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Metrological Requirements for Methanol and Ammonia as fuels for power generation and maritime propulsion

MaritimeMET Webinar

3rd June 2025

Stephen B. Harrison,
Managing Director, sbh4 consulting, Germany

MaritimeMET: Webinar Series

Mr. Stephen B. Harrison
Managing Director – sbh4 GmbH

Topic: Methanol and ammonia – high-potential, emerging clean fuels. Key metrological implications of their value chains and end-use cases as fuels for maritime propulsion and thermal power generation.

Date: 3rd June 2025
Time: 10:00 to 11:00 CEST
Register Here

Metrology for Green Maritime Shipping:
Emission control through traceable measurements and machine learning approaches

Visit our website for more information
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Follow us on Linkedin for project updates
https://www.linkedin.com/showcase/maritimemet-project/about/

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2x LinkedIn polls conducted in May 2025 confirm the value of metrological advances related to ammonia and methanol as maritime fuels.

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Which way to Maritime net-zero?

You can see how people vote. Learn more

Biofuels	37%
E-fuels ✓	40%
Nuclear	10%
On-board CCS	6%
On-board wind and solar power	7%

119 votes • Poll closed • Remove vote

Which sustainable maritime fuel will make it?

You can see how people vote. Learn more

E-Methanol - the standard ✓	33%
Green Ammonia - carbon free	26%
RLNG - LNG drop in	16%
Biodiesel - HFO drop in	12%
Hydrogen	13%

193 votes • Poll closed • Remove vote

Hydrogen, hydrogen derivatives and e-fuels

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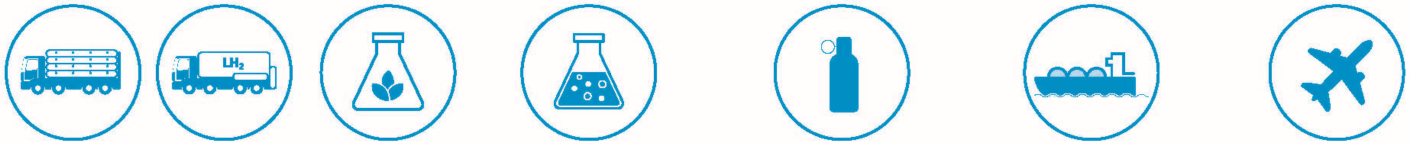

	Hydrogen Gas	Liquid Hydrogen	Liquid Ammonia (Green Ammonia)	Liquid Methanol (eMethanol)	Dimethylether (eDME)	Liquefied Natural Gas (eLNG)	Synthetic Aviation Kerosene (eSAF)
Ideal universal reaction	Compressed H_2	Liquefied H_2	$3H_2 + N_2 \rightarrow 2NH_3$	$3H_2 + CO_2 \rightarrow CH_3OH + H_2O$	$6H_2 + 2CO_2 \rightarrow CH_3OCH_3 + 3H_2O$	$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$	$10CO_2 + 31H_2 \rightarrow C_{10}H_{22} + 20H_2O$
Hydrogen yield	100 %	100 %	100 %	4/6 = 67 %	6/12 = 50 %	4/8 = 50 %	22/62 = 35.5 %
Volumetric energy density, LHV (MJ/L)	2.43 - 6.8	8.52	12.7	15.7	18.7 Liquefied gas at 20°C	22.2	35
Gravimetric energy density, LHV (MJ/kg)	120	120	18.6	19.9	28.4 Liquefied gas at 20°C	48.6	42.2
Infrastructure readiness for large scale deployment in mid-term	Low	Low	High	High	High	High	High
Transportation and storage temperature	Ambient	-253 °C	-33.3 °C	Liquid at ambient temperature	Liquefied gas at 4.2 bar 20°C	-162 °C	Ambient
Transportation and storage phase and pressure	Compressed gas at 250 to 700 bar	Liquid at amos-pheric pressure	Liquid at amos-pheric pressure	Liquid at amospheric pressure	Liquefied gas at 4.2 bar 20°C	Liquid at amospheric pressure	Liquid at amospheric pressure
Density	0.017 kg/L	0.071 kg/L	0.68 kg/L	0.79 kg/L	0.66 kg/L Liquefied gas at 20°C	0.46 kg/L	0.83 kg/L
Toxicity	Non toxic	Non toxic	TWA 25 ppm	TWA 200 ppm	TWA 1,000 ppm	TWA 1,000 ppm	TWA 30 ppm
Flammability (% in air)	4 - 74 %	4 - 74 %	14.8 - 33.5 %	6.0 - 36.5 %	3.4 - 18 %	4 - 15 %	0.7 - 4.8 %

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- Green hydrogen can be converted to green ammonia to make international transportation more cost effective.
- Conversion of hydrogen to ammonia has low cost and high hydrogen yield
- Other hydrogen derivatives, such as e-methanol and eLNG have higher volumetric energy density (reduced transportation and storage costs) but have a higher cost of production, due to the lower hydrogen yields

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1) Ammonia as a maritime fuel

Ammonia fuelled shipping is on the way.

- Large bulk carriers on order for ore shipment from Australia to China
- Multiple oil and gas offshore services vessels operational with ammonia fuel in the North Sea
- 2-stroke engines with diesel ignition dominate
- Fuel cells fed either with ammonia or pure hydrogen from cracked ammonia have been piloted

Ammonia is on the way in as a maritime fuel in combustion engines.

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- Kriti Future, delivered 10 Jan 2022
- Built for Avin International, Greece
- Jiangsu New Times Shipbuilding, China
- 156,700 tonnes deadweight, 274m long, Suezmax
- ABS LNG level 1 ready and ABS ammonia level 1 ready

- Bocimar has ordered ammonia powered 10 Capesize bulk carriers
- China State Shipbuilding Corp, Beihai, China
- 210,000 tonnes deadweight
- WinGD, two stroke, dual fuel X72DF engines
- Delivery 2025 / 2026

https://www.offshore-energy.biz/worlds-first-ammonia-ready-vessel-delivered/
https://www.offshore-energy.biz/mol-itochu-get-abs-aip-for-ammonia-bunkering-vessel/
https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/other/325_guide_ammonia_fueled_vessels/ammonia-fueled-vessels-sept21.pdf

WIN GD dual fuel diesel / ammonia engine. Diesel pilot flame enables ammonia combustion.

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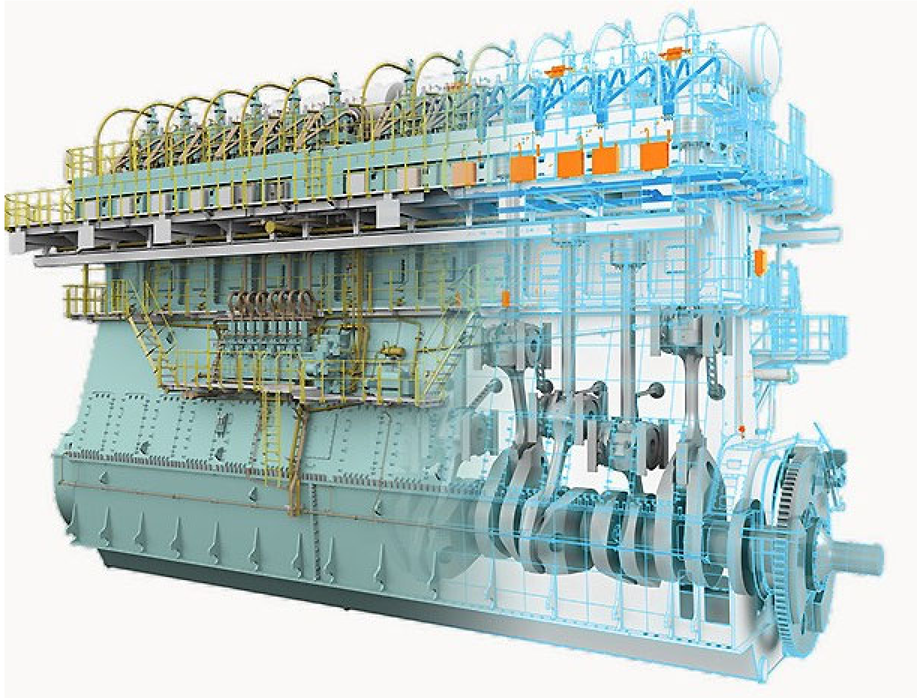

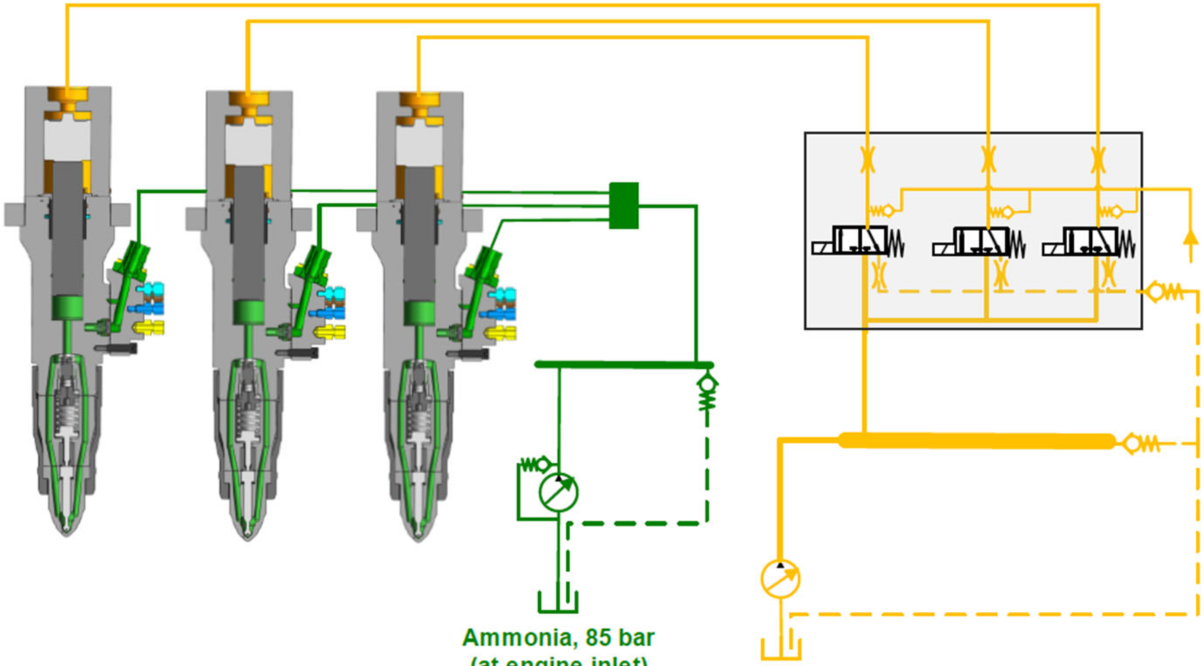

https://www.wingd.com/en/news-media/press-releases/future-fuel-ambitions-boosted-through-choice-of-wi/
https://www.wingd.com/Documents/Technical-Information-Notes/WinGD_TIN035_Dual-Fuel-Ammonia-Engine-Development

Burner development with pilot for ammonia ignition is ongoing. SCR for DeNOX must also be proven for ammonia-fired engines.

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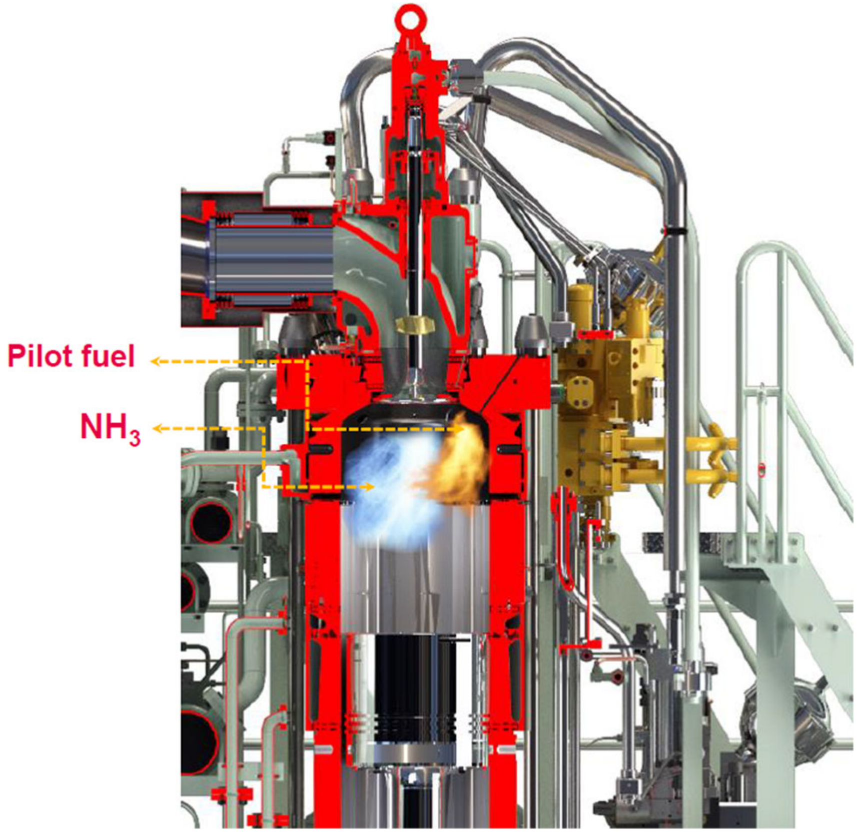

https://www.ammoniaenergy.org/articles/selective-catalytic-reduction-for-marine-ammonia-engines/
https://www.ammoniaenergy.org/wp-content/uploads/2022/08/Kjeld-Aabo-Ammonia-Energy-Association-aug-2022-australia3.pdf

Sensor requirements for ammonia-fuelled maritime emissions treatment may leverage diesel systems with SCR for DeNOx.

