Knowledge grows

Ammonia – zero carbon shipping fuel?

November 2019

Agenda

Yara – past, present and future

Green fertilizer production; ammonia is the building block

Ammonia as clean energy and shipping fuel

Yara – past, present and future


The power of one idea
Yara was there, asking brave questions and boldly collaborating to solve this human challenge.
Extract Nitrogen from the air.
The actions of our three remarkable founders saved lives, fed millions, and helped farmers create profitable businesses.
1905

Mission

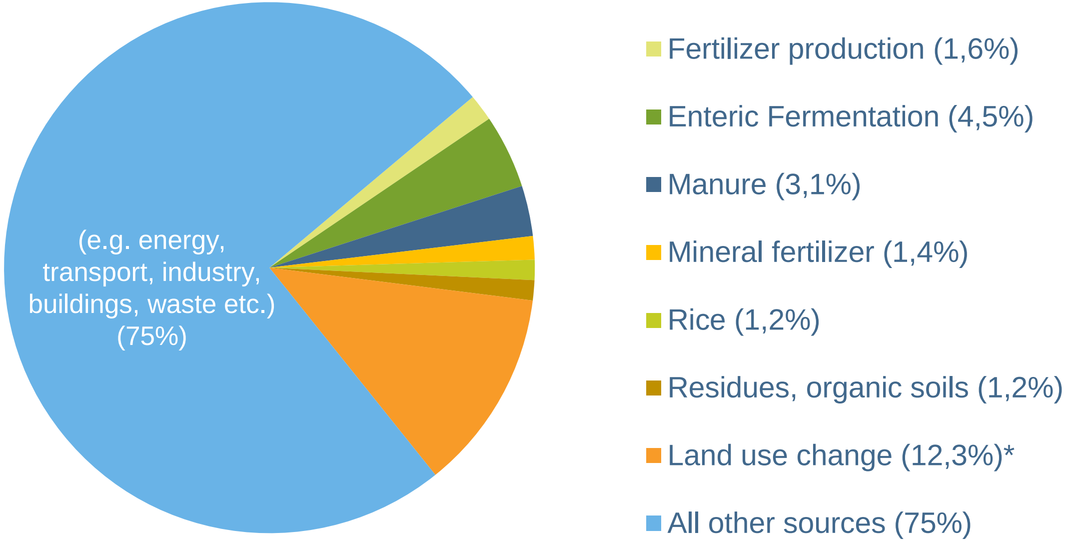
*Responsibly feed the world
and protect the planet*

Vision

*A collaborative society;
a world without hunger;
a planet respected.*

Contribution of the agricultural sector and land use change to global GHG emissions

Total: 49 Billion t CO_2-equivalents



The solution

- Carbon neutral production
- Circular economy
- Digital solutions
- Farmer practice
- Logistics and ammonia energy

Based Source: IPCC 2014 Climate change synthesis and AFOLU reports, FAOSTAT, IFA,
* Emissions only, no sinks such as afforestation considered

Our Ambition: towards climate neutrality

Yara's total greenhouse gas emissions halved by almost eliminating N_2O

Past 15 years

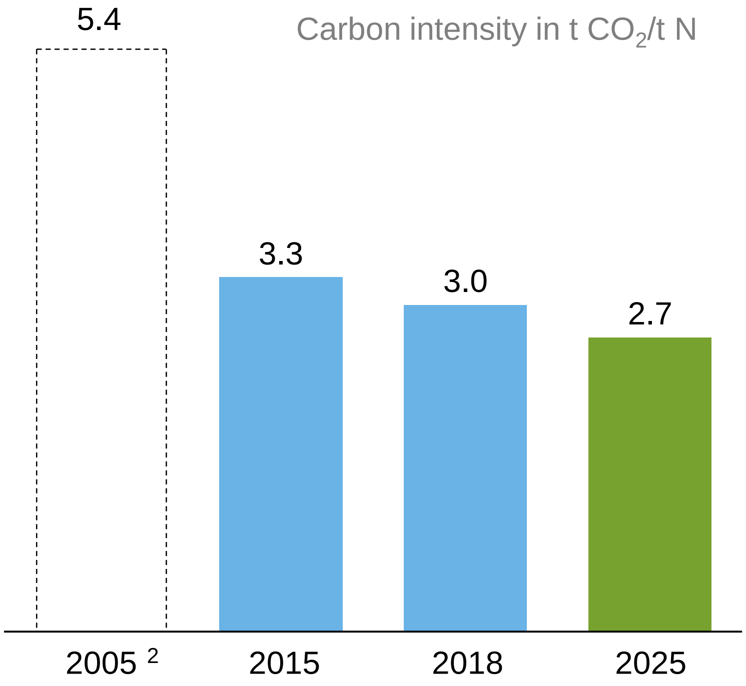
Further improving on world leading performance by CO_2 reduction target

