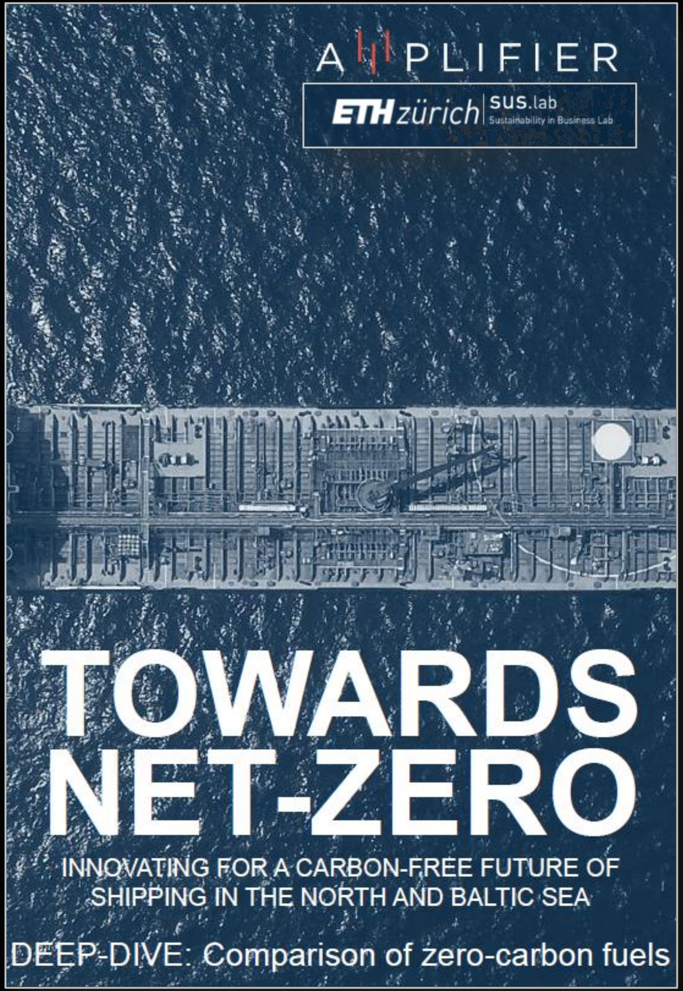
ENERGY AND NET-ZERO IN THE UK

DECARBONISING SHIPPING

BILL DAVID



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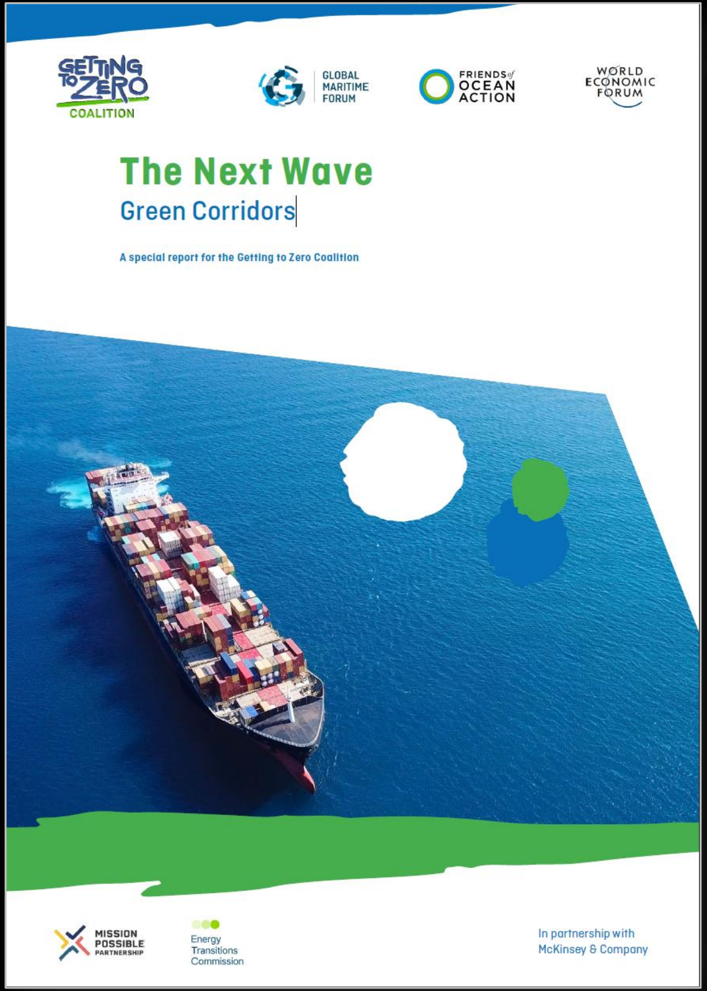

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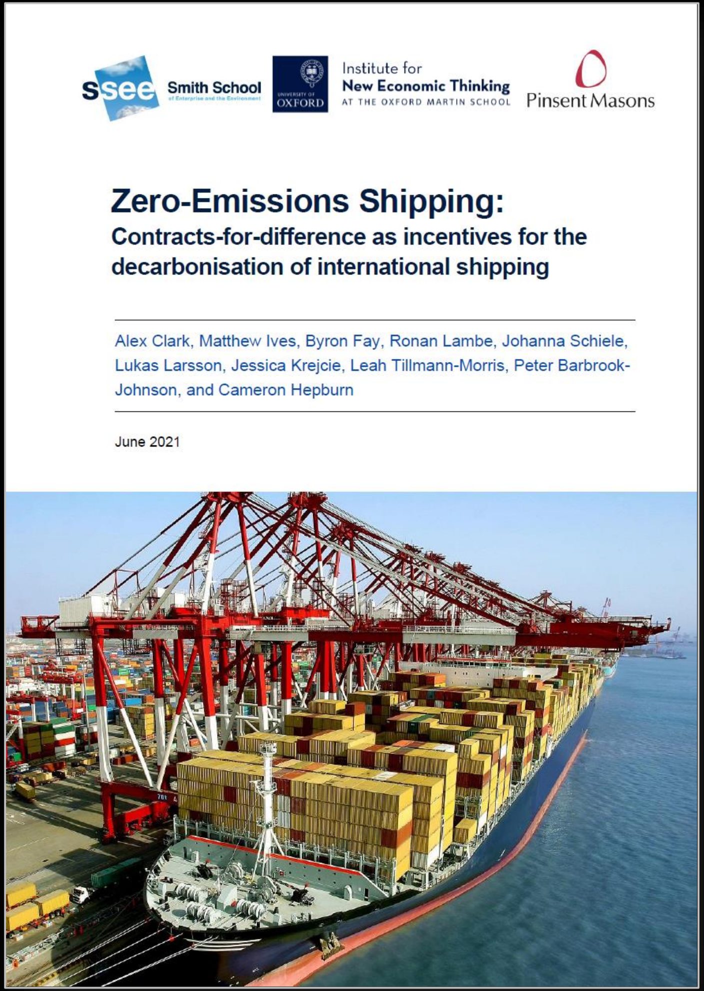


