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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	• Growing CO_2 emissions are the main cause of human activity induced global warming	• 3.2 t CO_2 / t fuel emitted during combustion + emissions during production & transport	• Zero CO_2 emissions during combustion (except for pilot fuel, which can be replaced with biofuel) • Upstream emissions depend on H_2 origin (fossil, fossil + carbon capture, renewables)	
N_2O	• A potent greenhouse gas with a GWP of 273x (IPCC AR6) CO_2 over 20 & 100-year horizons	• Very low – approximately 0.00018g N_2O/g fuel[1]	• Expected to be on par with diesel/fuel oil • Handled by engine tuning	
NO_X	• Includes air pollutants nitrogen monoxide (NO) and nitrogen dioxide (NO_2) • Main source in diesel cycle engines is thermal NO_X (N_2 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)	• 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 EGR[1]	• 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 NH_3	
NH_3	• 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)	• N/A	• Very limited NH_3 slip expected • Any unburnt NH_3 will be removed in the SCR and may eliminate need for adding urea/NH_3 to treat NO_X	
SO_X	• Sulphur oxide emissions are directly linked to the sulphur content of the fuel and are a major reason for the occurrence of acidic rain	• Compliance requires use of low-sulphur oil (0.5%/0.1%) or scrubber but some emissions remain	• No SO_X (except for pilot fuel)	
PM	• Consist of solid and liquid particles and result from the combustion of fuels	• Highest among marine fuels, HFO in particular	• >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

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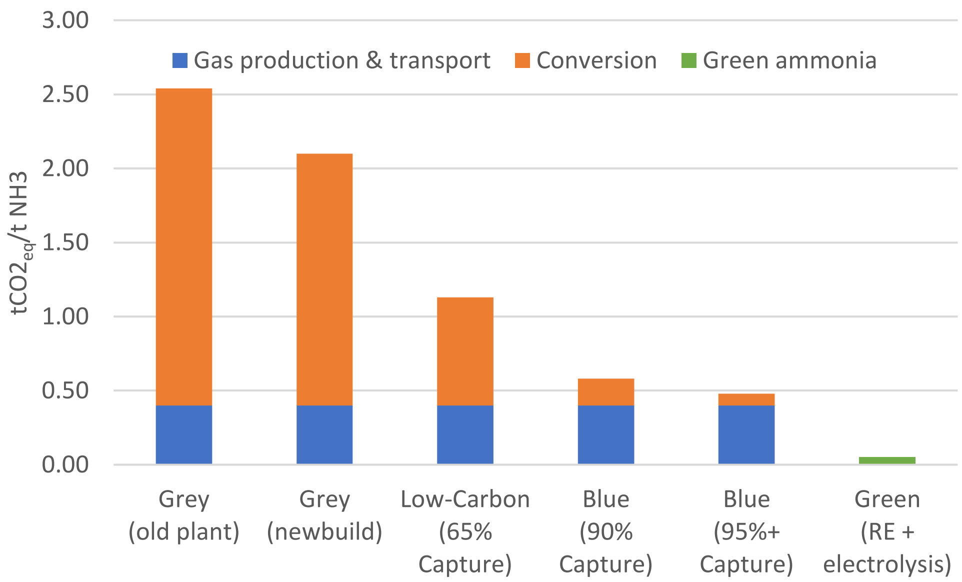
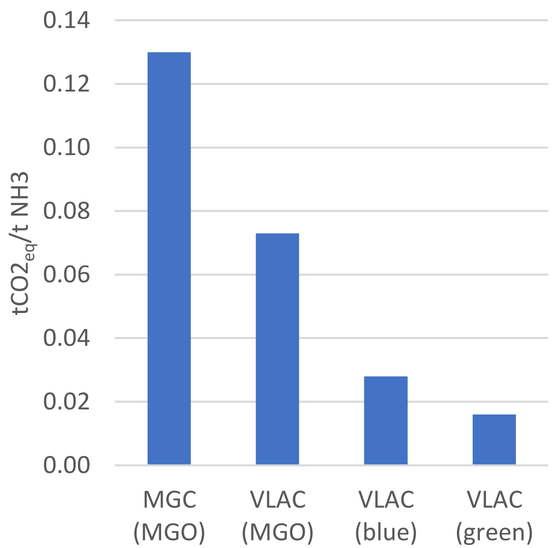
Not All Ammonia is Born Equal

