PROPELLING GROWTH: THE ROLE OF GREEN AMMONIA AS A CLEAN, SUSTAINABLE MARITIME FUEL

MariNH3

Clean, green ammonia engines for maritime

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WHY GREEN AMMONIA?

SUSTAINABLE FUEL

Near-zero carbon fuel suitable for long-distance shipping where batteries and hydrogen alone are less practical.

ENERGY STORAGE

High energy density and existing global infrastructure enable safe storage and bulk transport.

HYDROGEN CARRIER

Ammonia efficiently stores and transports hydrogen, releasing it onboard to power clean combustion.

EXECUTIVE SUMMARY

- Ammonia is well known as an industrial chemical, especially in the production of fertiliser and chemical products. Ammonia is also flammable, opening a new possibility to be used as a fuel.
- Ammonia is made, shipped and handled in bulk today. While it may present safety and environmental risks (like any fuel), these are understood.
- The MariNH$_3$ programme is a consortium of UK universities, alongside over 20 industrial partners, established to study the use of ammonia as a fuel in internal combustion engines, alongside broader socio-economic aspects of its uptake as a replacement for fossil marine fuel.
- The programme has successfully developed combustion and after-treatment technologies suitable for both retrofitting of existing engines (which would retain their existing marine diesel fuel alongside ammonia).

80 – 95 %
GHG REDUCTION

~180 YEARS
INDUSTRIAL HANDLING EXPERIENCE

BELOW IMO TIER III
NO_X LIMIT
Post-SCR ~ 0.5 g/kWh achieved

MARKET COULD TRIPLE BY 2050
GLOBAL AMMONIA DEMAND

AMMONIA PRODUCTION PATHWAYS

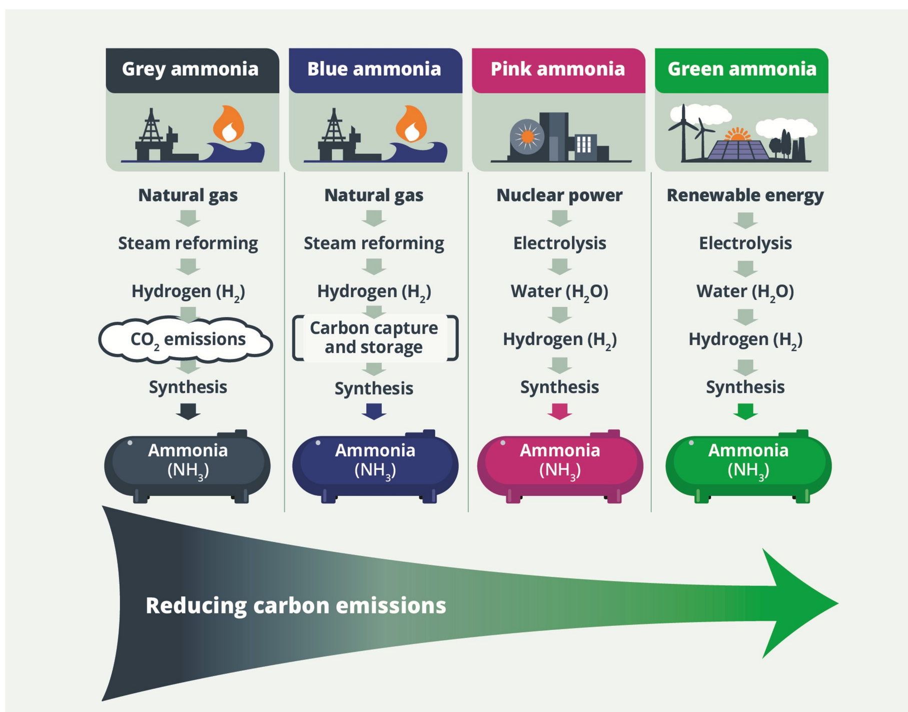

Fig :1 Ammonia Production Pathways

- Ammonia is a compound of nitrogen (abundant in the atmosphere), and hydrogen (a component of water).
- This means that it can be synthesised using only electricity, first to split the water into hydrogen and oxygen by electrolysis, then to extract nitrogen from the atmosphere to combine it with the hydrogen.
- If that electricity is sourced from renewables, it is potentially a zero-carbon fuel, called "green ammonia". If a more conventional natural gas route is used but the carbon released is sequestered (captured and stored), it is low carbon "blue ammonia" (see Figure 1).
- In both cases, the ammonia itself is identical to the existing well-known industrial chemical, meaning that equipment, processes and skills for its handling, storage and shipment are well established, needing only adaptation and roll-out to a marine environment.