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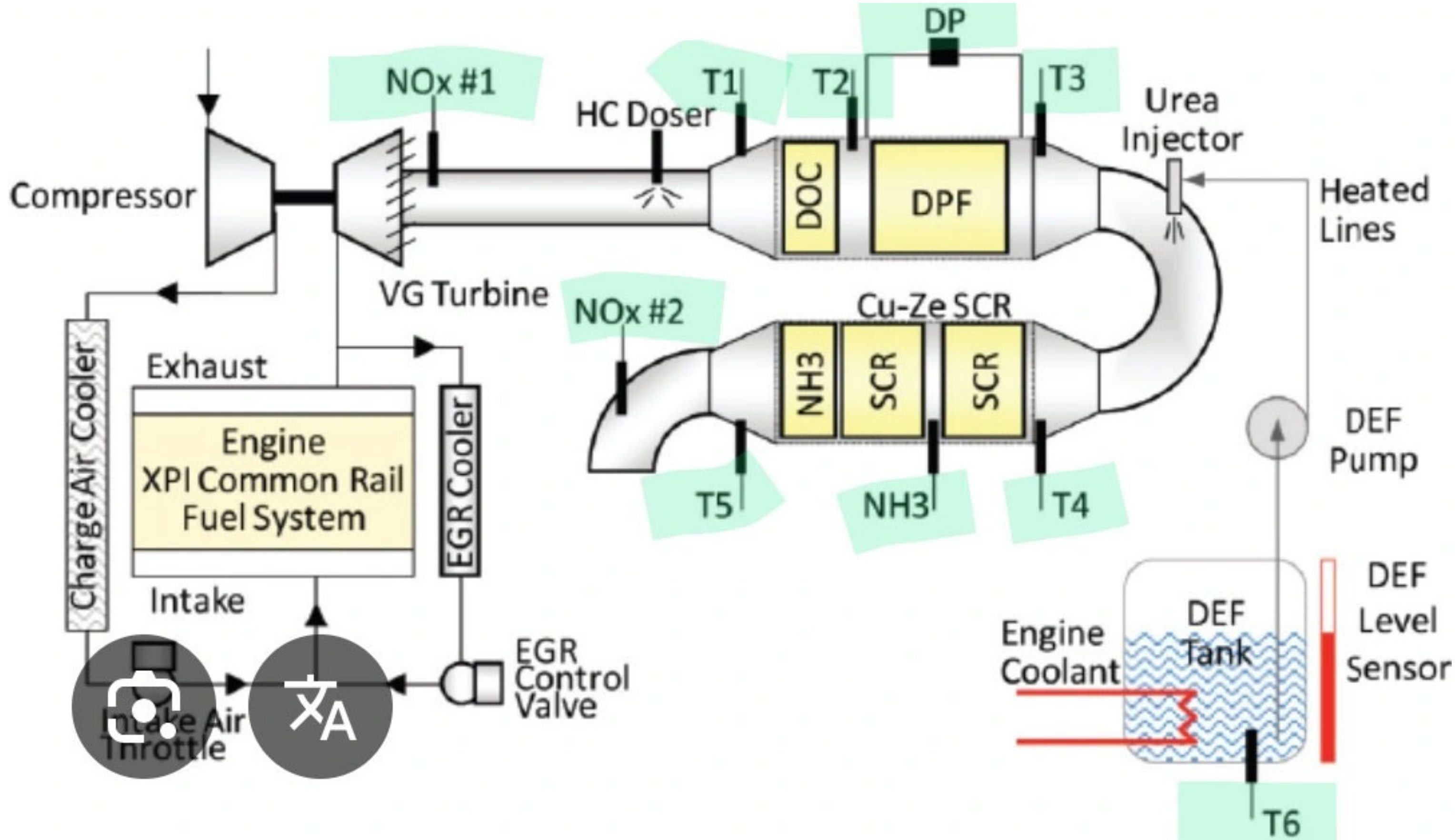

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2) Cracked and partially cracked ammonia as a maritime fuel

Port-side ammonia crackers and terminals are likely to be used for green / blue hydrogen imports to Europe and Asia.

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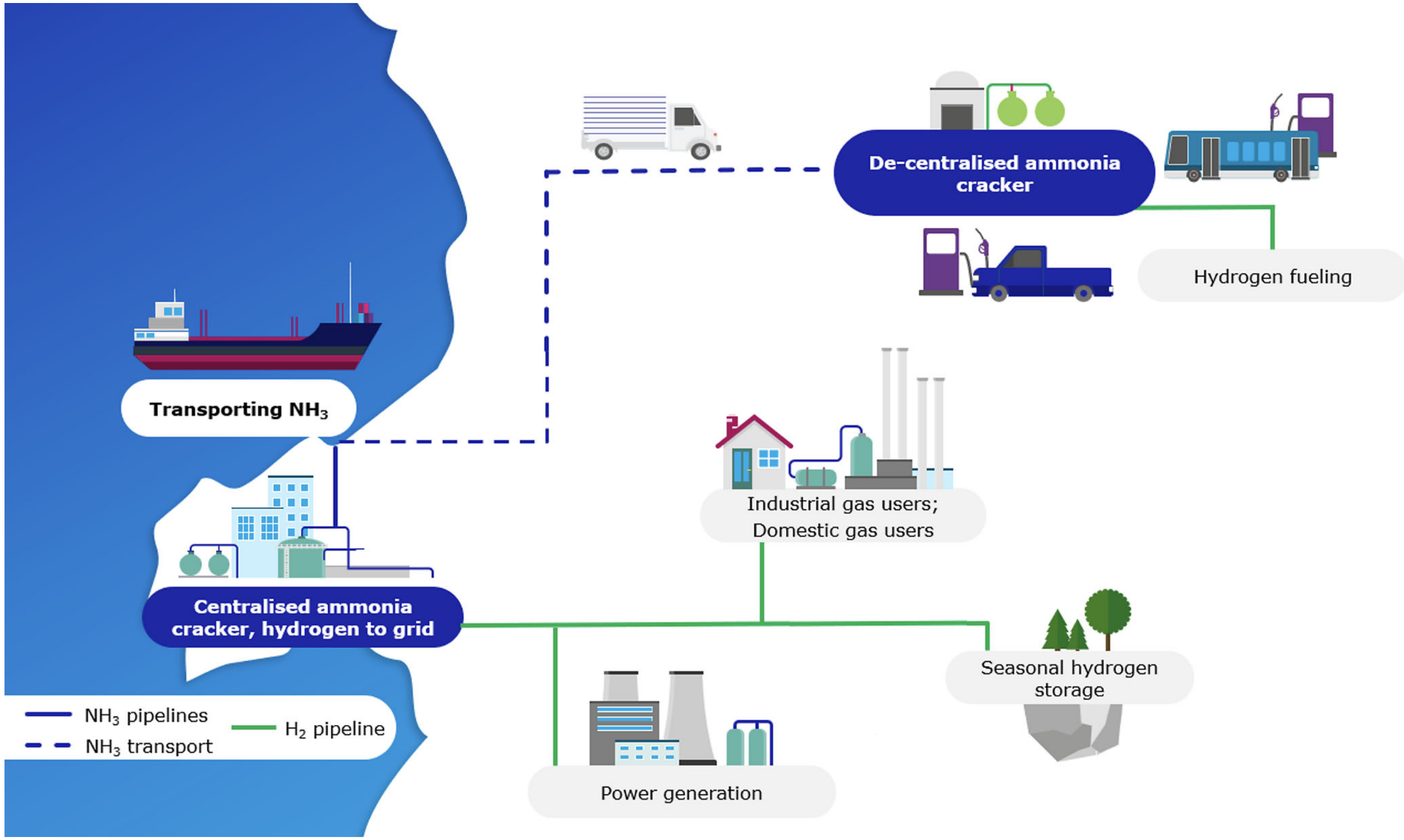

Centralised ammonia cracking can be decarbonised using ammonia as the fuel to drive the cracker.

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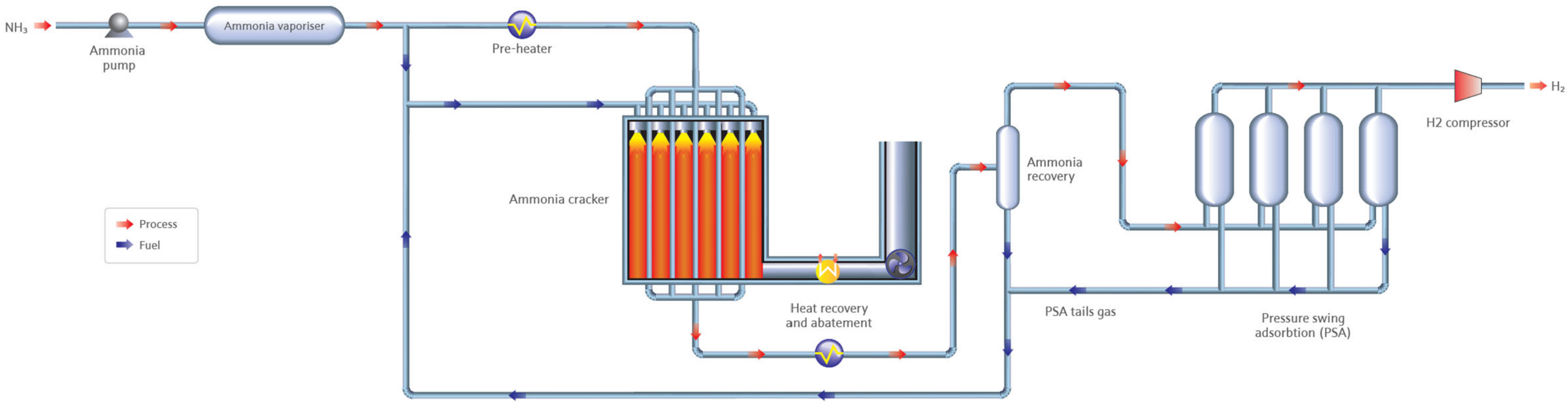

Graphic courtesy of Johnson Matthey

Partial cracking of ammonia can be used in maritime internal combustion engines or marine gas turbine engines. NOx emissions reduction is a major development challenge.

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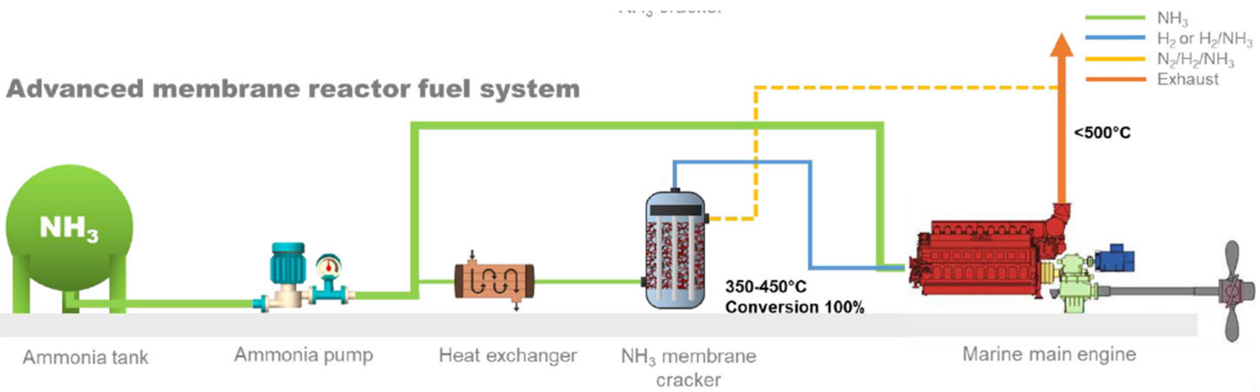

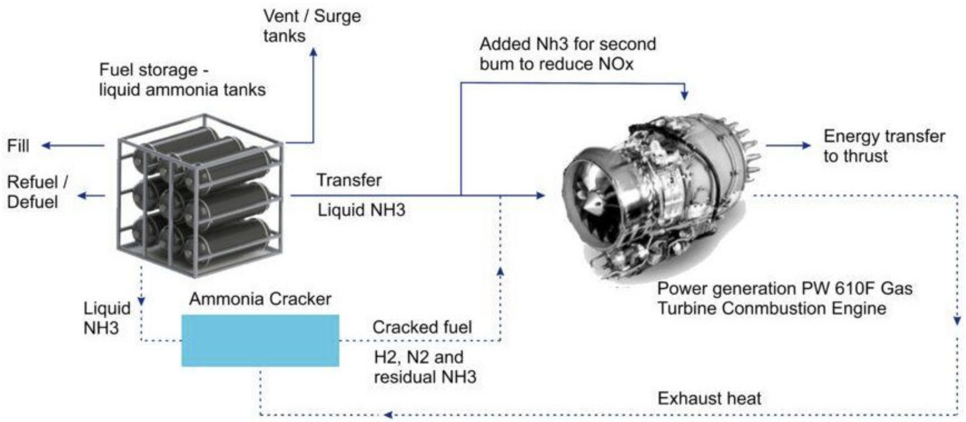

https://www.ammoniaenergy.org/wp-content/uploads/2020/12/Camel-Makhloufi.pdf

Ammonia can be cracked and used on a solid oxide fuel cell. Some ammonia may slip through the fuel cell, but after the catalytic converter the emissions are nitrogen and moisture.

