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Inaugural Symposium: The Role of Higher Education Institutes and Life Cycle Assessment in Achieving Sustainable Futures

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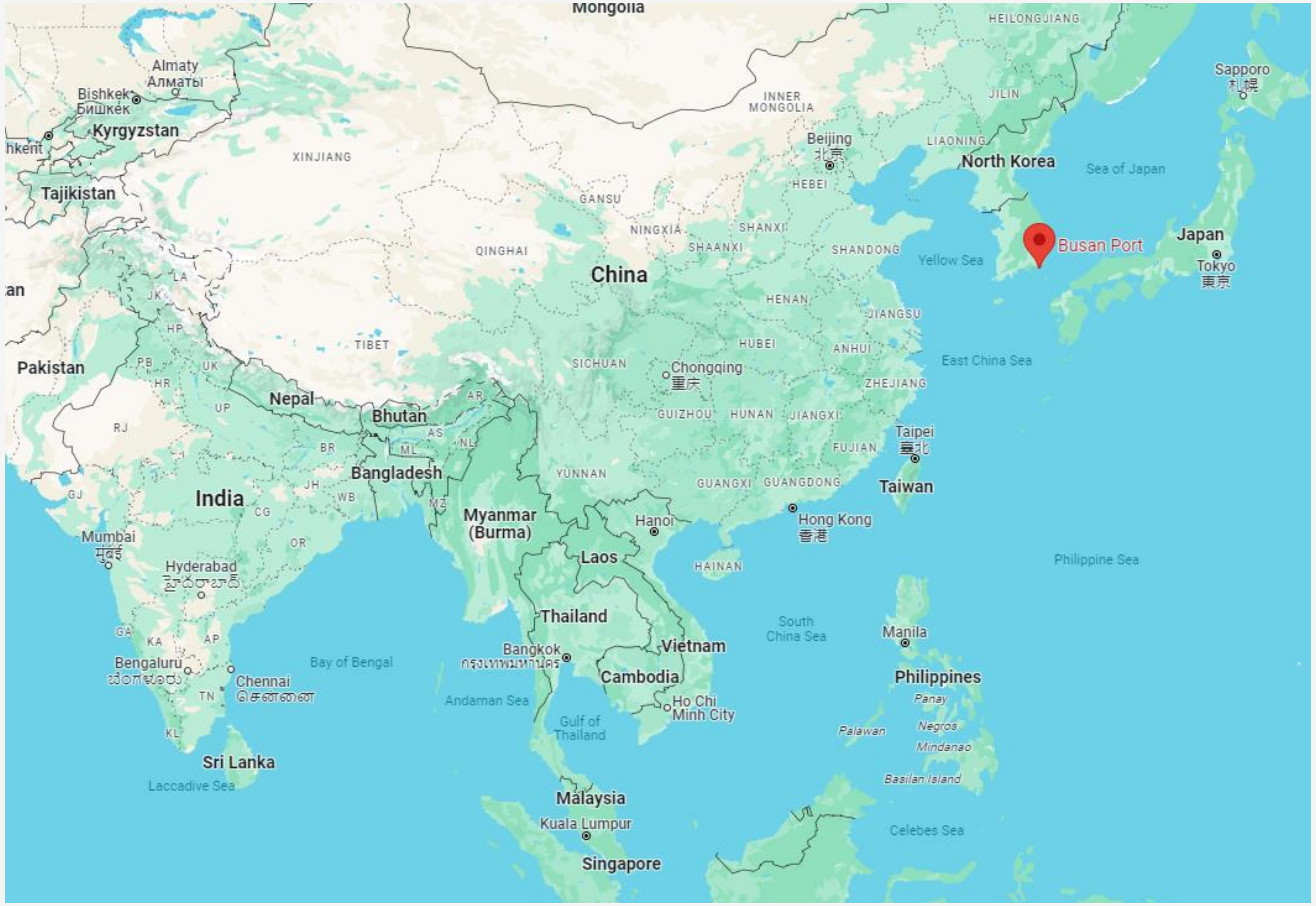
A Comparative Life Cycle Assessment of Marine Fuels: A Busan Port Case Study



Reference: Google Maps

Introduction & Objectives

- Maritime trade volume will triple by 2050 and greenhouse gases from international shipping could rise by up-to 250%
- Emission reductions will be driven by carbon-free marine fuels
- Life Cycle Assessment: objective tool to assess the environmental performance of a system
  - SimaPro software was used as it allowed personalised creation of inventories