Present

Ambition to become climate neutral by 2050

Future

Investing to reach CO_2 intensity reduction target in 2025 represent positive business cases for Yara



Our ambition:

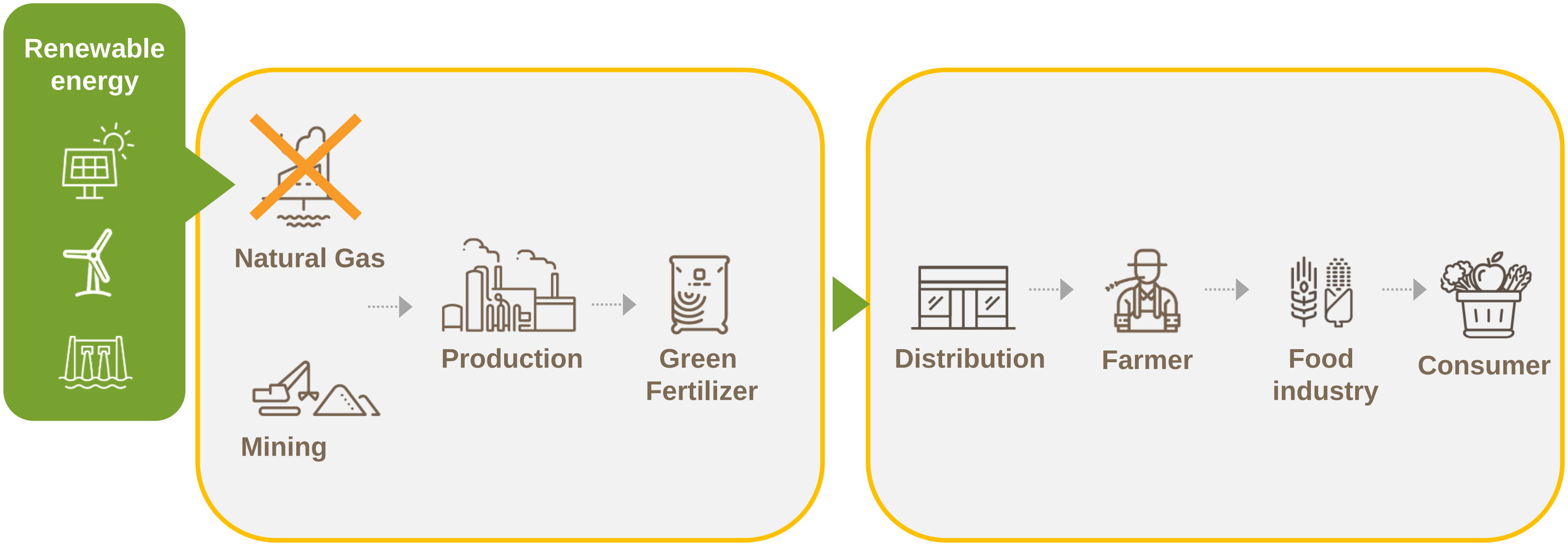
10% reduction[1] in CO_2eq intensity by 2025

- 2025 target reflects GHG emissions already considerably reduced from 2005
- Lower emissions improve our cost position
- Positive business cases; 200-450 MUSD capex required
- Supports our ambition to become climate neutral by 2050

[1] From 2018 base [2] Estimated based on historical data

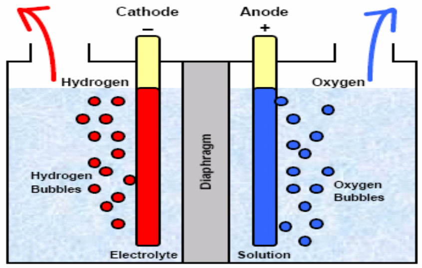
Green fertilizer production; ammonia is the building block

Yara aim to contribute to a fossil free food value chain by re-introducing renewable energy based fertilizer production

