

Ammonia: the other hydrogen

Energy Storage for Manufacturing and Industrial Decarbonization Workshop

“Energy StorM”

February 9, 2022

Trevor Brown, tbrown@ammoniaenergy.org
Executive Director, Ammonia Energy Association



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.

Members: global and cross-sectoral



Ammonia Energy Association

MEMBER LIST — February 2022

* indicates representation on Board of Directors

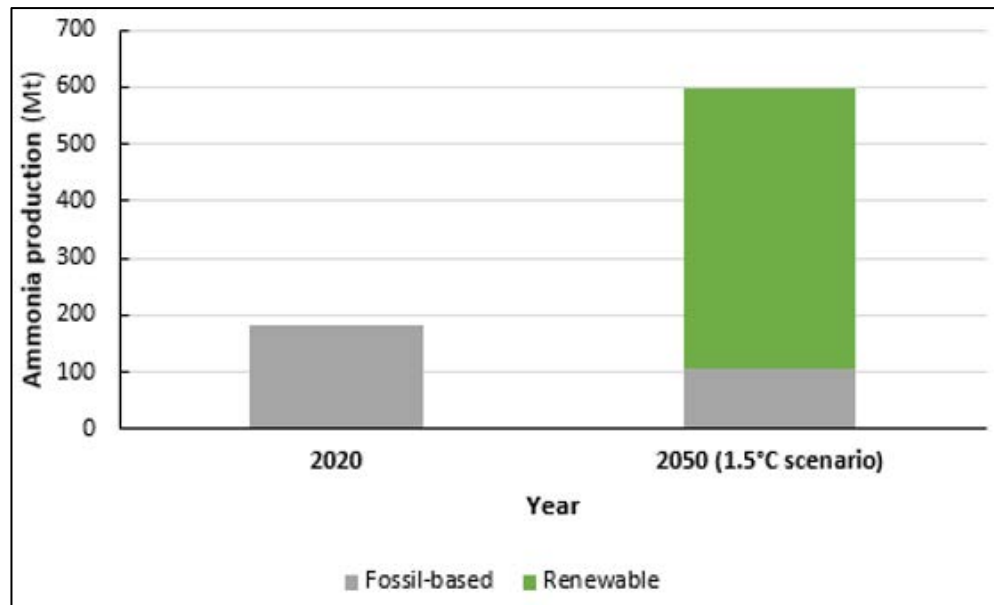
PLATINUM: bp, CF Industries*, CWP Global, Denbury, The Hydrogen Utility*, InterContinental Energy*, KBR*, LSB Industries, Mitsui & Co., Monolith Materials, Nutrien*, OCI*, Starfire Energy*, Yara*. **GOLD:** Acron, AFC Energy, Airgas, Aker Clean Hydrogen, Asian Renewable Energy Hub, Casale*, Enaex, Engie, Equinor, Fortescue Future Industries, FuelPositive, Haldor Topsoe*, 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, Intesa 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 Supply and Demand

IRENA says by 2050 (1.5° scenario):

- ~70 Mt (million tonnes) existing capacity shut down or converted from fossil to renewable inputs
- ~500 Mt new capacity with 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 for Fertilizers, etc