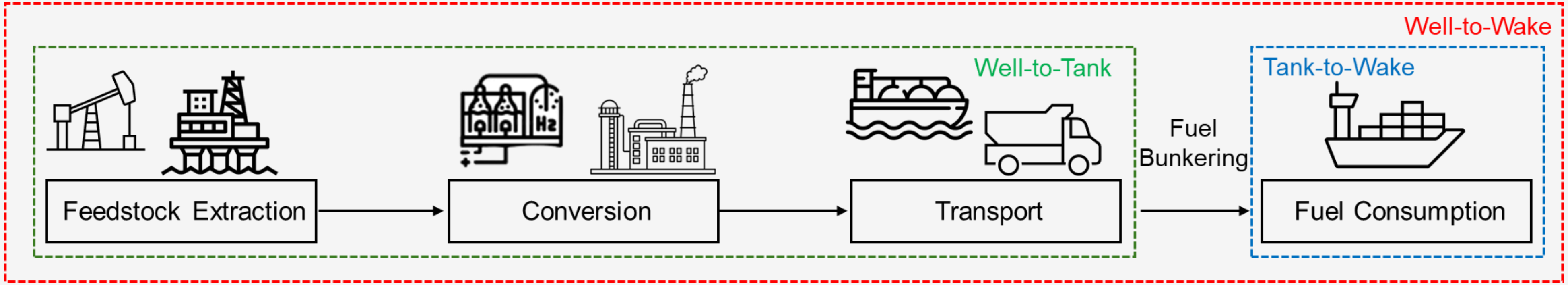
Objectives:

① Identify processes, inputs and outputs for a ship bunkering in the port of Busan

② Develop a strategy to compare different fuels and ship types

③ Conduct a comparative LCA to quantify Well-to-Wake emissions and assess the impact of each marine fuel

④ Propose a solution to guide governments and policymakers in making decisions towards sustainable development



Lifecycle of Marine Fuels

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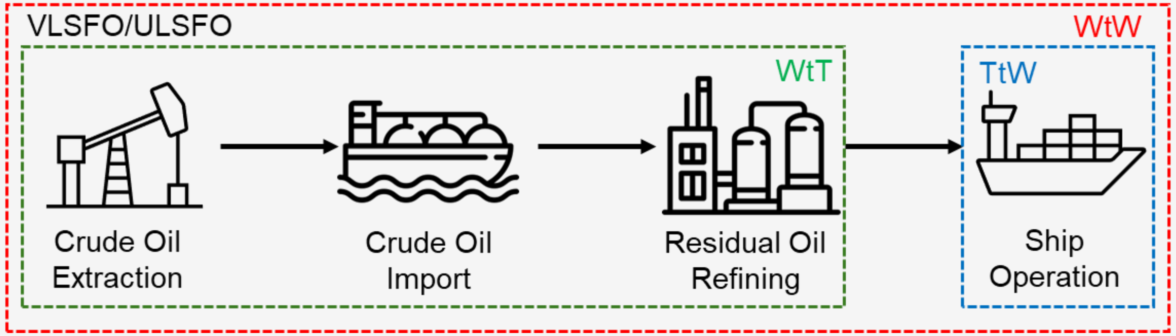
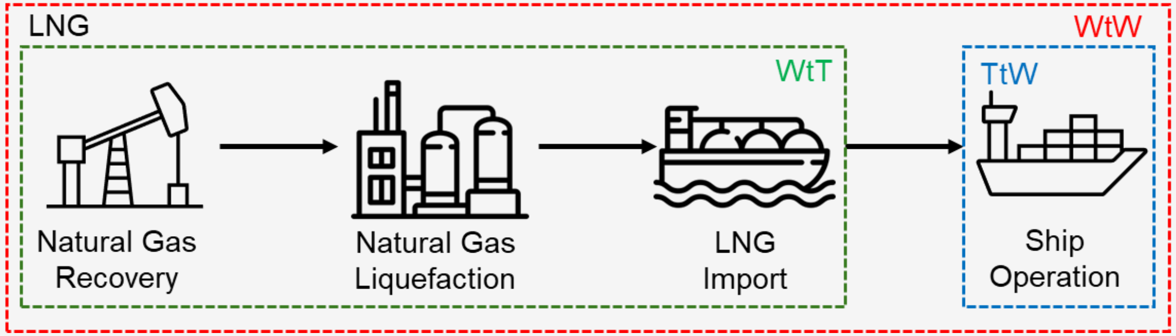
- Fuels of the present:
  - Very-low and ultra-low sulphur fuel oil (VLSFO and ULSFO)
  - Liquefied Natural Gas (LNG)

Marine Fuels	Production	Storage & bunkering	Safety	Capital cost
VLSFO/ULSFO				
LNG				

