Ingenostrum, IT Power Australia, JGC Holding Corporation, John Cockerill, Jupiter Ionics, Keppel Infrastructure, Mainspring Energy, MAN Energy Solutions, MicroEra Power*, Moda, Nebraska Public Power District, Neology, Netsco, New Energy Technology, NGLStrategy, Nordex, Northern Nitrogen, NovoHy, NYK Energy Transport (USA), Oceanic Vessels, Oiltanking, Osaka Gas USA, Renewable Hydrogen Corporation Canada, SAFCell, SBM Schiedam, Syntex, Terrestrial Energy, Unconventional Gas Solutions, UPC\AC Renewables, Varo Energy, Vopak.

Ammonia Production Methods

Current ammonia production: **183 Mt** [1] (all fossil-based, 55% urea [1])

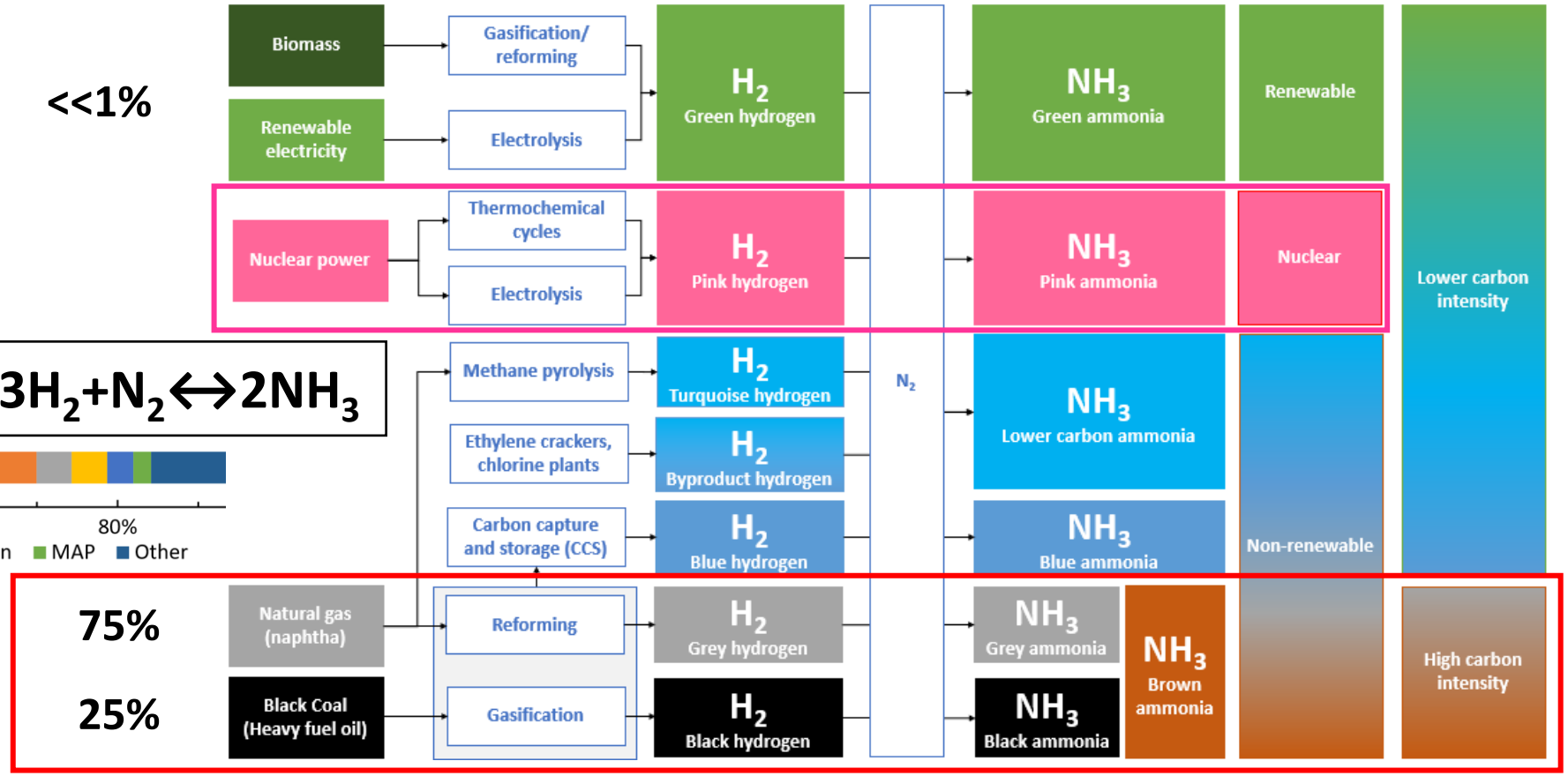
Sustains half the world population [2]

