

Clean Ammonia

Enabling an Accelerated and Affordable Clean Hydrogen Future - Fossil Energy Sector's Role. An NETL-GTI Workshop – September 27-28, 2021

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Ammonia Energy Association

A global industry association that advocates for the responsible use of ammonia in a sustainable energy economy.

Supply: decarbonize ammonia production.
Demand: adopt ammonia in energy markets.



Ammonia Energy Association



MEMBER LIST — September 2021

* indicates representation on Board of Directors

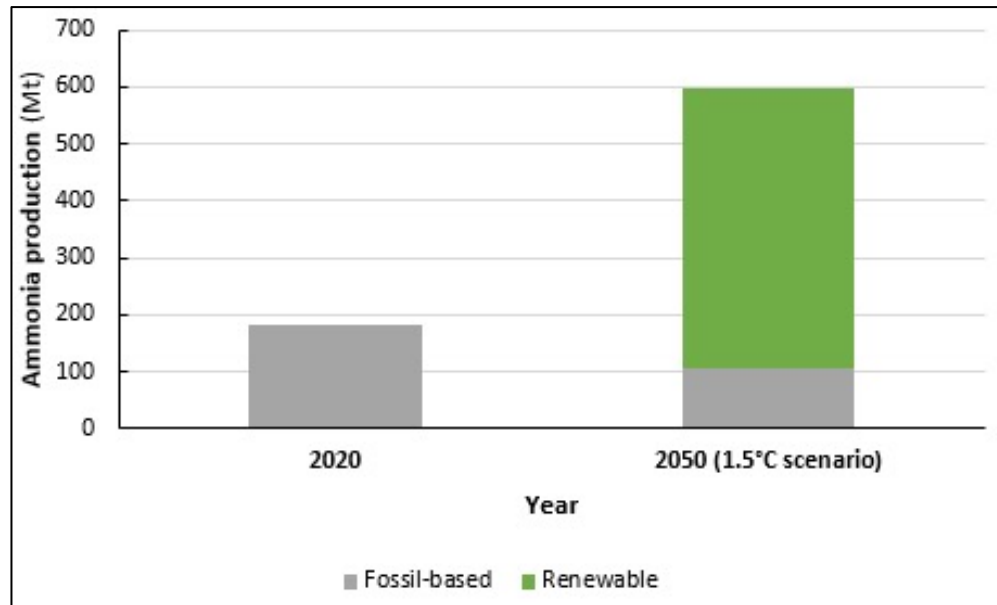
PLATINUM: CF Industries*, The Hydrogen Utility*, InterContinental Energy*, KBR*, LSB Industries, Monolith Materials, Mitsui & Co., Nutrien*, OCI*, Yara*. **GOLD:** Acron, AFC Energy, Airgas, Aker Clean Hydrogen, Asian Renewable Energy Hub, Casale*, Enaex, Engie, Equinor, Fortescue Future Industries, FuelPositive, Haldor Topsøe*, Hamilton Locke, Hydrofuel, Mitsubishi Heavy Industries, Origin Energy*, Proton Ventures*, Ridley Terminals, Starfire Energy*, Syzygy Plasmonics, thyssenkrupp Industrial Solutions*, Trammo, Tri-State Generation & Transmission. **SILVER:** AES Gener, Air Products, Ammonig, AmmPower, Amogy, Argus Media, BASF, Black & Veatch, Bureau Veritas, Burns & McDonnell, Casa dos Ventos, CDI Engineering, Consorcio Eólico, CRU Group, Cummins, EIFER, Enterprize Energy, Fertiberia, GenCell Energy, GTI, Gunvor Group*, H2Site, Horisont Energi, HyFuels Holdings, Intecsa Industrial, Linde, Lotte Fine Chemical, Maersk*, Mercuria, MineARC Systems, Nel Hydrogen*, OGS Global, Organics Group, Pacific Green Technologies, SagaPure*, Schoeller-Bleckmann Nitec, Shell, Sperre Industri, Stamicarbon, Thorium Energy Alliance*, TotalEnergies*, Tsubame BHB, Wabash Valley Resources, Wonik Materials, Woodside Energy. **MEMBERS:** AHMON, Air Liquide, Airthium, Apex Clean Energy, Ark Energy, Arizona Public Service, Arranged, AustriaEnergy, 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, MAN Energy Solutions, MicroEra Power*, Nebraska Public Power District, Netsco, New Energy Technology, Nordex, Northern Nitrogen, NYK Energy Transport (USA), Oceanic Vessels, Osaka Gas USA, Renewable Hydrogen Corporation Canada, SAFCell, SBM Schiedam, Syntex, Terrestrial Energy, UPC\AC Renewables, Varo Energy, Vopak.



