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Assessing a Louisiana-Japan Green Dry Bulk Corridor

A Feasibility Study for Dry Bulk Trade

October 2024

Executive Summary

This Feasibility Study examines the technical, economic, and operational feasibility of a green shipping corridor targeting the existing dry bulk trade between the US Gulf Coast and Japan.

The study arose from significant interest among both public and private stakeholders in investigating the possibility of decarbonizing dry bulk trade between two developed nations through utilization of zero or near-zero emission fuels. The US and Japanese national governments, as well as the private entities involved in the trade, share general goals of addressing emissions from international shipping, initiating ambitious first-mover projects that can catalyze alternative fuel production and deployment, and developing infrastructure to enable trade of low-carbon fuels.

The following analysis is the result of robust collaboration among the study's consortium members. The formation of this consortium and subsequent techno-economic analysis was led by RMI and the Maersk Mc-Kinney Moller Center for Zero Carbon Shipping. Cargill, Hy Stor Energy, and shipyards constructing zero-emission vessels provided invaluable insights throughout the process.

This analysis focuses on the feasibility and cost of deploying clean methanol in dual-fuel methanol bulk carriers before the end of this decade (2030); identifying the main cost drivers and opportunities to minimize the cost premium; and evaluating the impact of potential policy levers and regulatory regimes.

RMI

Mærsk Mc-Kinney Møller Center
for Zero Carbon Shipping

Cargill

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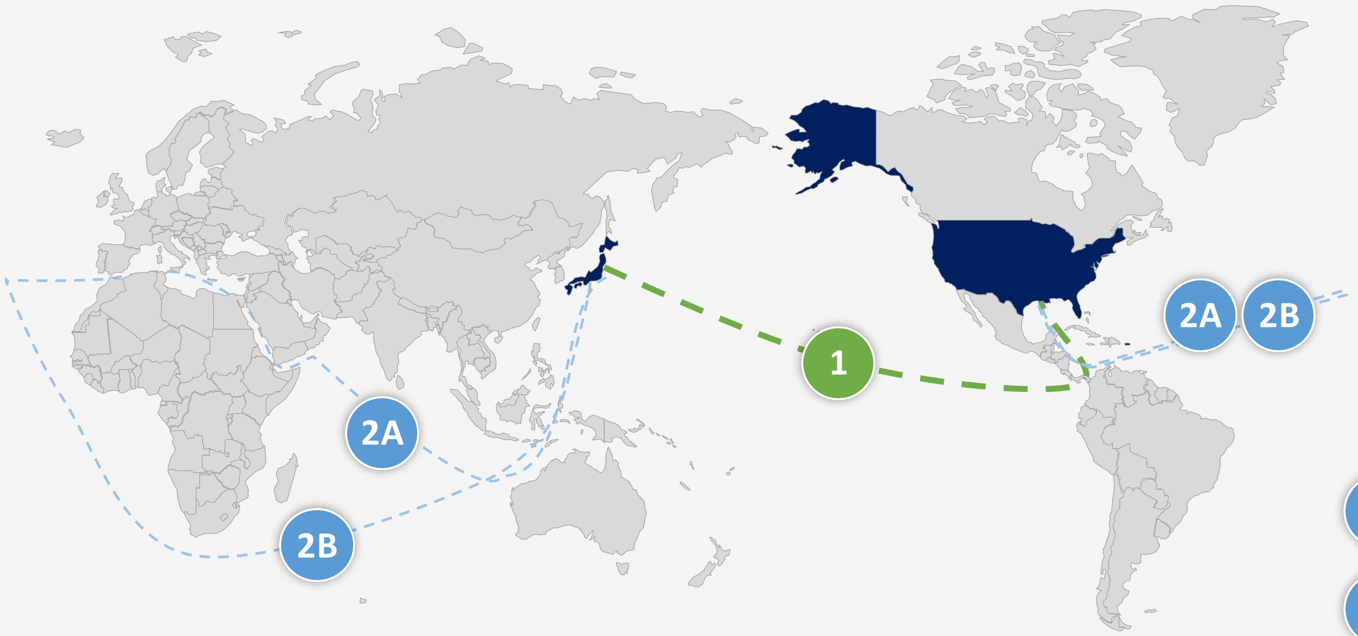
Key Findings

Vessel Delivery	**1.** Methanol dual-fuel bulk carriers will be available **as soon as 2025**, a significant early opportunity for large-scale consistent offtake for production projects in the United States and East Asia.
Regional Supply	**2.** Global demand for clean methanol will exceed supply this decade, creating competition; however, the US Gulf Coast is expected to be **a hub for methanol production and bunkering**, and methanol demanded represented by this corridor is a small percentage of total potential green fuel offtake from the United States and Japan.
Fuel Cost	**3.** E-methanol using electrolytic hydrogen as a feedstock **remains higher in cost relative to conventional fuel**: 3.5—4x the cost of HFO in this study's scenarios. The result is a large cost gap between conventional and green shipping.
Operational Changes	**4.** Given the increased costs and limited global supply of methanol, dedicated green corridors operating with **predictable vessel schedules** are likely required to secure access to methanol and ensure maximum utilization of dual-fuel vessels—**a significant operational change** for bulk commodities currently employing "tramp trade" or dynamic route planning
Policy & Market Mechanisms	**5.** Policies and incentive mechanisms, such as production incentives for zero emission fuels, have been effective at **narrowing the cost gap** between conventional and green shipping; additional levers examined, such as cost penalties on shipping's emissions, can be combined to further narrow the cost gap.
Willingness to Pay	**6.** Partnerships across that value chain that include **first-mover cargo owners** with ambitions to cut **scope 3 emissions** via green shipping are essential for success.

Analysis examines Panama Canal route—shortest and most common route between US Gulf Coast and Japan; Suez Canal or Cape of Good Hope offer “backup” routes during disruptions



- - Route for Feasibility Analysis
- - Alternative Routes

1. Assumes average vessel speed of 10 nm / hour based on AIS data and industry stakeholder validation.

1 Primary Route (Corridor analyzed)

- Panama Canal route ≈**9,400nm (one way)**
- Avg. journey ≈**1,900 hours round trip,** or ≈**80 days at sea**; vessel dedicated to corridor can make **4 round trips /year**[1]
- One-way voyage from Louisiana to Japan is feasible on a single methanol tank, but round-trip requires refueling at each end of corridor, or using fuel oil for part of voyage
- Routes exceeding 9,400nm unlikely to be feasible on methanol alone with current dual-fuel KSMX design; however, methanol can be used to decarbonize large percentage of route, switching to HFO for the remainder