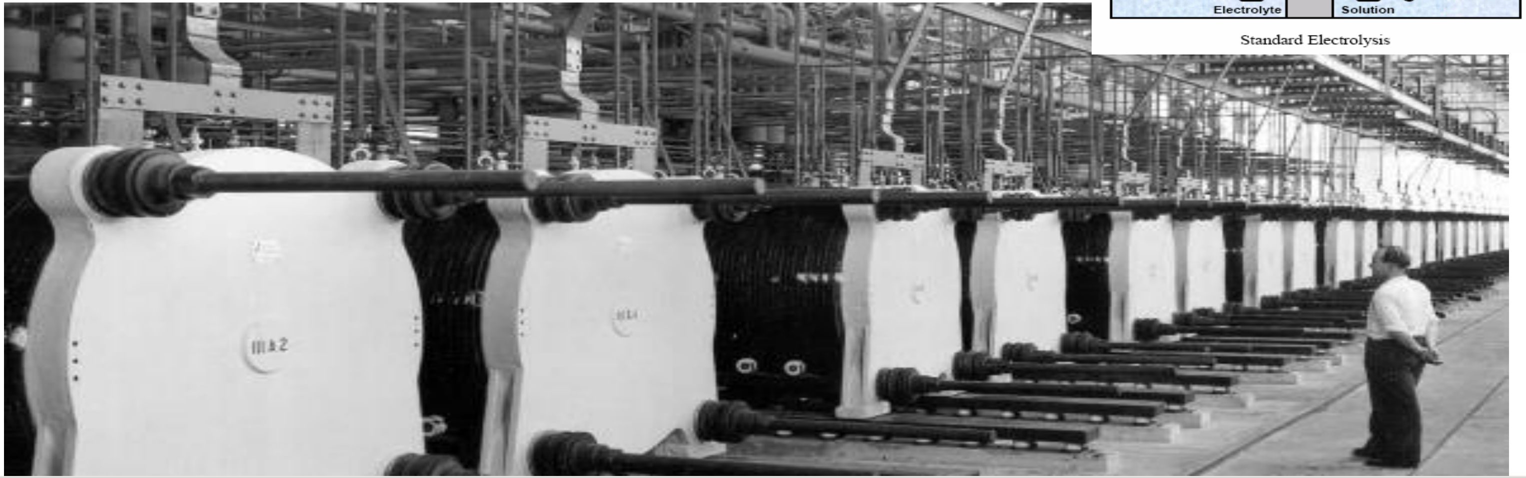


“Green” fertilizer production based on electrolytic H_2 production ~~is~~ was well established…