COMPARISON OF FOSSIL FUEL AND SUSTAINABLE FUEL (AMMONIA) COMBUSTION

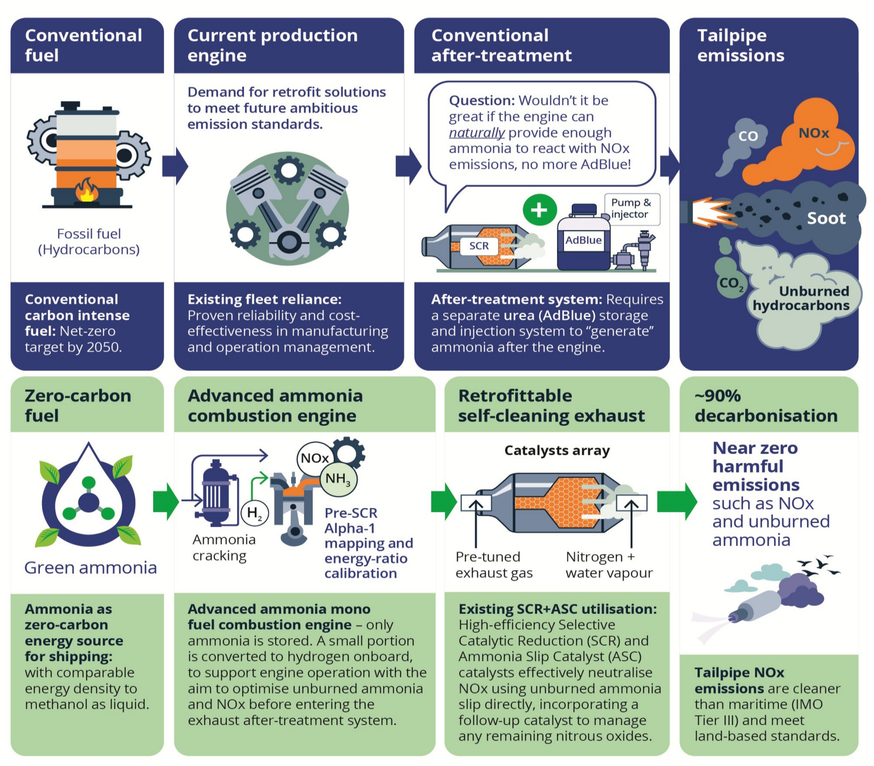

Fig :2 Comparison of fossil fuel and Ammonia Combustion

- The primary attraction of ammonia as a fuel lies in its potential for 100% carbon reduction during operation. However, ammonia combustion produces nitrogen-based species that must be carefully managed to avoid replacing a carbon problem with a nitrogen one.
- The three dominant species of concern are nitrogen oxides (commonly referred to as its chemical formula, NOx), nitrous oxide and unburned ammonia (also known as ammonia slip). The interaction between these in both the engine and its catalytic after-treatment is complex, where strategies to reduce one can often increase another.
- As such, the nitrogen pathway still requires fundamental research to enable a robust combustion system design. There is, however, one very useful interaction of these nitrogen-based gases that can be key to low emissions: ammonia (the fuel) can be reacted with nitrous oxides (the engine-out emissions) to create harmless nitrogen and water.

ENVIRONMENTAL IMPACT

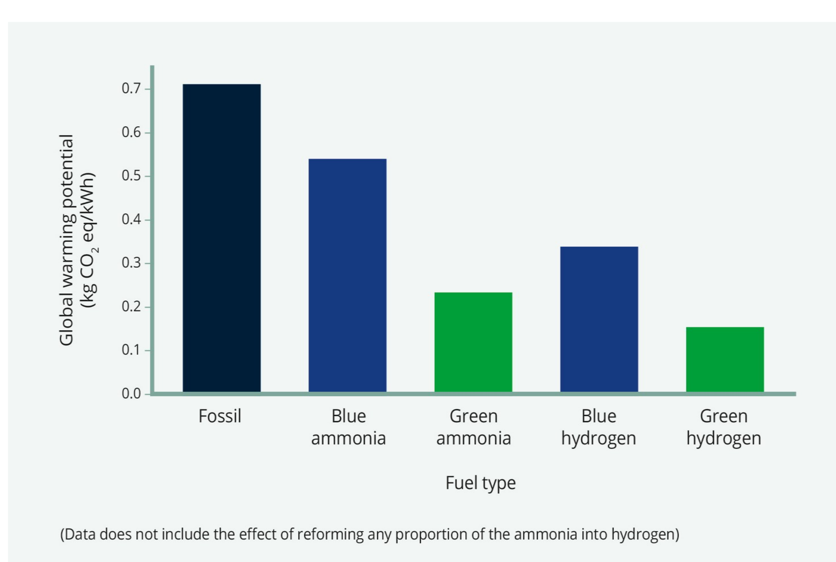

Fig :3 Global warming potential over 100 years for ammonia compared with fossil fuel marine diesel oil and hydrogen.

