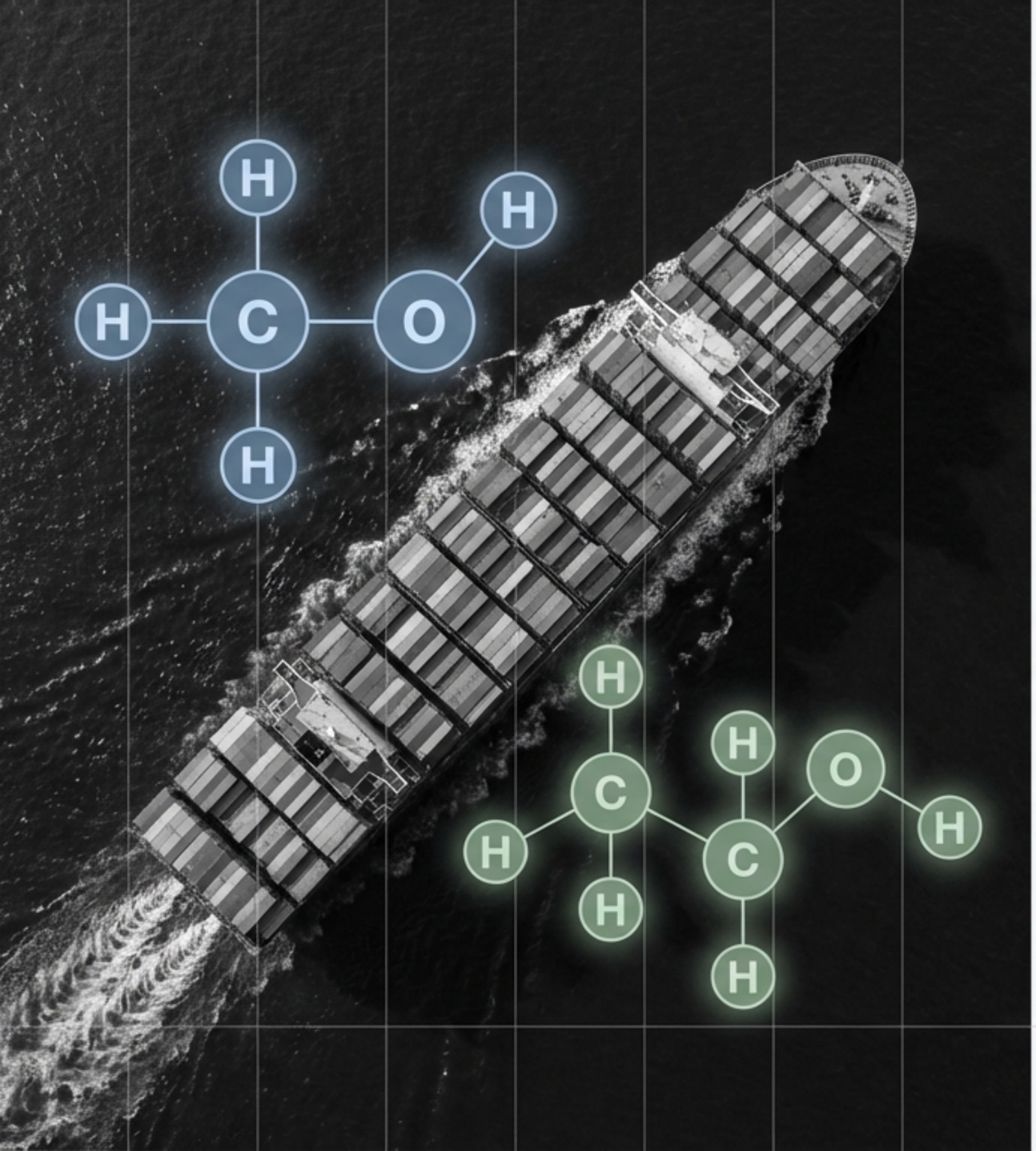
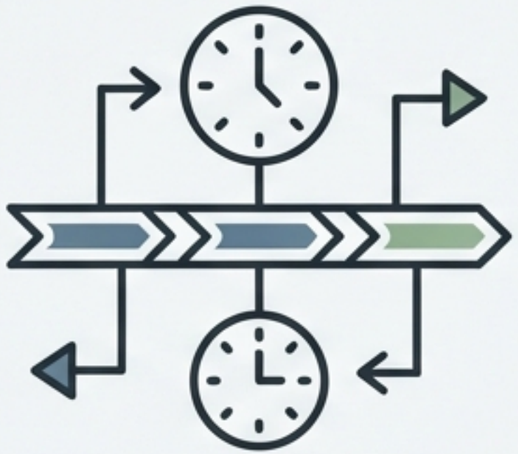


The Alcohol Era: Methanol vs. Ethanol in Marine Propulsion

A Comparative Analysis of Technical Feasibility, Supply Chain Readiness, and Decarbonization Potential for Two-Stroke Engines.