Ammonia is NH_3 , 82.2%wt nitrogen

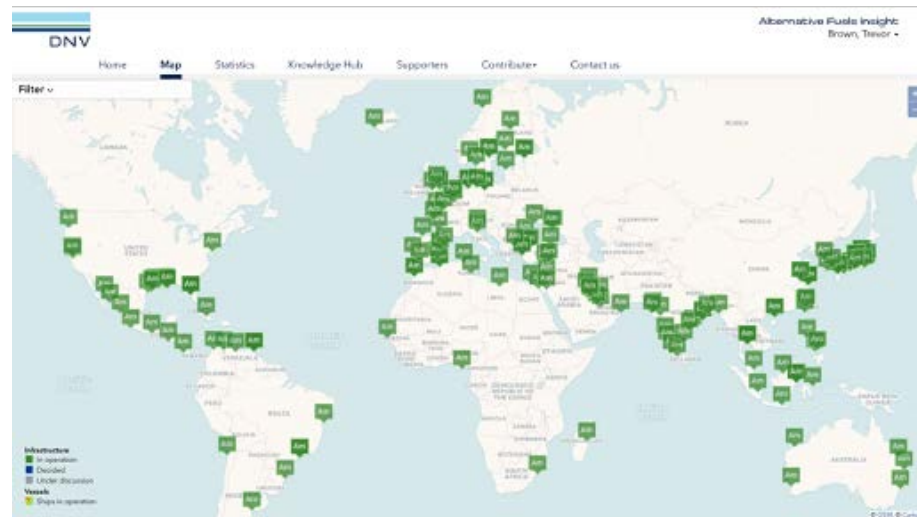
- U.S. produces 14 Mt, and imports 2 Mt
- Most upgraded to urea, AN, UAN, etc
- >10,000 ammonia storage sites in U.S.
- 20% of market is industrial: de NO_x , chemicals (eg, melamine, acrylonitrile), wastewater treatment, explosives (AN), metals refining, refrigeration, pharmaceutical, electronics.



Ammonia storage and distribution networks in the U.S., Royal Society policy briefing, “Ammonia: zero-carbon fertiliser, fuel and energy store,” February 2020, <http://royalsociety.org/green-ammonia>

Ammonia for Fertilizers, etc

- Global production: 180 Mt
- International trade: 18 Mt
- 196 ports with infrastructure for bunkering (import/export terminals)
- 150 years of safety knowhow, codes and standards, regulations, technologies, training.

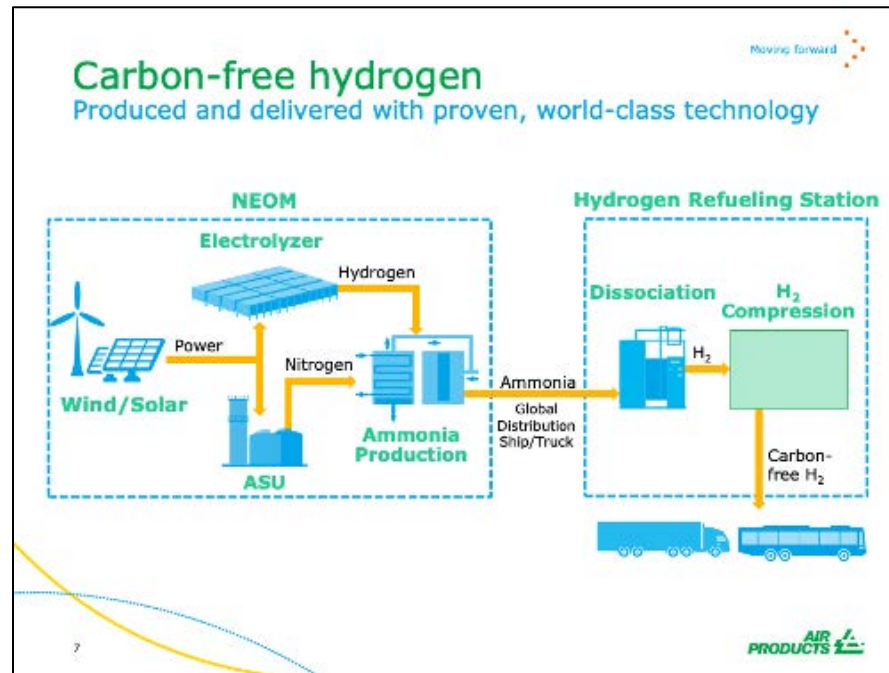


Global operational ammonia terminals (import/export tanks and infrastructure), DNV GL's Alternative Fuel Insight platform, <https://afi.dnvgl.com/Map>

Ammonia as a Hydrogen Carrier

Ammonia is NH_3 , 17.8%wt Hydrogen

- Liquid at -33°C (vs. -253°C)
- Energy density = 5.2 MWh/ton
- 50% more H than H_2 (volumetric)
- Ammonia pipelines: relative cost 0.5x natural gas, 0.25x hydrogen
- Ammonia tanks:
30,000 tonne tank holds 156 GWh
(largest battery on Earth: 130 MWh)
- Ammonia: useful for moving energy through time and space at scale