www.smithschool.ox.ac.uk/publications/
reports/zero-emissions-shipping.pdf

While a wide range of solutions to reduce GHG emissions in shipping exists, alternative fuels seem to be the only path to reach zero

Potentially most feasible (detail follows)

Measures to reduce GHG emissions

- Slow steaming
- Optimized route planning and weather routing
- Cold ironing/ on shore power supply
- More efficient port and cargo handling and logistics

- Improved hull designs and other ship design measures
- Frequent propeller polishing
- Air lubrication
- Alternative propulsion systems (e.g., wind assistance)
- Waste heat recovery

- Low-carbon fossil fuels
- Carbon-neutral bio fuels
- Carbon-neutral hydrocarbon fuels
- Zero-carbon fuels

Type	Description	Potential to reach zero-carbon
Low-carbon fossil fuels	Fossil fuels with a lower carbon footprint than conventional fossil fuels (e.g., LPG, LNG, Methanol)	Reduction by max. 20-30% vs. conventional fuels
Carbon-neutral bio-fuels	Fuels made from organic feedstock such as oils, sugars, or waste (e.g., Bio Diesel, Bio Methane, Bio Methanol)	Can be carbon-neutral, yet, scalability of production might be limited by resource and land requirements to produce biomass
Carbon-neutral hydrocarbon fuels	Synthetically produced (with the use of renewable energy and chemical compounds based on hydrogen and carbon (e.g., eDiesel, eMethane, eMethanol)	Can be carbon-neutral if produced with renewable energy and CO2 is captured
Zero-carbon fuels	Energy carriers that do not emit any CO2 to generate power (e.g., Hydrogen, Ammonia) or the direct use of electricity	Can be carbon-neutral if produced with renewable energy

Note: Carbon capture and storage not considered

Source: Faber et al., (2012): New Climate Institute (2019); Nordhaus (2013)

Zero-carbon fuels seem to offer a faster and most energy efficient route to transition compared to hydrocarbon fuels based on renewable electricity

	Feedstock supply	Fuel production	Fuel distribution	Fuel conversion (on ship)
Carbon-neutral hydrocarbon fuels from renewable electricity[1]	! • scarce availability for the next 10-20 years ! • in competition with all other maritime sectors and CCS ! • thermodynamic challenge of direct capture of CO_2 from air (DAC)	! • additional synthesis steps after H_2 production ! • feasibility and cost of (DAC) of CO_2 at scale ! • no large scale CH_4, CH_3OH synthesis available	+ • existing storage infrastructure and transportation can be used	! • 95% of engines would have to be modified for e-CH_4 and e-CH_3OH + • engines available
Zero-carbon fuels	+ • direct use of electricity is the most efficient wherever possible + • for H_2 and NH_3, two alternate paths: green (renewable electricity) and blue (natural gas with CCS)	+ • one step process to H_2 (electrolysis) + • integrated process (electrolysis and Haber Bosch) for NH_3 production	! • no global H_2 distribution infrastructure and high cost H_2 storage + • existing global NH_3 infrastructure + • green & blue NH_3 infrastructure proposals	! • all engines must be modified for both H_2 and NH_3 + • engines fully commercially available both H_2 and NH_3 within 3-5 years

Both transition paths require significant investments, however, zero-carbon fuels could offer a faster transition route as hydrogen (and other hydrogen-carriers) as they require less fuel production steps and can be produced from natural gas in combination with CCS.

1 Biofuels were excluded from the analysis due to concerns about food competition at scale. Future technology might be able to circumvent this issue, but is not currently ready for scale-up.

Zero-carbon fuels

- no global H_2 distribution infrastructure and high cost H_2 storage
- existing global NH_3 infrastructure
- green & blue NH_3 infrastructure proposals

- all engines must be modified for both H_2 and NH_3
- engines fully commercially available both H_2 and NH_3 within 3-5 years

MAN Energy Solutions is developing a fuel-flexible, two-stroke ammonia engine as a key technology in the maritime energy transition

Green ammonia is among several synthetic fuels key to establishing a greener shipping industry in the near future. MAN Energy Solutions aims to have a commercially available two-stroke ammonia engine by as early as 2024, followed by a retrofit package for the gradual rebuild of existing maritime vessels by 2025.

By Nils Lindstrand

"Today we have a chance to change the shipping industry and its environmental impact on a global scale," says Brian Østergaard Sørensen. A sailor who once taught thermodynamics, you can certainly argue that he has a suitable background for the task. Before receiving a degree in mechanical engineering from the Technical University of Denmark, Østergaard Sørensen had already earned the highest seafarer qualification – master mariner – allowing him to serve as shipmaster on any merchant ship anywhere in the world.

"Now I've found my place in the machine industry at MAN Energy Solutions," he says, where as Head of Two-Stroke Research and Development he and his team at the Research Center Copenhagen (RCC) are working on flexible fuel solutions that will allow engines to burn a broad variety of environment-friendly fuels, including methanol and ammonia. The company already aims to have a two-stroke ammonia engine for large-scale container ships available by 2024, and a year later a retrofit package to make existing ships capable of running on ammonia as well.