Prepared for Strategic Review.

Executive Summary: The Divergence of the ‘Fraternal Twins’



The Maturity Gap

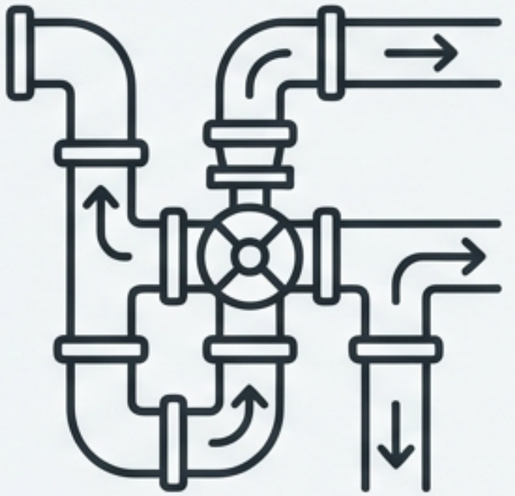
Methanol is the incumbent leader. MAN ES ME-LGIM technology has been operational for 10+ years with 600,000+ running hours.

Ethanol is the challenger, with WinGD targeting the first dedicated engine launch in 2026/2027.

The Physical Trade-off

Methanol offers the ultimate clean burn (zero soot due to no C-C bonds) but requires larger tank volumes.

Ethanol offers superior energy density (21.1 MJ/L vs 15.8 MJ/L), effectively **reducing cargo slot loss by ~30%** compared to Methanol.