Fuel pathway maturity map – green indicates mature technology and yellow shows that solutions exist but are limited by maturity/availability





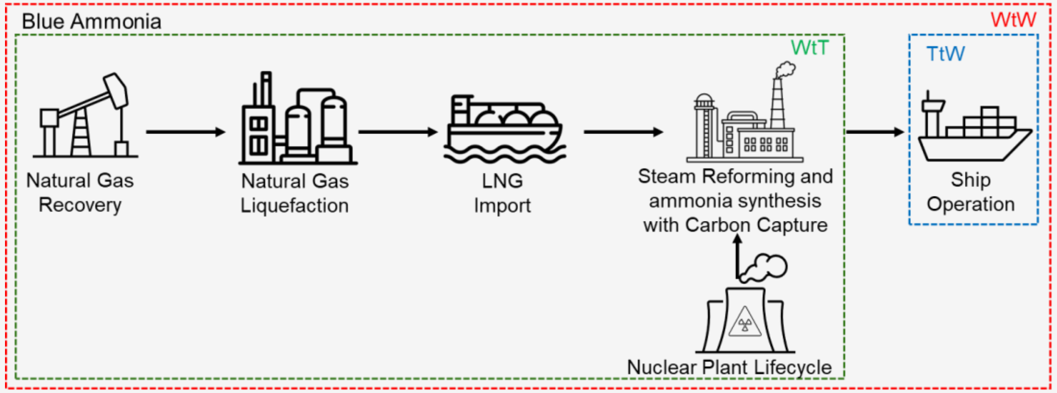
Lifecycle of Marine Fuels

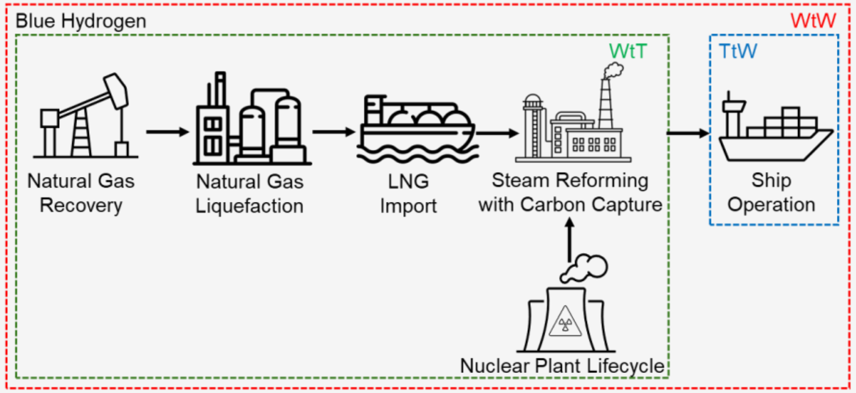
- Fuels of the future:
  - Ammonia
  - Hydrogen

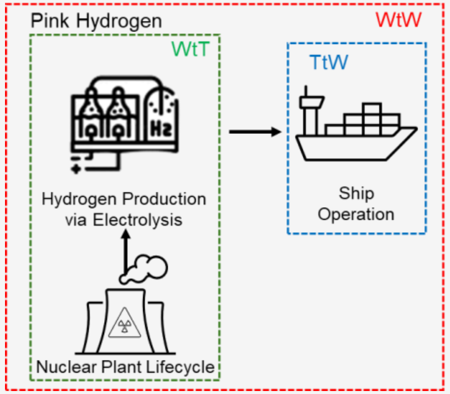
- Energy intensive conversion process
  - Nuclear power to supply electricity

Marine Fuels	Production	Storage & bunkering	Safety	Capital cost
Blue ammonia				
Blue hydrogen				
Pink hydrogen				

Fuel pathway maturity map –yellow shows that solutions exist but are limited by maturity/availability and red indicates that major challenges exist