Ammonia Supply and Demand

According to IRENA, by 2050 in a 1.5° scenario:

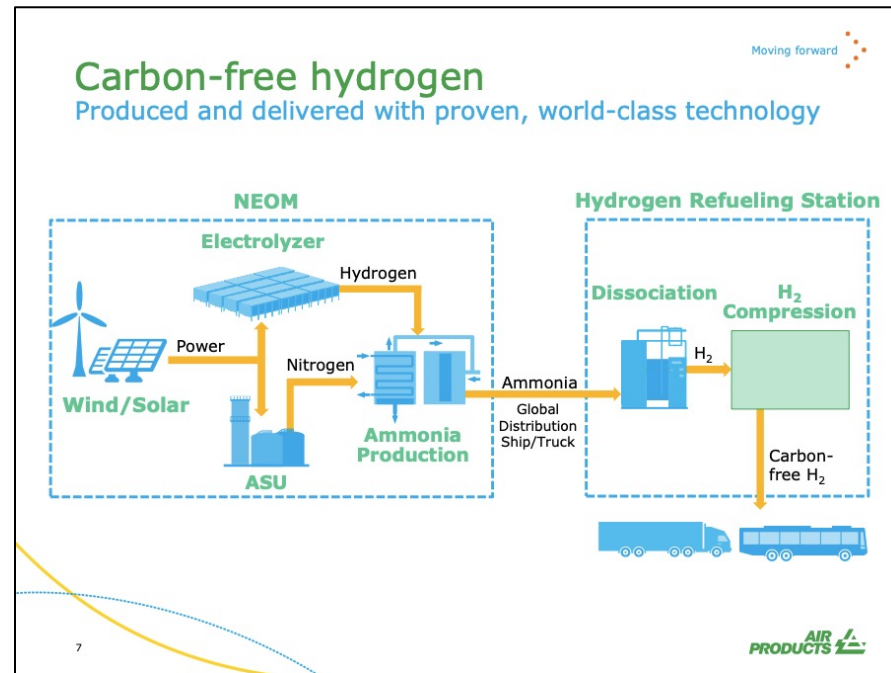
- ~70 million tonnes existing ammonia capacity shut down or converted from fossil to renewable inputs
- ~500 million tonnes new ammonia capacity developed using renewable inputs (electricity, biomass)



IRENA (Gielen and Saygin), “Zero-Emission Pathway for the Global Chemical and Petrochemical Sector,” *Energies* 2021, 14(13), 3772;
<https://doi.org/10.3390/en14133772> (chart by Kevin Rouwenhorst)