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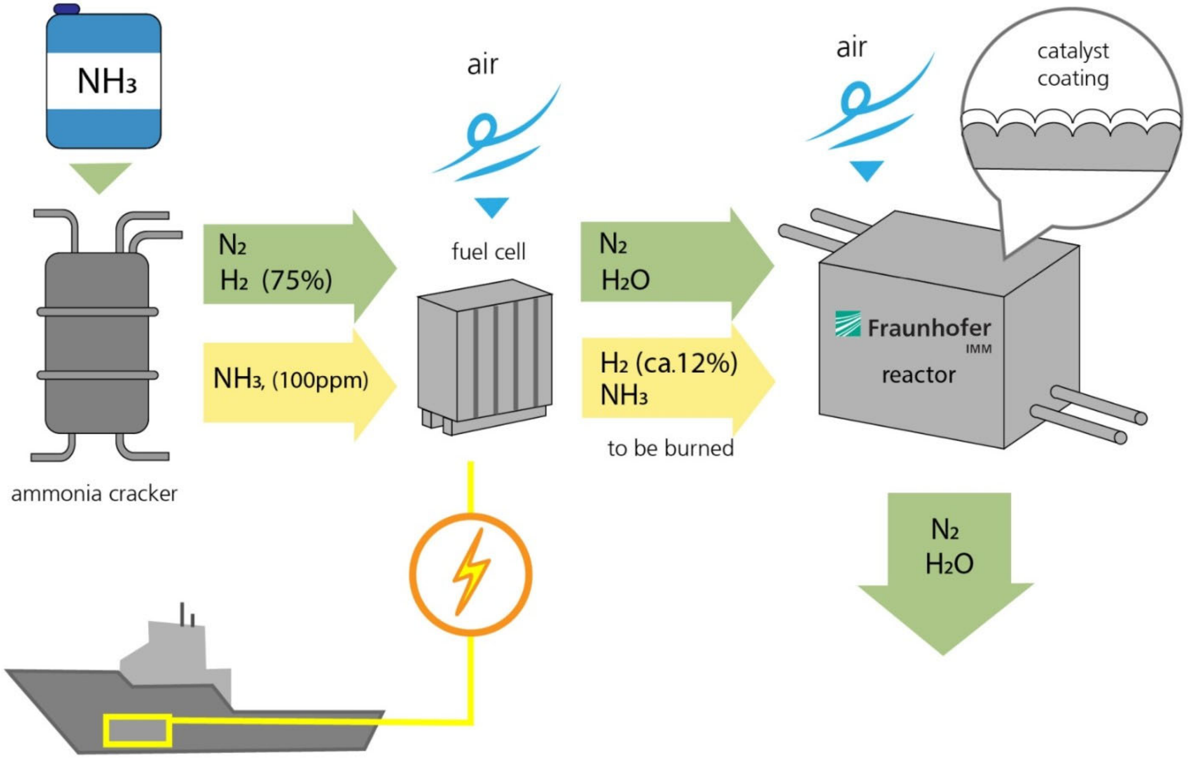
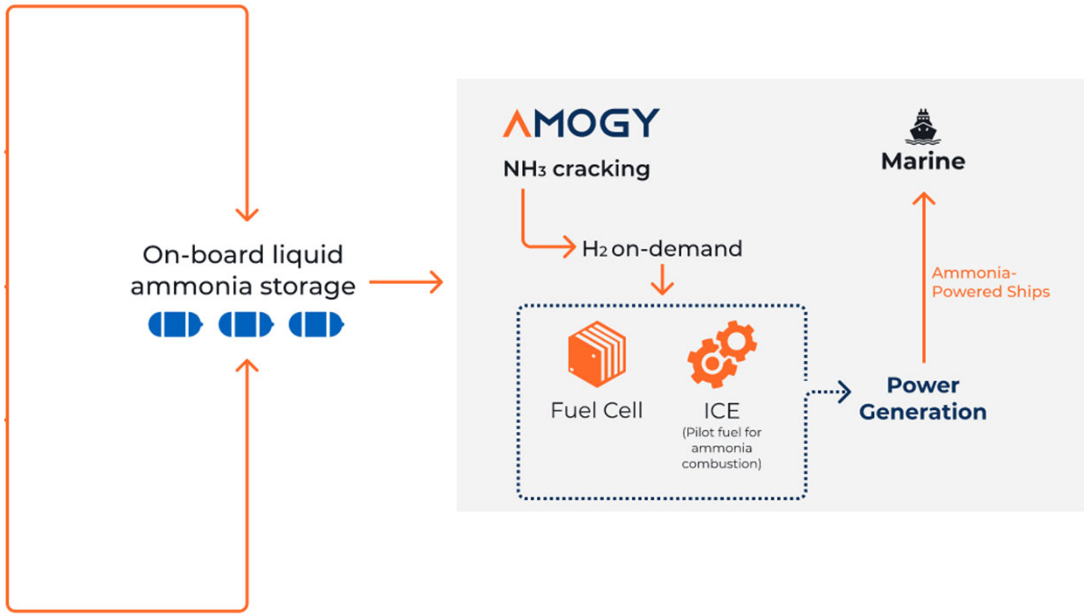


https://www.wartsila.com/encyclopedia/term/platform-supply-vessel-viking-energy

AMOGY using hydrogen from cracked ammonia on Low Temperature PEM fuel cells (LT PEMFC) for maritime mobility.



https://www.ammoniaenergy.org/wp-content/uploads/2020/12/Camel-Makhloufi.pdf
https://amogy.co/technology/

Cracked ammonia to high purity hydrogen from H2SITE cracking reactor to low temperature PEM fuel cell (LT PEM FC) for auxiliary power on Bertha B.

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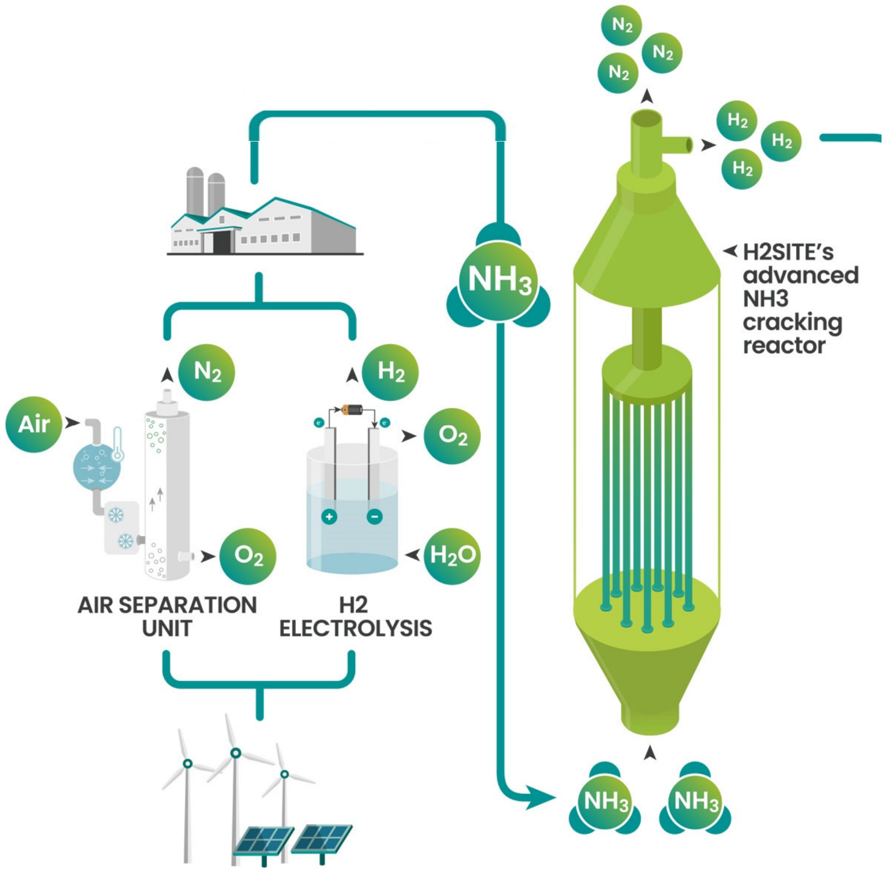

https://www.businesswire.com/news/home/20231121375797/en/H2SITE-has-Commissioned-the-First-On-Board-Ammonia-Cracking-System-Generating-High-Purity-Hydrogen-Coupled-with-PEM-Fuel-Cell
https://ammogen.co.uk/

Ocean Infinity: lean crew / unmanned ships using ammonia-based fuel cell system.

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- 8 vessels ordered by Vard Søviknes, Norway
- Armada 7801 delivered in 2023
- Built by Vard Vung Tau in Vietnam
- 78-metre length
- Launch and recovery of ROVs
- Multi-purpose offshore vessels

https://www.offshore-energy.biz/ocean-infinitys-first-two-high-tech-ammonia-ready-armada-ships-head-for-norway/

3) Ammonia for power generation

Variable renewable power sources must be integrated with molecular energy vectors (eg as ammonia) and subsequent thermal power generation to balance power supply and demand.

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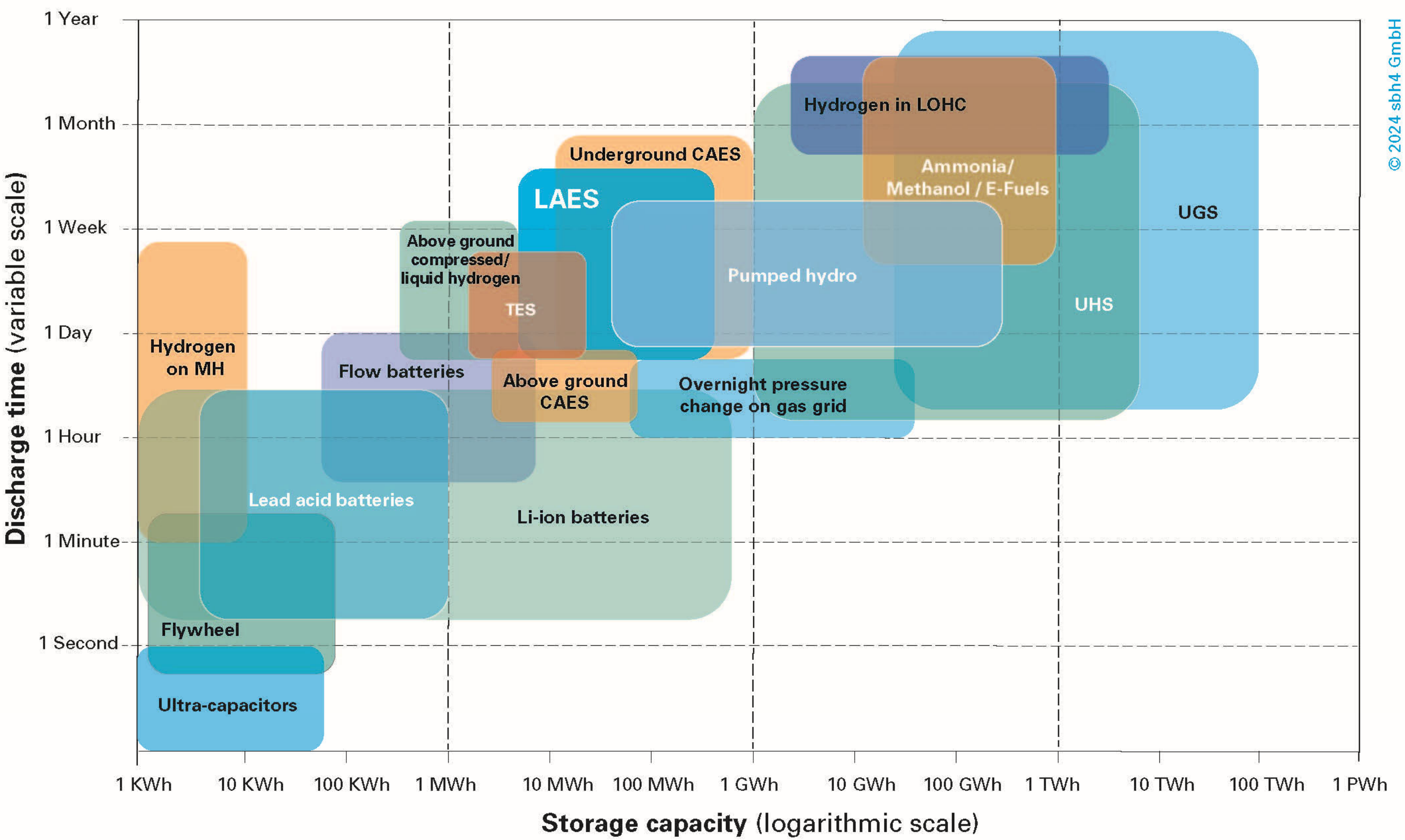
Power and energy transition

Renewable power and energy storage technologies, their capacity and discharge time



UHS: Underground Hydrogen Storage
UGS: Underground Natural Gas Storage
LOHC: Liquid Organic Hydrogen Carrier
CAES: Compressed Air Energy Storage
LAES: Liquid Air Energy Storage
MH: Metal Hydride
TES: Thermal Energy Storage

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Note: technologies may strech beyond the zones shown, but alternatives may become more cost-effective

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- Batteries and other technologies can store and discharge power and energy over short time frames
- For longer duration and high capacity, molecular energy storage is essential
- Trade of energy over long distances, especially ocean routes, also requires energy-dense molecular energy vectors such as ammonia, a hydrogen derivative

GE and IHI study to compare liquid hydrogen and ammonia supply chains for port-side power generation indicates favourable results for ammonia.