Model setup

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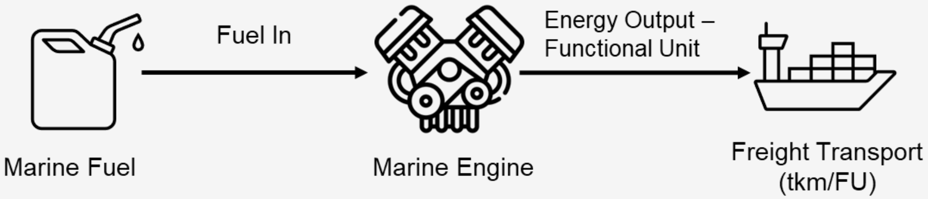
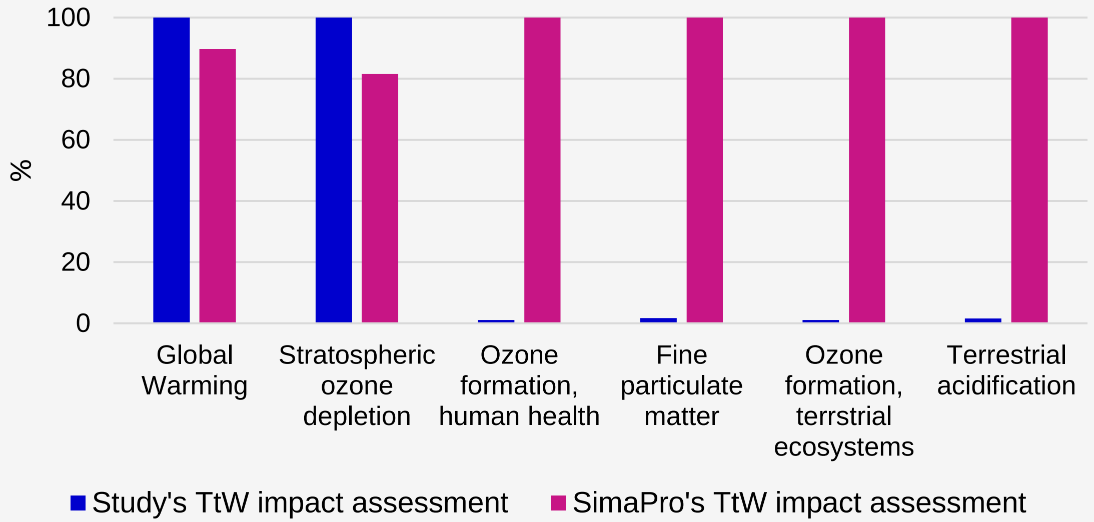
- Functional Unit (FU):
  - 1GJ of energy output after combustion

- Calculated the up-to-date emissions of vessels:
  - New regulations have been implemented – e.g. reduction in the sulphur content of fuels
  - SimaPro model used 2015 data

- Tank-to-Wake Impact assessment comparison between this study's ship model and SimaPro's ship model
  - Methane emissions were underestimated in 2015
  - Lower impact across all other categories due to fewer pollutants emitted (NOx, SOx, PM, CO, and N_2O)



Fuel	$LHV_{fuel}\left(\frac{MJ}{kg}\right)$	Engine efficiency (%)	Mass per FU (kg)
VLSFO/ULSFO	40.2	50	49.75
LNG	48.63	47	43.75
Ammonia	18.6	35	153.61
Hydrogen	120	30	27.78



Tank-to-Wake Analysis

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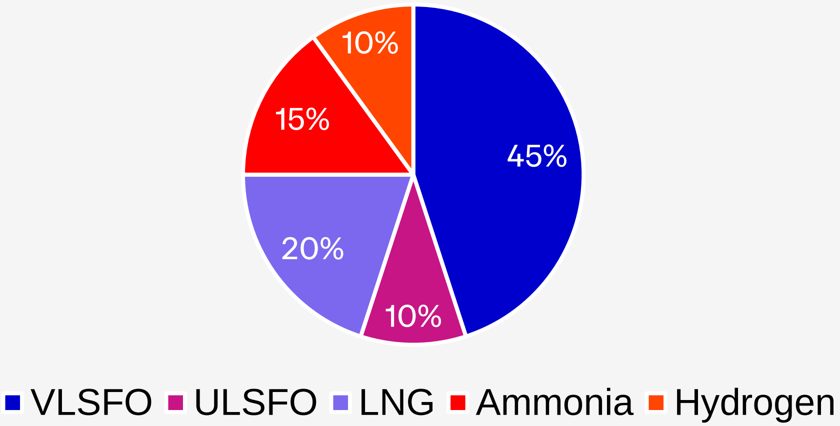
- International Maritime Organisation GHG reduction goals:
  - 20% reduction by 2030 compared to 2008 levels
  - 70% reduction by 2040 compared to 2008 levels