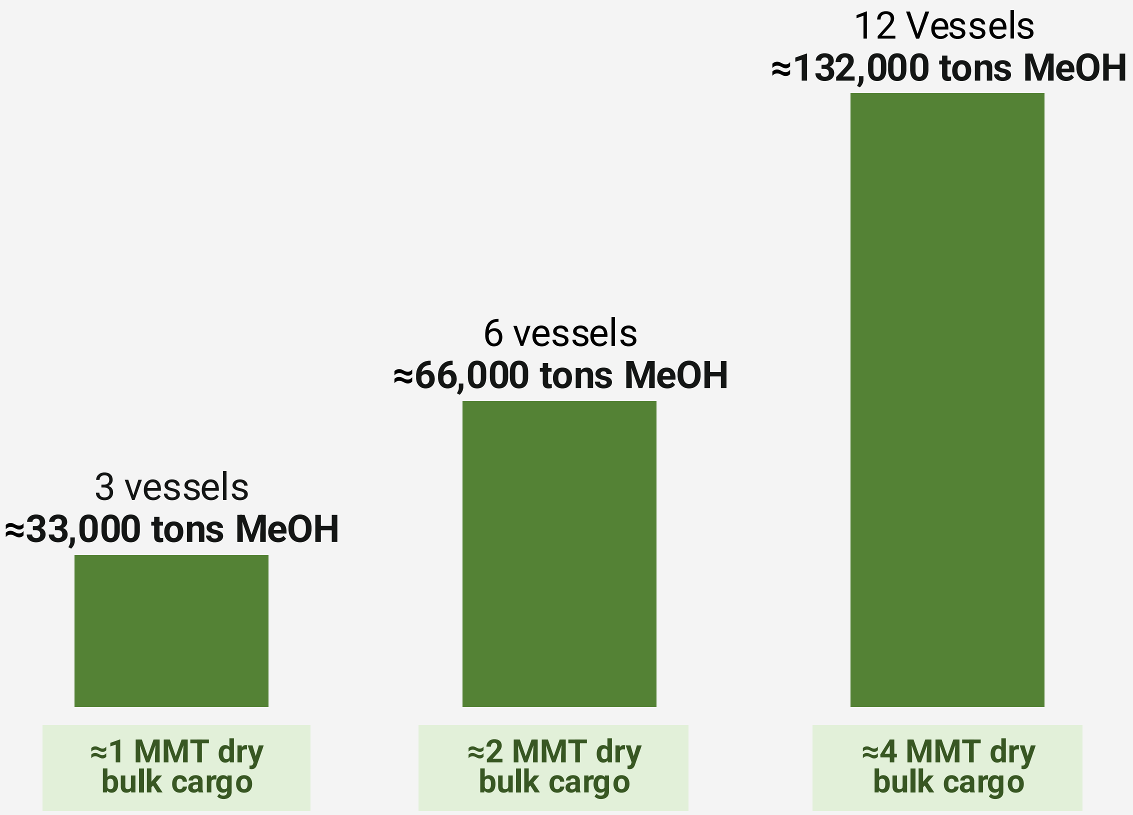
2A 2B Alternate Routes

- Drought conditions in 2023 prompted **Panama Canal Authority (PCA)** to limit daily vessel transits and diverted some dry bulk traffic to Suez route
- Suez Canal route ≈14,400 nm (>50% increase);
  Cape of Good Hope route ≈15,600 nm (>65% increase)
- These routes increase voyage distance by up to **6,000nm one way (~50 additional days roundtrip)**
- Despite longer distance both routes have historically been used for some dry bulk trade to East Asia

Dedicating 6 dual-fuel methanol vessels to corridor requires ~66,000 tons of clean methanol per year and decarbonizes the transport of ~2 million tons of dry bulk cargo

KMSX Vessel DWT=82,400 tons of dry bulk × **4** **Round Trips per year** ≈ **330,000** **Tons of dry bulk per vessel per year**

1 KMSX vessel uses 2,800 tons MeOH / trip × **4** **Round Trips per year** ≈ **11,000** **Tons of Methanol per vessel per Year**



- Methodology assumes methanol ships are dedicated to a Louisiana-Japan corridor and use exclusively methanol fuel
- Assumes **4 roundtrips/year** based on 40-day one-way voyage
- Assumes **2,800 tons methanol fuel consumed per round trip**, based upon vessel specs[1] of:
  - 2,500m^3 methanol tank capacity
  - 13,000nm range on methanol tank
- One way trip requires ≈**1,400 tons methanol**; tank capacity holds ≈**1,950 tons,** making refueling required for roundtrip using only MeOH fuel[2]

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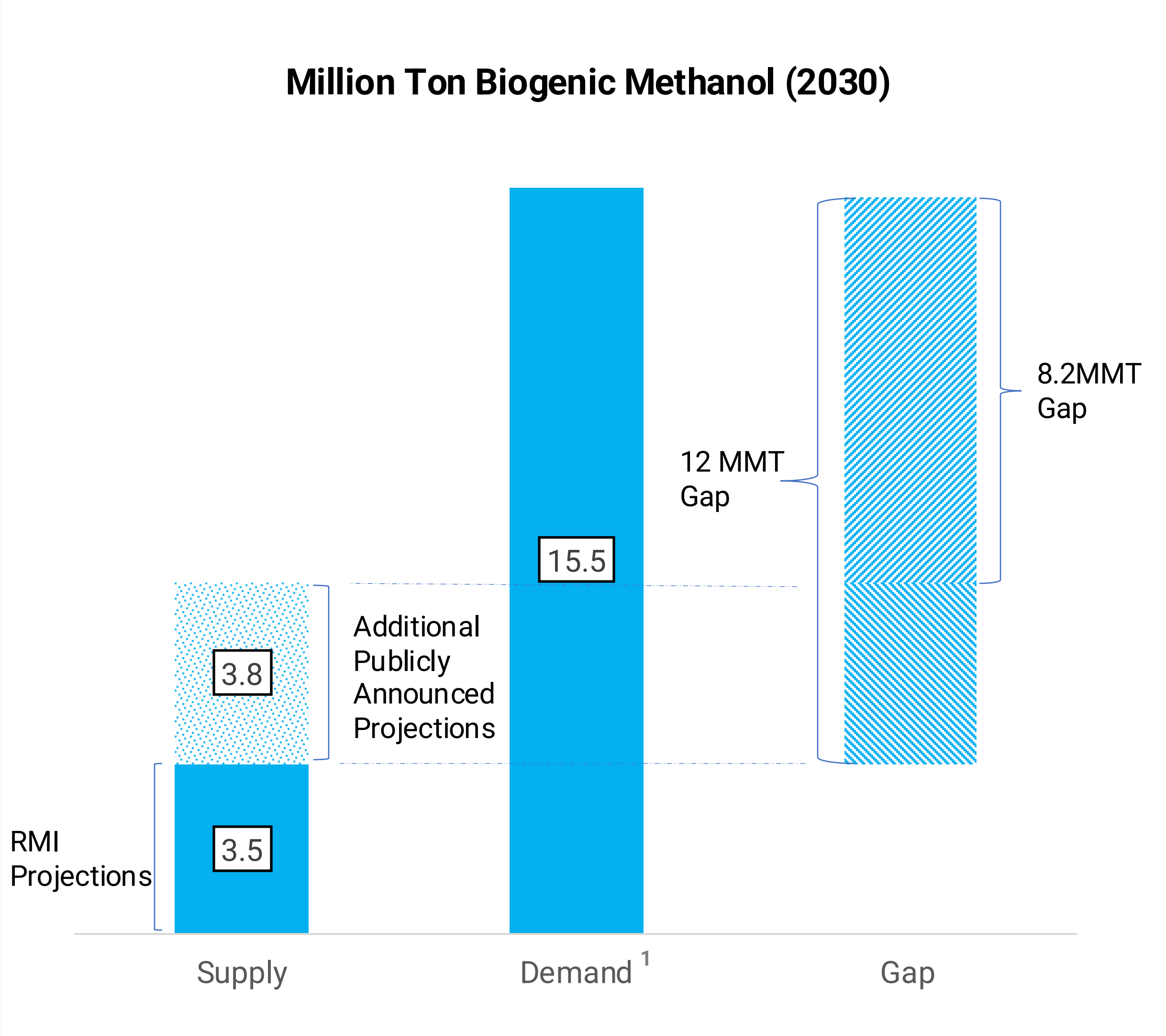
1. See Appendix for dual-fuel vessel specifications provided by consortium members
2. **Corridor Assumptions:** Average Round trip =**18,800 nm, 1,900 hours** ; **320 days at sea** per year

