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LCA of Ammonia Fuelled Marine Engines

Reese Murugan
28/06/2023

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Agenda

- Maritime Background
  - Alternative fuels
- LCA overview
- LCA Phases
  - “Well-to-tank”
  - “Tank-to-wake”
  - “Well-to-wake”
- Critical Gaps
- Conclusions & Future Work

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Overview: Shipping Sector Emissions

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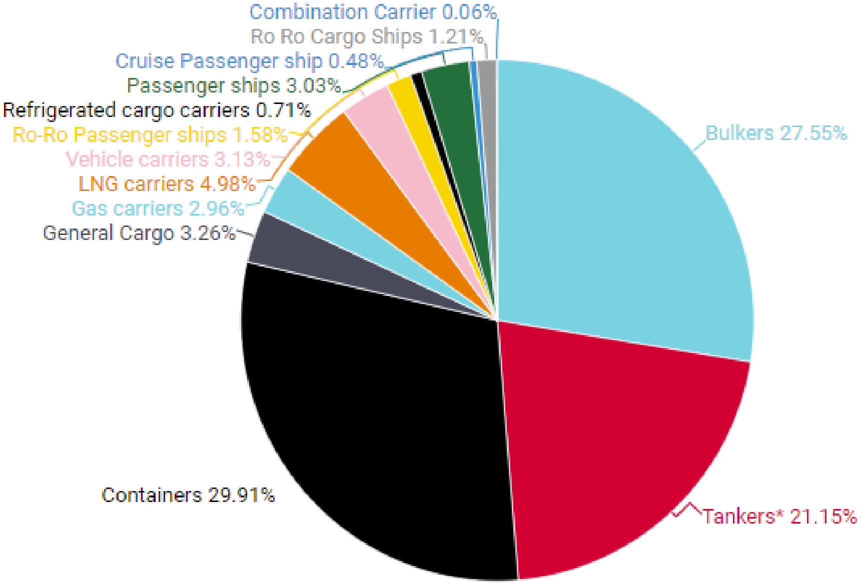
- 80% of all global goods transported by sea
- 2.8 - 3% of Global CO2 Emissions
- Expected to grow between 50%-250% by 2050
- Containers, Bulkers and Tankers make up most of the emissions
- **We need low carbon fuels**

IMO DCS share of CO2 emissions in 2019 (614m tonnes)



Lloyd's List

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Maritime Emission Regulations

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IMO regulations and guidelines

- Carbon Intensity Index (CII) – kgCO_2/transport work
- 40% Carbon intensity reduction by 2030, 70% reduction by 2050
- 50% overall CO_2 emissions reduction by 2050

European Commission "Fit for 55" strategy

- FuelEU Maritime
- AFIR
- RED
- Energy Efficiency Directive
- Energy Taxation Directive
- EU Emissions Trading System