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

Upstream & ammonia plant emissions



Well-to-Wake Transport emissions – US to EU



Notes:
1) 1tCO2eq/t NH_3 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 m^3 4) VLAC refers to Very Large Ammonia Carrier with capacity of 93,000 m^3

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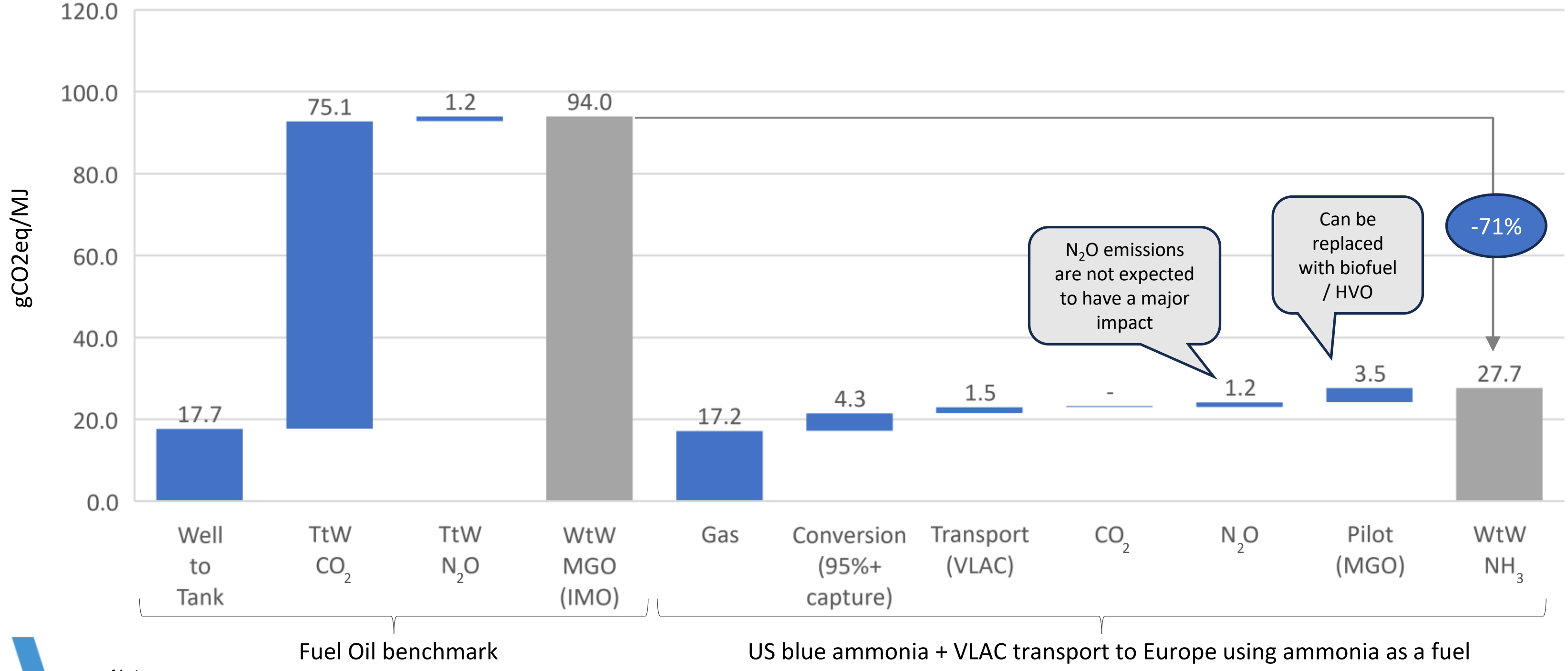
Blue Ammonia Delivers 70%+ GHG Emissions Savings as a fuel