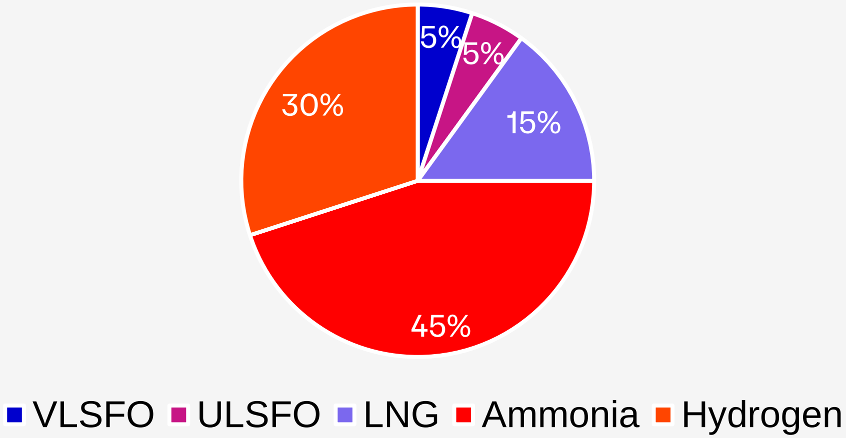
Year	Maximum GHG emissions per FU $\left(\frac{kg_{CO2eq}}{GJ}\right)$
2030	126.8
2040	47.0

- Conducted a comparative Tank-to-Wake study for the marine fuels
  - What is a possible fuel mix scenario for 2030 and 2040?

Impact Category	VLSFO	ULSFO	LNG	Ammonia	Hydrogen
GWP TtW $\left(\frac{kg_{CO2eq}}{GJ}\right)$	166	153	141	15.1	1.24



2030 Fuel Mix Scenario



2040 Fuel Mix Scenario

Cumulative Energy Demand

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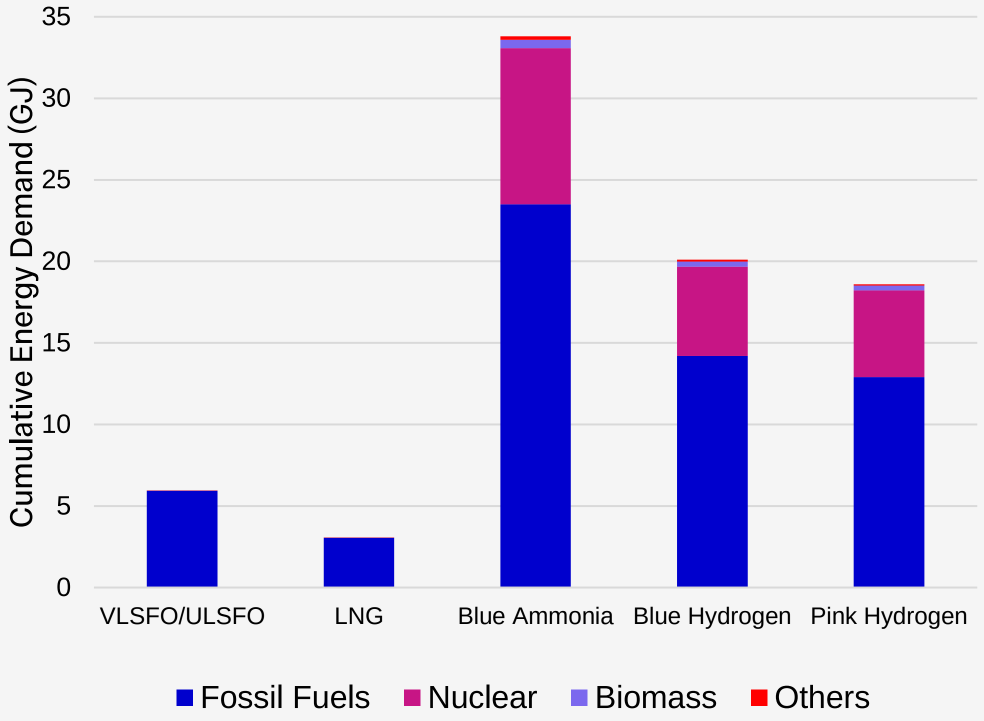
- How energy intensive are the production processes?
  - Breakdown of energy sources currently used

- Impact of using the national grid vs nuclear power on the Well-to-Tank global warming potential for ammonia and hydrogen fuels



Impact Category	Blue Ammonia		Blue Hydrogen		Pink Hydrogen	
	National grid	Nuclear power	National grid	Nuclear power	National grid	Nuclear power
GWP ($\frac{\text{kg CO2eq}}{\text{GJ}}$)	1.93×10^3	55	1.12×10^3	48.4	1.05×10^3	9.64