Source: EMSA

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Alternative Fuels

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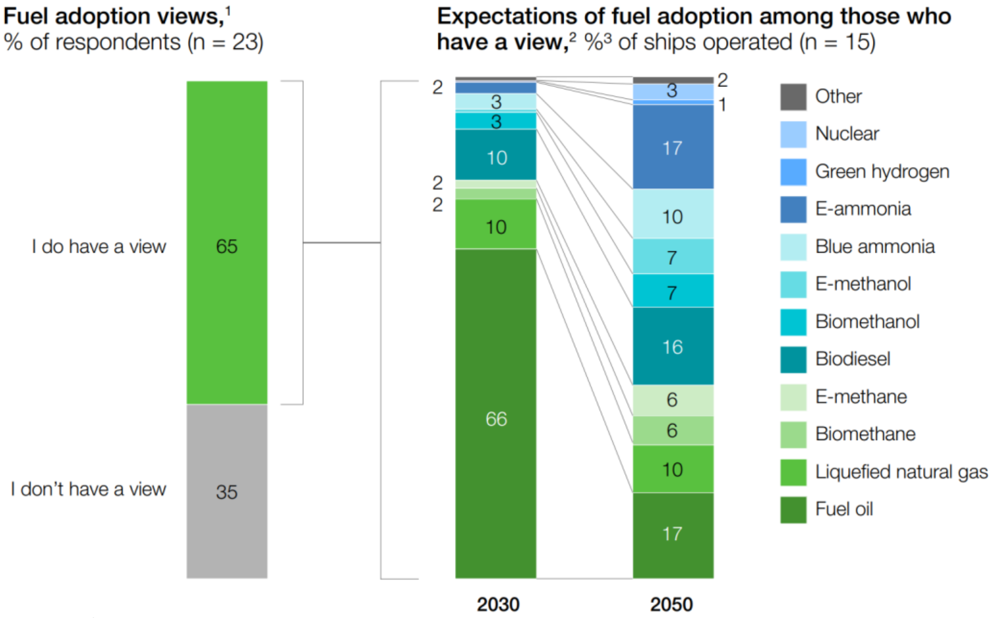
Two-thirds of shipping company respondents have views on what their fuel usage will look like in 2030 and 2050, although expectations vary.



Source: McKinsey

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Alternative Fuels

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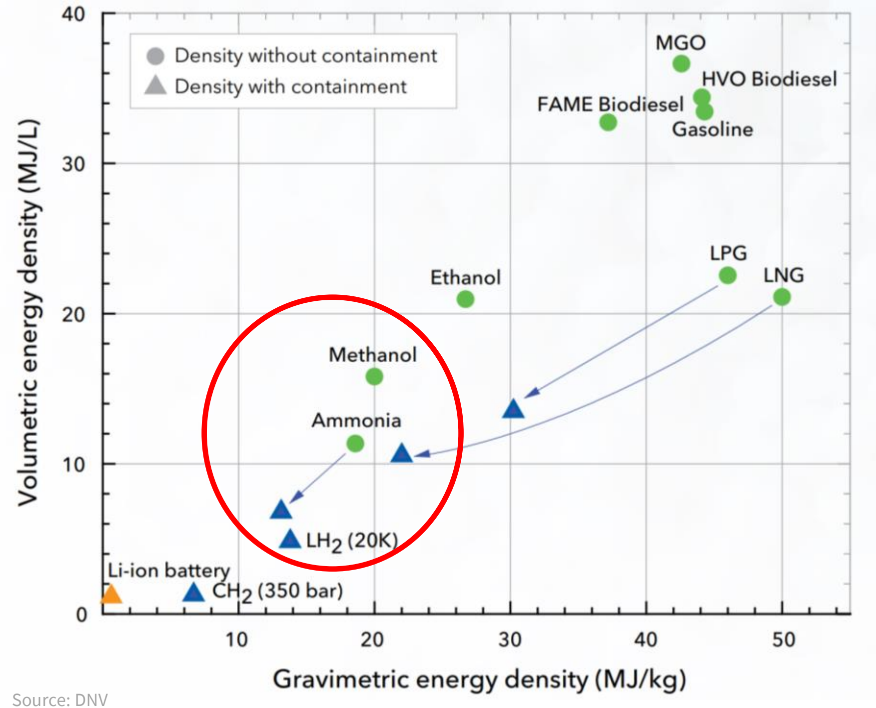

Source: DNV

- Liquid Hydrocarbons are energy dense
- Synthetic methanol is an easier "drop in" **but** requires a sustainable source of carbon.
- Ammonia is more energy dense than hydrogen, but poor combustion, toxicity and NOx issues.
- Hydrogen has great combustion properties, but can't be stored effectively
- Bio-fuels cannot fully replace diesel – feedstock limits and aviation requirements