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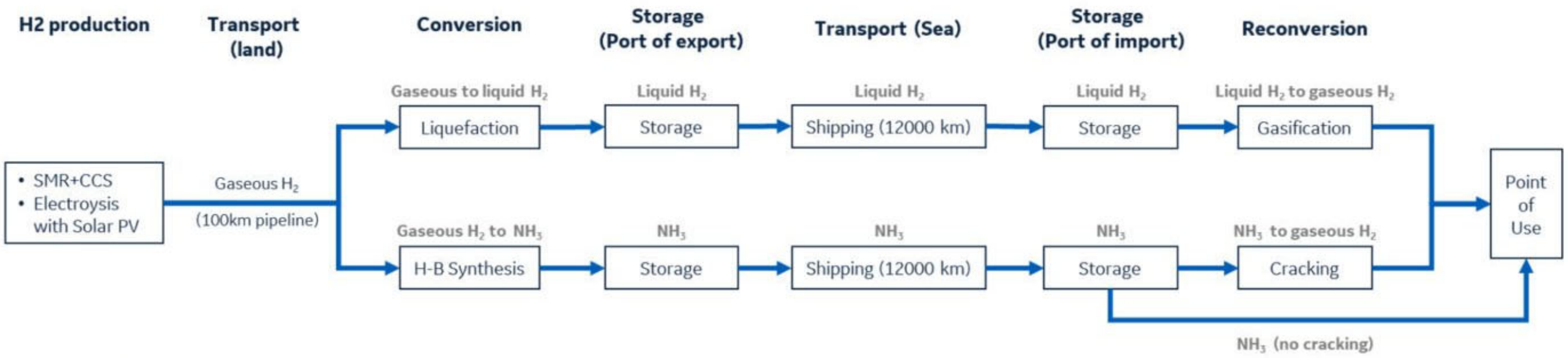

Out of scope

- Detailed plant engineering considerations including analysis of thermal efficiency differences between fuels
- Inland transportation of fuels in Japan (most power plants located on coast, assumed cost is minimal)
- Regasification of liquid H_2. Assumed to be minimal when using sea water for heat exchange.
- Detailed forecast of future LNG cost. (Study inputs are based on pre-Russo-Ukrainian War values)

In scope

- Production of blue H2 in the middle east
- Conversion, storage (at import/export terminals), marine transportation to Japan and reconversion of fuels
- Social cost of carbon for LNG+CCS case
- Impacts to CapEx and OpEx to the power plant
- Maritime shipping assumes conventional shipping fuels (HFO etc.)

https://www.powermag.com/ammonia-gas-turbine-combustion-has-economic-potential-ge-ihi-study-suggests/

Ammonia in efficient power generation cycles can yield a net electrical power generation efficiency of 55% or more. Almost as good as natural gas fired NGCC at 58%.

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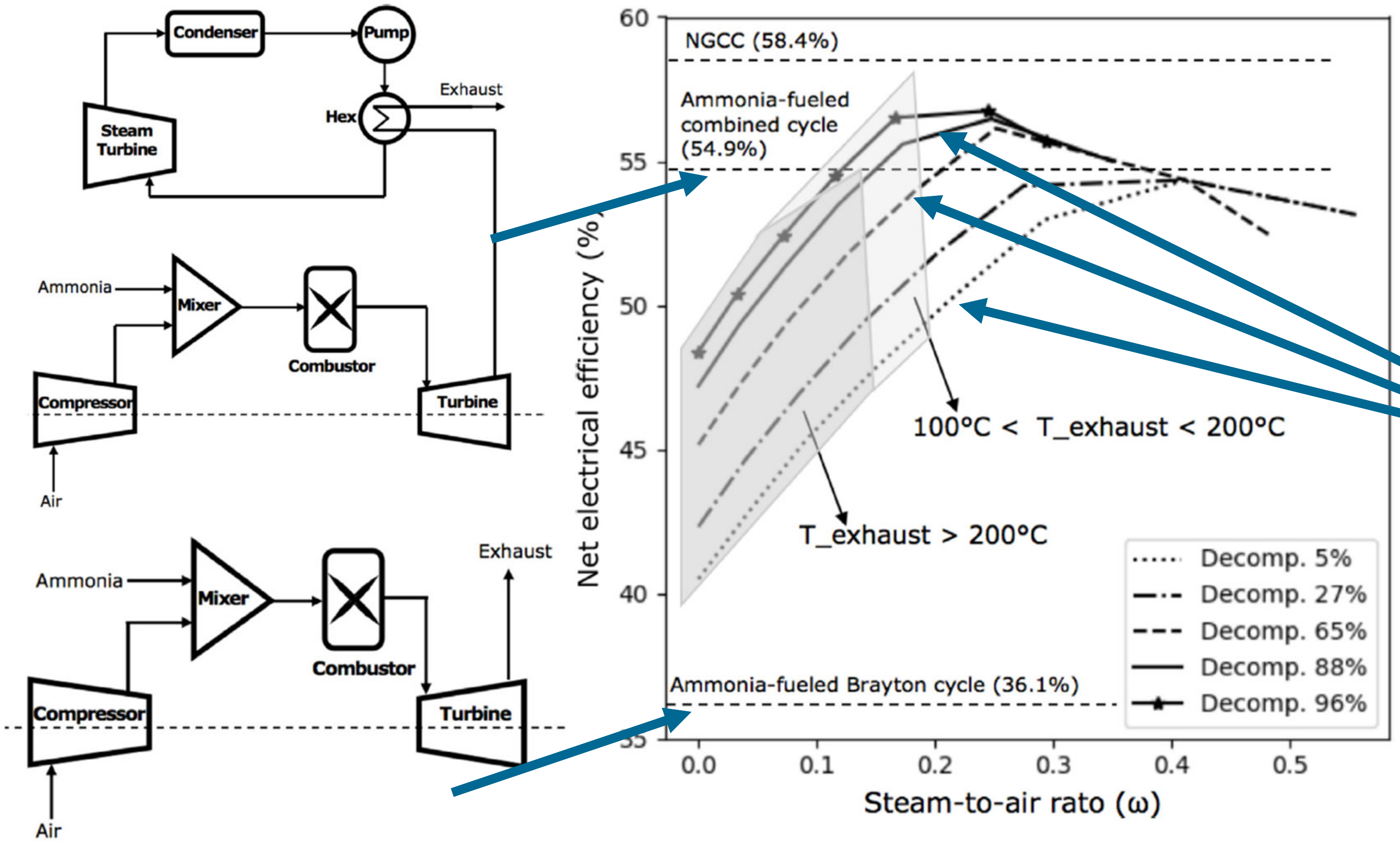

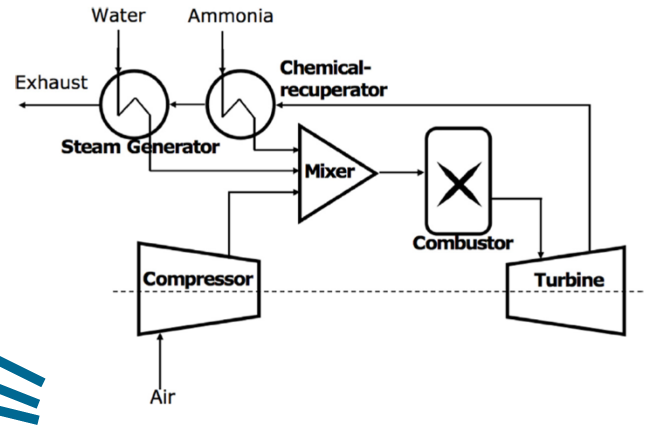

- **Ammonia CGHT Cycle: Chemical-recuperated and humidified gas turbine Cycle.**
- **Turbine exhaust heat is used to crack ammonia through thermal decomposition.**

Waste heat recovery optimization in ammonia-based gas turbine applications, Shen et al 2023

Direct use of liquid ammonia for power generation is less costly than cracking ammonia to hydrogen for power generation. The range overlaps with LNG plus post-combustion CCS.

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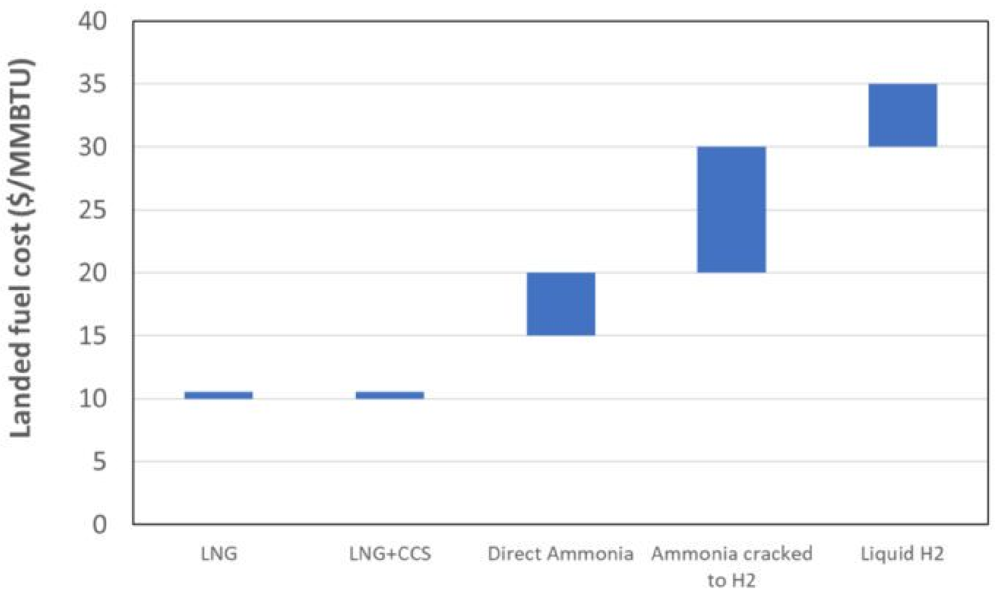
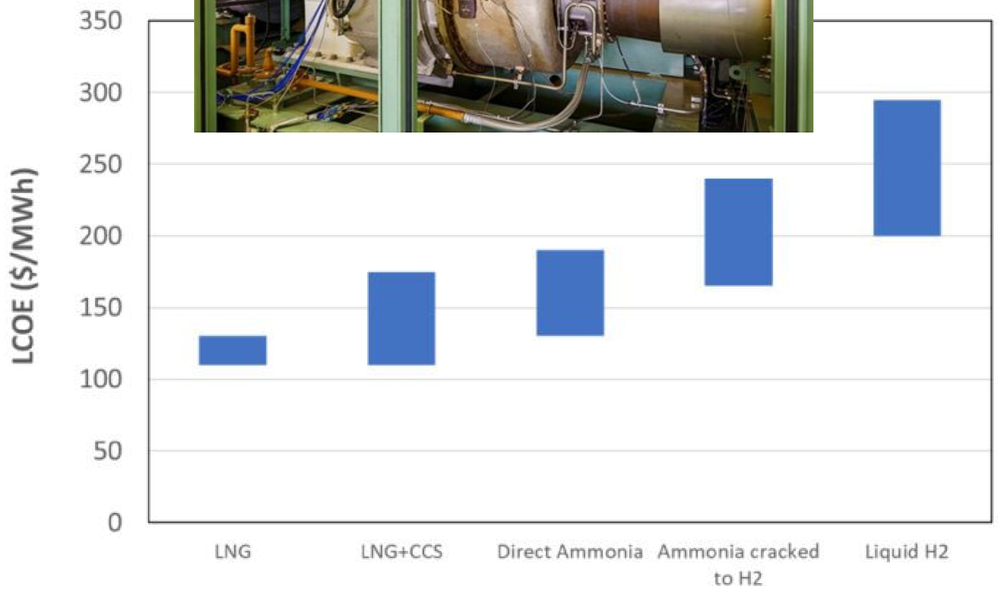
- 2MWe IM270 test turbine operated on pure ammonia at IHI in Japan
- Special liquid ammonia injection burner
- Air throttled to ensure good combustion
- NOx and N2O emissions mitigation are key challenges





https://www.powermag.com/ammonia-gas-turbine-combustion-has-economic-potential-ge-ihi-study-suggests/

Ammonia for power generation?
LinkedIn poll May 2025

- 45% / 55% split on yes / no
- Cost (not NOx) perceived to be the main obstacle
- Perception that turbines and gensets will be ammonia fuelled, slight bias towards turbines

Low-carbon blue / green ammonia for MW scale thermal power generation? Yes or no?