0.5 Gt CO_2/y
1.0% of CO_2 emission



We need to decarbonize!

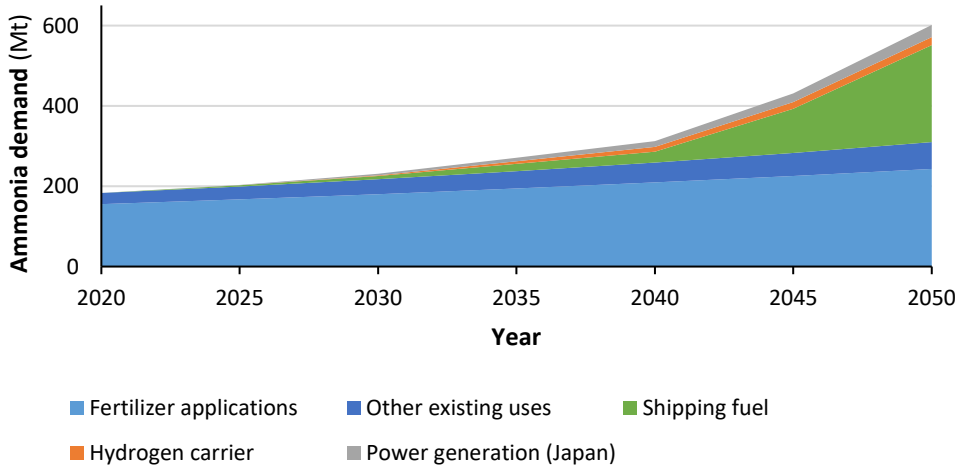
$3H_2+N_2 \leftrightarrow 2NH_3$

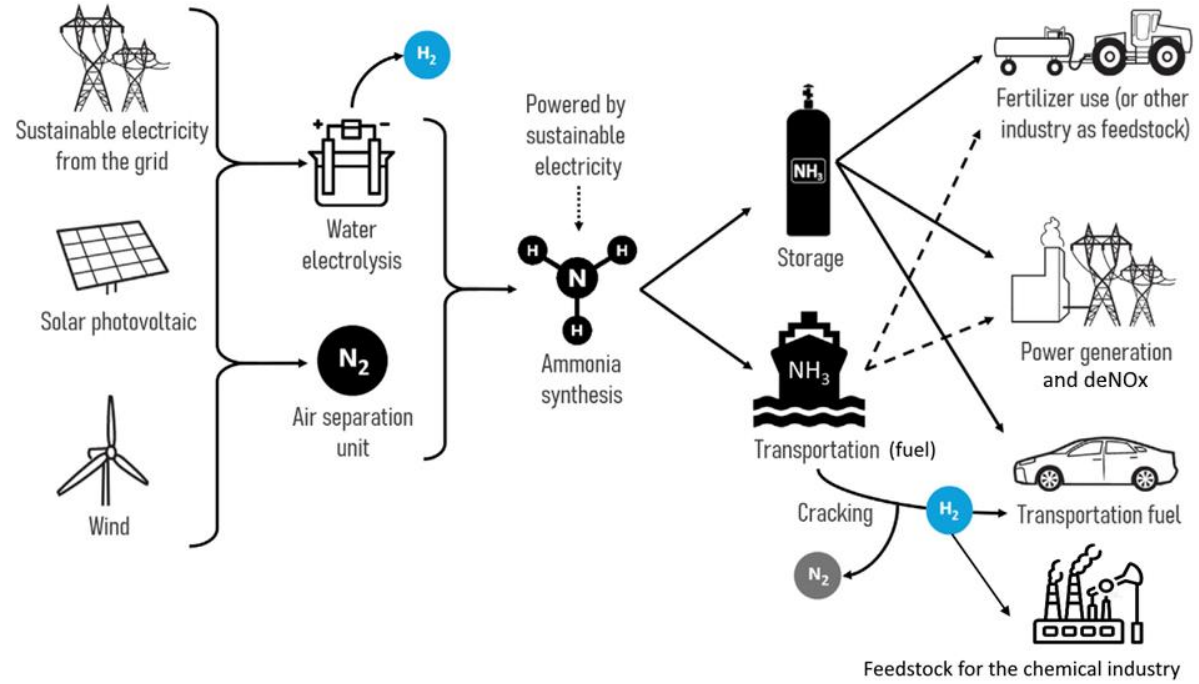


[1] https://www.ammoniaenergy.org/wp-content/uploads/2020/12/Oliver-Hatfield.pdf
[2] https://www.nature.com/articles/ngeo325

Ammonia Markets

- **Current uses**: fertilizer (85%) & chemical (15%), total **183 Mt** (2020)
- Ammonia as hydrogen carrier and zero carbon fuel
  - **New markets**: Hydrogen carrier (ammonia cracking), Transportation fuel (maritime), Stationary fuel (power plants) [1]
- Up to **600 Mt** demand by 2050