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LCA Overview

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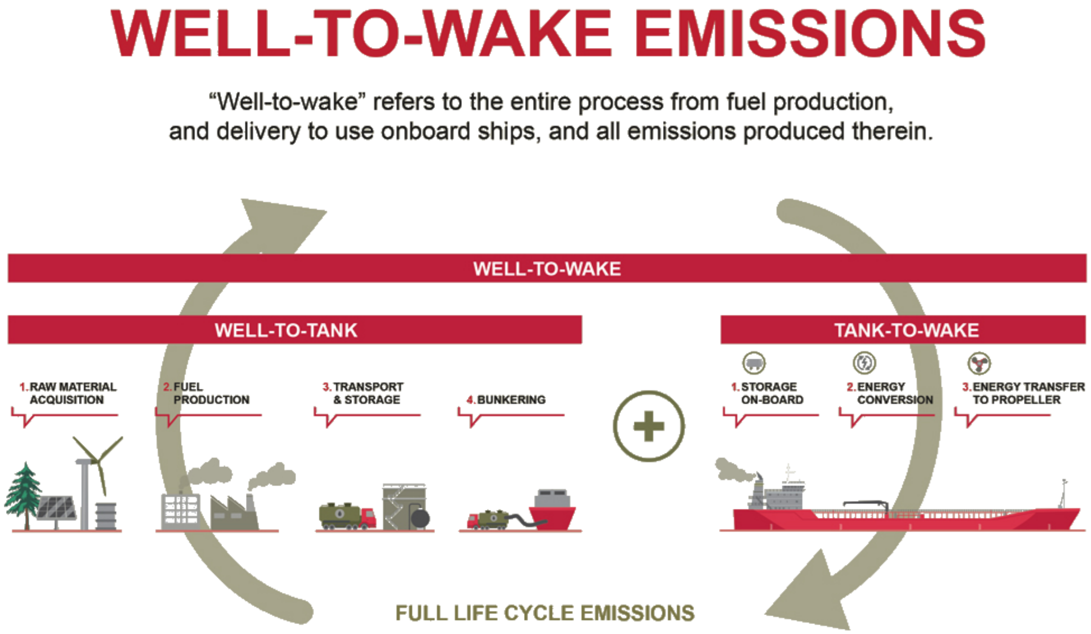

Source: Bureau Veritas

- **Goal:** to evaluate and compare the environmental impacts of different marine fuels from production to end use.
- **Scope:** 'well-to-wake' lifecycle phase of marine fuels

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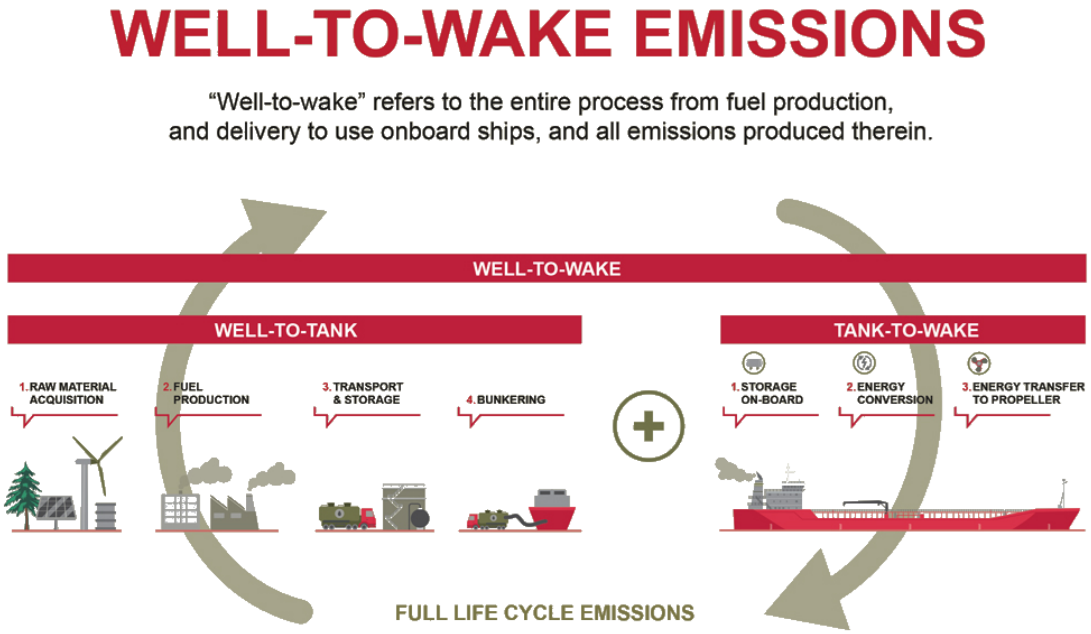

