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EPS Research

The Case for Ammonia

Ammonia Offers Superior Environmental Credentials as a Fuel

| | Description | Fuel Oil | Ammonia | NH ₃ vs FO |
|------------------|--|---|---|---|
| CO ₂ | <ul style="list-style-type: none"> Growing CO₂ emissions are the main cause of human activity induced global warming | <ul style="list-style-type: none"> 3.2 t CO₂ / t fuel emitted during combustion + emissions during production & transport | <ul style="list-style-type: none"> Zero CO₂ emissions during combustion (except for pilot fuel, which can be replaced with biofuel) Upstream emissions depend on H₂ origin (fossil, fossil + carbon capture, renewables) |  |
| N ₂ O | <ul style="list-style-type: none"> A potent greenhouse gas with a GWP of 273x (IPCC AR6) CO₂ over 20 & 100-year horizons | <ul style="list-style-type: none"> Very low – approximately 0.00018g N₂O/g fuel¹ | <ul style="list-style-type: none"> Expected to be on par with diesel/fuel oil Handled by engine tuning |  |
| NO _x | <ul style="list-style-type: none"> Includes air pollutants nitrogen monoxide (NO) and nitrogen dioxide (NO₂) Main source in diesel cycle engines is thermal NO_x (N₂ in air), though fuel NO_x (e.g. N in coal/ammonia) can also play a role Responsible for acidic rain, eutrophication, negative effects on respiratory tracts, smog Subject to strict IMO global limits (Tier II / III) | <ul style="list-style-type: none"> Main triggers are peak temperature & timespan of combustion Tier II is achieved by adjusting injection timing, pressure, exhaust valve timing, while Tier III limits require usage of SCR or EGR¹ | <ul style="list-style-type: none"> Expected NOx emissions on par/below fuel oil though test results still being tabulated Tier III compliance requires SCR, which can use ammonia fuel installed on-board instead of urea SCR breaks down the NO_x into N2 and water in the presence of NH₃ |  |
| NH ₃ | <ul style="list-style-type: none"> A tiny fraction of ammonia fuel may not be combusted and could escape in the exhaust Ammonia has a GWP of 0 (no direct effect) | <ul style="list-style-type: none"> N/A | <ul style="list-style-type: none"> Very limited NH₃ slip expected Any unburnt NH₃ will be removed in the SCR and may eliminate need for adding urea/NH₃ to treat NO_x |  |
| SO _x | <ul style="list-style-type: none"> Sulphur oxide emissions are directly linked to the sulphur content of the fuel and are a major reason for the occurrence of acidic rain | <ul style="list-style-type: none"> Compliance requires use of low-sulphur oil (0.5%/0.1%) or scrubber but some emissions remain | <ul style="list-style-type: none"> No SO_x (except for pilot fuel) |  |
| PM | <ul style="list-style-type: none"> Consist of solid and liquid particles and result from the combustion of fuels | <ul style="list-style-type: none"> Highest among marine fuels, HFO in particular | <ul style="list-style-type: none"> >90% reduction vs HFO |  |