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) N_2O emissions from fuel oil/MGO are estimated at 0.00018 g N_2O per g fuel (per Fourth IMO GHG Study and FuelEU), which translates into approximately 1.2 $gCO2_{eq}$/MJ using N_2O GWP of 273 (20/100yr basis) as per IPCC AR6. We have assumed ammonia engines will produce comparable N_2O emissions

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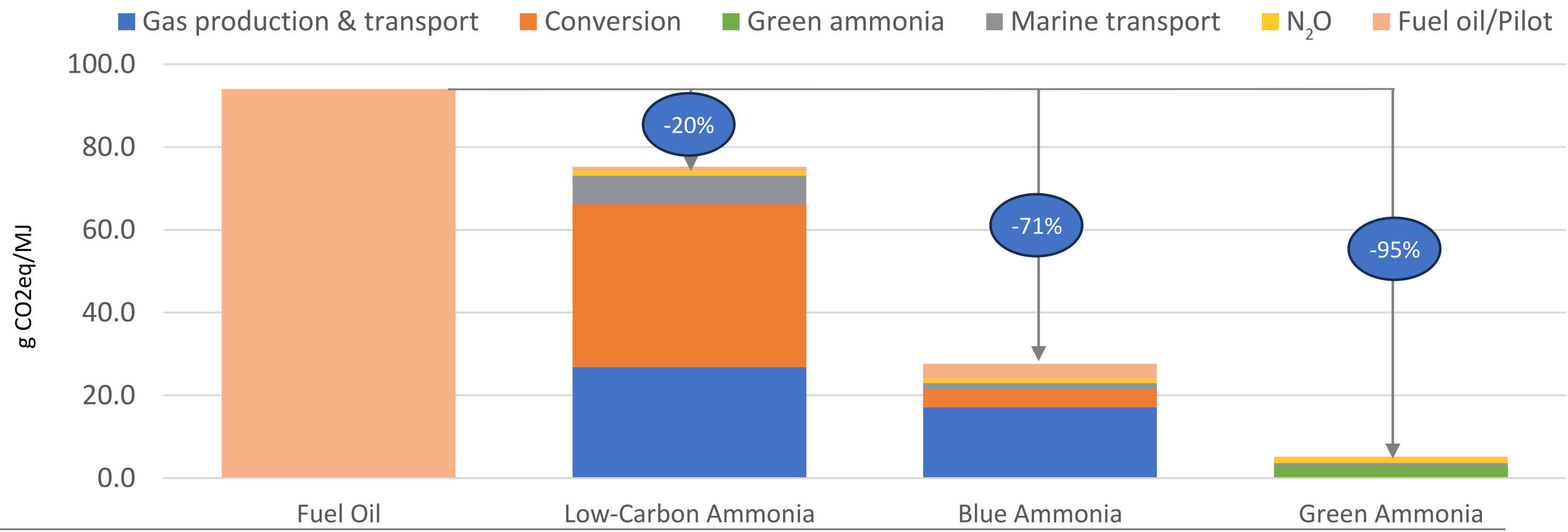
Ammonia Offers Potential to Meet Increasing GHG Ambitions

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



	Fuel Oil	Low-Carbon Ammonia	Blue Ammonia	Green Ammonia
Carbon capture		65%	95%+	-
Transport		MGC on fuel oil	VLAC on NH_3	VLAC on NH_3
Pilot fuel		MGO	MGO	Biofuel

Notes:
1) Pilot fuel emissions category reflect incremental emissions from incorporating pilot fuel vs using Low-Carbon, Blue or Green ammonia respectively, assuming a 5% pilot fuel energy fraction at full load.
2) We have assumed MGO is used as pilot in the case of Low-Carbon and Blue Ammonia, and Biofuel/HVO is used as a pilot in the case of Green Ammonia

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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 N_2O 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 N_2O
- Choice of transportation has an important contribution to lifecycle CO2 emissions. VLACs are capable of delivering ammonia at half the CO_2 footprint of MGCs when operating on fuel oil and their GHG emissions approach zero when operating on ammonia cargo as a fuel

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