Source: Bureau Veritas

Inputs

- Raw material/resources required
- Energy flow at each stage
- Water

Outputs

- Emissions to air, water, soil at each stage

LCA Overview

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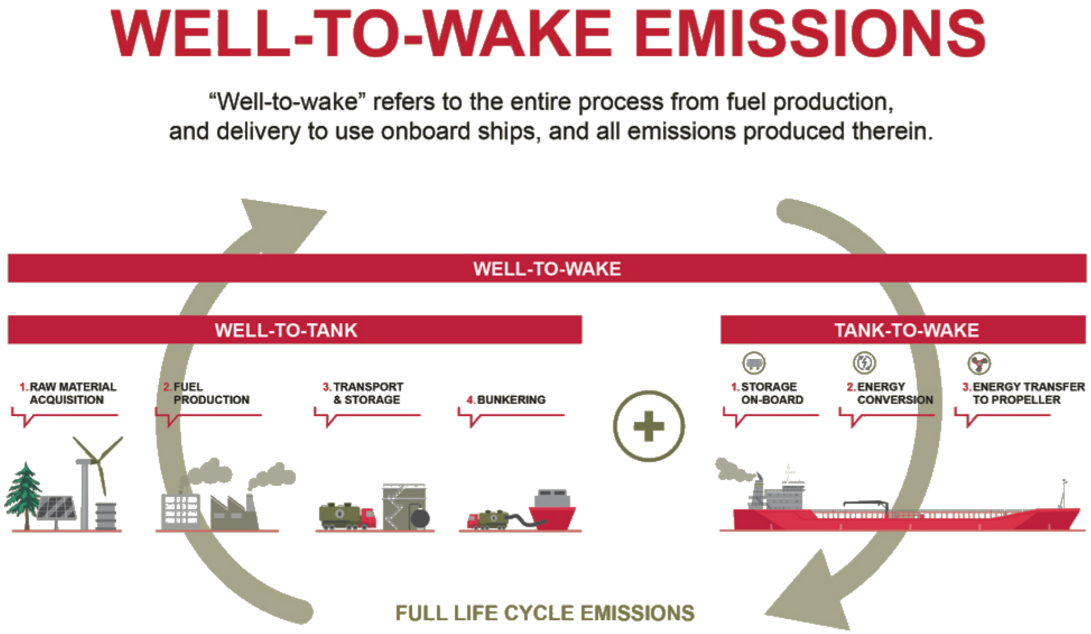

Source: Bureau Veritas

- Global Warming Potential ($kgCO_{2\text{-}eq}$/tonne-km)
- Air pollution
- Water pollution
- Nitrogen Cycle Impact

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“Well-to-tank” Phase

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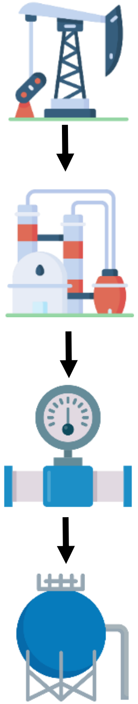
- Evaluate the inputs and outputs at each stage
- Quantify the GHG emissions
- Efficiency and Losses at each stage
- Brown vs Green vs Blue Fuels
- Explore different pathways - Grid Electricity vs Dedicated Renewables