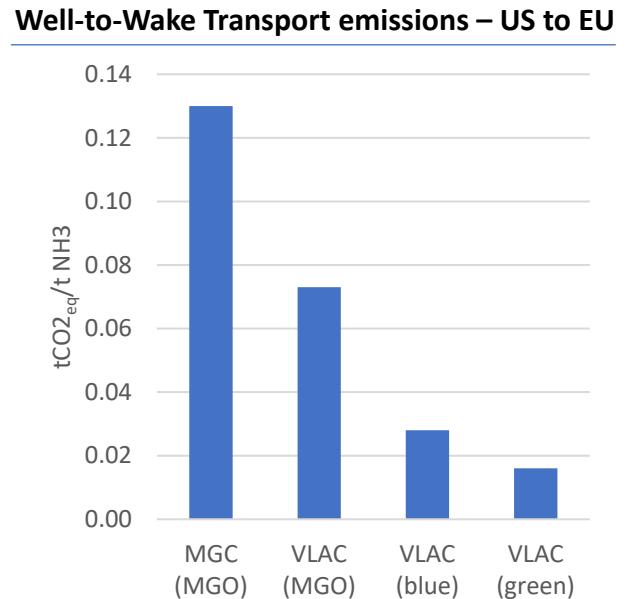
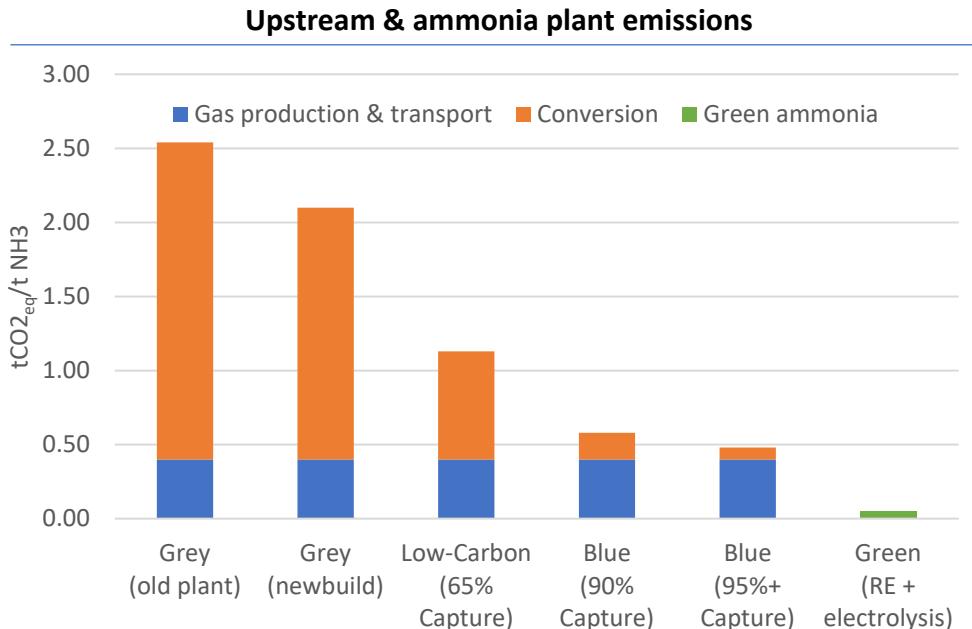
Notes:

1) As per Fourth IMO GHG Study and FuelEU regulation

2) SCR (Selective Catalytic Reduction) and EGR (Exhaust Gas Recirculation) are engine add-ons, which can provide additional reductions in NO_x emissions

Not All Ammonia is Born Equal

A case study of lifecycle emissions for ammonia produced in the US and shipped to Europe

