Modeling International Trade of Ammonia for Direct Use and as a Hydrogen Carrier in Korea

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Introduction

Background

- Korea aims to achieve net-zero greenhouse gas emissions by 2050, with imported clean energy expected to play an important role due to its high dependence on foreign energy resources.
- Traditionally used for fertilizer production, ammonia is increasingly considered an energy carrier and a direct fuel for decarbonizing hard-to-abate sectors.
- Direct ammonia utilization is attracting growing interest in maritime shipping through ammonia-fueled engines and in power generation through co-firing and ammonia gas turbine technologies.
- Unlike hydrogen carrier applications, direct ammonia utilization avoids the additional energy losses and costs associated with ammonia cracking.
- Evaluating both utilization pathways within an integrated energy system is essential for understanding future ammonia import requirements and sectoral demand.

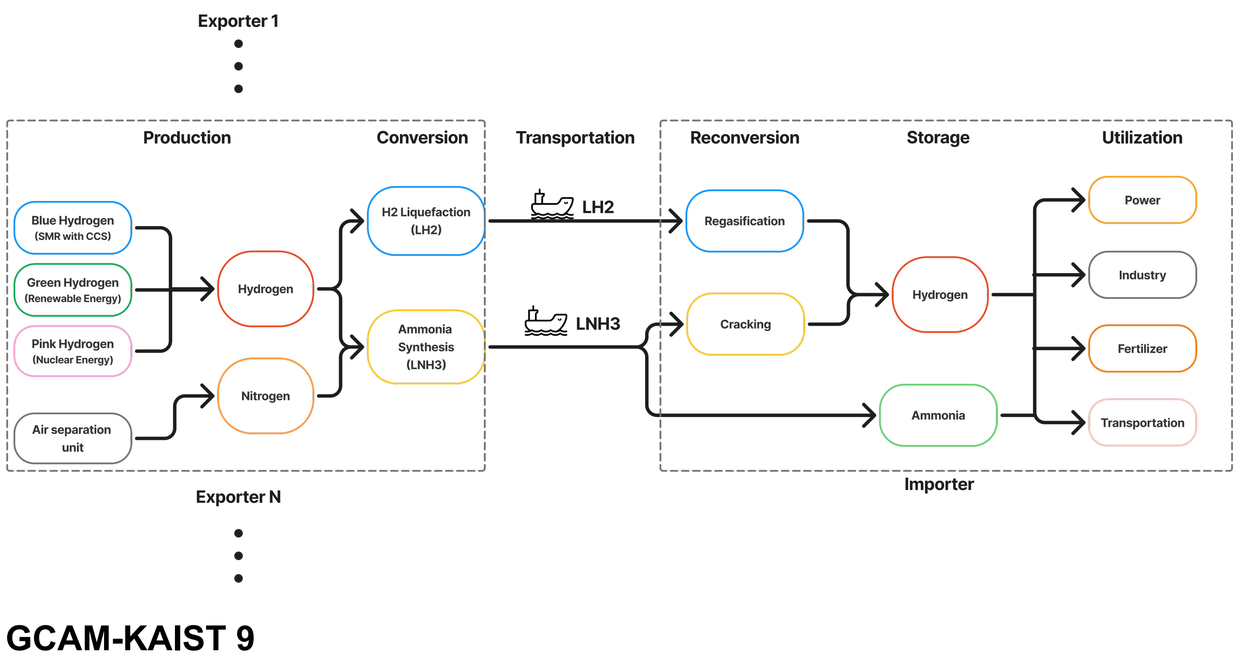
Research Question

Will ammonia become a major contributor to Korea's net-zero energy system?

Objectives

- Quantify ammonia imports into Korea and their allocation across end uses.
- Compare additional hydrogen requirements due to shipping losses for LH_2 and LNH_3 across exporting regions.
- Measure ammonia use by sector and analyze the main drivers.