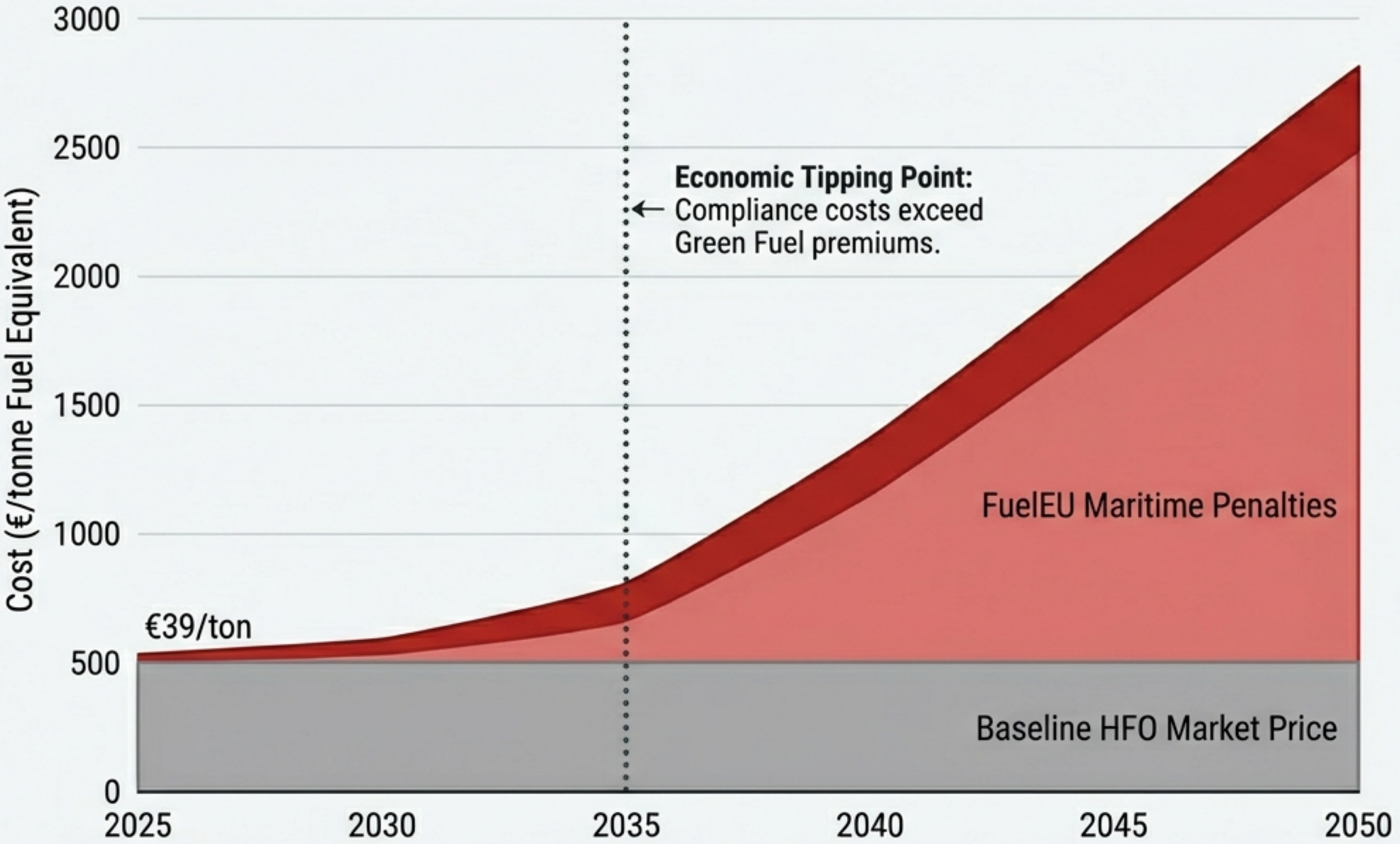


The Strategic Pivot

The industry is moving toward ‘Multi-Alcohol Ready’ platforms.

Future-proofing requires specifying materials compatible with both fuels—avoiding Titanium (**Methanol risk**) and specific rubbers (**Ethanol risk**)—to hedge against supply volatility.

The Cost of Inaction: Regulatory Tides Rising Against HFO

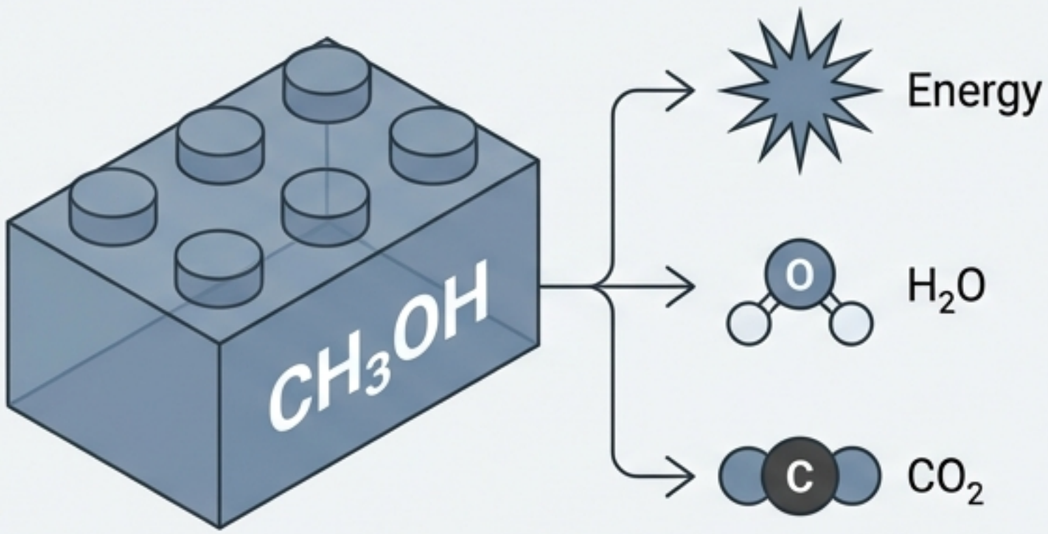


Regulatory Drivers:

- **FuelEU Maritime**: Progressive GHG intensity reduction mandates.
- **EU ETS**: Mandatory carbon market participation.
- **RFNBO Incentive**: 2x multiplier for e-fuels valid through 2034.