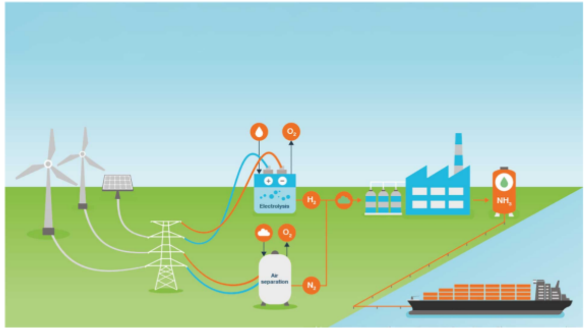
"This is obviously an ambitious undertaking," says Østergaard Sørensen. "2024 is a tough deadline, but we can meet it. The industry is already on board and working intensively with us towards greener maritime shipping."

Brian Østergaard Sørensen is Head of R&D Two-Stroke Businesses at MAN Energy Solutions in Copenhagen, where the company is developing a number of future carbon-free fuel solutions for the shipping industry.

> The final goal for two-stroke engines is to run them entirely on carbon-neutral and carbon-free fuels.

Brian Østergaard Sørensen, Head of two-stroke R&D, MAN Energy Solutions

The need for flexible fuel solutions



Green ammonia can be produced from renewable energies and is therefore a carbon-free shipping fuel.

According to the International Maritime Organization (IMO), maritime shipping emits around 940 million tons of carbon dioxide (CO2) per year and is responsible for around 2.5 percent of all greenhouse gas (GHG) emissions. Without mitigation, emissions are projected to grow by at least 50 percent over the next three decades, which is why the IMO has adopted mandatory measures to reduce 70 percent of emissions from ships by 2050 and eventually phase them entirely out within this century.

Ammonia has unquestionable advantages that could help create a sustainable maritime shipping industry. It can literary be produced from air and sunshine – and it's carbon-free. Moreover, as with methanol, solutions using ammonia build on established technologies and infrastructure, making the road to sustainability much shorter. However, it will take time to build capacity – and time to rebuild ships' two-stroke engines to run on ammonia. "The interest from shipping companies in new fuel technologies is huge today, and we already have a number of collaborations running. But the conversion to green engines also depends on economic realities." Østergaard Sørensen adds: "No shipping company can risk having its fleet stranded during the transition, which is why we need to create flexible solutions that allow a transition by degrees."

https://www.man-es.com/discover/two-stroke-ammonia-engine

Zero-carbon fuels

- all engines must be modified for both H_2 and NH_3
- engines fully commercially available both H_2 and NH_3 within 3-5 years

SOLID OXIDE FUEL CELLS (SOFCs)

Energy

Renewable Energy

Proactive

12:20 Wed 15 Sep 2021

view Ceres Power Holdings PLC (AIM:CWR, OTC:CPWHF)

Ceres Power awarded funding for two ship emission projects

Shipping accounts for over 2% of global greenhouse gas emissions

Initiative is being run by DoT and Innovate UK

Ceres Power Holdings PLC (LSE:CWR) has received funding for two separate projects as part of the Clean Maritime Demonstration Competition.

Run by the UK Department for Transport and delivered in partnership with Innovate UK, the £23mln initiative will aid 55 projects focused on the development of zero-emission vessels by 2025.

The two projects in which Ceres is involved will evaluate the most effective means to integrate its solid oxide fuel cell (SOFC) technology in megawatt-class cruise ship applications.

A consortium involving GE Power Conversion, MSC (Mediterranean Shipping Company) and Lloyd's Register, will explore how best to address the barriers to the adoption of fuel cells in large vessels.

A second consortium comprising Carnival UK, the University of Southampton, Shell and Lloyd's Register will look into the feasibility of using Ceres' SOFC technology to replace the use of diesel generators in cruise ships.

Ceres said the projects will allow it to demonstrate how its fuel cell technology can be used in the marine sector where the International Maritime Organization has mandated a 50% reduction in emissions by 2050 from 2008 levels.

ALKALINE FUEL CELLS (AFCs)

Energy

Renewable Energy

Proactive

07:37 Wed 01 Dec 2021

view AFC Energy PLC (AIM:AFC, OTC:AFGYF, ETR:QC8)

AFC Energy says fuel technology chosen to power zero-emission cargo ships

"The maritime industry's increasing reliance on Green Ammonia lends itself perfectly to AFC Energy's high energy-dense alkaline fuel cell technology"

Cargo ships are huge polluters currently

AFC Energy said its ammonia fuel cell technology was selected to power a new range of 'green' bulk cargo ships.

AIM-listed AFC will supply its new "S" series heavy duty maritime platform which is expected to host 2 x 600kW of alkaline fuel cell systems plus ammonia cracking technology within modular 40ft containers.

AFC will work with the ZeroCoaster Consortium, which is sponsored by the Norwegian Government and led by global shipping design and build partner Vard Engineering Brevik AS. The objective is to design next generation coastal cargo ships to accelerate the transition to zero-emission shipping solutions.

Vard, which is already a partner of AFC, has received approval in principle from certification agency DNV for the ZeroCoaster range of ammonia-fuelled vessels.

Vard has started commercial discussions with potential customers for ZeroCoaster ships featuring the power unit, AFC said, adding that to meet its decarbonisation targets for 2030 Norway alone is expected to require 1,100 low emission ships such as the ZeroCoaster.