Will green and/or blue (low-carbon) ammonia be used as a fuel for MW scale thermal power generation?

You can see how people vote. Learn more

Yes. But only on turbines. ✓	11%
Yes. But only on gensets.	5%
Yes. On turbines & gensets.	29%
No. It's too expensive.	39%
No. NOx will be too high.	16%

62 votes • 3d left • Undo

4) Ammonia co-firing for power generation

AIST in Japan has run a pilot project to co-fire ammonia with liquid fuels or natural gas on a micro gas turbine.

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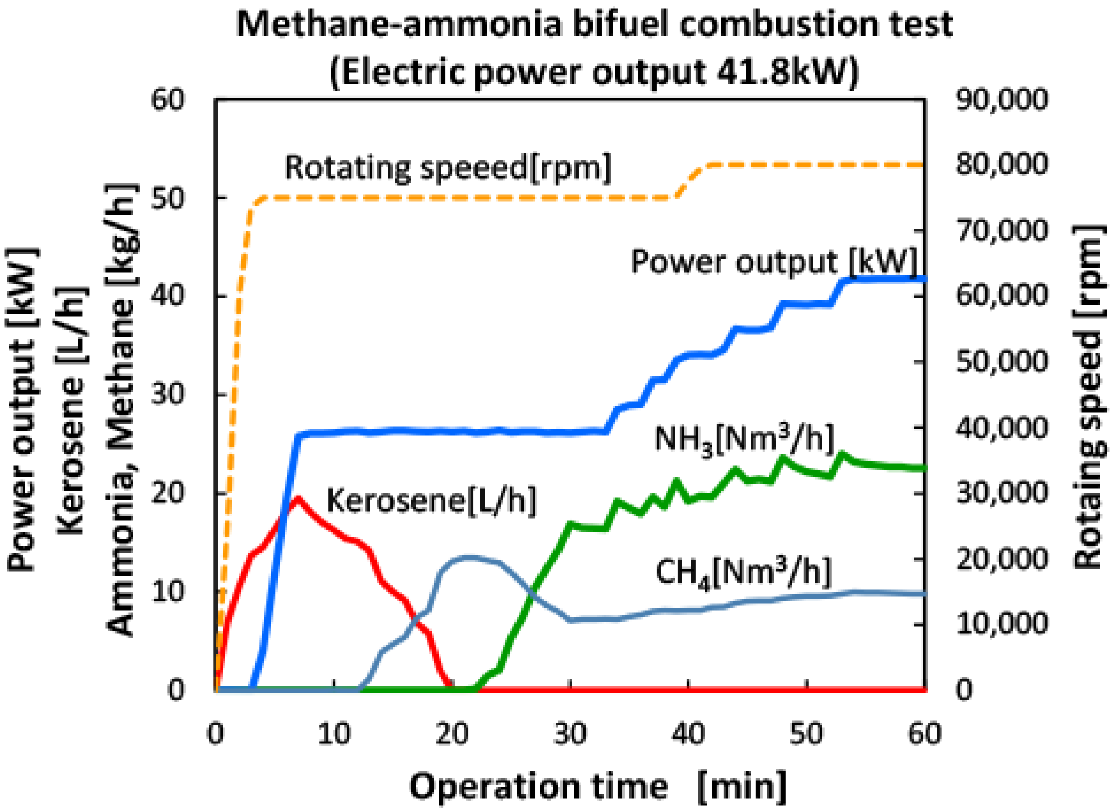

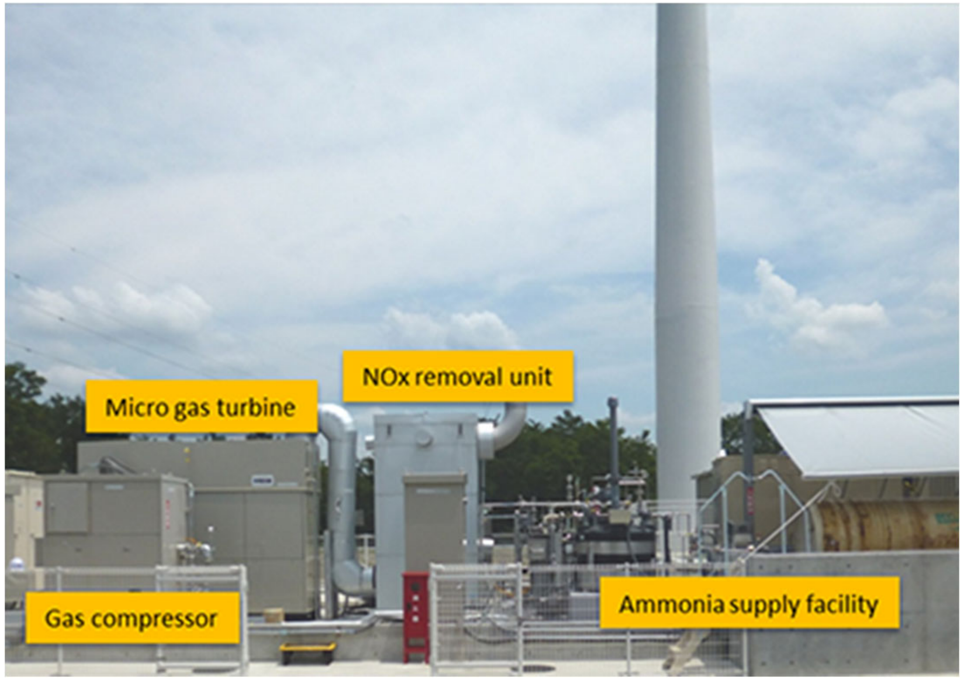

https://www.aist.go.jp/aist_e/list/latest_research/2016/20160412/en20160412.html

Ammonia co-firing on coal-fired power plants in Japan has been piloted. N_2O emissions monitoring will also be required.

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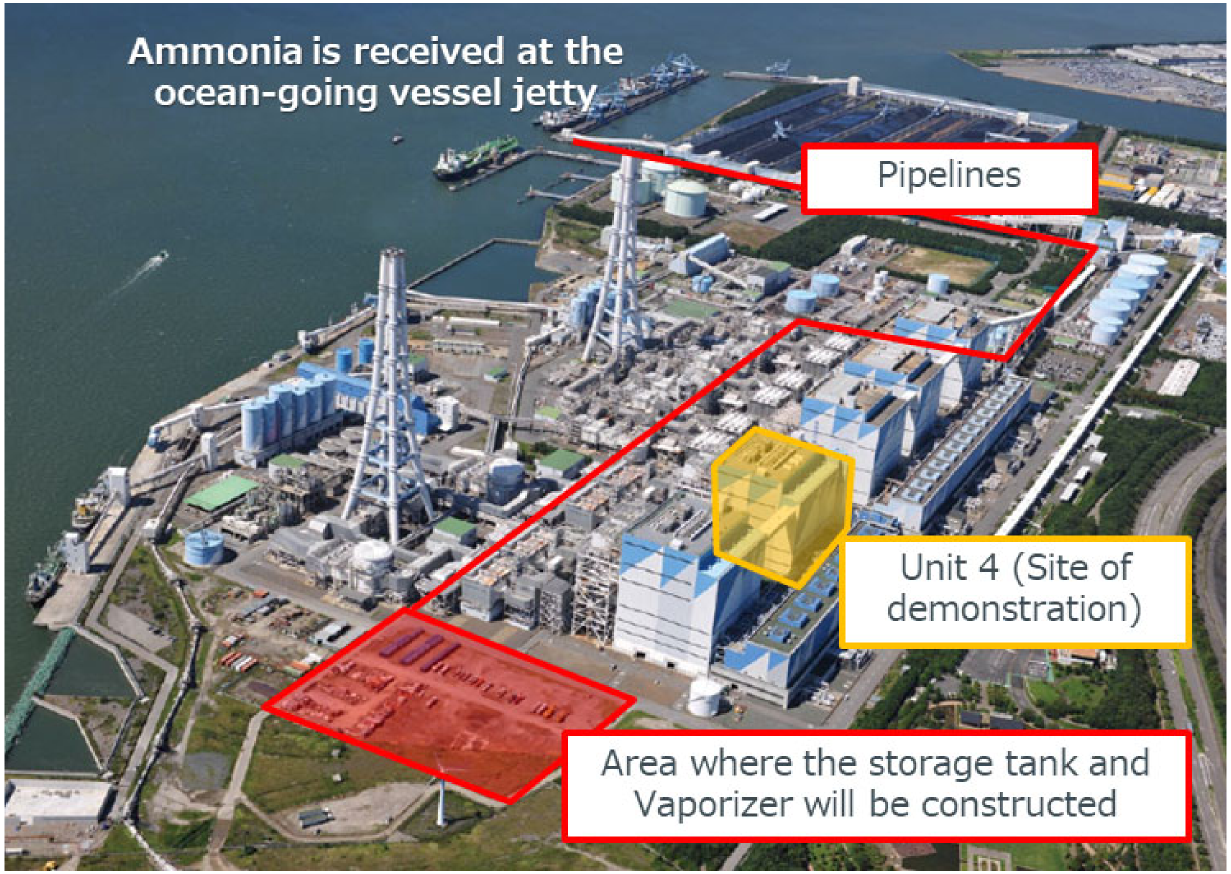

Buyer	JERA
Supply period	Long-term contract from FY 2027 into the 2040s
Quantity	Up to 500,000 tons per year
Delivery mode	FOB
Other	• As a rule, CO_2 is either not generated during ammonia production or is captured and stored. • JERA has the opportunity to participate in production projects

- JERA's Coal-fired Hekinan power station (4.1GWe)
- Demonstration project on unit 4 (1GWe)
- First commercial demonstration of 20% ammonia co-firing

https://www.jera.co.jp/english/information/20210524_677

https://www.reuters.com/business/energy/hooked-coal-power-japan-aims-ammonia-fix-2021-10-29/

JERA: Ammonia co-firing on coal-fired power plants in Japan

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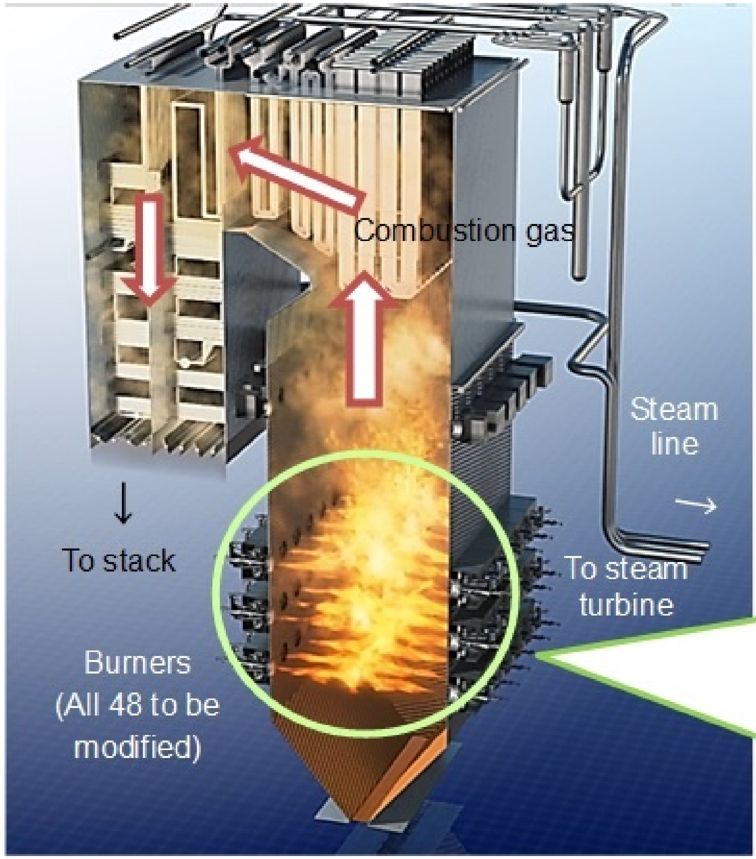
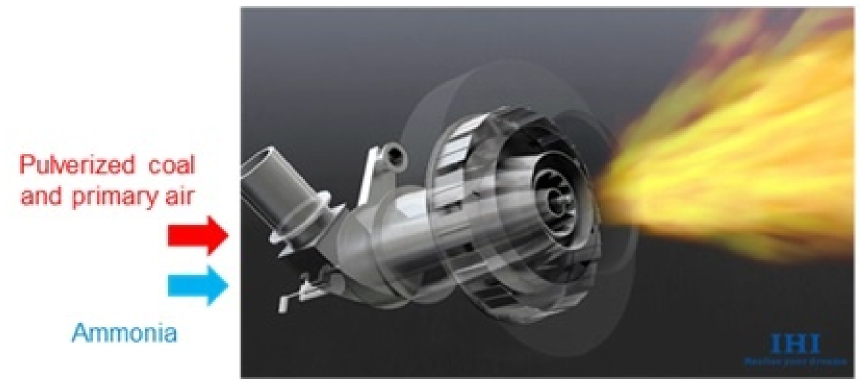


- JERA's Coal-fired Hekinan power station (4.1MWe)
- Demonstration project on unit 4 (1GWe)
- First commercial demonstration of 20% ammonia co-firing
- IHI collaborating for burner development



Outline Diagram of Ammonia Co-firing Burner (Existing Burners to be Partially Modified)

https://www.jera.co.jp/english/information/20210524_677

Power to Ammonia to Power will be a major driver of green ammonia demand, if China follows Japan and South Korea in this application.