Well-to-Wake Global Warming Potential

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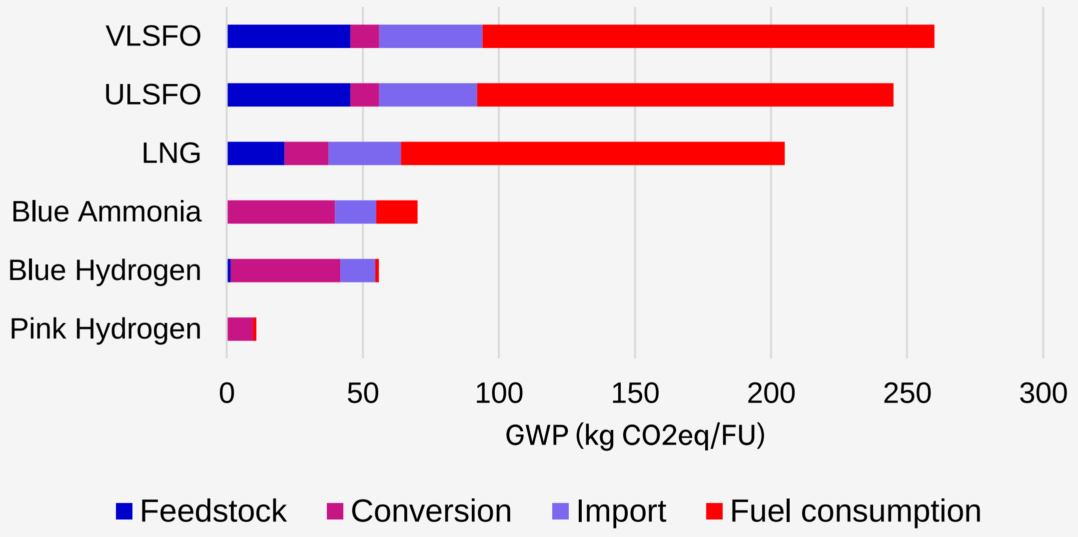
- VLSFO/ULSFO CO_2 combustion emissions: 61% of Well-to-Wake GWP
- LNG CO_2 combustion emissions: 59% of Well-to-Wake GWP
- Blue ammonia: 220 kg CO_2 emitted per FU from SMR with 90% carbon capture
  - Nuclear lifecycle: 19% of Well-to-Wake GWP
- Blue hydrogen: 205 kg CO_2 emitted per FU from SMR with 90% carbon capture
  - Nuclear lifecycle: 15% of Well-to-Wake GWP
- Pink hydrogen nuclear lifecycle: 72% of Well-to-Wake GWP



Conversion process	kWh/kg	kWh/FU
Ammonia via SMR and ammonia synthesis	16.5	2542
Hydrogen via SMR	49	1361
Hydrogen via electrolysis	55	1528

Well-to-Wake Impact Assessment

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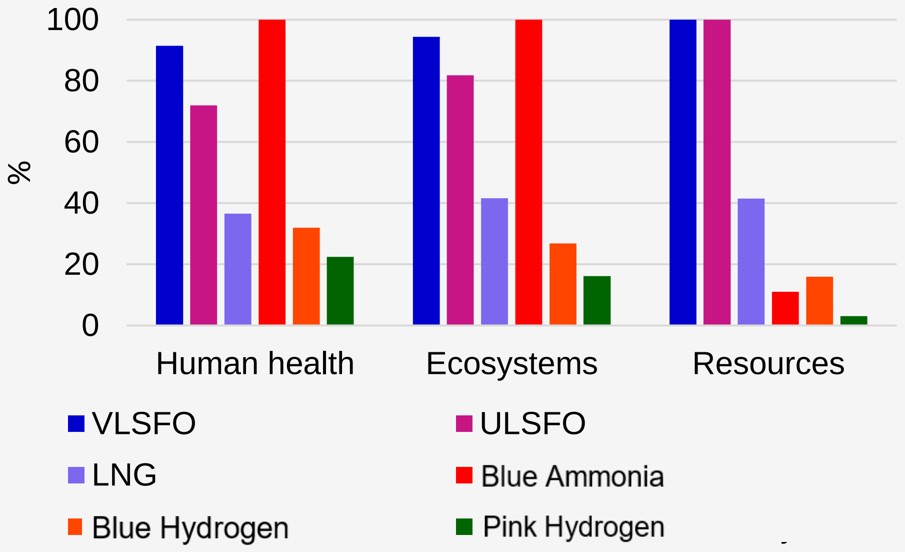
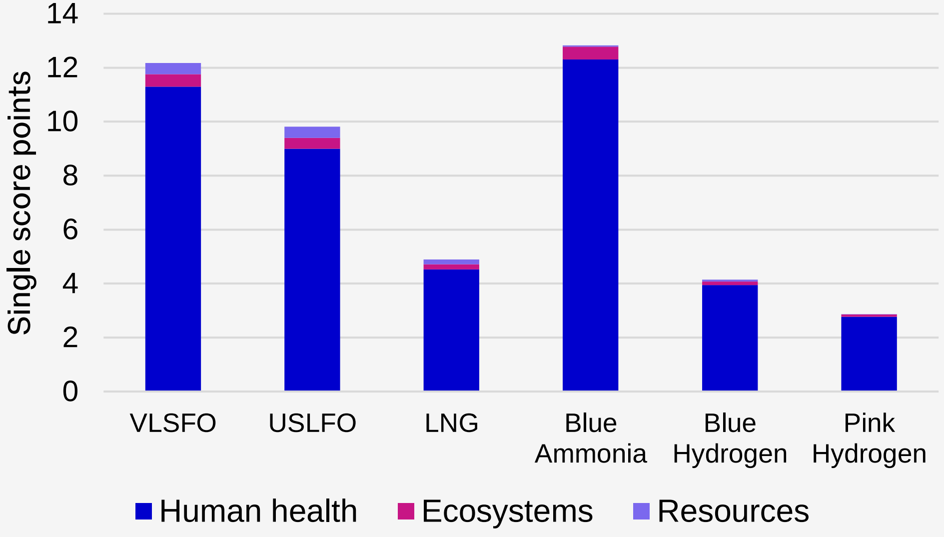
- Hydrogen is the least damaging marine fuel
- Ammonia is the most damaging fuel to human health and the ecosystem quality
  - NOx emissions are the major contributor – 17% higher NOx emissions per tkm than VLSFO
  - 11.2 NOx/kWh – selective catalytic reduction required in emission control areas
- LNG significantly reduces impact
  - 99% reduction in SOx/tkm compared to VLSFO
- International shipping impacts human health the most
  - Requirement for policymakers to set targets considering the entire Well-to-Wake lifecycle of a marine fuel