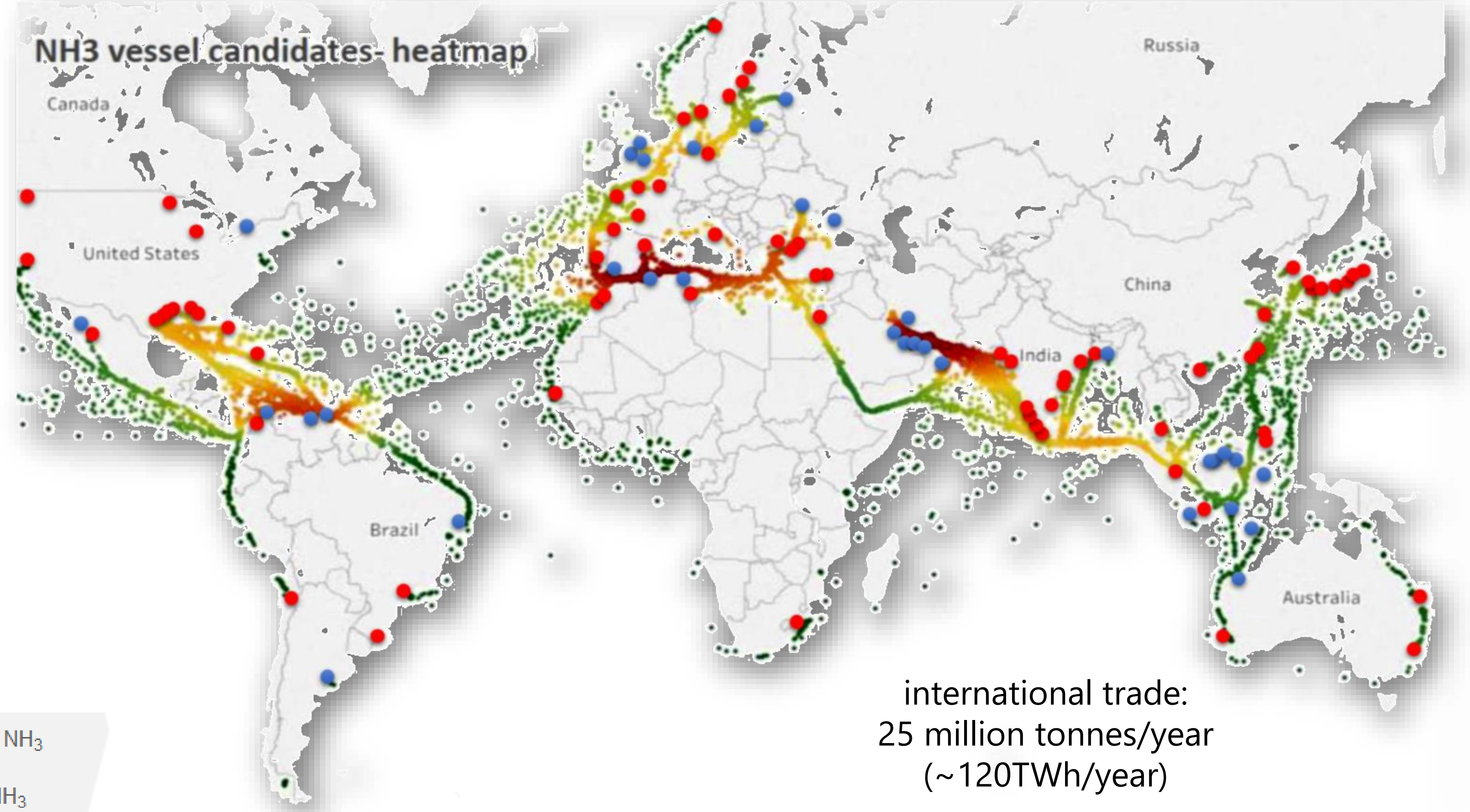
Andreas Buskop, Vard's engineering general manager, said: "We are pleased to have gained confirmation of our Approval in Principle (AiP) from DNV, highlighting what we understand to be a world first in ship design for ammonia fuel cell and cracker utilisation."

www.proactiveinvestors.co.uk/companies/news/960407/ceres-power-awarded-funding-for-two-ship-emission-projects-960407.html

www.proactiveinvestors.co.uk/companies/news/967857/afc-energy-says-fuel-technology-chosen-to-power-zero-emission-cargo-ships-967857.html

Zero-carbon fuels

Energy infrastructure $\rightarrow$ energy vector $\rightarrow$ $E(\boldsymbol{r}_B - \boldsymbol{r}_A, t_2 - t_1)$



- existing global NH_3 infrastructure
- green & blue NH_3 infrastructure proposals

international trade:
25 million tonnes/year
(~120TWh/year)

Zero-carbon fuels

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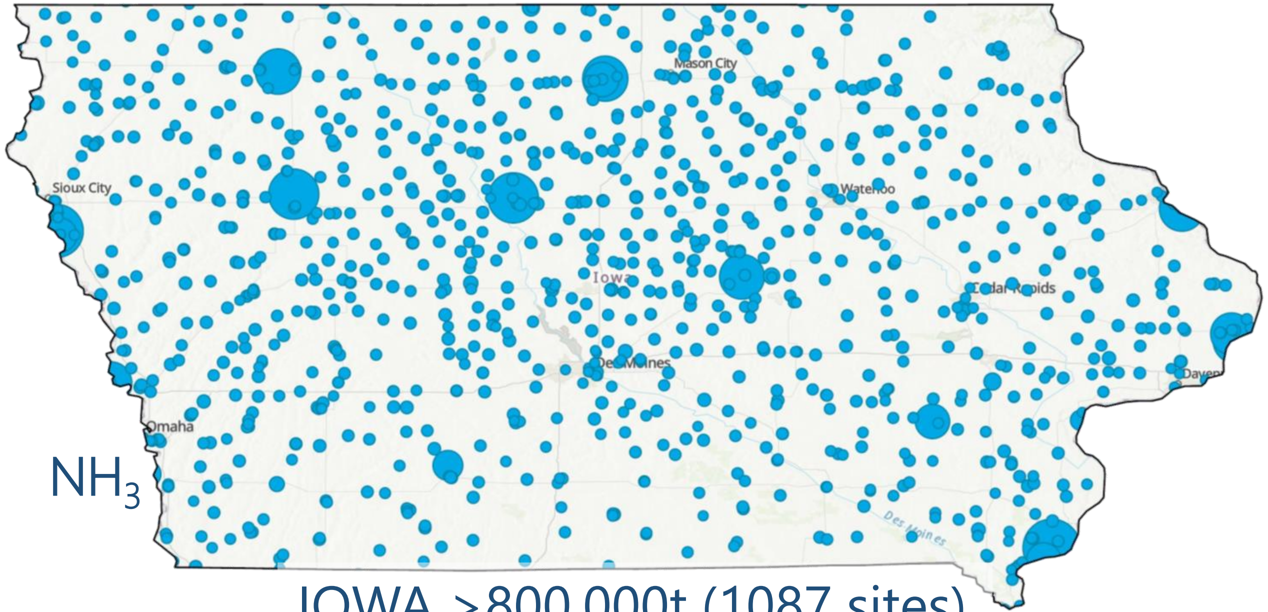
NH_3