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 as a Hydrogen Carrier

Uniper — “Green Wilhelmshaven”

- Coal-fired power plant to be converted to an ammonia import terminal & cracker
- 295,000 tpy hydrogen / 1.6M tpy ammonia
- 10% of German hydrogen demand in 2030



Uniper — “Hyport”

- Offtake agreement with OQ and Deme for renewable ammonia from Oman
- 250 MW wind+solar, operational by 2026
- Future expansion to 1.3 GW

Uniper press release, “Uniper Plans to Make Wilhelmshaven a Hub for Climate friendly Hydrogen,” April 2021,
<https://www.uniper.energy/news/uniper-plans-to-make-wilhelmshaven-a-hub-for-climate-friendly-hydrogen>

Uniper press release, “HYPORT® Duqm signs cooperation agreement with Uniper to explore green ammonia offtake,” July 2021,
<https://www.uniper.energy/news/hyport-duqm-signs-cooperation-agreement-with-uniper-to-explore-green-ammonia-offtake>

Ammonia for Maritime Fuel

New ammonia vessel announcements every week:

- July 14: Wärtsilä completes full-scale tests, low emission engine to be available 2023.
- July 21: MAN 2-stroke engine to be demonstrated in three vessels by 2025: oil tanker, container ship, ferry.
- July 29, 2021: Nutrien and Exmar: deploy ammonia carrier vessel by 2025, ammonia fuel from Geismar.
- July 29, 2021: CF Industries, Nutrien, Yara, TotalEnergies, ABS, etc: 34 corporations in Joint Study Framework led by Itochu in Singapore.

See: <https://www.wartsila.com/media/news/14-07-2021-wartsila-launches-major-test-programme-towards-carbon-free-solutions-with-hydrogen-and-ammonia-2953362>,
<https://www.ammoniaenergy.org/articles/engimmonia-project-gets-eu-funding/>,
<https://www.nutrien.com/investors/news-releases/2021-nutrien-and-exmar-partner-building-vessel-powered-low-carbon-ammonia>, <https://www.itochu.co.jp/en/news/news/2021/210729.html>

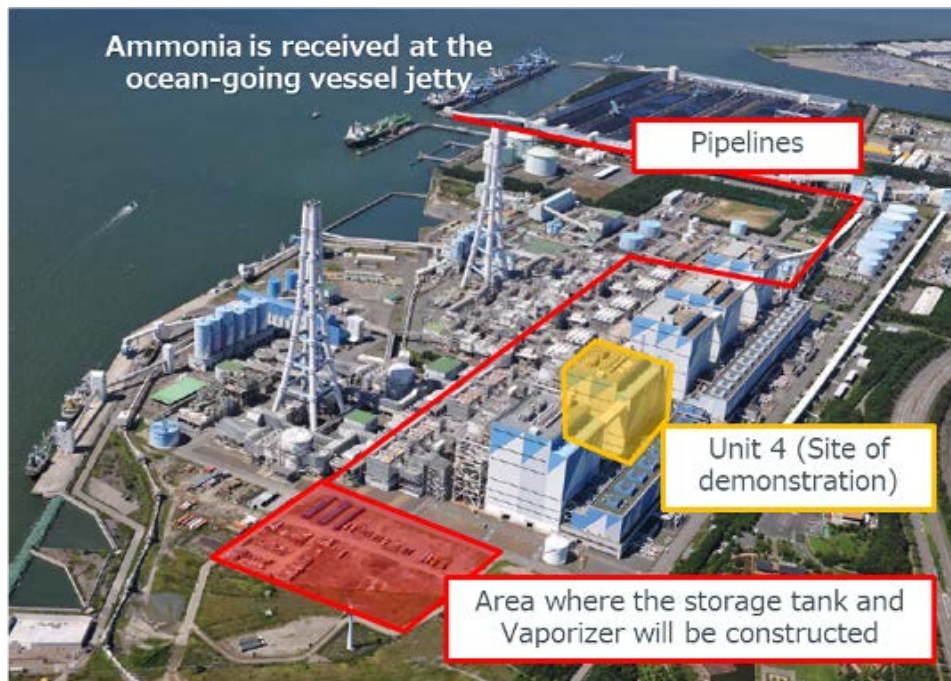


Wärtsilä Marine LinkedIn post, October 2021,
https://www.linkedin.com/posts/wartsila-marine_destinationdecarbonisation-decarbonisation-activity-6853968217510170625-40Iu