Notodden	1927 - 1968
Rjukan	1929 - 1971
Glomfjord	1953 - 1991

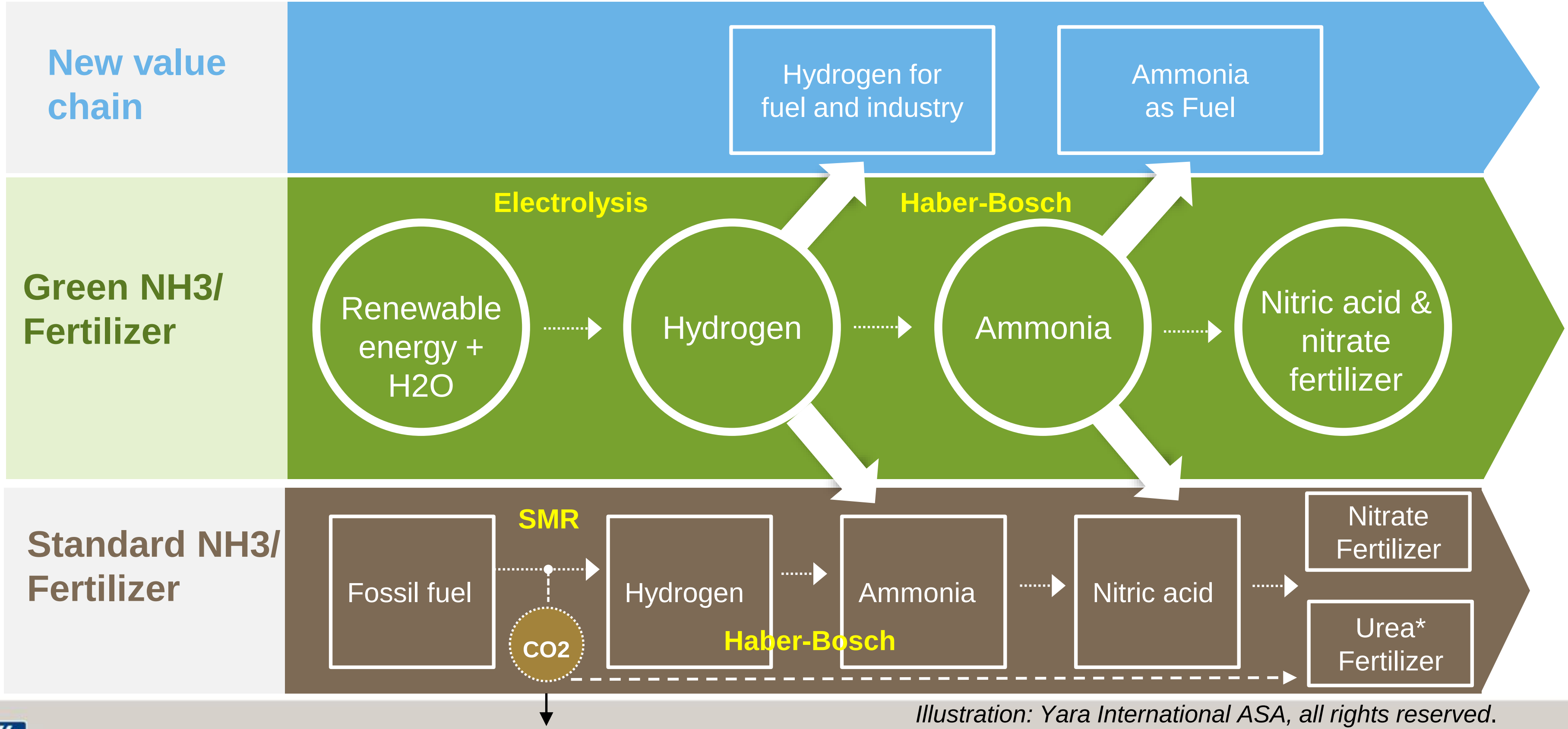


Standard Electrolysis



Green ammonia https://vimeo.com/302819360/9edaadd189

A Green Transformation via Hydrogen & Ammonia to Fertilizer



* To produce zero-carbon urea, green ammonia to be recombined with carbon-negative CO_2

First steps are taken, in cooperation with full value chain

News

Yara and Lantmännen lead the way towards world's first fossil free food chain

Yara an Lantmännen take a pioneering role in transforming the food system. A pilot project with the ambition to introduce the world's first certified fossil free food chain w...

Yara and ENGIE to test green hydrogen technology in fertilizer production

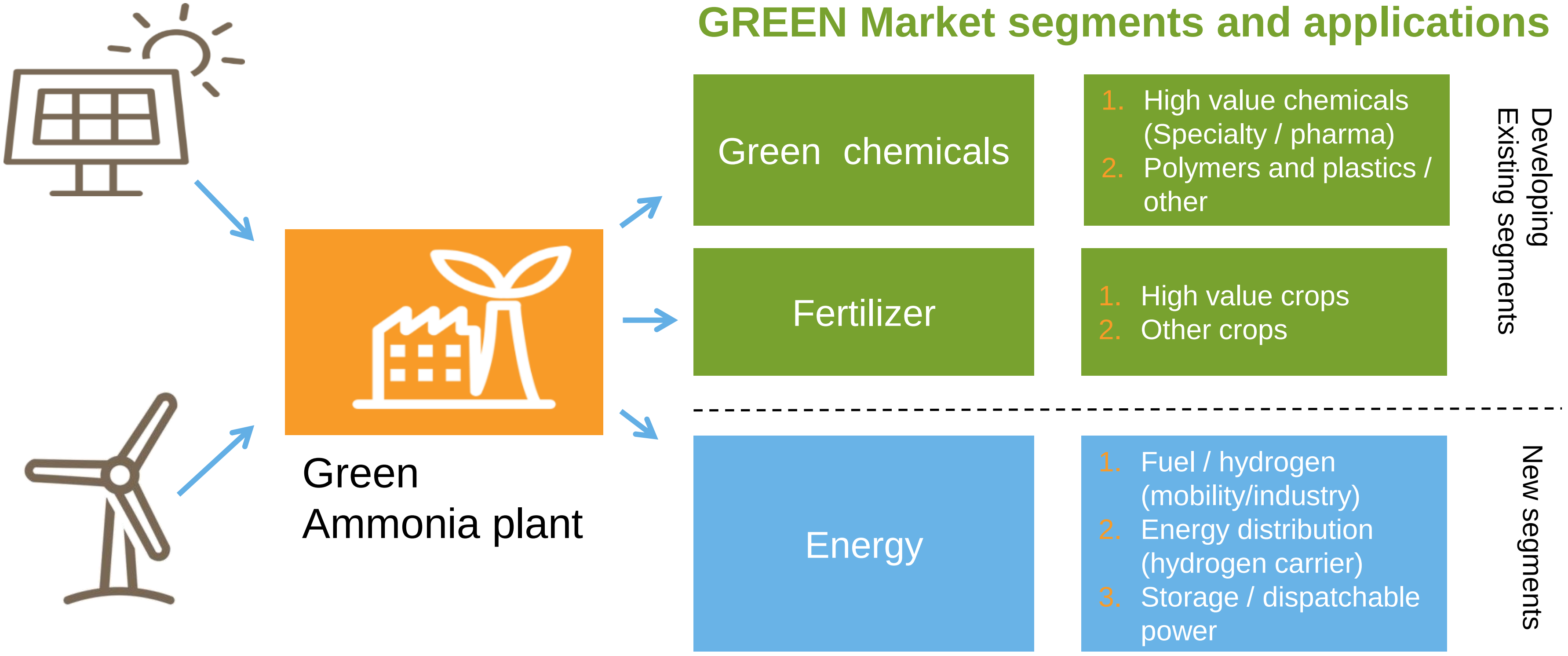
Yara and Nel collaborate to reduce electrolyzer costs; announce green ammonia pilot in Norway by 2022