IOWA >800,000t (1087 sites)

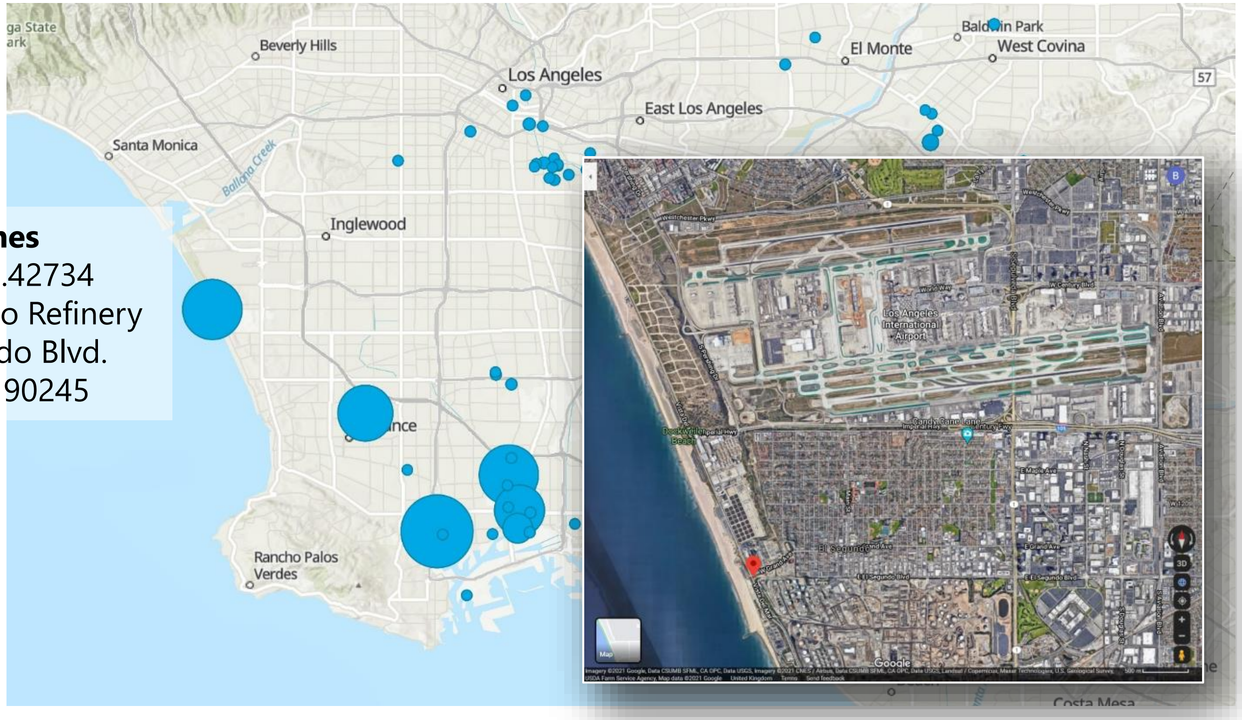
AMMONIA (US infrastructure)

US (>10,000 sites)

US capacity: 24.2Mt NH_3/year
US production: 22.2Mt NH_3/year

20Mt NH_3/year
$\cong$ 70TWh/year $\equiv$ 70TWh/year

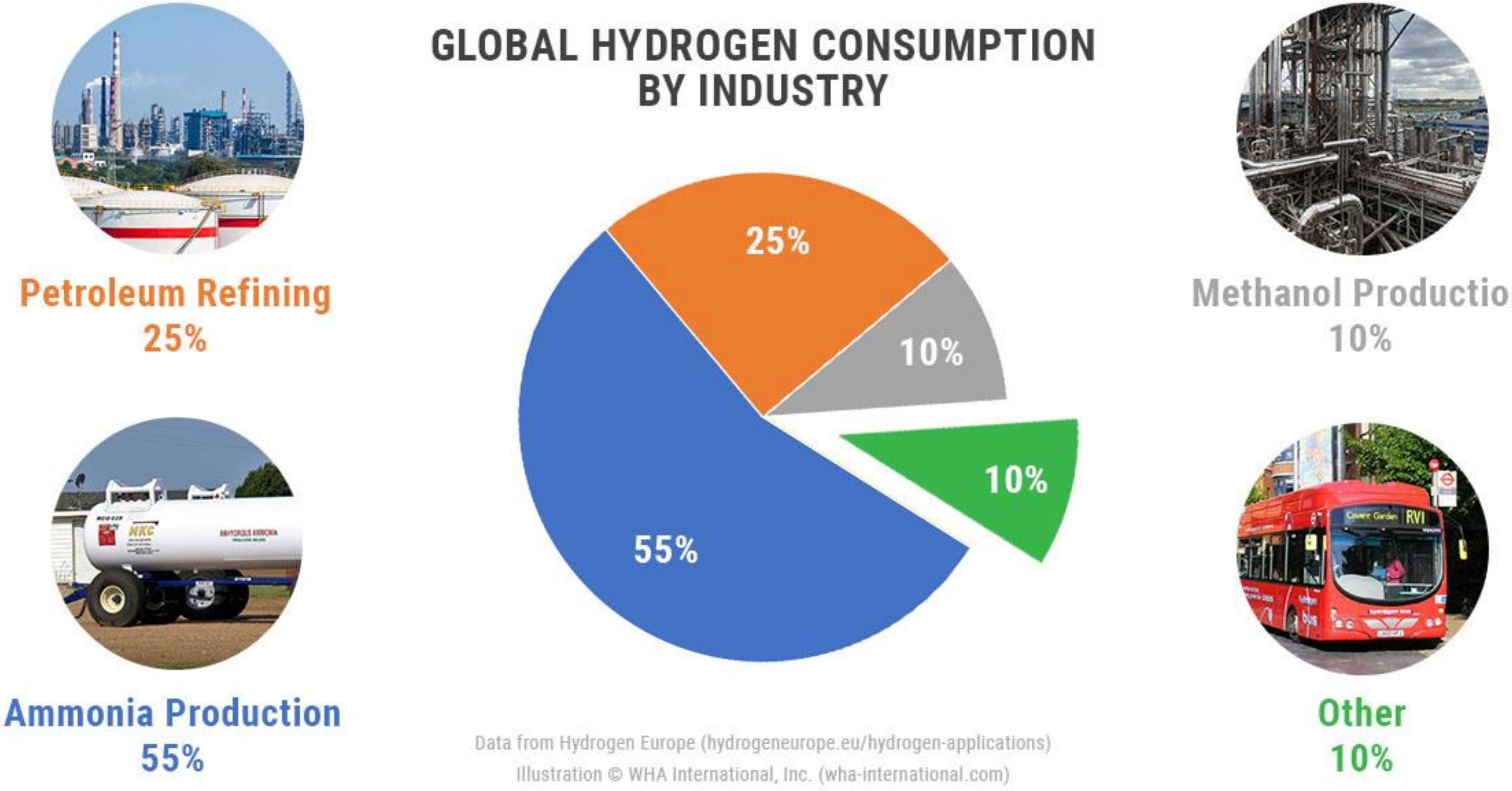
30000 tonnes
33.916311 -118.42734
Chevron El Segundo Refinery
324 W. El Segundo Blvd.
El Segundo CA 90245