Uncertainty Analysis

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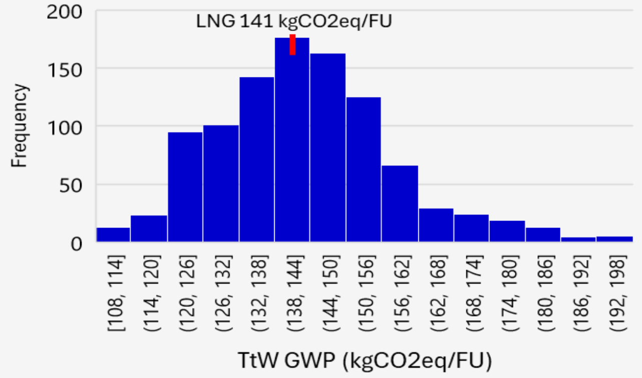
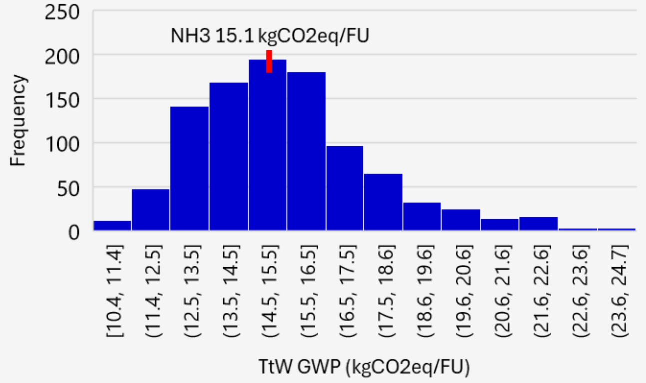
- No ammonia and hydrogen fuelled vessels are commercially available
  - Nascent engine technology
  - High uncertainty of engine efficiency, NOx and N_2O emissions

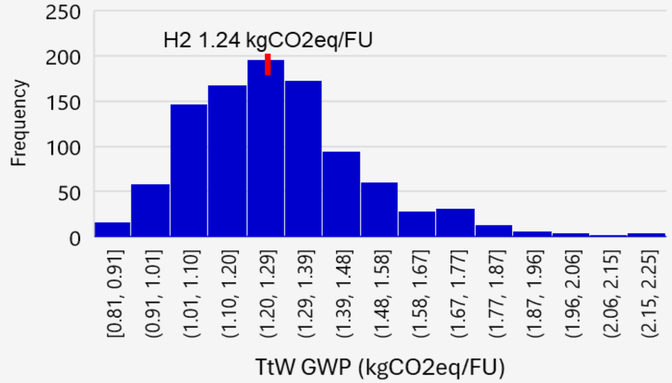
- Monte Carlo simulation to evaluate the impact of a 5% standard deviation of engine efficiency on Tank-to-Wake GWP for LNG, ammonia and hydrogen
  - Assumed a normal distribution