by Trevor Brown **AUGUST 23, 2019**

This week, two Norwegian companies, fertilizer producer Yara and electrolyzer manufacturer Nel, announced an agreement to test Nel's "next generation" alkaline electrolyzer at an ammonia production site. The parties expect to begin operating a 5 MW prototype in 2022, feeding green hydrogen directly into Yara's 500,000 ton per year ammonia plant at Porsgrunn.

YARA

Yara explores the value potential from green ammonia in different value chains



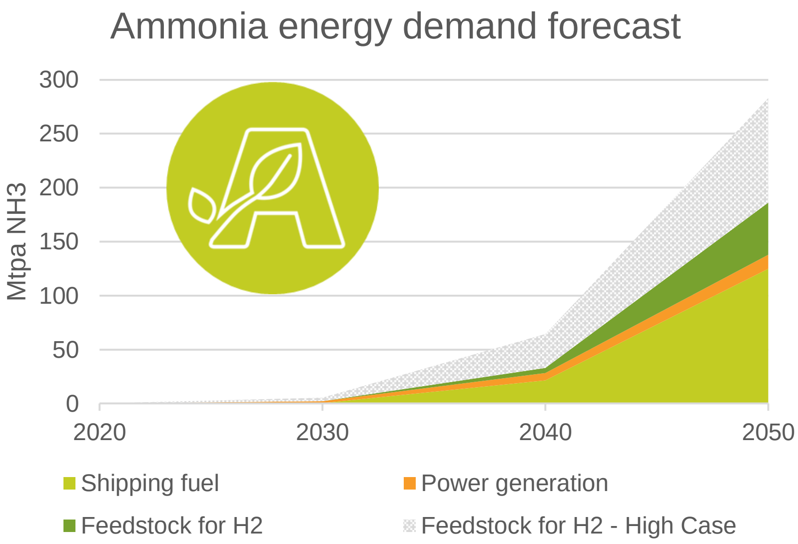
Ammonia as clean energy and shipping fuel

Clean Energy could double the global demand for ammonia

- Ammonia Energy is receiving increasing attention and can shift the ammonia market

AMMONIA ENERGY ASSOCIATION

- **Power generation**
  - E.g. Japan aims to co-fire power plants with ammonia
- **Shipping fuel**
  - Ammonia can constitute 25% of marine fuels by 2050 (DNV-GL)
- **H2 carrier**
  - Ammonia as energy storage and transport vector (H2 economy) can emerge as deep decarbonization begins



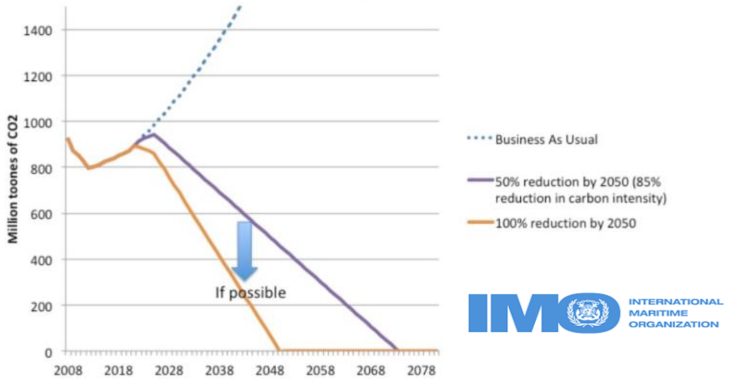
* Lloyd's/Umas/IMO/DNVGL/IEA etc

The shipping sector aims to decarbonize – zero carbon fuels are needed and ammonia is increasingly recognized as the best zero emission fuel

- IMO strategy (2018): 50% GHG emission cuts by 2050
- Norwegian parliament has ratified a resolution to make world heritage fjords zero emission already by 2026
- The shipping sector has since the launch of the IMO strategy strongly accelerated the search for decarbonized solutions

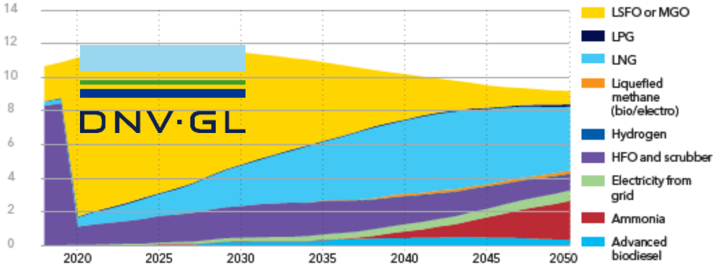
- DNV-GL is forecasting 35% of marine fuels to be carbon neutral in 2050; of which 25%-points will be NH3