While there will be global scarcity and competition for methanol this decade, Gulf Coast ports will likely serve as early methanol bunkering hubs due to existing infrastructure and proximity to low-cost production



- Several factors—including scarcity of methanol production projects relative to global ship orders and scarcity of biomass and CO_2 feedstocks — will likely give rise to competition among ports seeking to bunker methanol for the growing fleet

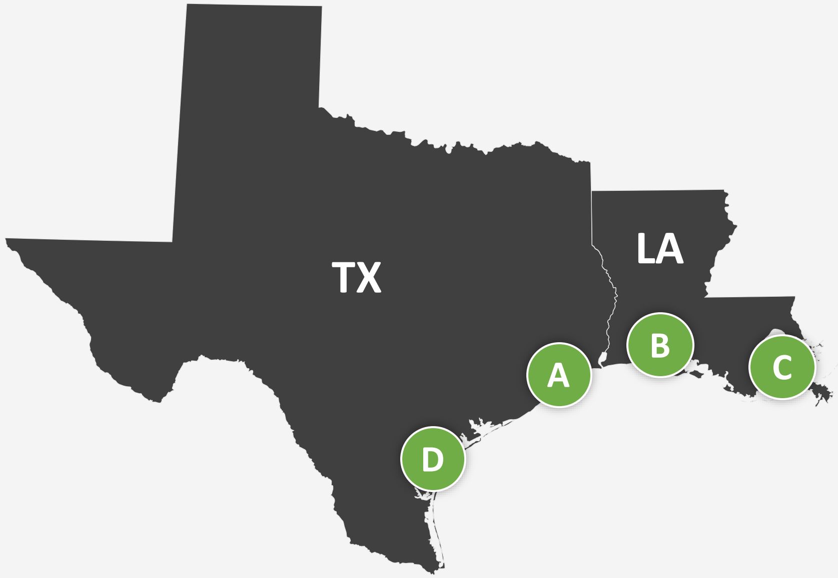
- The US Gulf Coast region (ports in Texas and Louisiana) is a top competitive export region for North American bunkering of green methanol, according to recent RMI trade flow analysis[1]

- RMI projection of methanol supply availability excludes production projects using non-biogenic CO2 feedstock, and projects for which offtake sector is non-shipping end uses

1. Based on RMI analysis in the *Oceans of Opportunity* report (April 2024) derived from IMO 2030 target of 5% of shipping energy demand satisfied by ZEF, with supply split across methanol and competing fuels .

Significant methanol infrastructure (>400,000 tons) already exists on the Gulf Coast

Map of Methanol Storage Facilities in the US Gulf Coast



	Largest Methanol Storage Facilities	
	City / Region	Storage Capacity (MT)
A	Houston, TX	275,000[1]
B	South Louisiana, LA	> 50,000 *
C	Baton Rouge, LA	> 50,000 *
D	Corpus Christi, TX	> 50,000 *

Source: DNV's Alternative Fuels Insight

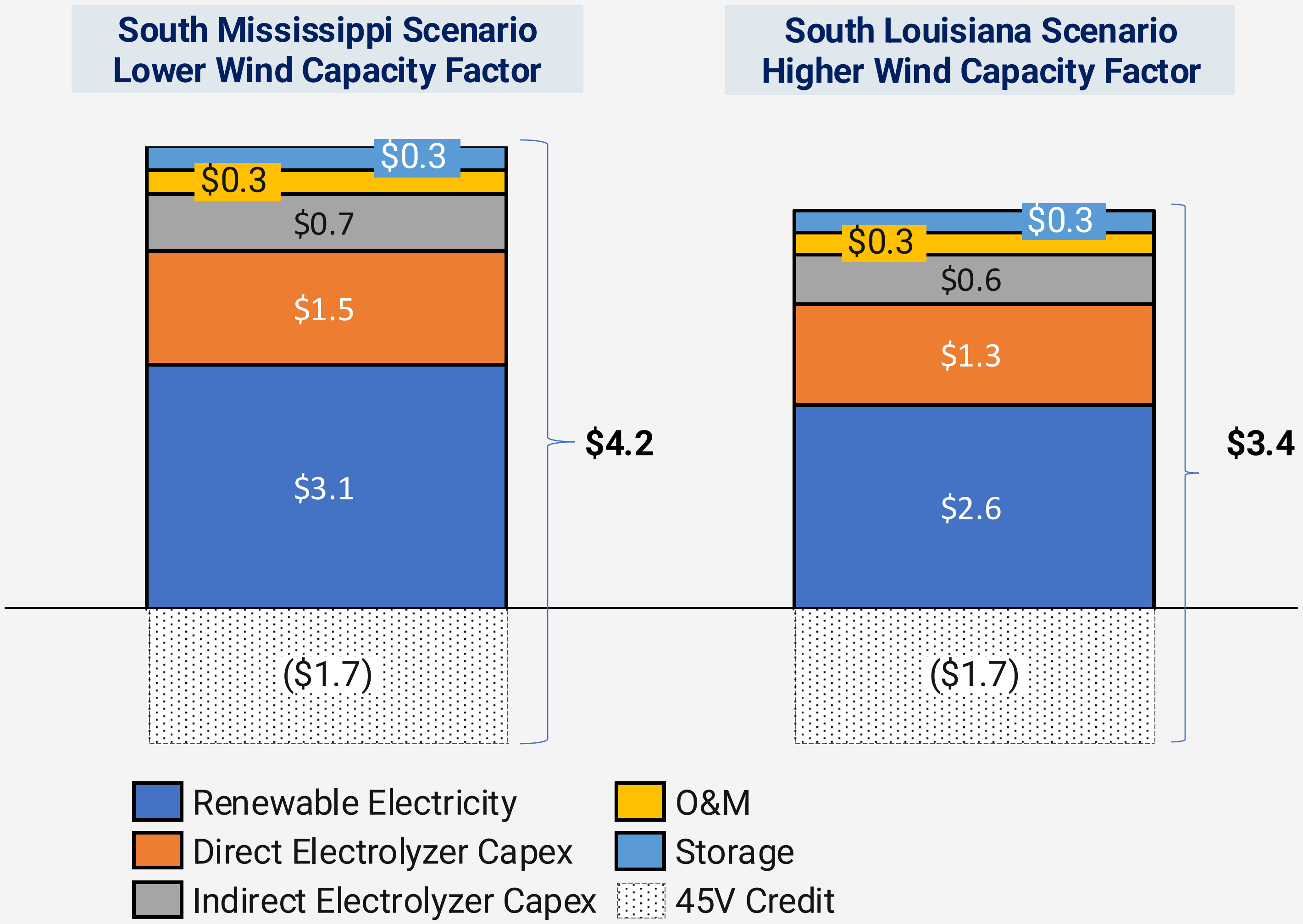
1. Capacity as reported by the Port of Houston.
* DNV classifies storage facilities as either 'larger than 50,000' or 'smaller than 50,000' tons; precise storage volumes not available.