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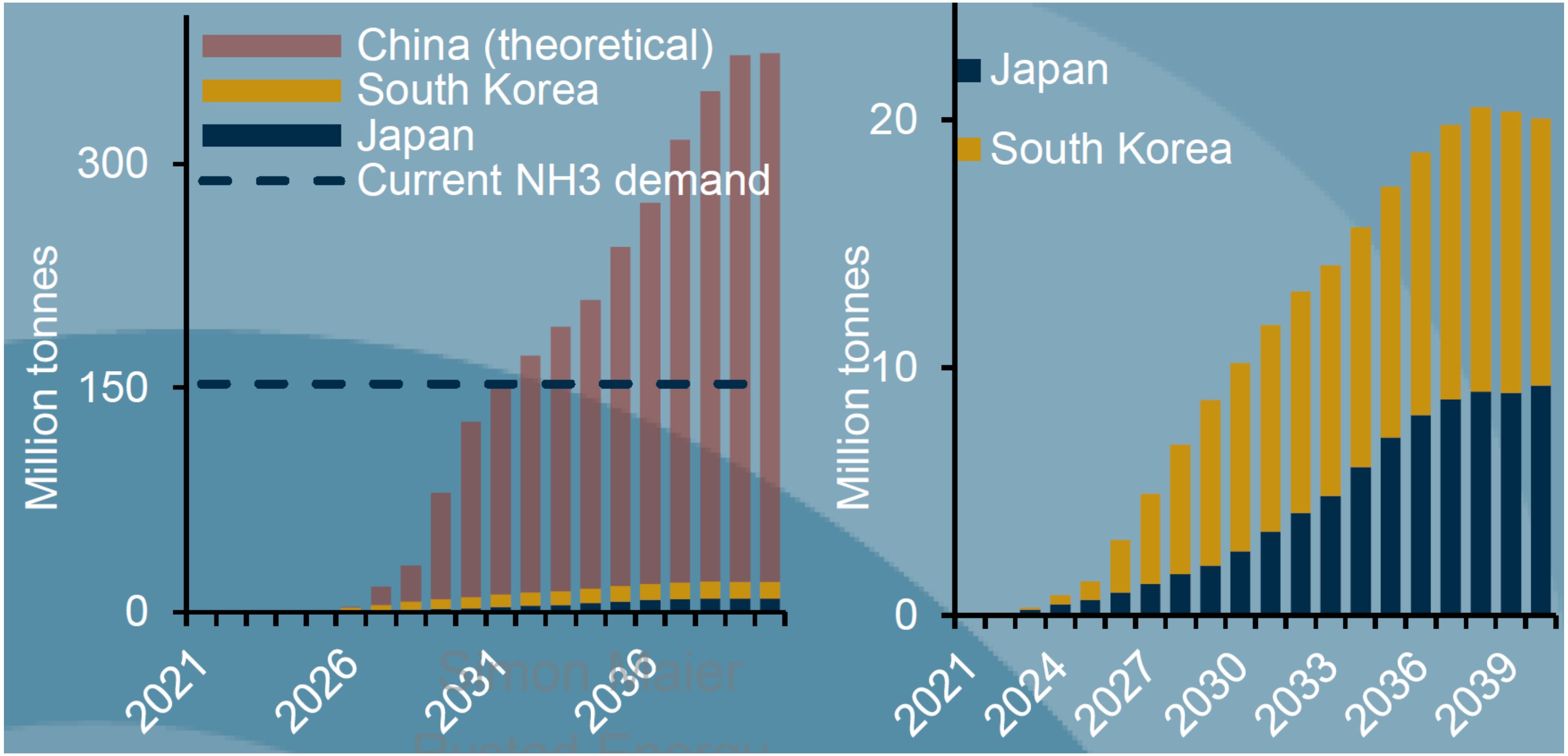

5) Deep dive on N_2O emissions monitoring

Ammonia combustion pathways are complex and can result in N_2O emissions. N_2O is an extremely potent GHG.

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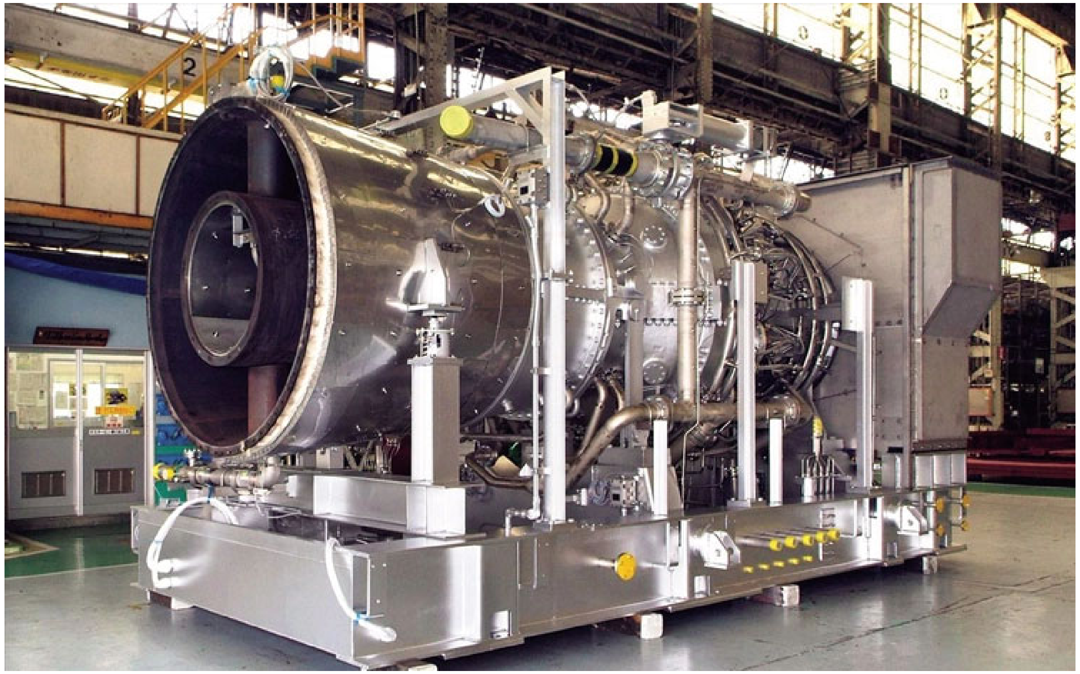

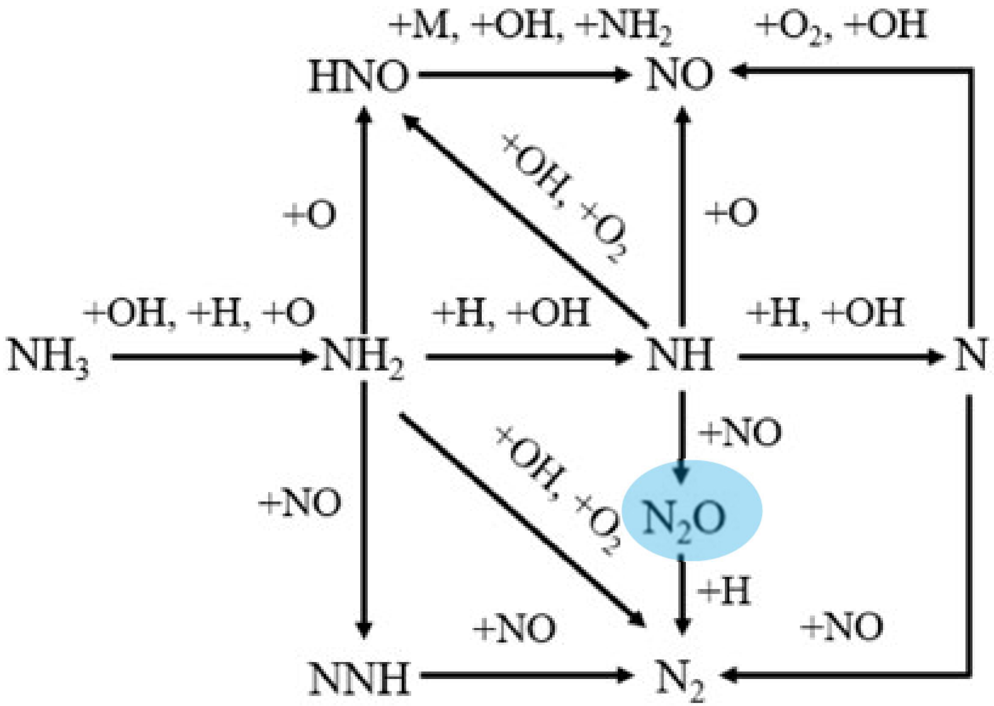

https://power.mhi.com/news/20210301.html
https://www.frontiersin.org/articles/10.3389/fenrg.2021.760356/full

Partial cracking of ammonia to hydrogen can increase the flame speed to reduce N_2O emissions.

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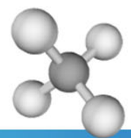
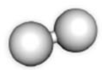
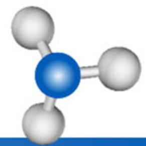
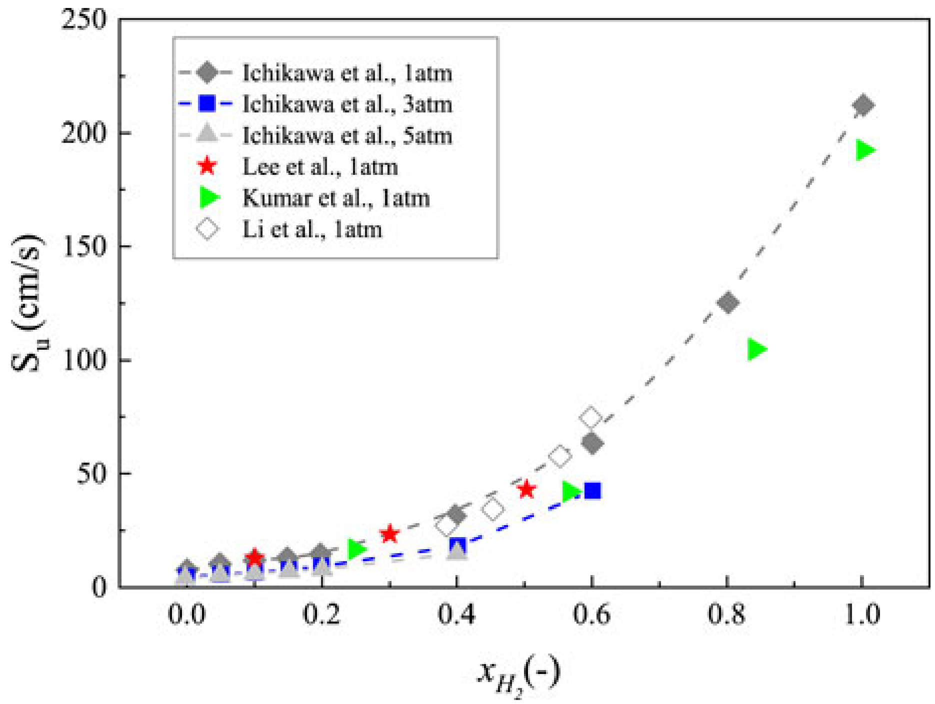




Characteristics		Methane	Hydrogen	Ammonia
Formula		CH_4	H_2	NH_3
Molecular weight	grams/mol	16	2	17
Boiling temperature	°F (°C)	-258.7 (-161.5)	-423.2 (-252.9)	-28 (-33.3)
Lower flammability limit (LFL)	%	4.4	4	15
Flame speed	cm/sec	~30-40	~200-300	~6-7
Adiabatic flame temperature	°F (°C)	~3565 (~1963)	~4000 (~2204)	~3270 (~1799)
Lower Heating value	MJ/Nm³ (BTU/scf)	35.8 (911.6)	10.8 (274.7)	14.1 (360)



https://www.frontiersin.org/articles/10.3389/fenrg.2021.760356/full

N_2O generation can be controlled by cracking of ammonia to yield circa 20%to 30% hydrogen and burning with a stoichiometric or a slightly oxygen-rich flame.