- Frequency of LNG's Tank-to-Wake GWP > ULSFO's Tank-to-Wake GWP (153 kgCO_{2eq}) was approximately 20%

- Ammonia's and hydrogen's Tank-to-Wake GWP remained low
  - Demonstrated the fuels' suitability to meet the IMO's GHG reduction targets







Conclusion & Implications for Policymakers

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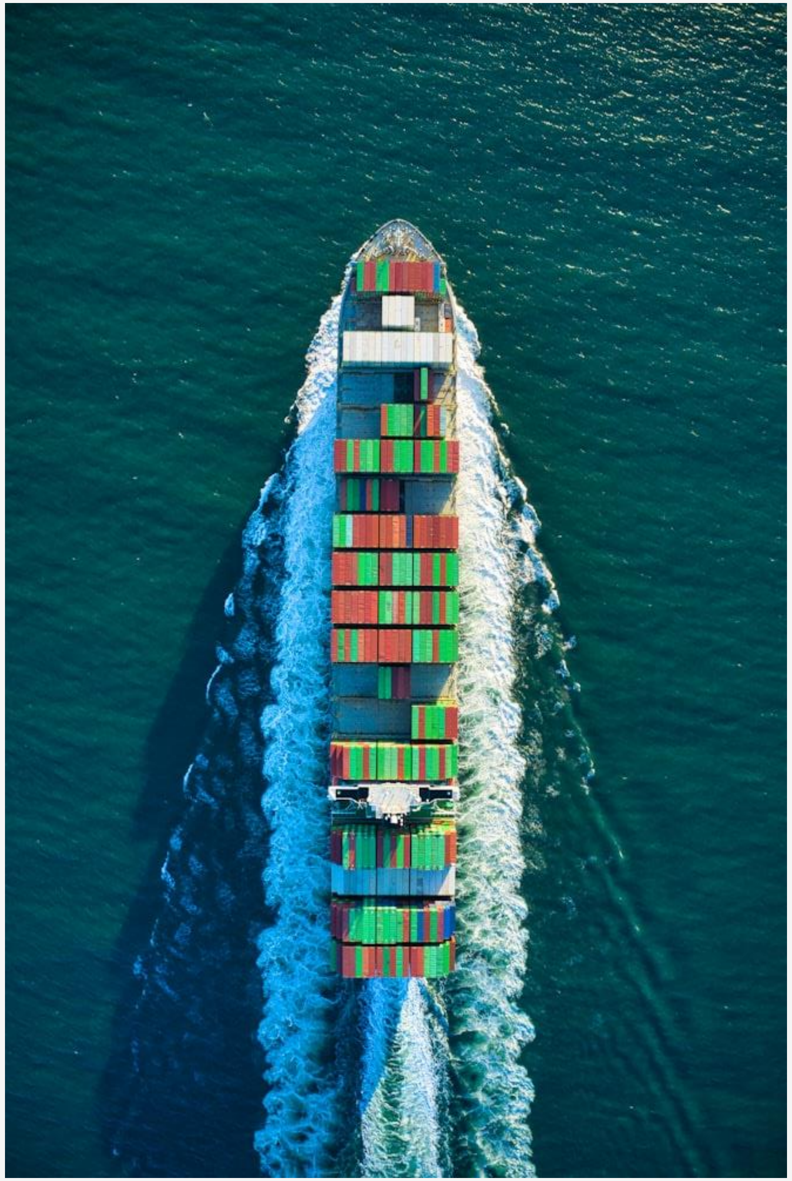
- Only ammonia and hydrogen are suitable to meet the IMO GHG reduction goals for 2030 and 2040
  - Failure to consider Well-to-Wake lifecycle may shift emissions upstream

- South Korea aims to produce ammonia and hydrogen domestically
  - Must be powered by net-zero energy systems
  - Nuclear power was identified as a suitable solution

- The IMO must consider Well-to-Wake emissions and total impact
  - Reductions in NOx emissions are necessary for ammonia
  - Guidelines and targets are required for alternative fuels to aid all relevant stakeholders

- This study's findings can serve as a valuable foundation for the IMO and the South Korean government in developing decarbonisation strategies



Reference: https://unsplash.com/photos/aerial-view-of-blue-and-white-boat-on-body-of-water-during-daytime-FPKnAO-CF6M

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Evaluated the lifecycle of 4 marine fuels for Busan, guiding governments in establishing policies towards sustainable development

Thank you for listening!

Any Questions?