KEY TAKEAWAYS

- US Gulf Coast stores significant volumes of grey methanol, with **10+ facilities** across Gulf and the Mississippi region
- Current storage capacities are **largest at Port of Houston;** infrastructure for methanol is also advanced at many ports
- Given existing port-side methanol storage facilities in the region, **barriers to new construction** (or repurposing of existing infrastructure) **should be low**
- Green methanol certification mechanisms are necessary for blending grey and green storage, and will need to be considered independent of physical storage capacity
- Bunkering out of existing facilities feasible by **truck or small bunker ships**

Quality wind resource location are key for attaining lower levelized cost of hydrogen (LCOH)—the largest cost component of methanol production

Levelized Cost of Electrolytic Hydrogen ($/kg) 2028



SCENARIO DESCRIPTION

- Scenarios demonstrate impact of siting project at Gulf Coast locations near Port of New Orleans, with **different wind capacity factors**; technology costs and solar capacity factors kept constant
    - **South Mississippi** wind capacity factor =18%
    - **South Louisiana**: wind capacity factor =25%

KEY FINDINGS

- Superior wind location yields **LCOH 20% lower**, due to **higher electrolyzer utilization** and **lower LCOE**
- Modeled **LCOH falls below $2/kg in West Texas** where wind capacity factor is 40%; requires longer transport distance to port
- **$1.7/kg impact of 45V** credit reflects the full $3/kg credit **levelized over the lifetime of the project**

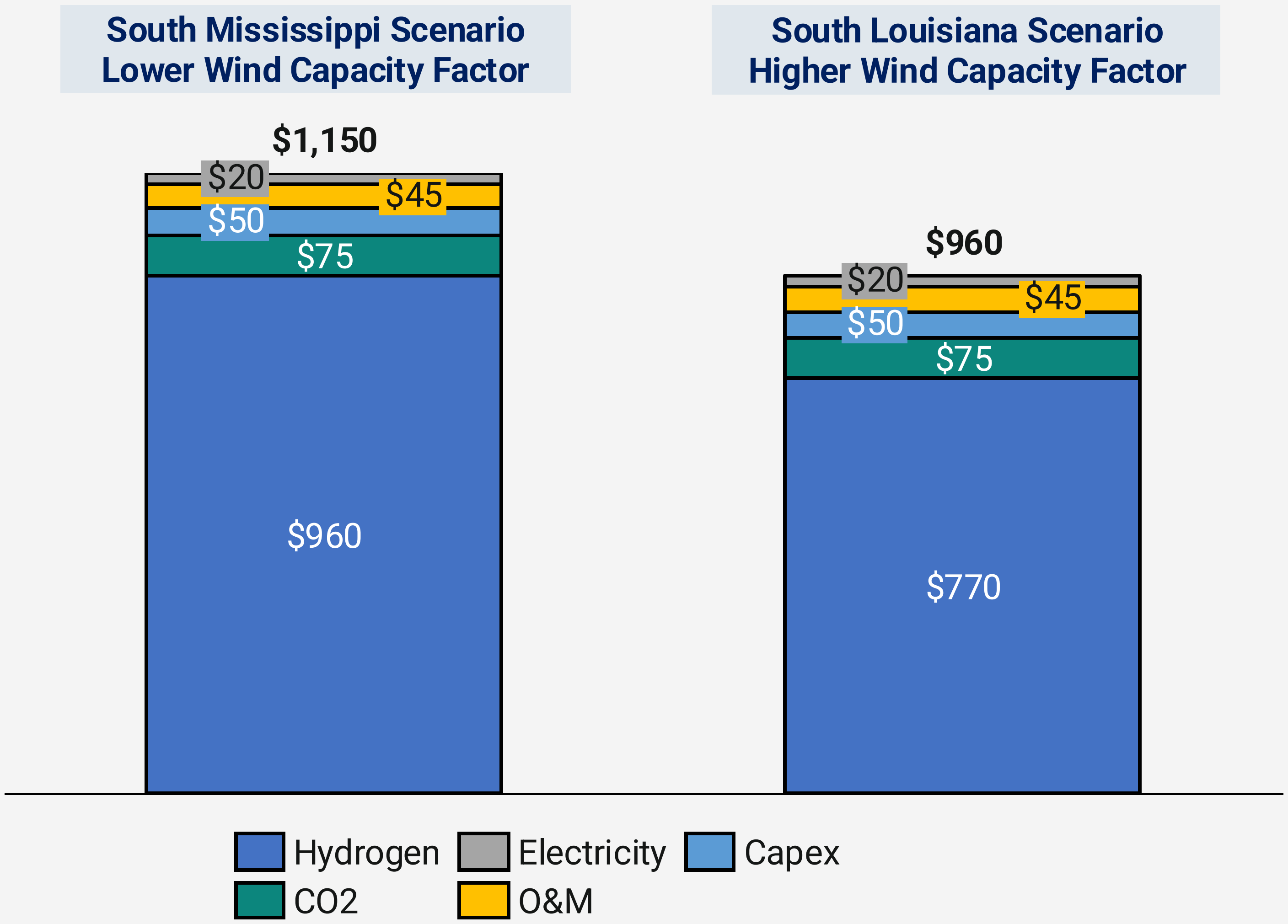
STORAGE ASSUMPTION

- Salt cavern storage assumed across all locations; future analysis can evaluate LCOH delta between salt cavern and pipeline storage if needed

See Appendix for LCOH Methodology and Capital Cost and Financing Assumptions

Hydrogen is the main cost driver in the production of e-methanol; >80% of the production cost of e-methanol can be attributed to hydrogen production costs