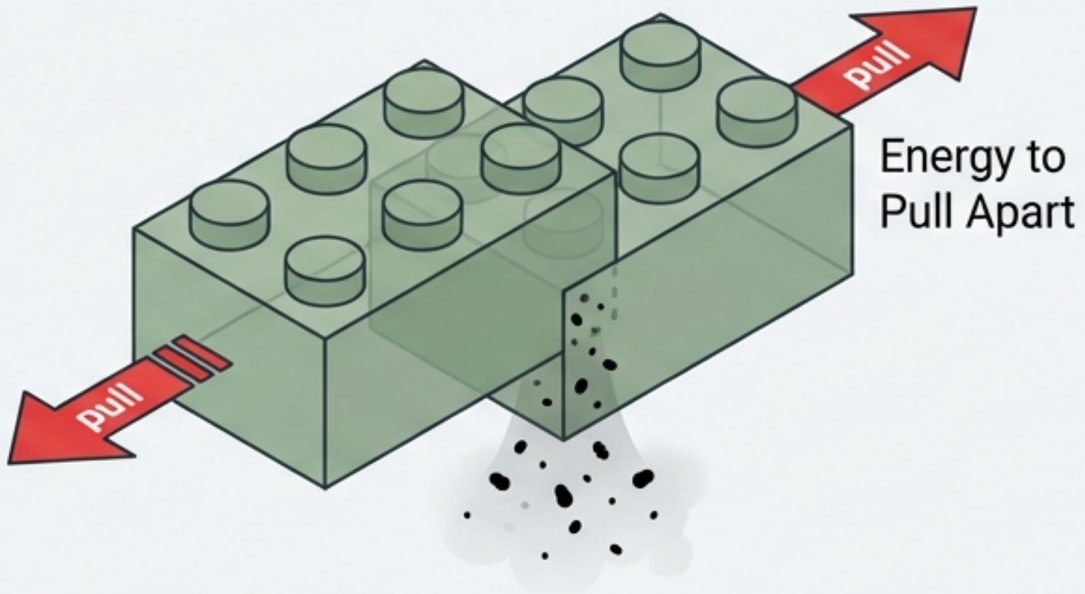
The Physics of the Bond: Why One Carbon Atom Matters

Methanol: The Single Brick



- No Carbon-Carbon (C-C) bond.
- Oxidation: Dissolves instantly.
- Result: Zero Soot / No Particulate Matter (PM).

Ethanol: The Interlocked Bricks

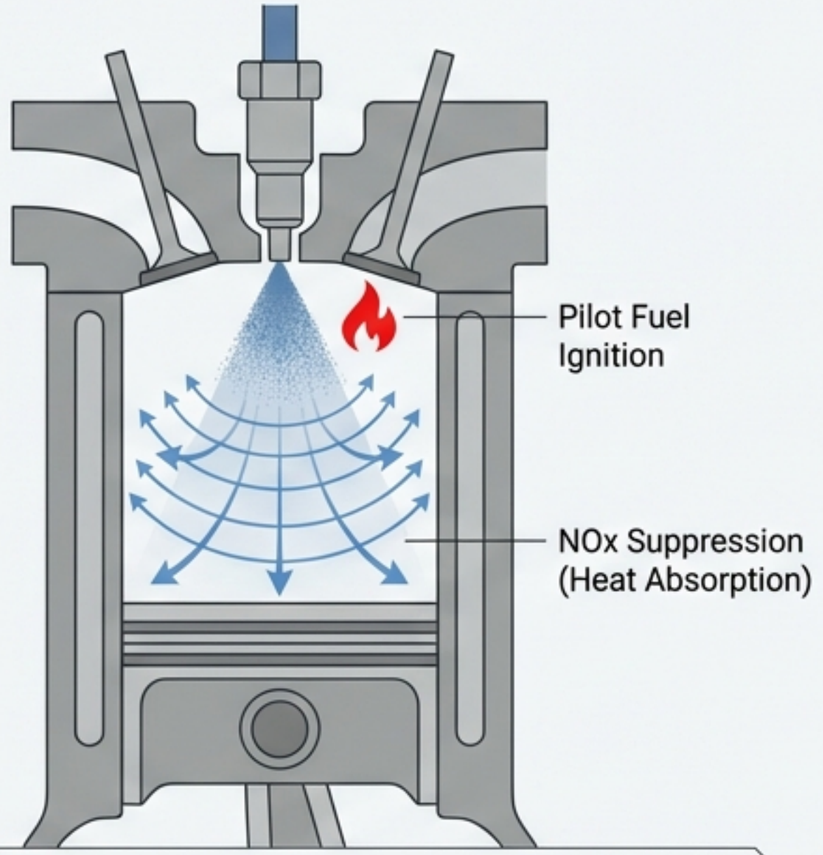


- Contains C-C bond.
- Oxidation: Requires energy to break the carbon chain.
- Result: Extremely clean, but potential for micro-soot under stress.

Implication: Methanol provides a 'limit advantage' in exhaust treatment, potentially eliminating the need for particulate filters required for zero-emission zones.