Ammonia as a Hydrogen Carrier

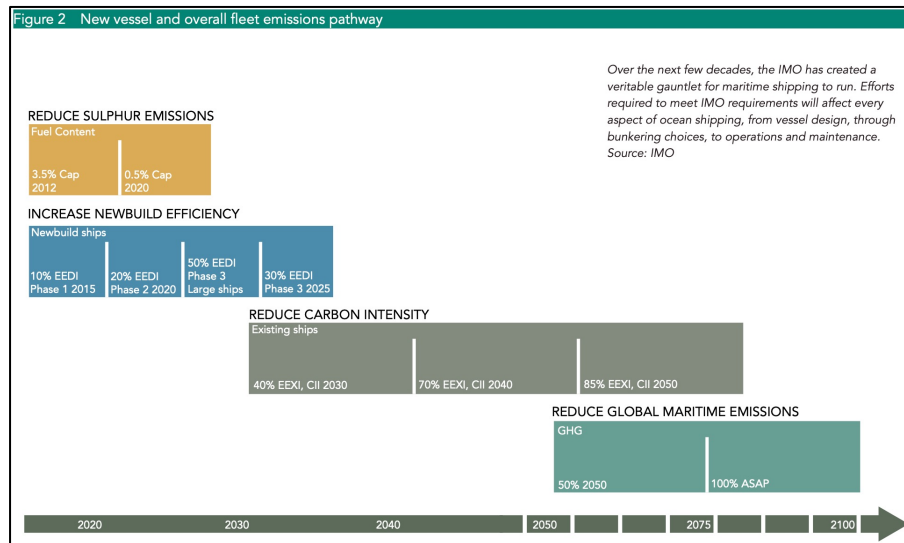
- Ammonia (NH_3) is 17.8% Hydrogen
- Liquid at -33°C (vs. -253°C)
- 50% more H_2 than H_2 (volumetric)
- Ammonia pipelines: 1/2 cost of natural gas, 1/4 cost of hydrogen
- Ammonia tanks:
60,000 tonne tank holds 90 GWh
(largest battery on Earth: 0.129 GWh)
- Ammonia cracking: energy penalty, but competitive for long-duration / long-distance hydrogen transport



Air Products investor presentation, "Carbon-Free Hydrogen: The Energy Source of the Future," July 07, 2020 <http://investors.airproducts.com/static-files/b0595961-b2ac-45ff-89c5-7d9d8837a363>

Ammonia for Maritime Fuel

- IMO: Initial GHG Strategy, 2018
- Reductions in carbon intensity for existing fleet (CO₂e/ton-km):
 - 40% by 2030
 - 70% by 2040
 - 85% by 2050
- COP26 Climate Champions / GTZ: Zero-carbon molecules are 5% of fuel mix by 2030: (60 GW electrolyzers, 30 million tonnes ammonia)
- Ammonia / LPG gas carriers represent ~2% of fuel mix



New vessel and overall fleet emissions pathway. Carbon-Neutral Consulting:
“The Ammonia Report,” February 2021 <https://carbonneutralconsulting.com>

Ammonia for Electric Power

Japan — METI Road Map:

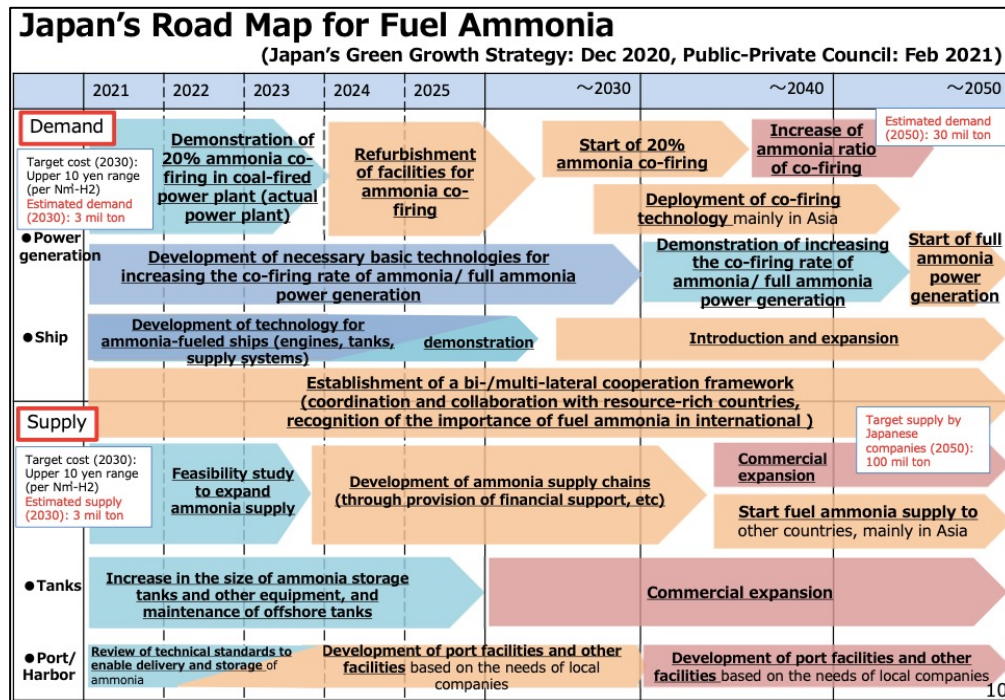
- Ammonia-coal co-combustion:
3 million tonnes by 2030
- Ammonia turbine:
30 million tonnes domestic, but
100 million tonnes regional
demand by 2050