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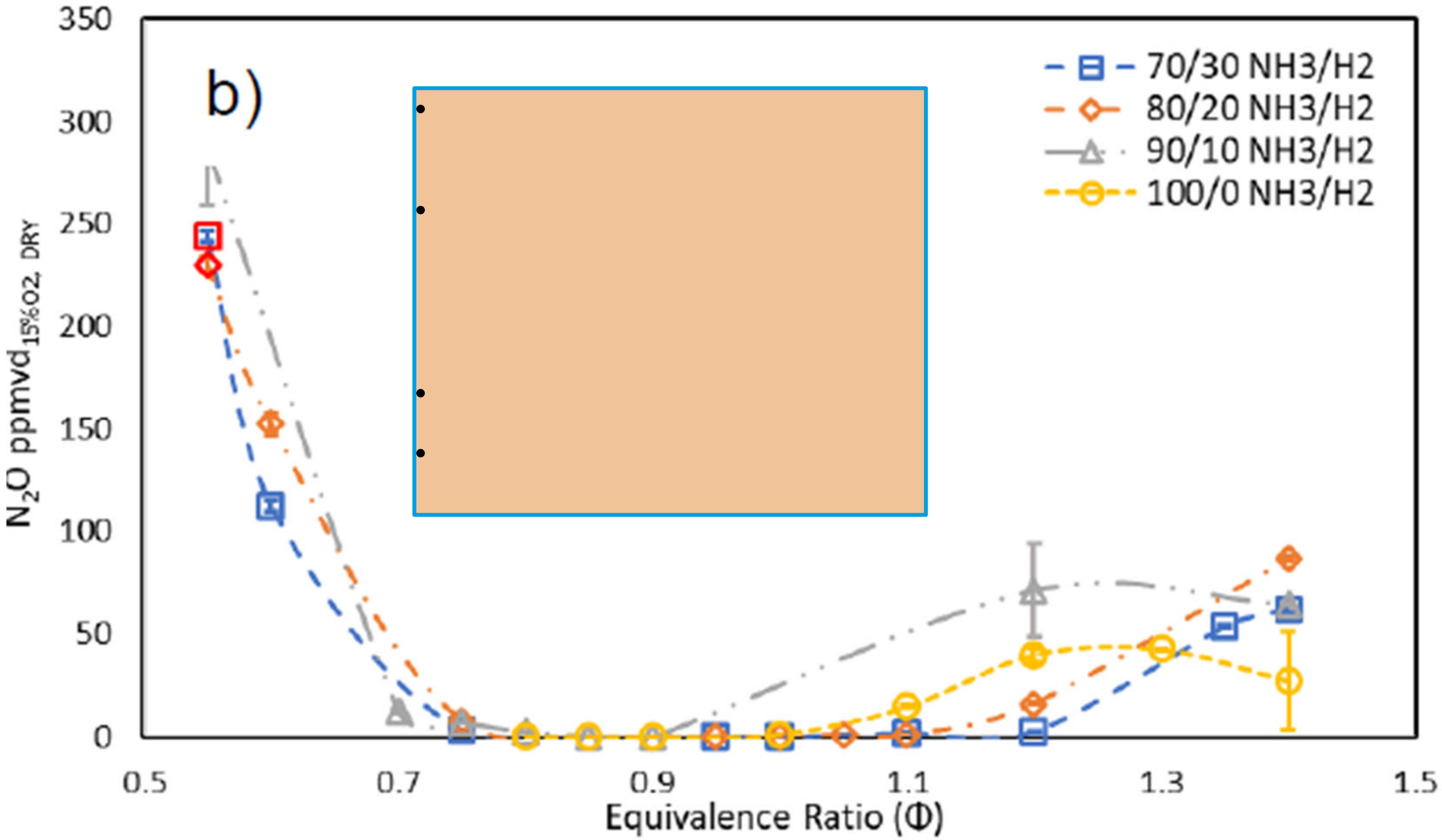
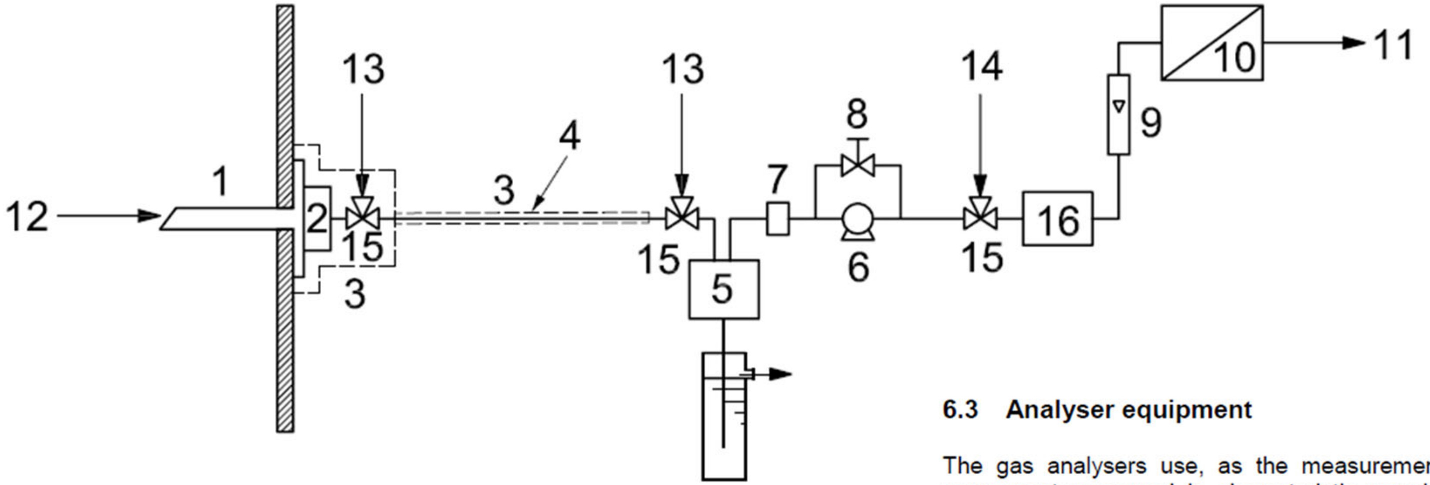


A Rosemount CT5100 QCL gas analyser was used for this 2021 paper

Nitrogen Oxides as a By-product of Ammonia/Hydrogen Combustion Regimes

Syed Mashruk[a,*], Marina Kovaleva[a], Cheng Tung Chong[b], Akihiro Hayakawa[c], Ekenechukwu C. Okafor[d], Agustin Valera-Medina[a]

https://www.emerson.com/en-us/catalog/rosemount-ct5100-continuous-gas-analyzer



Key

1 gas sampling probe
2 primary filter
3 heating (for use as necessary)
4 sampling line (heated as necessary)
5 sample cooler with condensate separator
6 sample pump
7 secondary filter
8 needle valve
9 flow meter
10 N_2O analyser
11 output
12 inlet for zero and span gas (preferably in front of the nozzle) to check the complete system
13 inlet for zero and span gas to check the conditioning system and N_2O analyser
14 inlet for zero and span gas to check the converter and N_2O analyser
15 valve
16 converter for CO oxidation

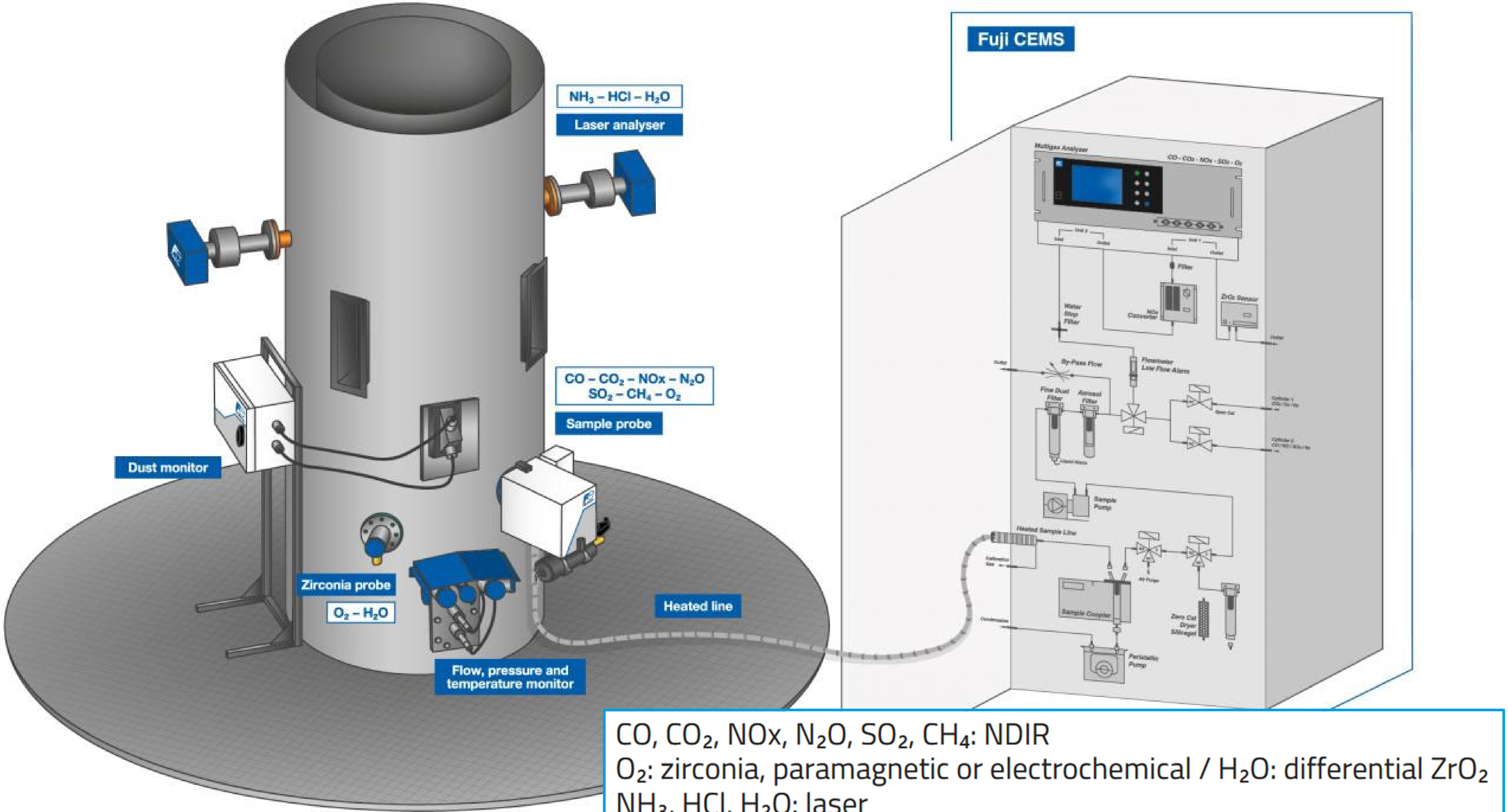
6.3 Analyser equipment

The gas analysers use, as the measurement principle, the absorption of infrared radiation (IR) by the component measured in characteristic wavelength ranges. The analysers operate according to the non-dispersive IR method (NDIR), while the selectivity of measurement is achieved by the radiation detector which is filled with the component to be measured. A schematic diagram of a typical analyser is given in Figure A.1.

Special attention should be given to CO and CO_2 interference, since for detection of N_2O the absorption at around 4,5 µm is usually used, while CO has its absorption at 4,5 µm to 4,7 µm and CO_2 has its absorption at 4,3 µm. The CO interference can be excluded by using the converter (see 6.2.8). The CO_2 sensitivity requires determination with CO_2 test gases. During real operation, CO_2 requires simultaneous measurement to yield data for real-time correction of the N_2O readings. In many instruments, this CO_2 interference correction is

INTERNATIONAL STANDARD **ISO 21258**

Stationary source emissions — Determination of the mass concentration of dinitrogen monoxide (N_2O) — Reference method: Non-dispersive infrared method



CO, CO_2, NOx, N_2O, SO_2, CH_4: NDIR
O_2: zirconia, paramagnetic or electrochemical / H_2O: differential ZrO_2
NH_3, HCl, H_2O: laser

Example commercial systems from CRU using NDIR for N2O measurement.