1. Fuel Extraction
2. Fuel Production and Refinement
3. Transportation and Distribution
4. Port Storage and Bunkering

Ammonia Production

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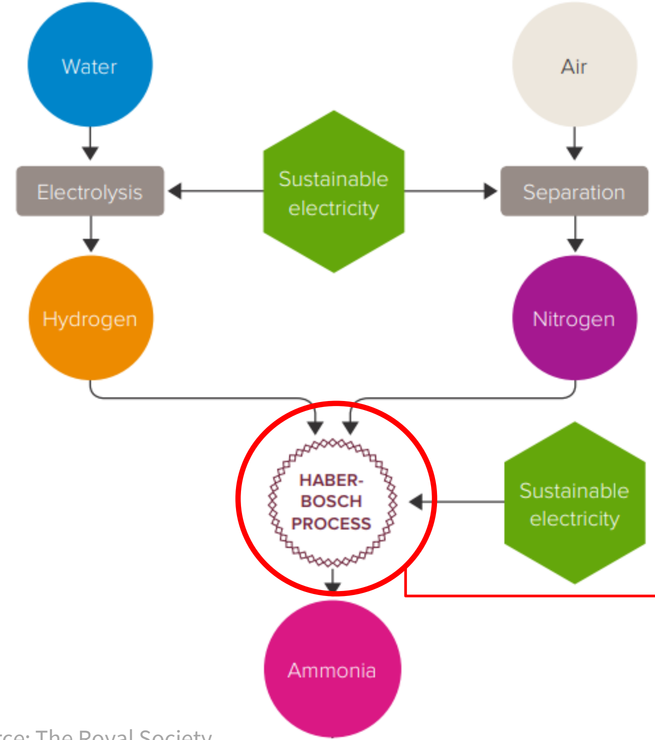
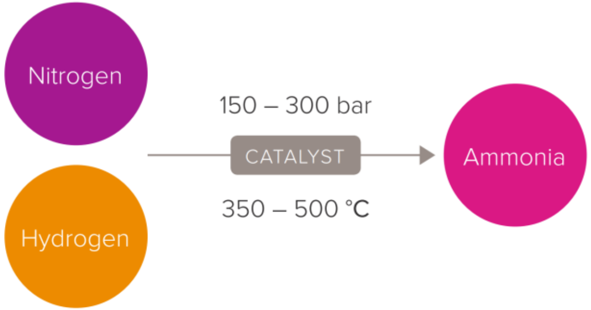


- Combines Nitrogen and Hydrogen together
- ~ 1% of annual global CO_2 emissions.
- Hydrogen Production is responsible for ~90% of the entire process power consumption



Source: The Royal Society

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Ammonia Production Emissions