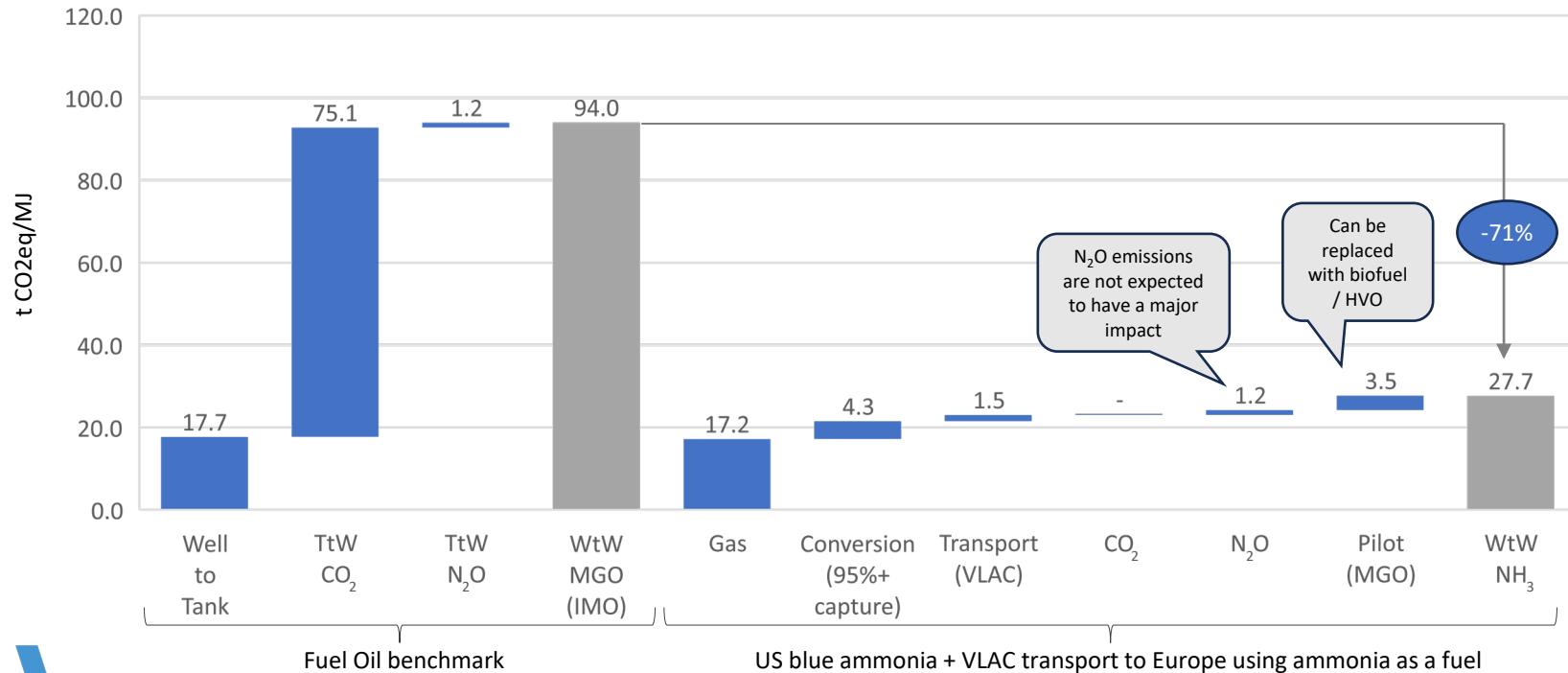


Notes:

- 1) 1tCO2eq/t NH₃ translates into 54gCO2eq/MJ based on an LCV of 18.6 MJ/kg
- 2) Significant volumes of ammonia is already being produced in the US from natural gas with partial carbon capture (60-65%) – this is referred to as “Low-Carbon ammonia” in this presentation, while the “Blue ammonia” designation is customarily applied to ammonia produced with 90%+ carbon capture
- 3) MGC refers to Medium-sized Gas Carrier with typical capacity of 38-40,000 m³ 4) VLAC refers to Very Large Ammonia Carrier with capacity of 93,000 m³

Blue Ammonia Delivers 70%+ GHG Emissions Savings as a fuel

Well-to-Wake emissions from ammonia as a fuel compared to fuel oil on a like-for-like basis