Pathways for international shipping's CO2 emissions



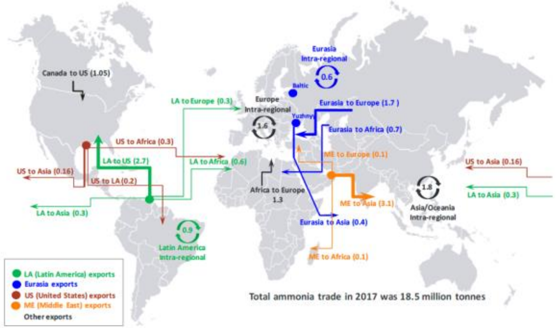
Energy use and projected fuel mix 2018-2050 for the simulated IMO ambitions pathway with main focus on design requirements

Units: EJ/yr



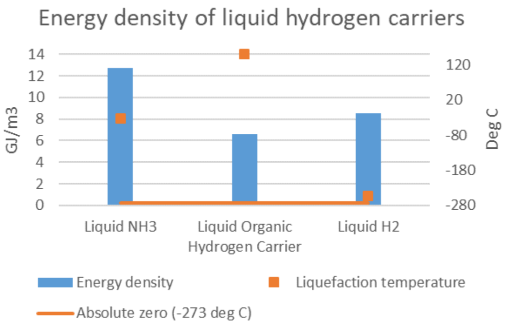
Yara is the world's largest player in ammonia trading and shipping and holds best practice in production and handling

- Out of a globally traded NH3 volume of 20 Mtn/yr, Yara holds about 25% of the market
- Yara has a fleet of 12 ammonia carriers operating globally
- Yara's base chemicals unit serves industrial customers with ammonia for different applications across Europe, by truck, rail and barge
- Our footprint can give us a key role to take the lead in developing an ammonia fuel market for early movers



IEA points at ammonia as a mature and efficient hydrogen carrier

- Ammonia advantages:
  - High technology maturity
  - High energy efficiency
  - Existing infrastructure starting point
- Ammonia disadvantages:
  - Toxicity
  - Low hydrogen reconvertion purity



Selected properties of hydrogen carriers

		Liquid hydrogen	Ammonia	LOHC (MCH)
Process and technology maturity*	Conversion	Small scale: High Large scale: Low	High	Medium
	Tank storage	High	High	High
	Transport	Ship: Low Pipeline: High Truck: High	Ship: High Pipeline: High Truck: High	Ship: High Pipeline: High Truck: High
	Reconversion	High	Medium	Medium
	Supply chain integration	Medium/high	High	Medium
Hazards**		Flammable; no smell or flame visibility	Flammable; acute toxicity; precursor to air pollution; corrosive	Toluene: flammable; moderate toxicity. Other LOHCs can be safer.
Conversion and reconversion energy required***		Current: 25–35% Potential: 18%	Conversion: 7–18% Reconversion: < 20%	Current: 35–40% Potential: 25%
Technology improvements and scale-up needs		Production plant efficiency; boil-off management	Integration with flexible electrolysers; improved conversion efficiency; H_2 purification	Utilisation of conversion heat; reconversion efficiency
Selected organisations developing supply chain		HySTRA; CSIRO; Fortescue Metals Group; Air Liquide	Green Ammonia consortium; IHI Corporation; US Department of Energy	AHEAD; Chiyoda; Hydrogenious; Framatome; Clariant

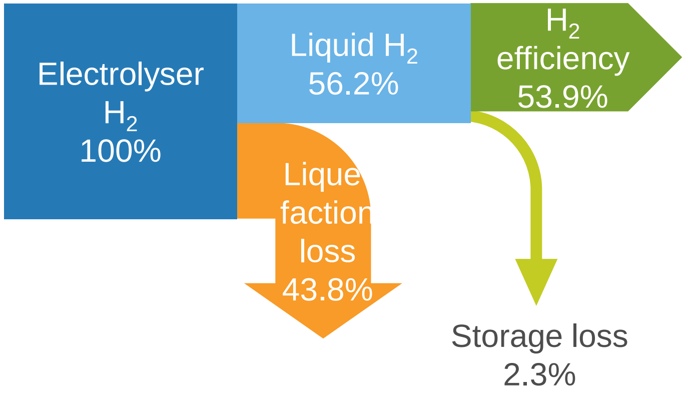
* High = proven and commercial; Medium = prototype demonstrated; Low = validated or under development; Small scale = < 5 tonnes per day; Large scale = > 100 tonnes per day.