Research Framework

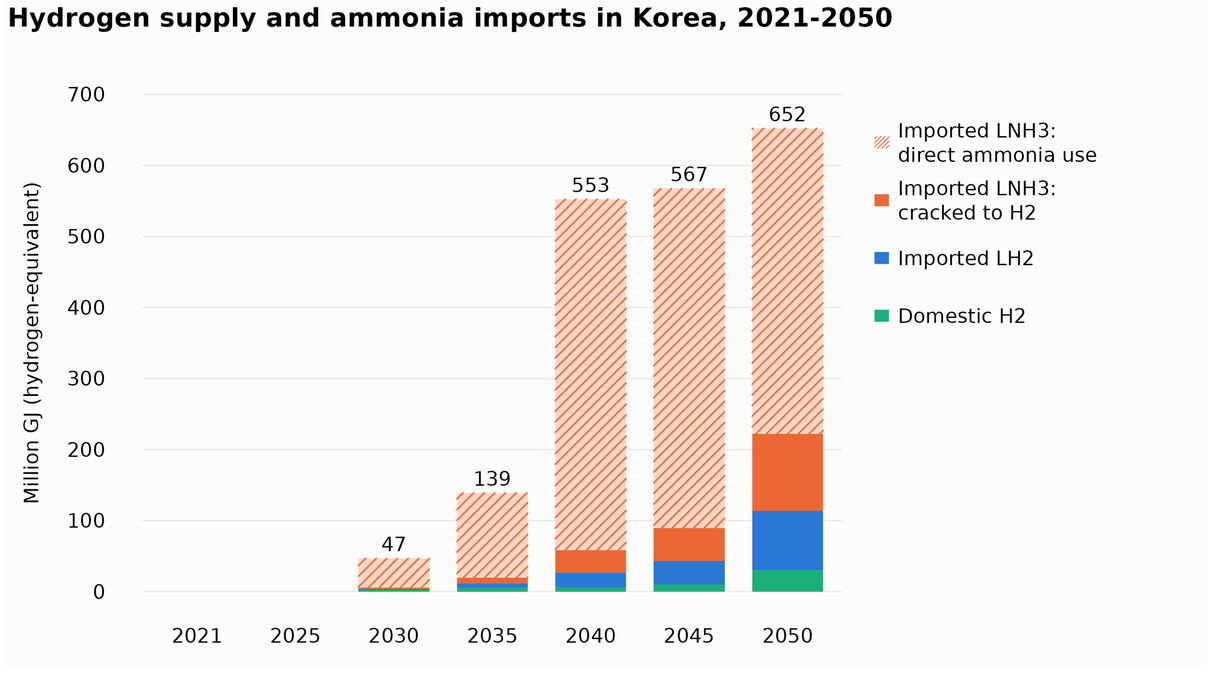


GCAM-KAIST 9

- GCAM-KAIST 9, an extended version of GCAM v9, incorporates Korea's socio-economic development, climate policies, and technological characteristics into an integrated climate assessment framework.
- We introduce an international LH_2 and LNH_3 trade framework covering 30 exporting regions, with Korea as the sole importer.
- The extended framework links hydrogen production in exporting regions with conversion, international shipping, reconversion, and end-use applications in Korea.
- Hydrogen production includes multiple technological pathways, while imported ammonia can either be cracked into hydrogen or consumed directly in power generation, industry, fertilizer production, and international shipping.
- Transportation requirements differ across exporting regions, allowing the model to examine the influence of shipping distance on LH2 and LNH3 delivery.
- Carbon prices are set to align with Korea's carbon neutrality target by 2050 to help identify its influence on fuel competitiveness.