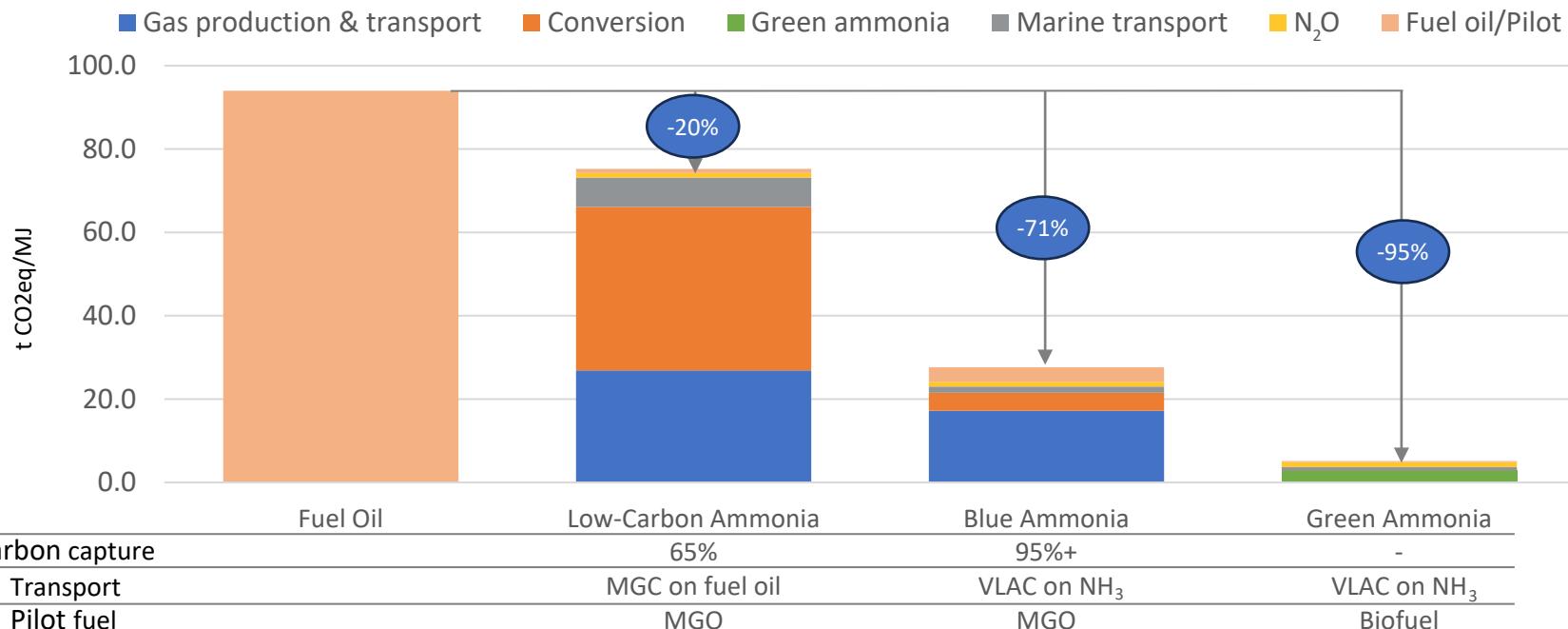
Notes:

- 1) Assumes Blue ammonia is produced from Responsibly Sourced Gas (RSG) with certified low upstream methane intensity
- 2) Pilot fuel emissions reflect incremental emissions from the use of MGO pilot fuel versus blue ammonia assuming a 5% pilot fuel energy fraction at full load
- 3) N₂O emissions from fuel oil/MGO are estimated at 0.00018 g N₂O per g fuel (per Fourth IMO GHG Study and FuelEU), which translates into approximately 1.2 tCO₂eq/MJ using N₂O GWP of 273 (20/100yr basis) as per IPCC AR6. We have assumed ammonia engines will produce comparable N₂O emissions



Ammonia Offers Potential to Meet Increasing GHG Ambitions

Utilising Low-Carbon ammonia being produced today with partial CC is already better than using fuel oil



Summary: The Case for Ammonia

- Our detailed analysis of all key environmental pollution criteria re-affirms that **ammonia has superior environmental credentials as a fuel**
- The full lifecycle/Well-to-Wake GHG emissions of ammonia vary based on feedstock, technology and transportation choices, however, **Low-Carbon ammonia already being produced today with partial carbon capture delivers >20% WtW CO₂eq savings** compared to using conventional fuels
- **New blue ammonia plants are capable of delivering 70%+ savings, while green ammonia is expected to deliver 90-95%+**
- While N₂O emissions testing results should be closely monitored, all indications are that their impact on **overall GHG footprint will be limited** given small volumes, despite high Global Warming Potential (GWP) of N₂O
- Choice of transportation has an important contribution to lifecycle CO₂ emissions. VLACs are capable of delivering ammonia at half the CO₂ footprint of MGCs when operating on fuel oil and their GHG emissions approach zero when operating on ammonia cargo as a fuel