** Toxicity criteria based on inhalation.

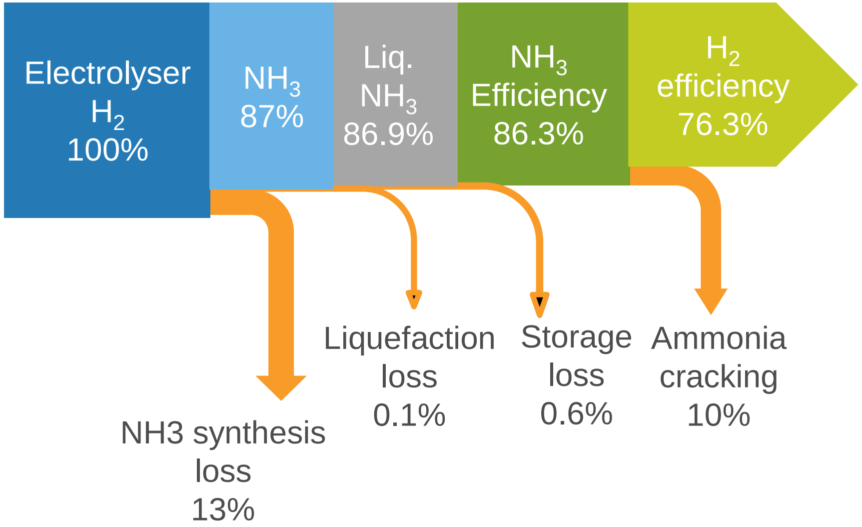
*** Given as a percentage of lower heating value of hydrogen; values are for hydrogen that could be used in fuel cells; lower-purity hydrogen would require less energy.

The ammonia fuel value chain is more energy efficient than the liquid hydrogen value chain

Hydrogen Liquefaction & Storage



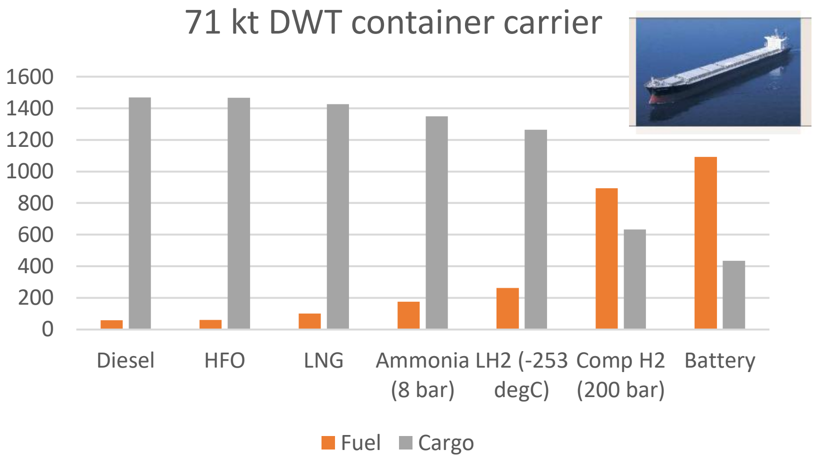
Ammonia Synthesis, Liquefaction & Storage



Ammonia use has a 15% loss, whilst liquid hydrogen has a loss of 46%, from H2 production to direct use at customer. When cracking ammonia back to hydrogen at the end-customer the ammonia loss would be 25% in total

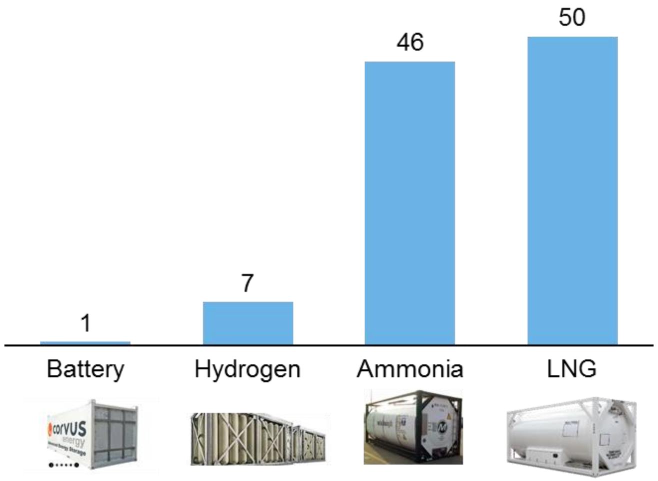
Ammonia has superior energy density compared to compressed H2 and batteries, and is a feasible option for deep sea shipping