Zero-carbon fuels

- no global H_2 distribution infrastructure and high cost H_2 storage

ENERGY INFRASTRUCTURE $\rightarrow$ energy vector $\rightarrow$ $E(\boldsymbol{r}_B - \boldsymbol{r}_A, t_2 - t_1)$

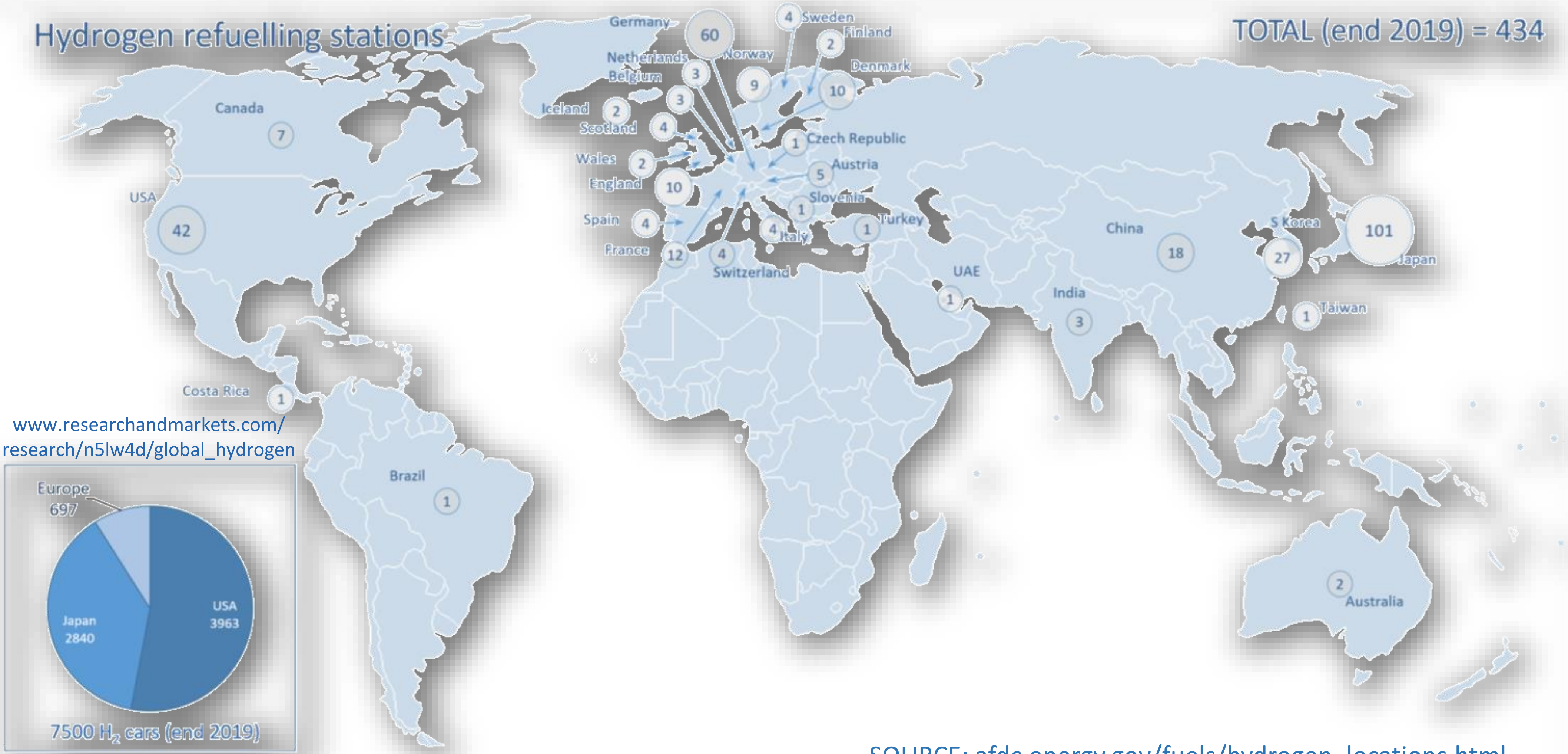


Zero-carbon fuels

- no global H_2 distribution infrastructure and high cost H_2 storage

500 × 100kg/day × 250 days/year = 12500 H_2 tonnes/year
≅ 420GWh/year

c.f. 182Mt/yr (NH_3) ≅ 870,000GWh/year



SOURCE: afdc.energy.gov/fuels/hydrogen_locations.html