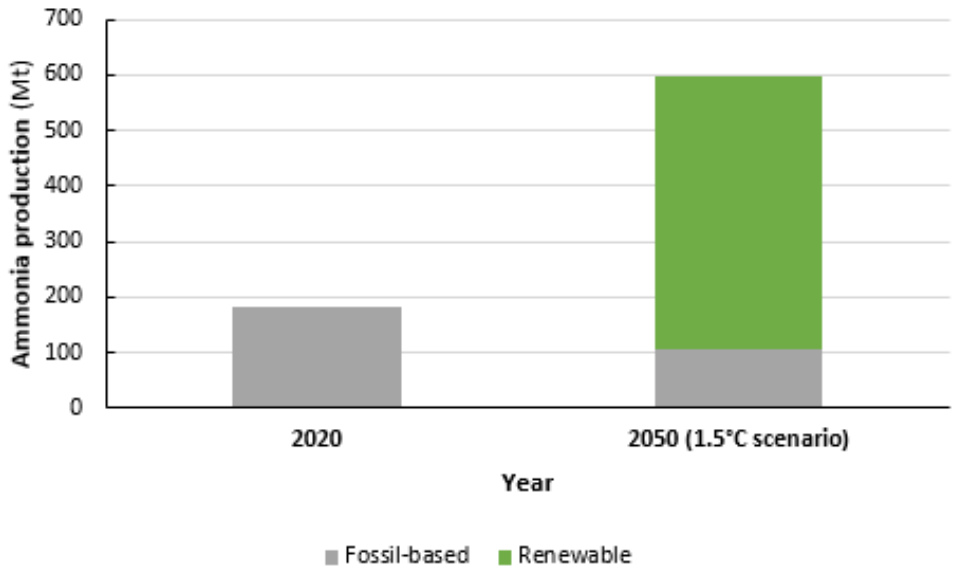


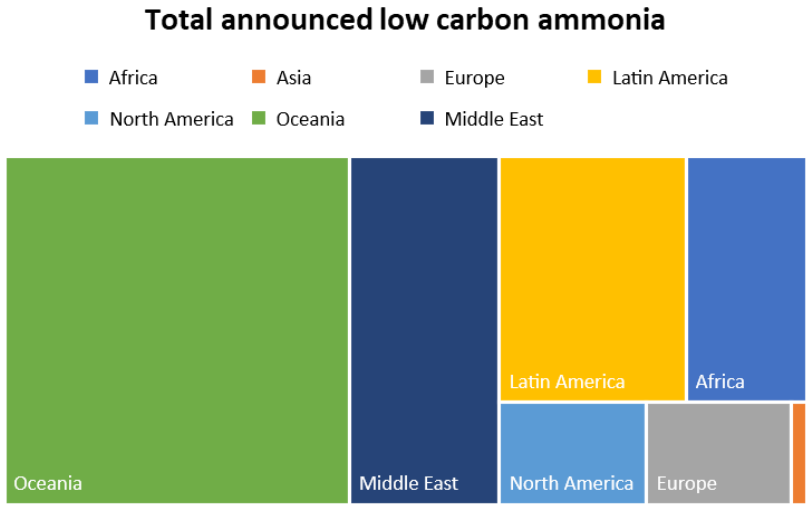
[1] https://www.sciencedirect.com/science/article/abs/pii/S0959652621007824

Decarbonizing ammonia production

IRENA 1.5°C scenario [1]:

- **Decarbonize current assets**: 70 Mt/y existing fossil assets shut down
- **Renewable development**: 500 Mt/y new capacity required
- **Announcements for low carbon ammonia**: 55 Mt/y by 2030

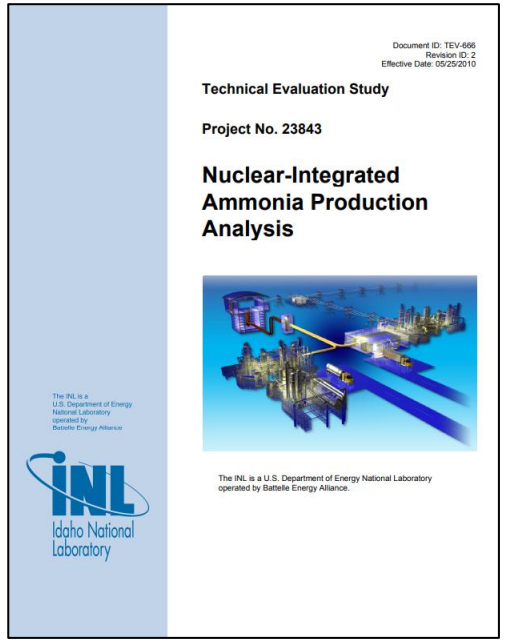




[1] https://www.mdpi.com/1996-1073/14/13/3772