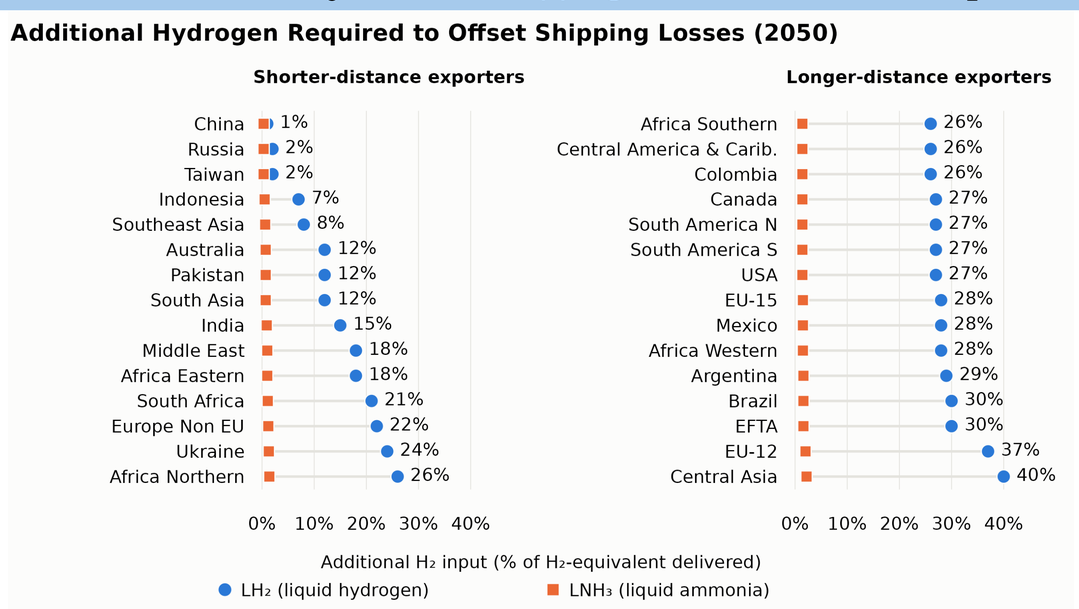
Preliminary Results

Result 1: Direct use accounts for 80% of imported ammonia in 2050



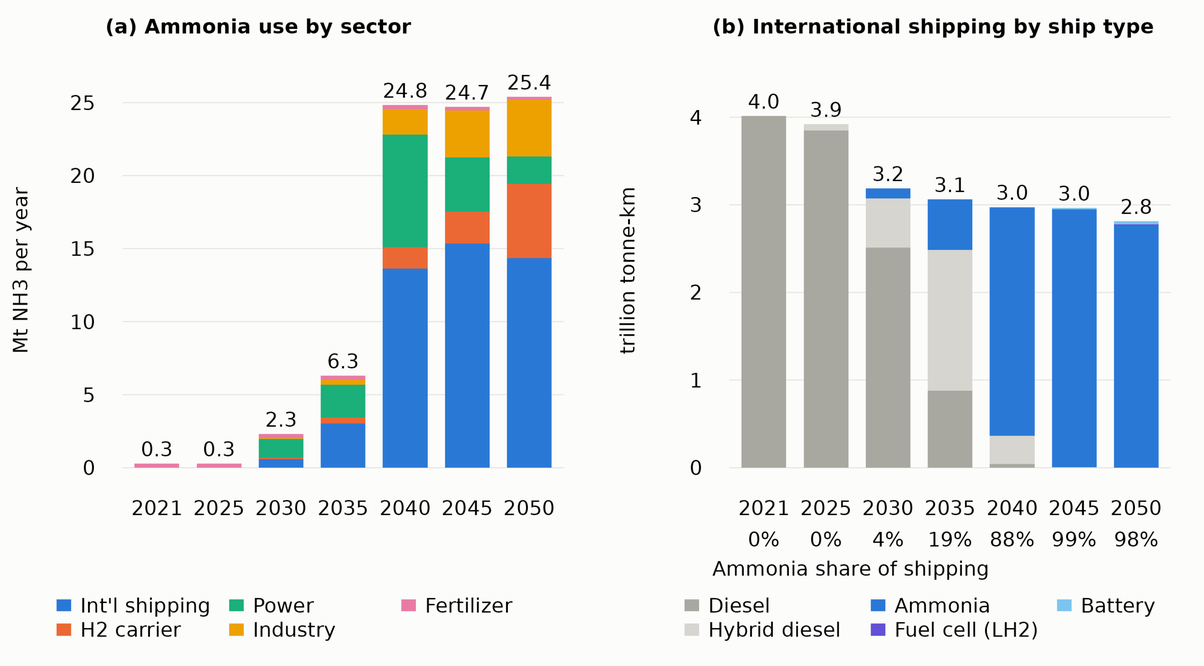
- Total modeled hydrogen-equivalent supply reaches approximately 652 million GJ in 2050, including 539 million GJ from imported ammonia.
- Of the imported ammonia, approximately 430 million GJ (80%) is allocated to direct utilization, suggesting that direct ammonia applications may become a major driver of future import demand.
- The relatively diversified exporter structure suggests that Korea could source ammonia from multiple regions rather than depending exclusively on a single major supplier.
- The leading LNH_3 exporters are Australia (9%), the USA (9%), and China (8%), reflecting a diversified supply structure.
- The leading LH_2 exporters are China (14%), Australia (11%), and Russia (9%), with China accounting for the largest share.