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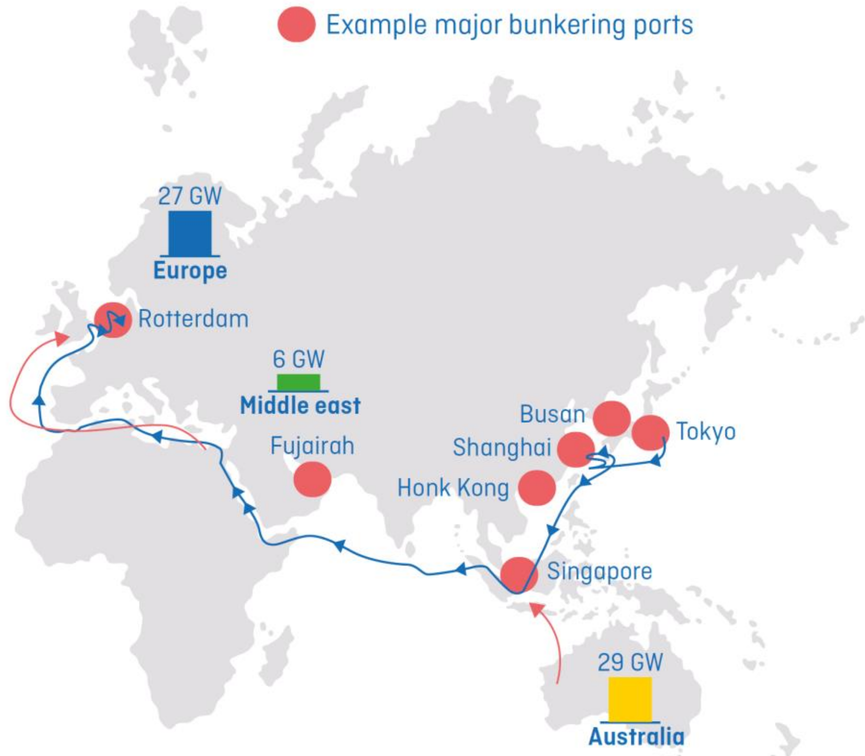
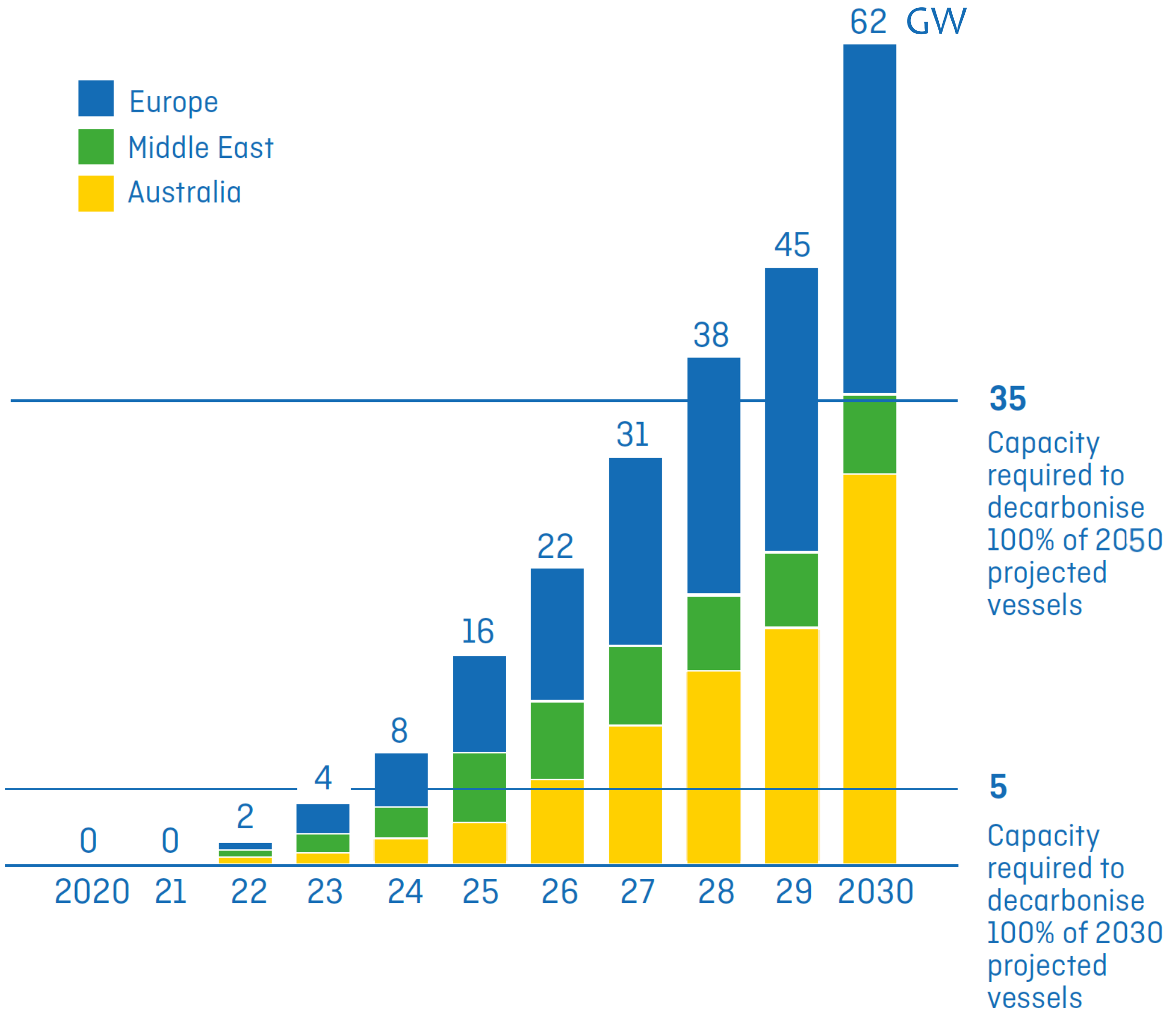


Announced green hydrogen electrolyser capacity by 2030 and current bunkering locations on route, *electrolyser capacity (GW)*

Projected cumulative capacity ramp up from announced green hydrogen projects, *electrolyser capacity (GW)*



Source: Ship & Bunker (2021); Hydrogen Council estimates of hydrogen capacity ramp up (2021)