- Compressed hydrogen and batteries is practically unfeasible for energy storage on deep sea cargo
- Could imply a loss of >50% of the storage volume of a 71kt container vessel
- Ammonia has 30%-40% higher volumetric energy density than liquid H2



- For smaller scale vessels, 20 feet ammonia containers offer a large energy storage
- Below a comparison of energy content of different 20'' container energy storage options

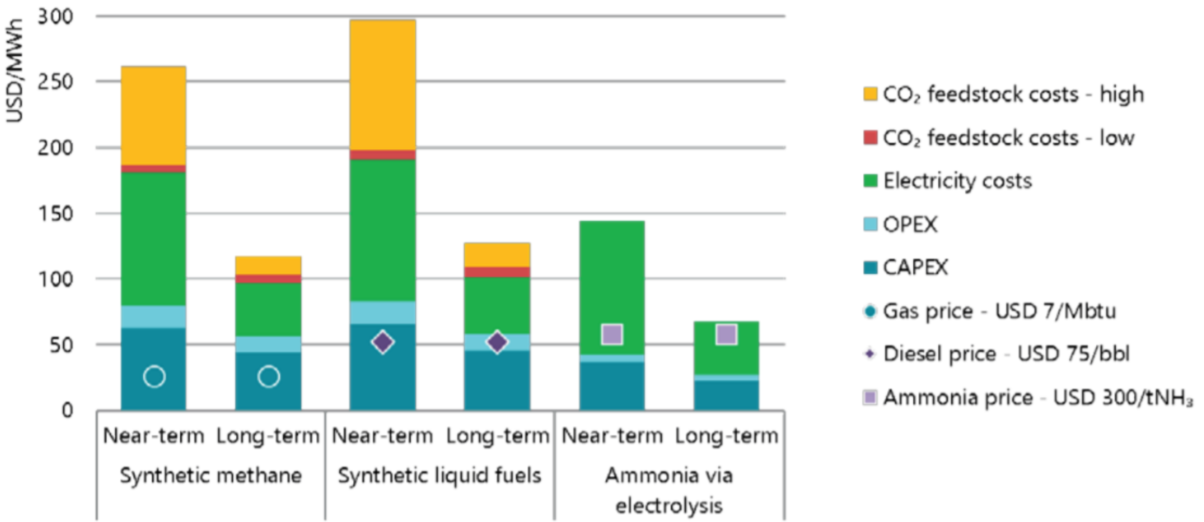
MWh available electric energy on vessel



Carbon based synthetic fuels are less energy efficient and face a challenge in accessing sustainable CO2 feedstock

- Synthetic methane, ethanol or other hydrocarbons have higher energy density and is simpler to handle than ammonia
- However, the production of these fuels will require more energy to produce than ammonia
- Production of such carbon based e-fuels will require a source of CO2, which will further drive cost and potentially compromise climate neutrality

Figure 22. Indicative production costs of electricity-based pathways in the near and long term



Notes: NH_3 = ammonia.; renewable electricity price = USD 50/MWh at 3 000 full load hours in near term and USD 25/MWh in long term; CO_2 feedstock costs lower range based on CO_2 from bioethanol production at USD 30/tCO_2 in the near and long term; CO_2 feedstock costs upper range based on DAC = USD 400/tCO_2 in the near term and USD 100/tCO_2 in the long term; discount rate = 8%. More information on the underlying assumptions is available at www.iea.org/hydrogen2019.

Source: IEA 2019.

Key barriers for ammonia as shipping fuel and how can we work to overcome them?

Yara is developing partnerships to explore and remove barriers for ammonia as shipping fuel

	Bunkering infrastructure	Fuel cost	Perception Safety	Regulatory	Technology
Barrier description	**Security of supply** and **scalability** of infrastructure	Ammonia fuel will need long term high carbon price. Today **beyond 250 USD/tn CO2** to compete with LNG IC	Perceived ammonia **safety risks can be a barrier for uptake** of NH3 fuel	**Currently no rules for use ammonia as fuel**; an IMO process for NH3 fuel is expected to take 10 years.	**No proven technologies at marine full scale** yet.
How to close the gap?	Starting point is decent with 20 Mtn/ yr global trade. Industry collaboration required to gradually develop infrastucture to match demand	Access to **low cost** renewable **energy** and/or large scale development of CCS will be the key to bring fuel costs down.	**Demonstration projects** must be handled with utmost caution, building on global best practice and competence.	Establish first projects based on the **IGF code** for alternative design must be applied (as for LNG until recently).	Both SOFC and ICE technologies are being developed, and should be demonstrated whithin 3-5 years

- The key to overcoming the barriers is to identify the viable demonstration conecpts
- Yara aims to participate in 1-2 strong consortia to establish viable demonstration cases
- Yara can offer a fuel value chain perspective as well as expertise in ammonia handling and safety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