Levelized Cost of E-Methanol Production ($/ton) 2028



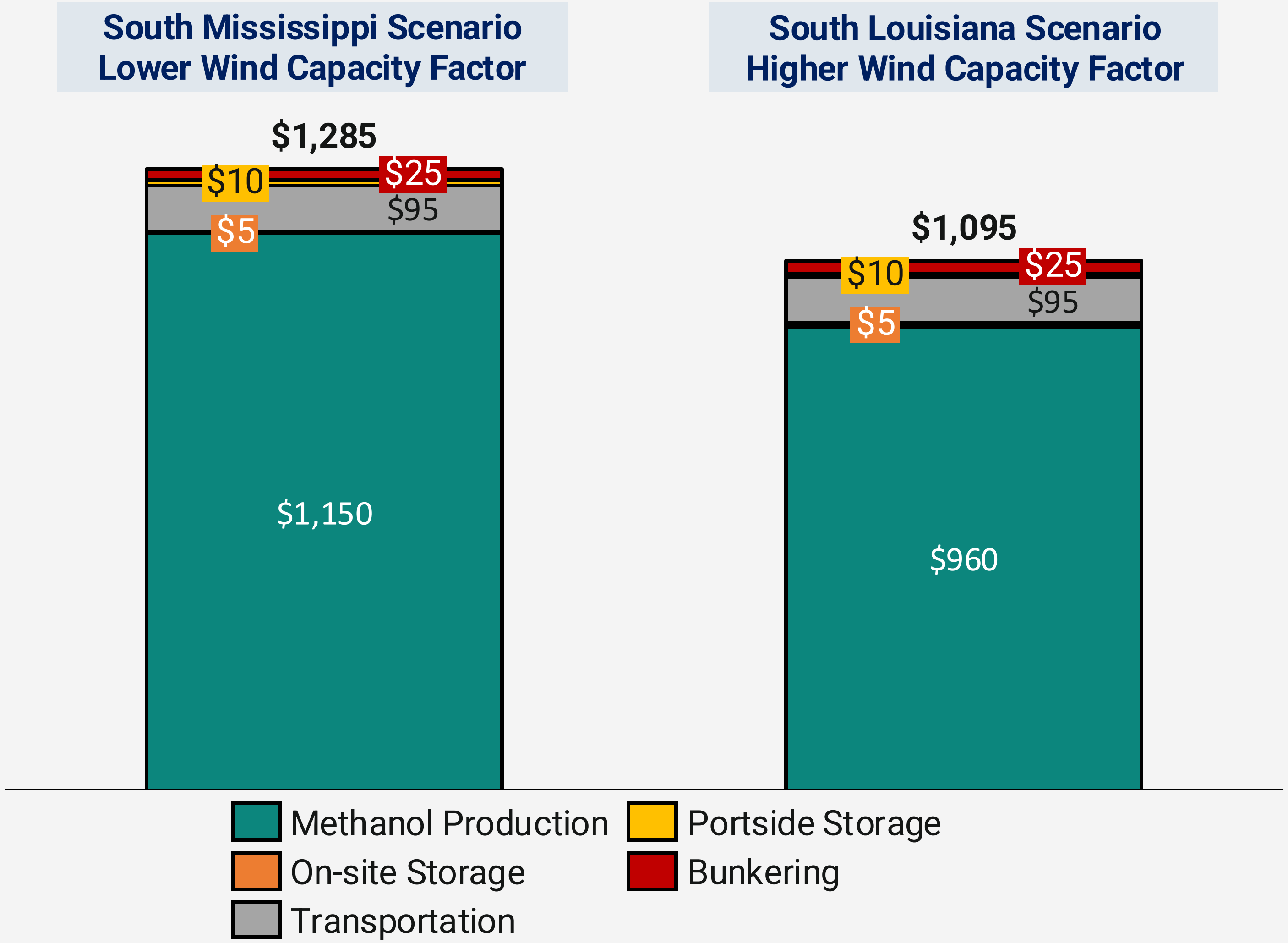
KEY FINDINGS

- Excluding hydrogen, other cost components total ~$190/ton of e-methanol
- E-methanol production cost is ~20% higher in lower quality wind resource location (Mississippi scenario)
- After hydrogen, the cost of CO_2 is the highest input –cost can vary widely by source; biogenic CO2 is necessary for e-methanol to achieve full emission reduction potential
- Assumes $45/ton CO_2 cost, based on literature review of capture costs for least-cost biogenic sources; industry feedback indicates real and anticipated CO_2 demand from e-fuel producers currently driving prices higher

See Appendix for LCOM Methodology and Capital Cost and Financing Assumptions

Methanol transportation and storage costs are small part (10-15%) of total delivered fuel cost; share of total increases as production cost declines

Levelized Cost of Delivered E-Methanol ($/ton) 2028



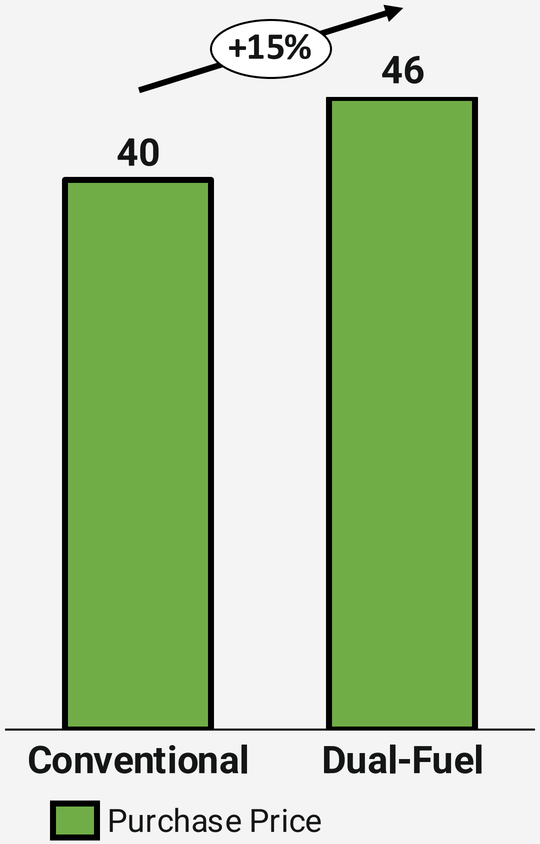
KEY FINDINGS

- **Storage, transport, and bunkering costs total ~$135/ton of methanol**
- **Total delivered cost of e-methanol** is **~3-4x** the cost of HFO on an energy equivalent basis (assuming HFO cost of $600/ton)
- Modeled transportation costs assume new pipeline build, accounting for 5-10% of delivered methanol cost in scenarios evaluated
- Other transportation methods, including **existing pipelines, rail, or barge** will be **less costly**, but will still represent a relatively small proportion of overall delivered cost
- New bunkering infrastructure costs are modeled, but may be duplicative given potential existing availability of existing infrastructure (bunkering and portside storage)