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https://mru-instruments.com/product/swg-200-in-situ-continuous-emission-monitor/

Example commercial system from CRU using FTIR for N2O and NH3 measurement.

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Gas Comp.	Cert. Range	Supp. Range 1	Supp. Range 2
CH_4	0 - 15	0 - 50	0 - 500
CO	0 - 75	0 - 300	0 - 1500
HCl	0 - 15	0 - 90	0 - 200
HF	0 - 3	0 - 10	—
N_2O	0 - 50	0 - 100	0 - 500
NH_3	0 - 10	0 - 75	—
NO	0 - 200	0 - 400	0 - 1500
NO_2	0 - 50	0 - 100	0 - 1000
SO_2	0 - 75	0 - 300	0 - 2000

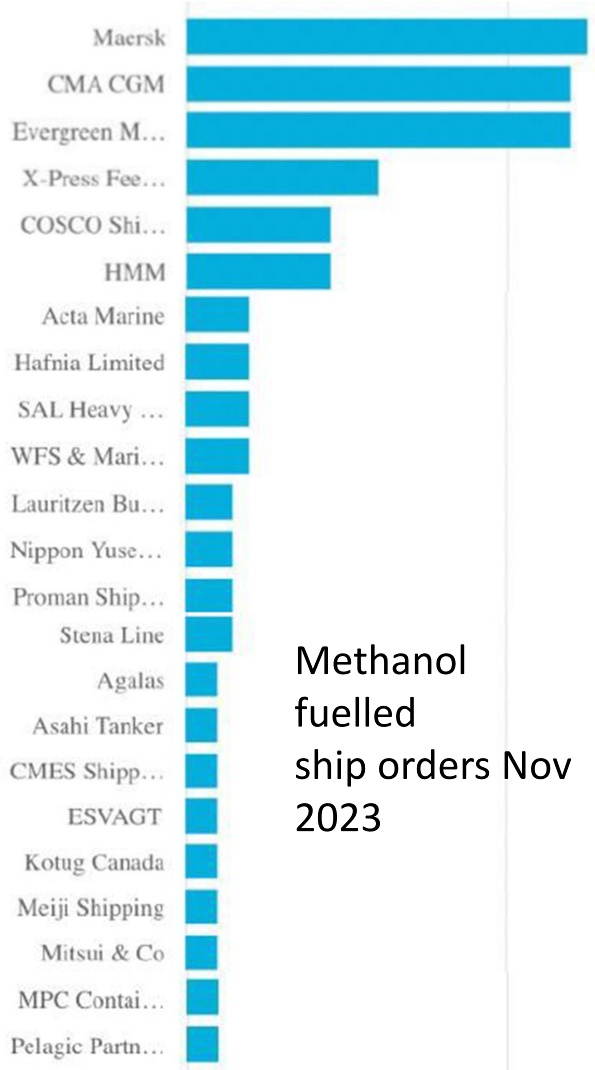
Table 1 — Gas Components and Ranges in mg/m^3 Addressed by the TÜV & MCERTS certified MGS300 system. For availability of additional gases and ranges, please contact MKS for more information.

6) Methanol as a maritime fuel

Methanol-fired internal combustion engine ships exist, and orders for many more have been placed.

Stena Germanica – methanol fueled ferry

Cajun Sun – methanol tanker
Copyright Methanex



Methanol fuelled ship orders Nov 2023

Methanol Marine Fuel, Gregory Dolan,
Motorship Propulsion and Future Fuels, 21 November 2023

Danish island ferry to use reformed methanol on an Advent SereneM HT PEM fuel cell (HT PEMFC) for motive power.

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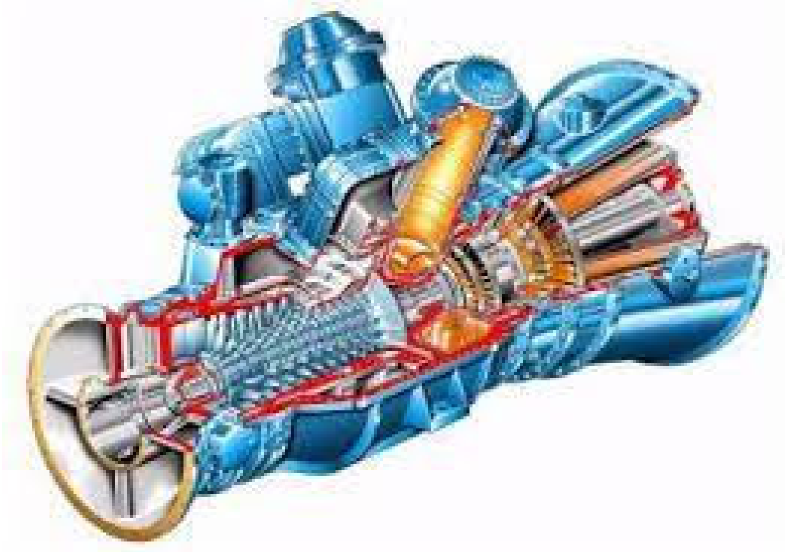
https://www.energycluster.dk/en/laeso-ferry-service-going-green/

7) Methanol for Power Generation

The potential use of grey methanol as a transportable liquid fuel for power generation came in focus around 2007 / 2008 when the gas / crude spread favoured liquid fuels from gas over fuel oil. Reduced crude prices and the mass adoption of LNG as a transportable liquid fuel eliminated the case for grey methanol for power generation. The progressive adoption of low-carbon methanol may re-ignite interest in methanol for power generation.



Methanol to Power demonstration, 2007

- Methanol Holdings (Trinidad) Ltd
- MAN Turbo THM1304 for methanol
- Twin shaft gas turbine
- Suitable for mechanical shaft and power generation
- 8.5MW, 28% efficiency on methanol

http://www.methanol.org/wp-content/uploads/2016/06/Methanol-to-Power-PPT-Hayden-Furlonge-MHTL.pdf

Methanol fired power generation has been piloted and shows very low particulate and NOx emissions, for example DOR and Israel Electric Company.

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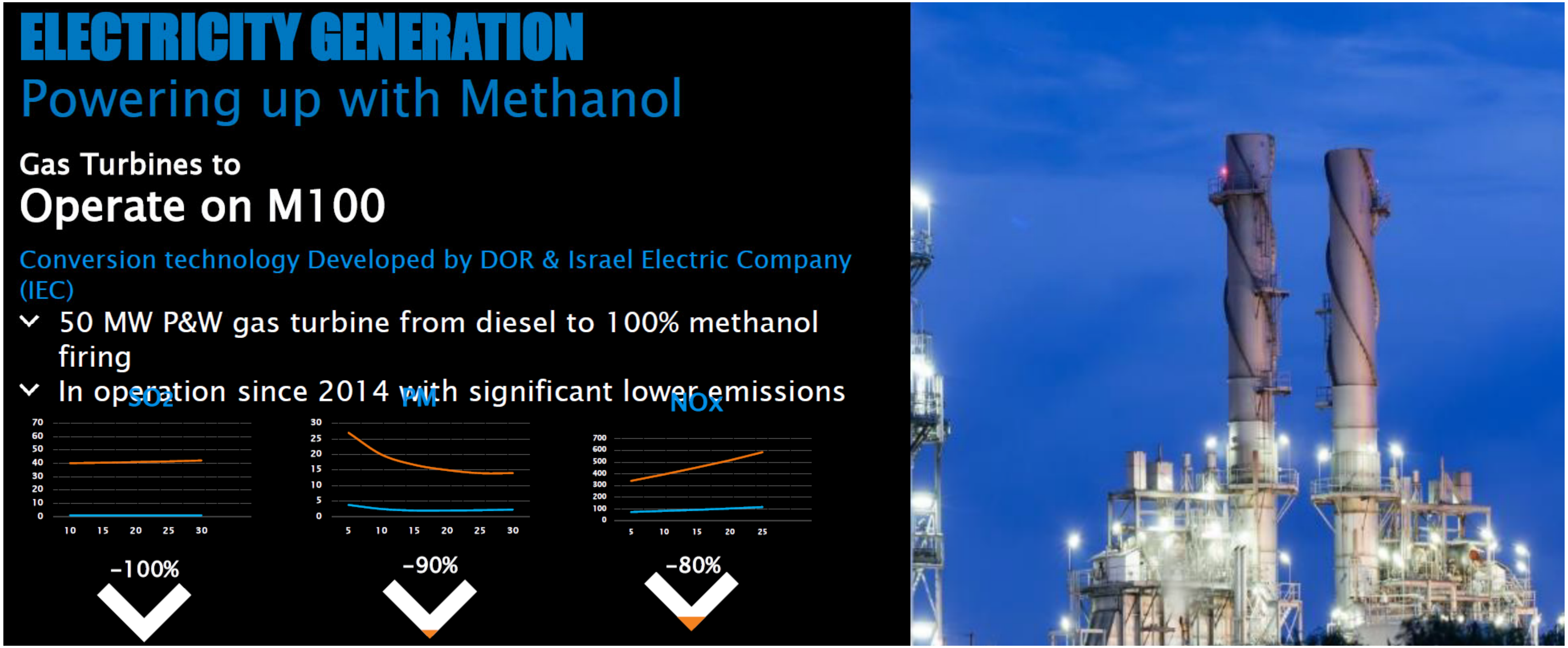

https://www.dormotors.com/wp-content/uploads/2021/04/Dor-Motors-Methanol_Summary-1.pdf

Power to Methanol to Power: SFC Energy EFOY direct methanol fuel cell (DMFC). Methanol is diluted with water, then fed to the fuel cell.

SIQENS reformed methanol to high temperature PEM fuel cell (HT PEMFC). The HT PEMFC is tolerant of CO in the reformate. An LT PEMFC cannot tolerate CO in the hydrogen feed.

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6) Methanol production and GoO certification – biogenic CO_2 fraction and LCA

E-methanol production is the basis of Power to Methanol to Power. European Energy Kassø (west of Aabenraa) 32,000 tonnes per year e-methanol facility under construction, Nov 2023. Using Siemens Energy Silyzer 300 PEM electrolysers and Clariant's MegaMax® CO2 hydrogenation catalyst.

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Images courtesy of European Energy

E-methanol production is the basis of Power to Methanol to Power. Carbon Recycling International: 4,000 tonne per day of methanol from geothermal CO2 in Iceland to 100,000 tonnes per year methanol production facility at Jiangsu Sailboat, China. Recycling 150,000 tonnes per year of CO2, captured from ethylene oxide production.

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https://www.carbonrecycling.is/

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Introduction to Stephen B. Harrison and sbh4 consulting

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Stephen B. Harrison is the founder and managing director at sbh4 GmbH in Germany. His work focuses on decarbonisation and greenhouse gas emissions reduction. E-fuels, hydrogen, ammonia and CCTUS are fundamental pillars of his consulting practice.

In support of the European Commission through CINEA in 2023, Stephen evaluated seven CCS, hydrogen and e-fuels submissions to the Third Innovation Fund. The fund allocated €2 billion to large-scale decarbonisation projects in Europe. In 2024 he supported the European Commission's EISMEA with venture capital investment due diligence services.

Stephen has served as the international expert and team leader for three ADB projects related to CCTUS and renewable hydrogen deployment in Pakistan, Palau and Viet Nam. He has also supported the IFC and work bank on e-fuels and green hydrogen strategy development projects in Namibia and Pakistan. In 2021, he specified more than 2GW of electrolyser capacity for green hydrogen projects.

With a background in industrial and specialty gases, including 27 years at BOC Gases, The BOC Group and Linde Gas, Stephen has intimate knowledge of e-fuels, hydrogen, ammonia and carbon dioxide from commercial, technical and operational perspectives. For 14 years, he was a global business leader in these FTSE100 and DAX30 companies.

Stephen has extensive buy-side and sell-side M&A due diligence and investment due diligence advisory experience in the energy and clean-tech sectors. Private Equity firms and investment fund managers and green-tech start-ups are regular clients. He also supports operating companies in their mission to decarbonise their scope 1, 2 and 3 GHG emissions.

As a member of the H2 View and **gas**world editorial advisory boards, Stephen advises the direction for the leading hydrogen-focused international publications. Through H2 VIEW, World Hydrogen Leaders and Sustainable Aviation Futures, he has led Masterclasses covering many hydrogen, SAF and hydrogen derivatives themes in virtual and live sessions.

Stephen served on the Scientific Committee for CEM2023 in Barcelona and chaired the session related to CEM from clean energy systems. Stephen was session chair for the e-fuels and hydrogen propulsion track at the Bremen Hydrogen Technology Exhibition in September 2023 and will chair the same stream at that conference in Berlin in 2024. He was also conference chair for day-2 of the CO2 utilisation Summit in Hamburg in 2023. Stephen also served on the Technical Committee for the Green Hydrogen Summit in Oman in December 2022 and the Advisory Board of the International Power Summit in Munich in September 2022.