Nuclear-based ammonia

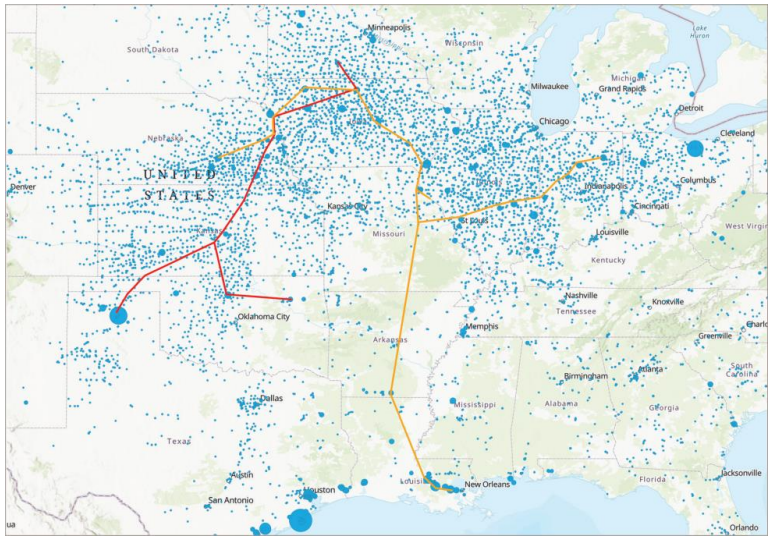
- Nuclear as zero carbon energy alternative for ammonia production
  - **Benefits**: constant electricity supply (baseload)
  - Not frequently discussed in 1.5°C scenarios for ammonia production
- **Reports in literature**: mainly focus on nuclear hydrogen
  - '*Nuclear-Integrated Ammonia Production Analysis*' (Idaho NL) [1]
- **Whitepaper**: '*Nuclear-based ammonia production*' (AEA)
  - Assessment of nuclear energy coupled with ammonia synthesis