JERA and IHI Corporation:

- Co-combustion began Aug 2021

Mitsubishi Power:

- 40 MW ammonia gas turbine
- Low NO_x, available ~2025



METI, Fuel Ammonia Road Map, February 2021,

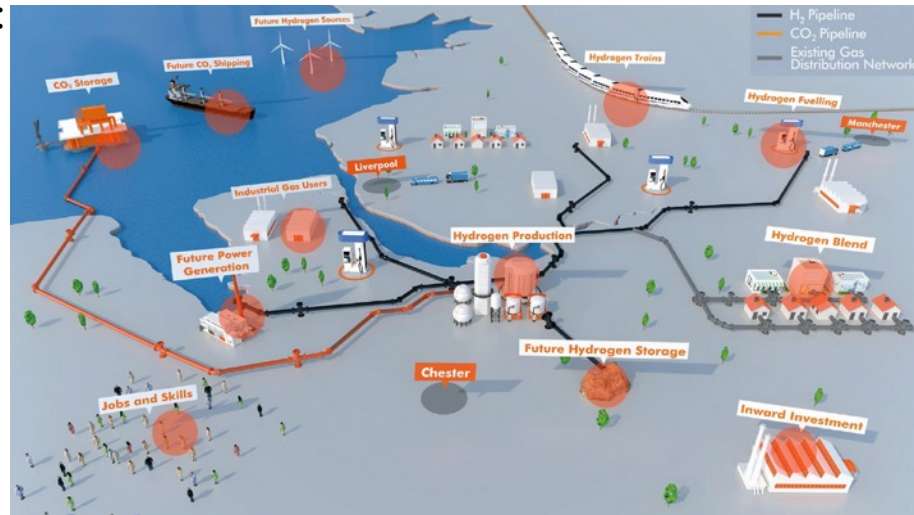
<https://www.ammoniaenergy.org/articles/japans-road-map-for-fuel-ammonia/>

Ammonia Revamps — Carbon Exports

Announced projects (low-carbon capacity):

- CF, Ince: ~200,000 tonnes ammonia
- CF, Billingham: ~400,000 tonnes
- OCI, Beaumont: 365,000 tonnes
- ADNOC, Ruwais: ~1 million tonnes
- PAU, Sulawesi: ~660,000 tonnes
- SAFCO, Jubail: ~1 million tonnes
- Nutrien, Redwater: ~250,000 tonnes
- Nutrien, Geismar: ~200,000 tonnes

Definitions and thresholds are required:
these volumes are not equally low-carbon.



HyNet North West project map (including CF Ince), <https://hynet.co.uk>
CF Fertilisers press release, “CF Fertilisers Welcomes Carbon Capture and Storage (CCS) Funding Related to Hynet North West Project,” March 2021, <https://www.cffertilisers.co.uk/media-centre/news/cf-fertilisers-welcomes-carbon-capture-and-storage-ccs-funding-related-to-hynet-north-west-project/>

Low-Carbon Ammonia Certification

AEA is facilitating the development of a Low-Carbon Ammonia Certification Scheme.

- Absolute emission intensity (LCA) of ammonia
- Boundaries:
 - well-to-gate (scopes 1, 2, and upstream 3)
 - extendable well-to-tank or -wheel/wake
- Production pathways defined and explicit
- International, cross-sectoral harmonized framework
- Aim: pilot certification in 2023, operational in 2024
- Provide your input:
 - [ammoniaenergy.org/certification/](https://www.ammoniaenergy.org/certification/)
 - certification@ammoniaenergy.org



Ammonia Energy Association, Low-Carbon Ammonia Certification Scheme, public consultation phase: discussion paper and survey.
<https://www.ammoniaenergy.org/certification/>