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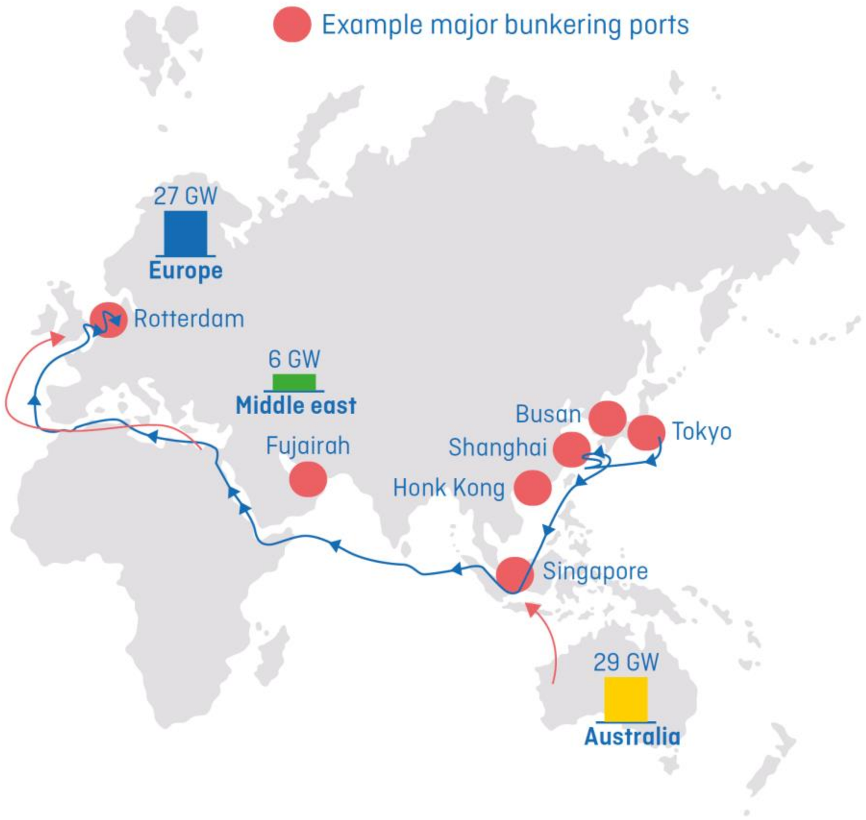


Source: Ship & Bunker (2021); Hydrogen Council estimates of hydrogen capacity ramp up (2021)

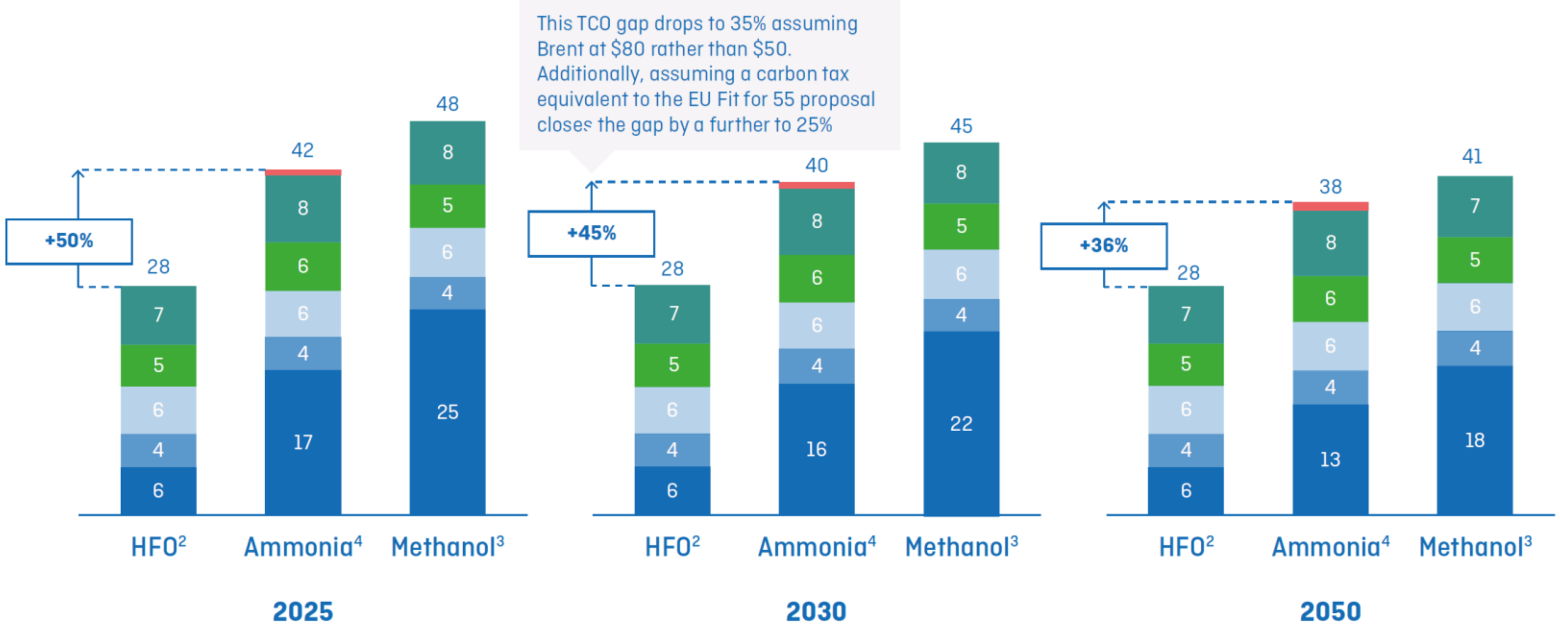
USDm per vessel/year[1]

Main assumptions used '25-'30-'50:

Cost of crude: Brent at \$50 (flat rate)
Renewable electricity: 25-21-16 USD/MWh
Electrolyser capex: 980-930-630 USD/kW

Bunkering cost accounts for approximately 2% of fuel cost

- Total fuel
- Opex (incl. maintenance)
- Voyage cost
- Total capex
- Annual cost of capital
- Cargo capacity loss



[1]Based on vessel >15,000 TEU with bunkering in Middle East; Typical speed of 18 knots and 8 annual canal transits (Suez)
[2]ICE HFO with LSFO as fuel (100%)
[3]ICE Methanol with 97% green methanol fuel use with Direct Air Capture (DAC) and 3% LFSO
[4]ICE Ammonia with 95% green ammonia and 5% LFSO

Source: Team analysis based on the Maersk Mc-Kinney Moller Center for Zero Carbon Shipping NavigaTE model