[1] https://art.inl.gov/NGNP/NEAC%202010/INL_NGNP%20References/TEV-666%20Nuclear-Integrated%20Ammonia%20Prod.pdf

Nuclear-based ammonia

- **1980s**: first mentions of nuclear ammonia in wake of oil crises [1]
  - Nuclear reactors to power alkaline electrolysis for hydrogen production
  - Hydrogen combined with nitrogen to form ammonia via **Haber-Bosch process**
  - Ammonia transport via pipeline throughout the USA (currently >3000 km)
- Did not come to fruition because of low cost of fossil fuels
- **Today**: CO_2 taxation & decreasing cost of solar & wind, advanced nuclear reactors



[1] https://www.sciencedirect.com/science/article/abs/pii/0360319982901288

Coupling nuclear with ammonia synthesis

	Conventional nuclear reactor	Ammonia plant
Time to build (average)	7.5 years	3 years
Size range	1000 MW	20-700 MW
Cost	70 USD/MWh (electricity market)	40-60 USD/MWh (fertilizer/fuel)
Safety	Depends on whether integrated on same site	

We need smaller, lower CAPEX nuclear plants, e.g. small modular reactors or long term operation

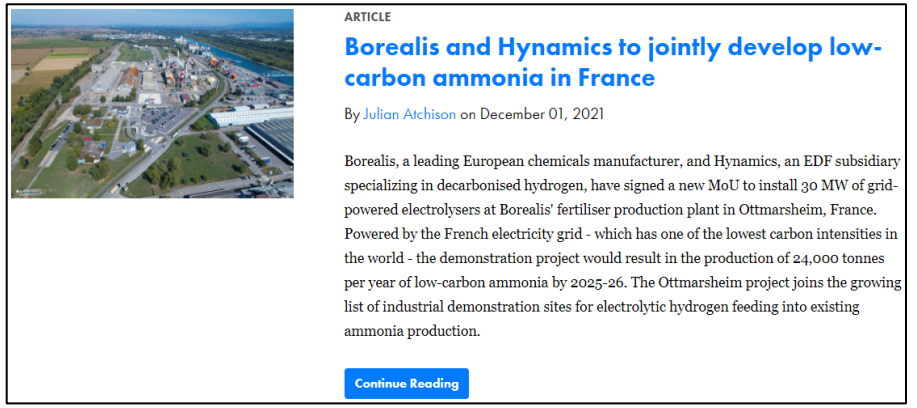
…combined with steam electrolysis (less energy consumption = lower ammonia cost)

…combined with solar PV, wind (pink/green ammonia)

… and we need demonstrations with current technology!

Ottmarsheim (France) (TRL 7)
30 MW, grid-connected electrolysis

71% of French electricity from nuclear



[1] https://www.iea.org/reports/projected-costs-of-generating-electricity-2020
[2] https://art.inl.gov/NGNP/NEAC%202010/INL_NGNP%20References/TEV-666%20Nuclear-Integrated%20Ammonia%20Prod.pdf
[3] https://www.ammoniaenergy.org/articles/borealis-and-hynamics-to-jointly-develop-low-carbon-ammonia-in-france

Thank you for your attention!