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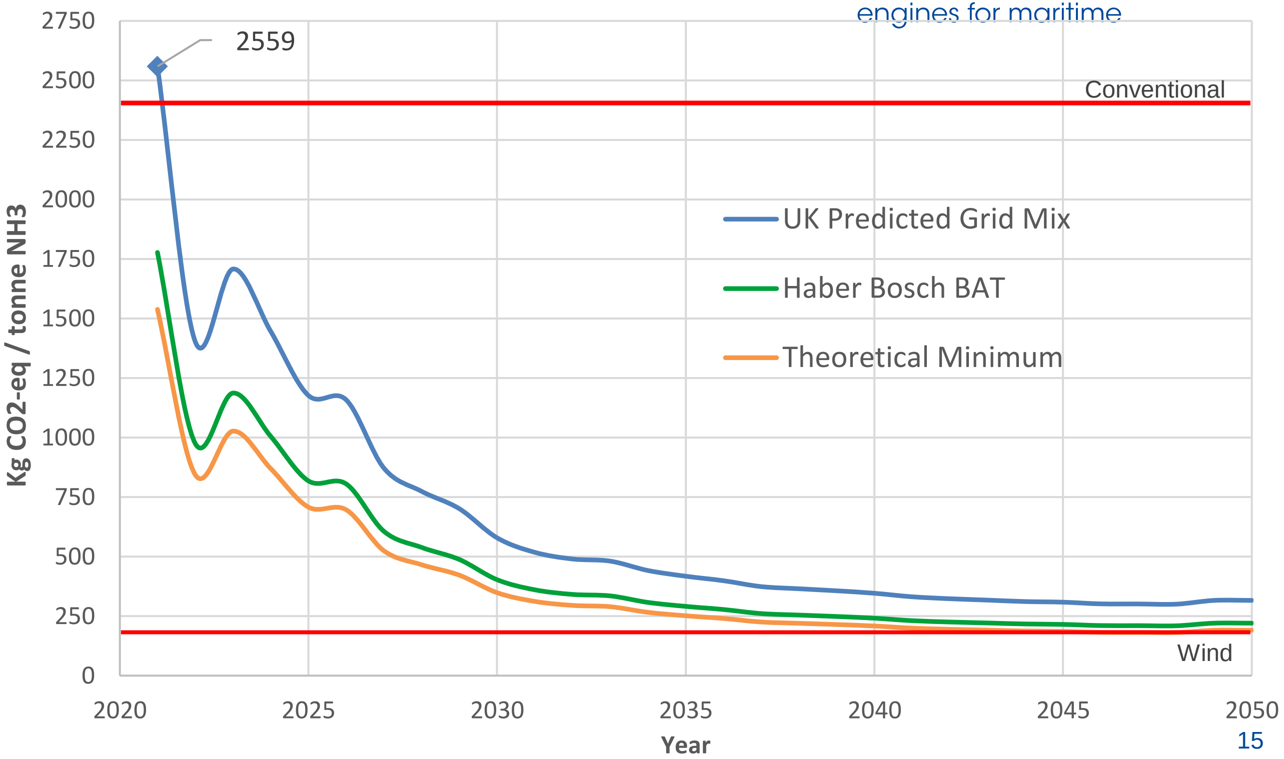
- Electricity consumption for Current Haber Bosch Process = **36.0** GJ/ tonne NH_3
- Hydrogen from PEM electrolysis at 60.1% efficiency
- Best Available Technology (BAT) = **26.0** GJ/tonne NH_3
- Theoretical Minimum = **22.5** GJ/tonne NH_3
- Conventional Vs Wind



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Use Phase – "Tank-to-Wake"

- Vessel Model based on actual vessel characteristics
  - Fuel Consumption
  - Speed-Power Curve
  - Average speed
  - Main/Aux engine efficiencies
  - Fuel Consumption
  - Stowage factor

- Fuel type (NH_3, H_2, CH_3OH, Dual fuels, Bio/synthetic diesel) + Storage

- Powertrain type (ICE, Fuel Cell, Ammonia cracker, 4-stroke gensets)

- Direct emissions from tailpipe + indirect emissions from each stage

1. On-board Storage
2. Energy Conversion
3. Energy to Propellor

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Route Evaluation – “WTW”

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- Using GREET Marine Module, and combining WTT + TTW
  - Evaluate emissions across a different routes
  - Potential green shipping corridors

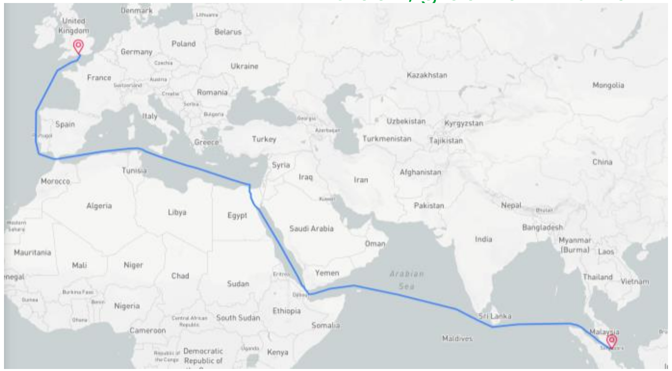
Example Scenarios evaluating emissions from:

1. Existing shipping routes (Singapore – Rotterdam)
2. Potential ammonia import countries (Middle East – UK)

- Consider range reductions– Storage volume and mass sacrifice

- Identify bunkering port locations along a given route

- Identify Ammonia production pathways for given countries



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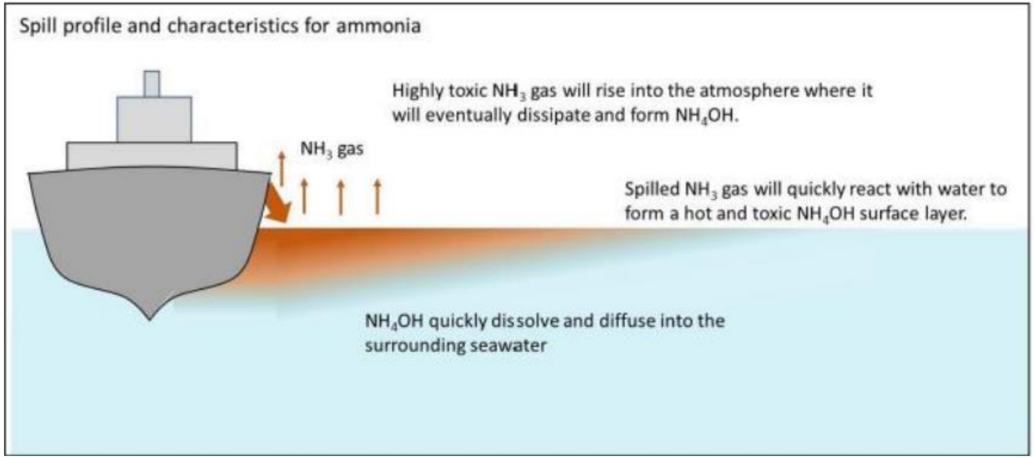
Critical Gaps

- Emission Slip Data
  - Ammonia
  - Nitrogen Di-oxide (N_2O)
  - NO_x (NO, NO_2)
- Spills/Leakage/Other environmental factors – Nitrogen Cycle
- LCA Input Data
  - reliability, assumptions, lag



Spill profile and characteristics for ammonia

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Conclusions & Further Research

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- LCA will used to evaluate emissions related to:
  - Fuel Production Pathways and Processes
  - Fuel Production Transportation and Storage Pathways
  - Regional/Country specific production pathways
  - Vessel model use-phase (direct and indirect)
  - Bunkering and Refuelling locations

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Conclusions & Further Research

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- NH_3 as a Hydrogen Carrier +NH_3 Cracker
- NH_3 Genset vs Prime Mover (2 Stroke vs 4 Stroke?)
- Weather Pattern effects on route optimisation
- Port microgrids – Shoreside electrolysers?
- Bunkering feasibility
- Safety/Handling – NH_3 vs H_2
- Hybridisation – How this affects LCA?
- Evaluate the techno-economics alongside the LCA

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Green Ammonia Production

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Power Generation Scenario	HB CO_2 emissions ($tCO_2:tNH_3$)
Coal	11.17
Gas	4.387
Gas CCUS	1.338
Solar	0.821
Hydrogen	0.383
Wind	0.14
Hydro-power	0.05
Renewable Mix	0.7375

Able to Model:

- Different Electricity Generation Scenario
- Dedicated Renewables vs Grid Electricity
- Specific Mix scenarios (Wind/Solar)
- Regional/ Country specific electricity mixes
- Regional/ Country specific transmission and distribution losses