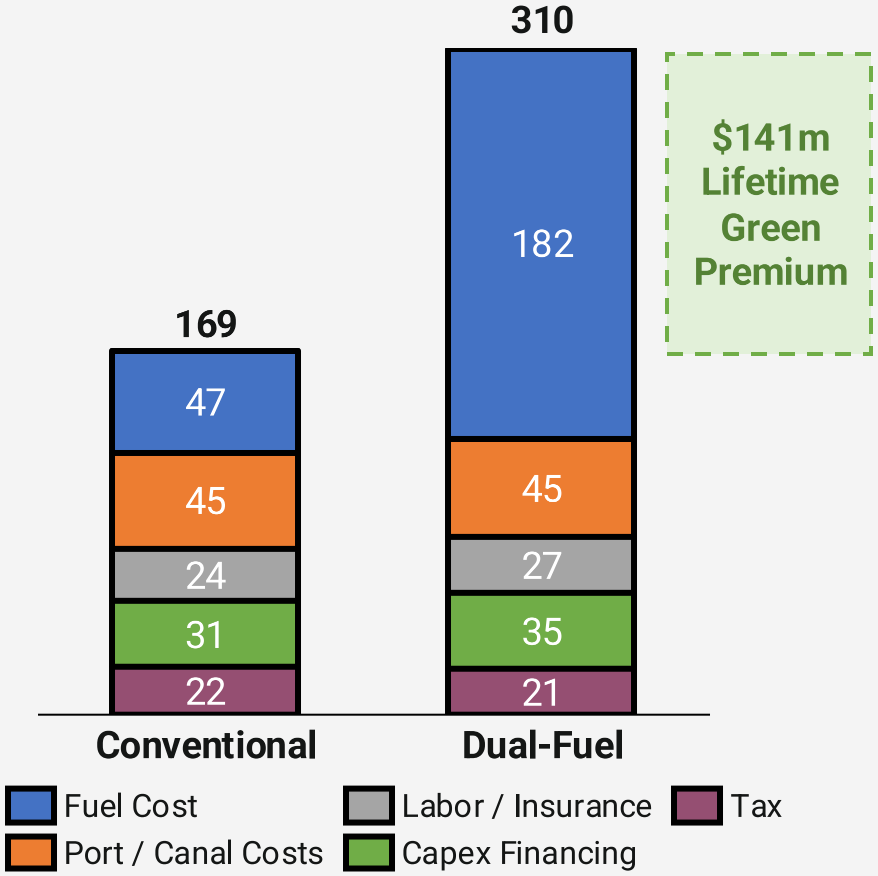
Assumes ~ 200 km pipeline transport to Port of New Orleans at ~ $0.9mm per km of new rural pipeline construction; assumes one storage tank at production (on-site storage) and two storage tanks at port (portside storage)

Total Cost of Ownership for dual fuel KSMX over lifetime of vessel is 1.8x conventional, driven mostly by fuel cost

Capex (in millions USD)



Total Cost of Ownership, Vessel Lifetime[1] (NPV in millions USD)

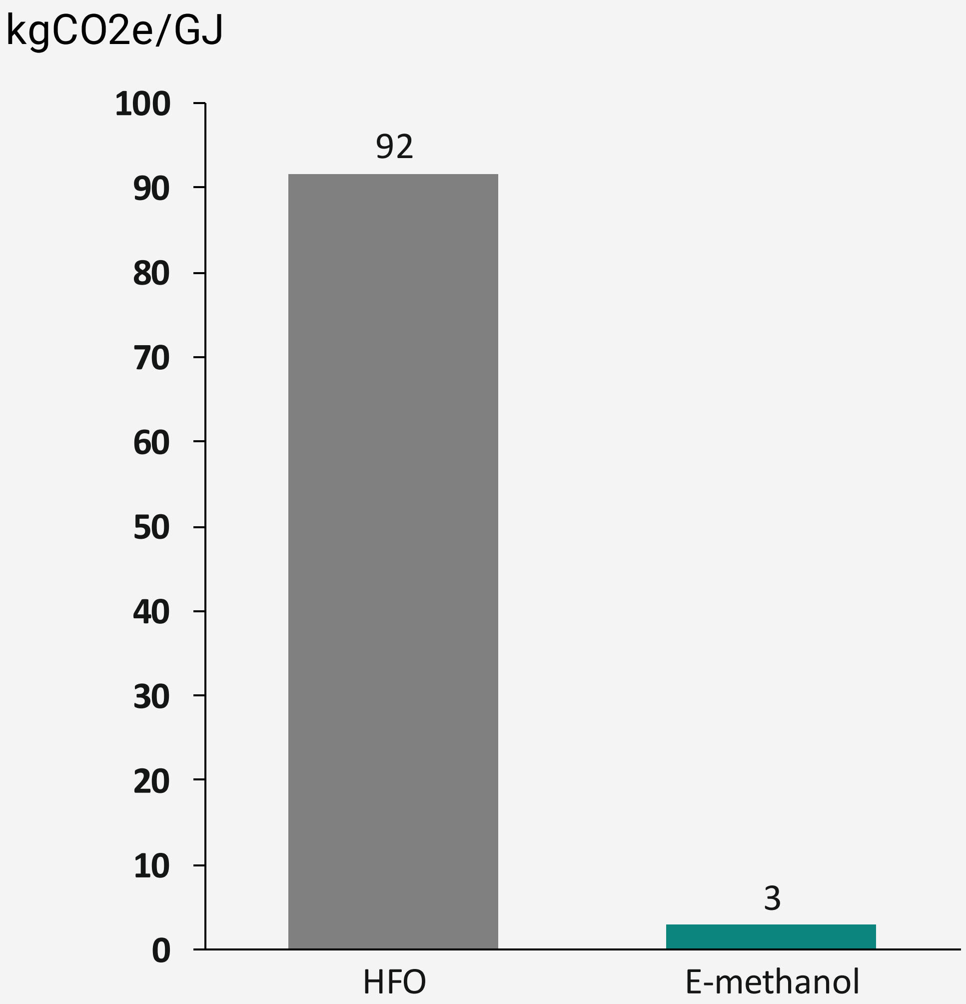


KEY FINDINGS

- Total Increased Cost of Ownership over 30-year lifetime of the vessel is modeled at approximately $141 million, **or an average of $4.7 million per vessel per year**
- **Fuel cost** is the main driver of increased TCO, accounting for **over 95% of the increase** relative to conventional bulk carrier in the moderate scenario
- **Upfront capex** increase of 15% for vessel purchase represents **about 3% of total green premium** over lifetime of asset (on NPV basis)
- TCO keeps fuel cost constant for methanol and VLSFO. **First movers** in supply and demand enable green methanol to be deployed today – resulting in **cost declines** over the life of the vessels. In conjunction with expected price increases for fossil fuels, the **annual cost gap is expected to decrease** over time.