Ammonia for Electric Power

JERA and IHI Corporation:

- Ammonia/coal co-combustion tests: August to December 2021
- 2024: 1 GW-scale demonstration
- 20% ammonia by energy content, later increasing to 50%.
- ~500,000 tpy fuel ammonia for each generating unit



JERA press release, “JERA and IHI to Start a Demonstration Project Related to Ammonia Co-firing at a Large-Scale Commercial Coal-Fired Power Plant,” May 2021, https://www.jera.co.jp/english/information/20210524_677

Ammonia for Electric Power

Mitsubishi Power: 40 MW ammonia gas turbine

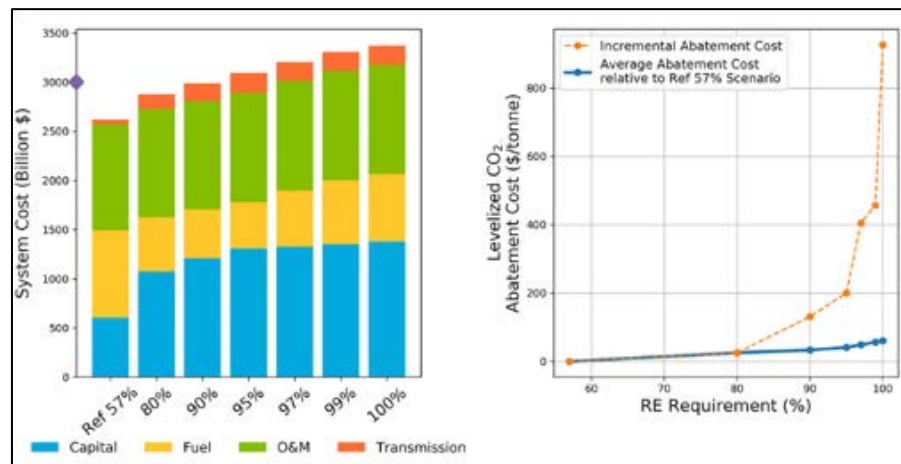
- Commercialization ~2025
- Direct combustion of ammonia
- Low NO_x combustor + SCR



Mitsubishi Power press release, “Mitsubishi Power Commences Development of World’s First Ammonia-fired 40MW Class Gas Turbine System,” March 2021,
<https://power.mhi.com/news/20210301.html>

Ammonia for Electric Power

- Energy importers (Japan, Korea, EU): “electrify everything” is inefficient, direct use of molecules is preferable.
- Energy exporters (Mid East, Russia, U.S.), domestic role for molecules is barely considered in electricity system.
- Sector coupling ignored.
- Resilient, 100% carbon-free grid requires carbon-free molecules.
- Despite relatively high capital cost (low capacity factor), ammonia enables lowest 100% carbon-free LCOE



Cole et al., Quantifying the challenge of reaching a 100% renewable energy power system for the United States, Joule (2021), <https://doi.org/10.1016/j.joule.2021.05.011>

Ammonia New Builds — Mega-Ammonia

Announced projects (ammonia and power capacity):

- AREH (Australia): 9.9 Mt, 26 GW (FID 2025)
- Svevind (Kazakhstan): 15 Mt, 45 GW
- Aman (Mauritania): <20 Mt, 30 GW
- Al Wusta (Oman): <10 Mt, 15 GW
- WGEH (Australia): 20 Mt, 50 GW
- Grand Inga Dam (DRC): >20 Mt, 40 GW
- SAREH (Saudi Arabia): ~10 Mt, 15 GW

“Oil & Gas scale” green ammonia by 2035:

- >100 million tons per year
- >200 GW wind+solar or hydro



Asian Renewable Energy Hub site map, Western Australia EPA, Report and recommendations of the Environmental Protection Authority, April 2020,
<https://www.ammoniaenergy.org/articles/green-ammonia-at-oil-and-gas-scale-the-15-gw-asian-renewable-energy-hub/>