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Route Evaluation – WTW

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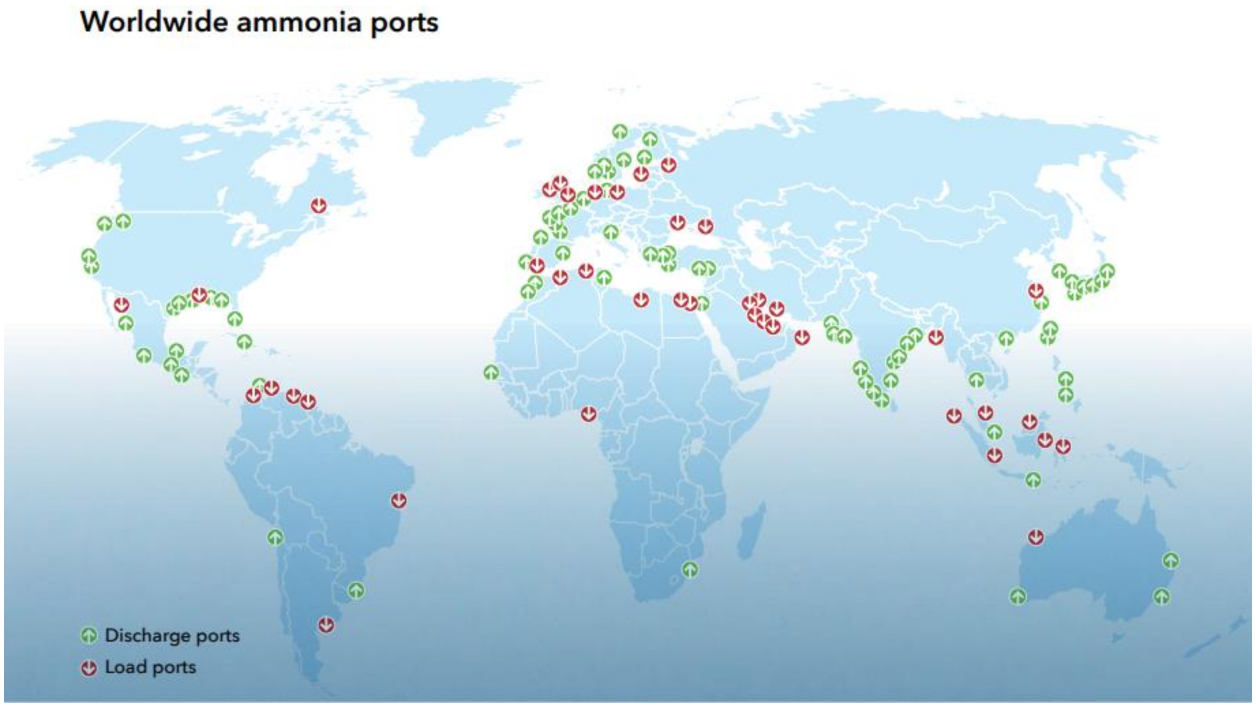

Source: Ammonia as a Marine Fuel, DNV

- ~122 existing port handling facilities
- ~55 New ammonia plants announced to be completed before 2030 (IRENA ,2022)
- Green Corridors can be mapped

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Combustion Characteristics

Ammonia is a **"poor"** fuel

- Low burning velocity
- High auto ignition temperature and energy
- High quench distance

Hydrogen is a "**good**" fuel

- Fire and explosion risk
- Very low minimum absolute minimum ignition energy

Methanol is a "**decent**" fuel

- Sits in between H_2 and NH_3
- But it contains Carbon

Species	Hydrogen	Ammonia	Methanol
Formula	H_2	NH_3	CH_3OH
LHV (MJ/kg)	120	18.8	19.9
Laminar Burning Velocity @λ = 1(m.s^{-1})	3.51	0.07	0.36
Auto-ignition temperature (K)	773-850	930	712
Absolute minimum Ignition Energy(mJ)	0.02	8	0.14
Flammability Limit in air (vol. %)	4.7-75	15-28	6.7-36.5
Quench distance (in)	0.0354	0.869	0.106

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