1. Total cost of ownership models allow apples-to-apples comparison of costs across the entire lifetime of the assets, inclusive of all upfront and future costs. This TCO models the cash outflows of a vessel over a 30-year asset lifetime, including financing and inflation assumptions. Includes labor and other operating expenses, validated through stakeholder feedback. Fuel costs for methanol and VLSFO are kept constant over 30-year asset lifetime, modeling Louisiana scenario of $1,095/ton of methanol. Model assumes 320 operational days per year, 10 port calls annually, and 8 canal crossings; 11,000 tons of methanol burned per vessel per year; 5,500 tons of conventional fuel burned per vessel per year

E-methanol can offer near-zero well-to-wake (WtW) emissions; at $1,095/ton of delivered methanol, abatement cost is ~$230/ton of abated CO_2e emissions over lifetime of the vessel



- E-methanol assumed to yield **97%-100% emissions reduction** relative to HFO on a well-to-wake (WtW) basis based on:
  - Zero emission electrolytic hydrogen production (dedicated renewables, no grid electricity)
  - Carbon-free electricity used for methanol synthesis
  - Biogenic CO_2 feedstock

- Factors contributing to residual WtW emissions (<3 kg CO_2e/GJ) include:
  - Energy inputs associated with processing biomass feedstock and capturing resulting biogenic CO_2
  - Emissions associated with CO2 transport from capture site to methanol synthesis plant
  - Emissions associated with transport from methanol plant to port

*Analysis does not include emissions associated with pilot fuel necessary for methanol combustion; pilot fuel will likely make up ~5% of dual fuel bulk carrier's total energy in near-term

Cost gap between e-methanol and fossil fuel in Year 1 is $9—$11 million per vessel per year; operating 6 vessels results in gap of ~$50-$70 million in Year 1

Year 1 Corridor Green Premium for Fuel (in millions USD)

		Vessels Deployed		
		3 Vessels	6 Vessels	12 Vessels
Fuel Cost Scenarios	Louisiana Scenario	~$28	~$54 *	~$106
	Mississippi Scenario	~$33	~$67	~$133

* Baseline Green Premium used in subsequent cost gap analysis

COMMENTARY

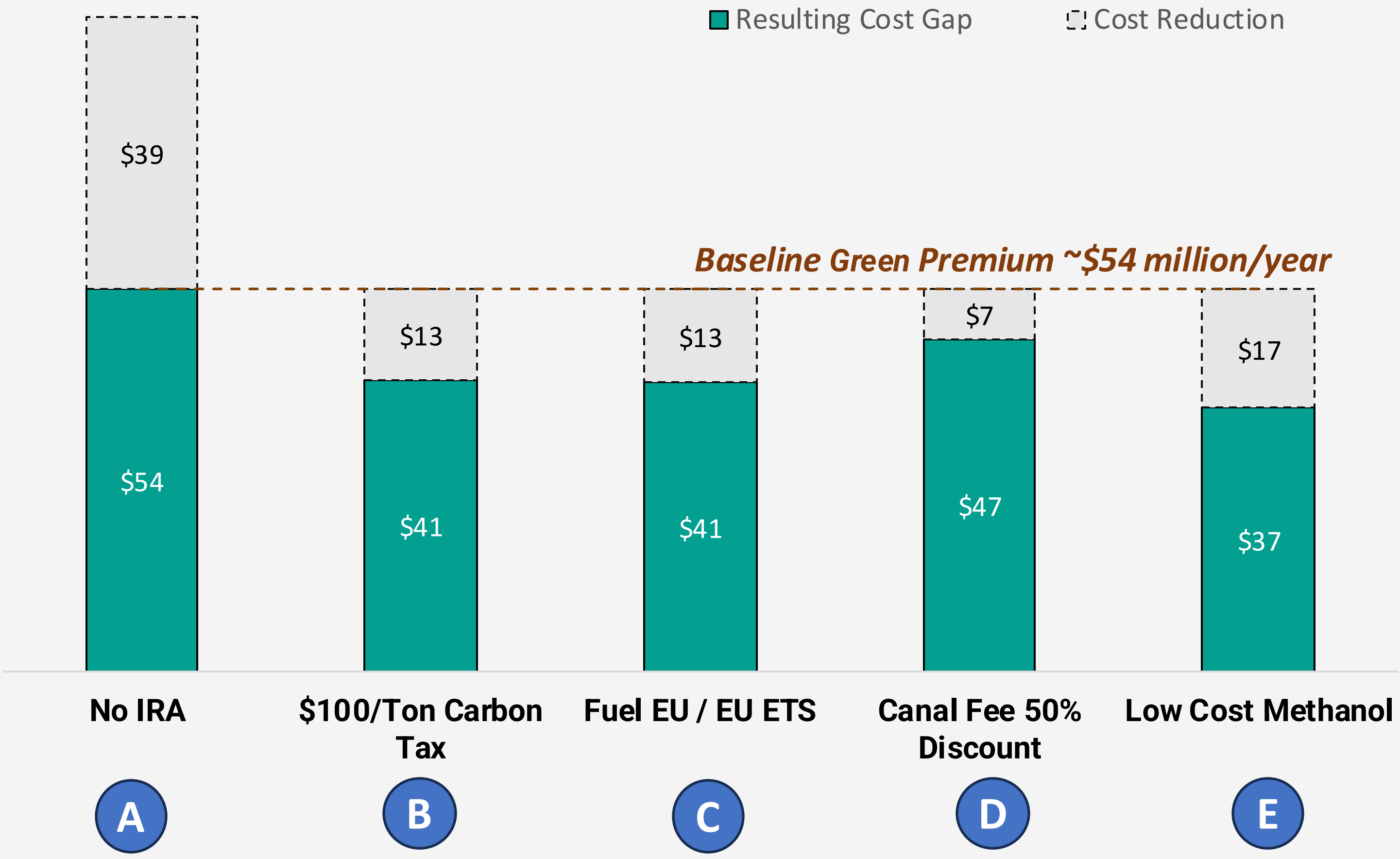
- Isolating additional fuel costs in Year 1 provides insight into cost gap that must be addressed near-term via policy levers and/or cargo owner willingness to pay; cost gap expected to be largest in year 1 and decline as methanol cost declines
- Year 1 green premium shown here does not include the upfront vessel premium and additional OpEx costs taken into account in TCO analysis on previous slide

Five scenarios modelled to estimate the change in Year 1 cost gap of green fuel in different policy or fuel availability environments

Regulatory	A	**No IRA H2 Tax Credit**	Reflects the impact of eliminating IRA 45V tax credit for hydrogen production ($3/kg)
	B	**Carbon Tax**	Introduces $100/ton carbon tax on shipping emissions to reflect the impact of a potential IMO policy mechanism imposing a cost on shipping emissions
	C	**EU ETS + Fuel EU**	Represents impact of two existing EU policies — EU ETS and Fuel EU — on green shipping cost gap by modeling penalties on shipping emissions
Value Chain	D	**Panama Canal Fee Discount**	Represents favorable treatment of green shipping at Panama Canal by modeling a 50% discount on canal fees for methanol-fueled vessels, relative to incumbent
	E	**Low-Cost Methanol Availability**	Represents availability of methanol at lower delivered cost, assuming $850/ton delivered, based on the lowest cost option on market, per industry survey and internal analysis