ECONOMIC IMPACT

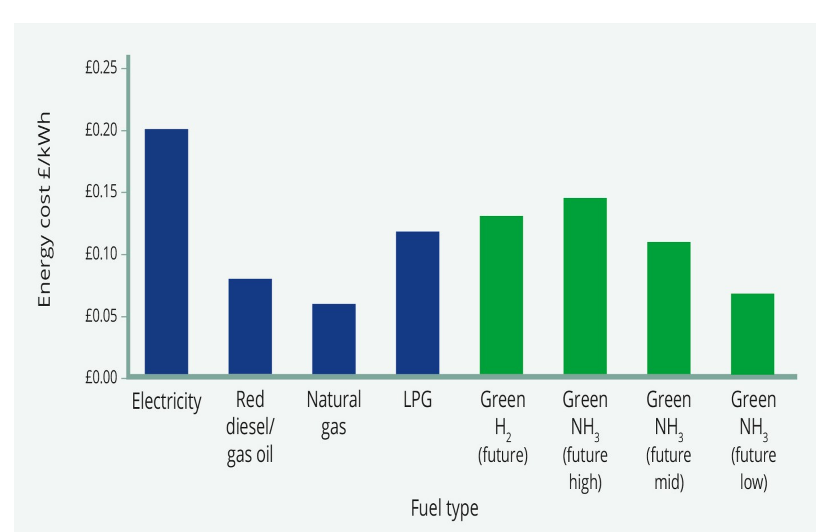

Fig :4 UK bulk energy costs by fuel type.

KEY CHALLENGES OF AMMONIA COMBUSTION

- Can it be burned efficiently?
- Can it be burned cleanly?
- Can it be handled safely as a fuel?

COMBUSTION AND EFFICIENCY

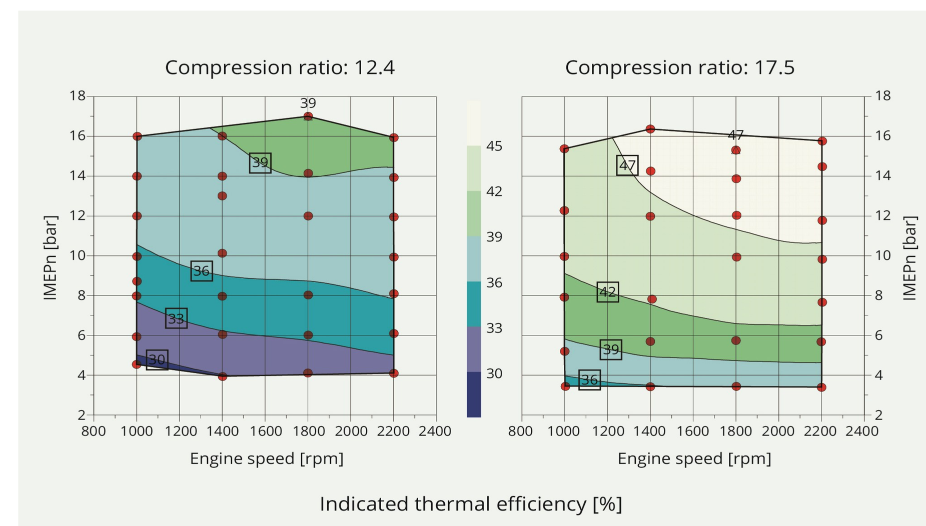

Fig 5 : The variation of thermal efficiency in an adapted single cylinder gasoline engine at compression ratios of 12.4 and 17.5 across various speed and load conditions

- Initial research conducted on an adapted single cylinder gasoline engine shows promising results, achieving 39% indicated thermal efficiency at the lower compression ratio of 12.4.
- When the engine was further modified to be more in line with conventional diesel engine configuration (a compression ratio of 17.5), the indicated thermal efficiency increased by ~20%, achieving peaking at 47% indicated thermal efficiency.