Result 2: LNH_3 has lower shipping-related losses than LH_2



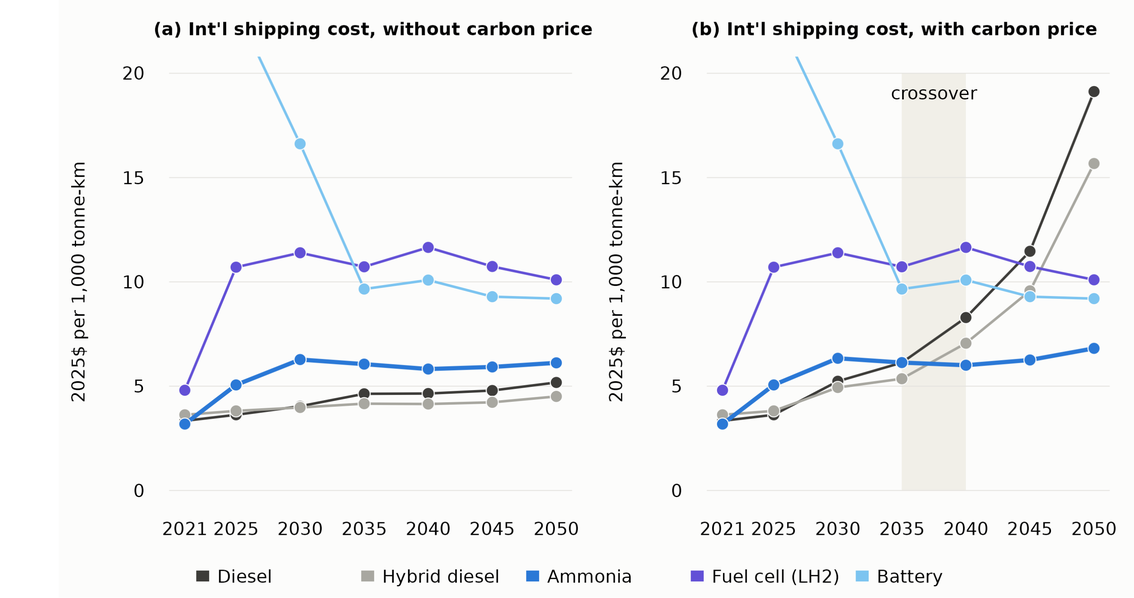
- LH_2 shipping requires substantially more additional hydrogen input as transportation distance increases, reaching approximately 40% of delivered hydrogen for Central Asia.
- In contrast, the additional input required for LNH_3 shipping remains below approximately 2.2% across exporting regions, indicating significantly lower shipping-related losses.

Result 3: Ammonia reaches a 98% shipping share by 2050



- International shipping accounts for approximately 57% of total ammonia use in 2050, with 14.4 Mt NH3 out of 25.4 Mt NH3.
- Power-sector ammonia consumption increases during the transition, reaching 7.7 Mt NH3 in 2040, before declining toward 2050.
- Under the modeled net-zero scenario, the ammonia share of international shipping activity increases from 19% in 2035 to 88% in 2040 and 98% in 2050, indicating a rapid transition toward ammonia propulsion.

Result 4: Carbon pricing makes ammonia-fueled ships competitive by 2040



- Without carbon pricing, conventional diesel-based shipping technologies remain less costly than ammonia propulsion throughout the modeled period.
- With carbon pricing, the relative competitiveness changes substantially. Ammonia-fueled ships become the lowest-cost option from approximately 2040.
- By 2050, modeled diesel shipping costs approach $19 per 1,000 tonne-km, compared with approximately $6–7 for ammonia-fueled shipping (2025 USD).
- These findings highlight the important role of carbon pricing in determining the economic competitiveness of alternative marine fuels.

Discussion

- The results highlight the expanding role of ammonia beyond conventional fertilizer production, particularly through direct fuel applications in international shipping.
- The dominance of direct ammonia utilization highlights the importance of considering direct-use applications alongside hydrogen carrier pathways when assessing future ammonia trade and demand.
- Carbon pricing strongly influences the relative competitiveness of ammonia propulsion, indicating that future adoption depends on both technological characteristics and policy conditions.
- The current model does not account for N_2O and NOx emissions from ammonia combustion. Future assessments should incorporate N_2O-related climate impacts and NOx-related air-quality impacts.

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