IRA has cut green premium by ~40%; a carbon tax on shipping emissions similar to EU regulations could reduce a further ~25%

Year 1 Cost Gap of Green Shipping on Corridor ($ millions)



KEY FINDINGS

- The IRA reduces the cost gap by over 40%, as shown in Scenario A
- Penalties on shipping emissions similar to EU regulations, whether from IMO or Japanese side, could further reduce the cost gap by another ~25%
- A demand-side policy in Japan, such as the government's proposed contract-for-difference mechanism, has potential to yield significant reduction, but cannot yet be quantified
- Availability of low-cost methanol, modeled here at $850/ton in delivered cost, is meant to represent the low end of available market prices, based on industry survey and internal analysis
- In a scenario without subsidies, like IRA in the US, the delivered cost of e-methanol will be in the range of $1500-$1700 USD/t

Feasibility study highlights near-term availability of green methanol and dual-fuel dry bulk vessels on corridor; IRA has significantly cut green fuel premium, but additional policy levers and coordination needed to realize deployment by 2030

Summary

- Clean methanol dual-fuel bulk carriers are available to decarbonize shipping on this corridor by 2025, and represent **a first of its kind opportunity** in green shipping; the IRA has reduced the cost gap between conventional bunker fuel and e-methanol by approximately 40%

- Clean methanol is expected to remain higher in cost in 2030 (3.5—4x incumbent fuel) yielding a **significant cost gap between green shipping and the status quo**— an estimated $50-$70 million per year to operate 6 vessels on the corridor

- **Additional market mechanisms and policy interventions** should be further evaluated in the next phase of analysis; demand-side incentives, penalties on shipping emissions, and canal fee discounts can significantly reduce the green shipping cost gap to stimulate market development in the short-term

- **Ambitious first-movers across the maritime value chain,** motivated to address scope 3 emissions through green shipping are essential for implementing green corridor projects and closing part of the cost gap. Collaboration is a key component of green corridors. First movers can work together to create innovative contracting structures and partnerships with shared risk-reward benefits.

Next Steps: RMI is working across multiple initiatives to leverage the most favorable policy environments and create effective demand-side mechanisms

Developing a Maritime Book and Claim system

IMPACT: Create a credible and transparent credit mechanism that allows cargo owners to access and support decarbonized maritime transport

Enabling zero-emission fuel supply at ports

IMPACT: Accelerate development of zero-emission port fuel infrastructure and catalyze uptake of zero-emission fuels

Advocating for IMO policies to catalyze e-fuel deployment

IMPACT: Advance regulatory mechanisms that will target the most scalable fuel solutions

Next Steps

- Engage cargo owners in industries with strong scope 3 decarbonization goals; explore leveraging maritime book & claim system to link the bulk corridor's decarbonization potential with cargo owners' willingness to pay
- Explore trade routes centered around high value cargo, with the US Gulf Coast as one end point, and regions with regulatory incentives in the other end of the corridor

Appendix I: Dual Fuel Methanol Bulk Carrier Specifications

Conventional and dual fuel Kamsarmax have roughly equivalent cargo capacity or operational capabilities; maximum range using only methanol fuel is 45-50% of conventional bulk carrier range using VLSFO

Characteristic	Methanol (Dual-Fuel) KSMX compared to conventional	Impact
Fuel Tank – Volume	Two tanks: VLSFO tank is roughly same volume as conventional KSMX tank; methanol tank is 5-10% greater volume than VLSFO tank	Dual-fuel vessels have **an additional fuel tank**, more total fuel tank volume, and **near- instant fuel switching capabilities**
Fuel Tank – Tons	Two tanks: VLSFO tank roughly same as conventional KSMX tank; methanol tank holds about 10% less volume than VLSFO tank	
Cargo Hold Size	Roughly equivalent cargo hold size	Dual-fuel vessels do not sacrifice cargo space despite additional fuel tank
Range – 100% on VLSFO	Roughly equivalent range on full VLSFO tank alone	Can operate like conventional KSMX using VLSFO Range is significantly reduced if limited to methanol With both tanks combined, dual-fuel vessel has 40%-50% greater range than conventional KSMX
Range – 100% on Methanol	45-50% of range on full Methanol tank alone	
Pilot fuel %	Requires approximately 10% additional pilot fuel by weight	Dual-fuel vessels require pilot fuel for methanol combustion; impacts WtW emissions if pilot fuel is not decarbonized

Appendix II: Methodology and assumptions for cost modeling

Levelized Cost of Hydrogen (LCOH) Methodology and Assumptions

- Models behind-the-meter electrolytic hydrogen production using a linear optimization model, optimizing for the lowest capex to achieve an annual and hourly hydrogen production target. Solves for renewables and electrolyzer capacity size and hydrogen storage size, using location-specific hourly renewable production profiles. Yields a levelized cost of hydrogen over the lifetime of the plant, including applicable tax credits and depreciation schedules.

- **Electrolyzer Stack +BOP**: \$900/kW | **Electrolyzer Indirect Capex:** \$467/kW | **Wind Capex %:** \$1,300/kW | **Solar Capex:** \$1,070/kW
- **Tax Rate**: 25% | **Target IRR:** 12% | **Debt %:** 70% | **Cost of Debt:** 8% | **WACC:** 7.8% | **Plant Life:** 30 Years | **Inflation:** 2%

Levelized Delivered Cost of Methanol (LCOM) Methodology and Assumptions

- Models levelized cost of methanol production over a 30-year asset lifetime, using LCOH result for hydrogen feedstock and assumed CO_2 feedstock cost. Total delivered includes methanol synthesis costs, in addition to methanol storage, transport, and bunkering costs. The levelized cost of methanol represents a net-present value of the project cash flows, levelized over lifetime production volumes

- **CO2 feedstock:** \$45/ton || **New Pipeline Capex:** \$0.9 million/km | **Methanol synthesis capex** : ~\$124 million for plant size of 250,000 tpa
- **Tax Rate**: 25% | **Target IRR:** 12% | **Debt %:** 70% | **Cost of Debt:** 8% | **WACC:** 7.8% | **Plant Life:** 30 Years | **Inflation:** 2%

Total Cost of Ownership (Vessel TCO) Methodology and Assumptions

- Assuming a price per ton of cargo shipped, operating costs for the vessel, and capital expenditure requirements, the TCO model estimates the net present value of owning and operating a ship today over the lifetime of the vessel. The comparisons between conventional dual fuel vessels also include changes in fuel usage and fuel expense

- **Tax Rate**: 25% | **Target IRR:** 12% | **Debt %:** 70% | **Cost of Debt:** 8% | **WACC:** 7.8% | **Vessel Life:** 30 Years | **Inflation:** 2%