EMISSIONS

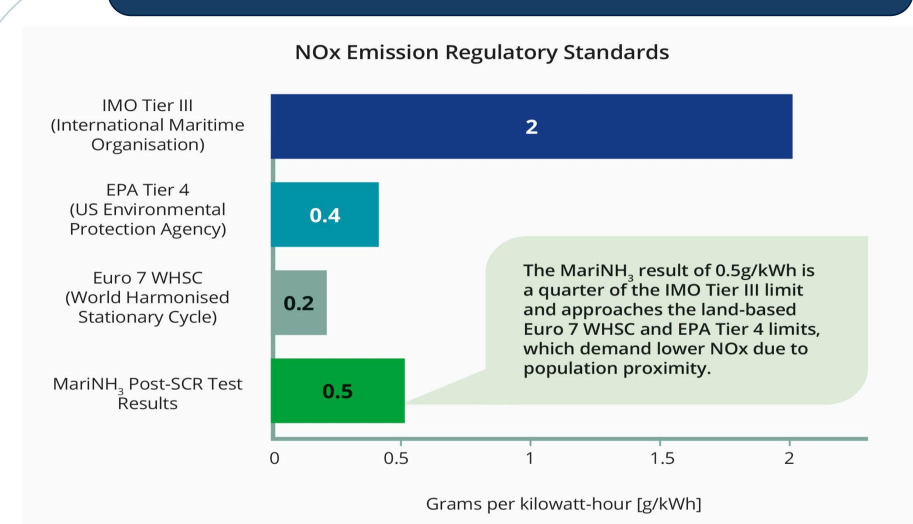

Figure 6: Post-SCR Nitric Oxides (NOx) Performance Benchmark: experimental results beyond maritime & meeting land-based standards [1][2].

- MariNH$_3$ research results show NOx emissions measured after the exhaust catalyst (Figure 7) are well below the International Maritime Organisation (IMO) Tier III regulatory limit of approximately 2.0 g/kWh at 2000 rpm (with higher permissible level at lower engine speeds).
- The achieved ultra-low values also reach land-based standards for off-road and stationary engines as prescribed by the EPA and Euro7 WHSC standards which are 5-10 times more stringent.

MARINH$_3$ RESEARCH PROGRAMME

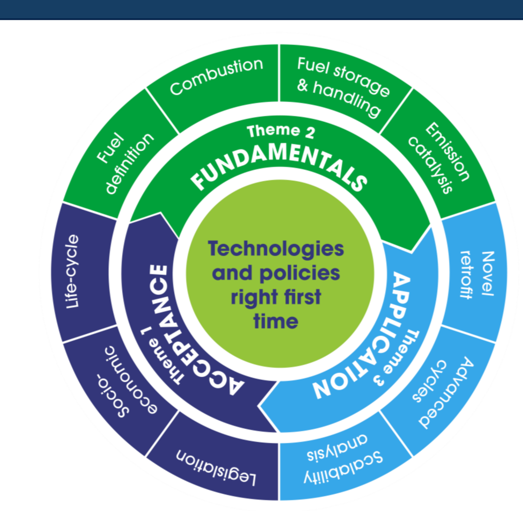

Figure 7: Overview of the MariNH$_3$ Research Programme: its three research themes and investigative focus within each.

More information about the Propelling growth white paper can be obtained by scanning the QR code or visit *https://marinh3.ac.uk/outputs/reports/*

CONCLUSION AND RECOMMENDATIONS

1. **ESTABLISH MARKET INCENTIVES** — Create clear policy and financial signals to unlock early investment and scale adoption.
2. **ENABLE PORT-SIDE AMMONIA ECOSYSTEMS** — Invest in storage, bunkering ,safety systems and standards at key maritime hubs.
3. **BUILD TRAINING AND SKILLS** — Develop workforce capable for safe handling, operations and maintenance.
4. **IMPROVE PUBLIC AND STAKEHOLDER UNDERSTANDING** — Communicate benefits, address concerns and build trust through transparency.
5. **CONTINUE RESEARCH AND INNOVATION** — Advance engine technology, emissions control and systems integration.

FUTURE RESEARCH

(1) Engine combustion and emission control
(2) Advanced engine concepts
(3) Ammonia fuel cells
(4) Inherently safe fuel storage
(5) Fugitive emissions
(6) Economics and policy

REFERENCES

(1) I. M. Organization, "Revised MARPOL Annex VI – Regulations for the Prevention of Air Pollution from Ships," *Regulation*, vol. 13, no. NOx, 2020, [Online]. Available: https://www.imo.org/en/ourwork/environment/pages/nitrogen-oxides-%28nox%29-%E2%80%93-regulation-13.aspx?

(2) "• Coastal Virginia Offshore Wind Commercial Project Outer Continental Shelf DRAFT Preconstruction Air Permit No," in *OCS-R3-01 - EPA*. [Online]. Available: https://www.epa.gov/system/files/documents/2024-01/final-2.1-draft-cvow-c-ocs-air-permit-ocs-r3-01.pdf

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