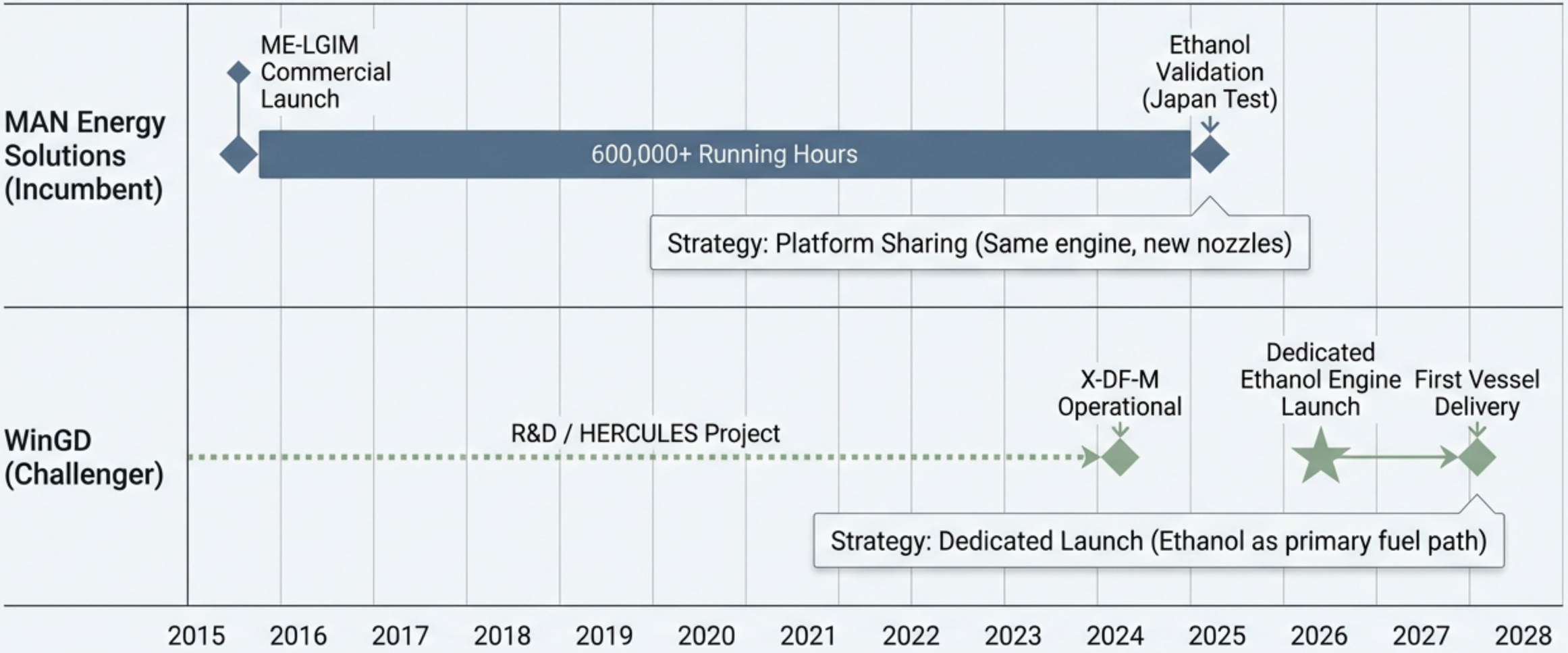
Combustion Dynamics: The Cooling Effect and Efficiency

Property	Methanol	Ethanol	HFO (Reference)
Latent Heat of Vaporization	**1109 kJ/kg** (High)	845 kJ/kg (Med)	~270 kJ/kg (Low)
Energy Density (LHV)	15.8 MJ/L	**21.1 MJ/L**	36.0 MJ/L
Oxygen Content	~50%	~35%	~0%
Ignition Method	Pilot Fuel (5%)	Pilot Fuel (5%)	Compression



Both alcohols absorb massive heat during vaporization, naturally suppressing thermal NOx formation. Methanol has the superior cooling capability.

The OEM Landscape: Maturity vs. Aggression



Material Compatibility: The Hidden Engineering Constraints

PROHIBITED FOR BOTH

Zinc, Aluminum, Brass, Lead.

METHANOL RISKS

Titanium:

⚠ **FATAL / RED LIGHT** ⚠

Risk of Stress Corrosion Cracking (SCC).

Rubbers:

- Nitrile / Buna-N (Red Light)
- Compatible: EPDM, Neoprene (Green Light)

ETHANOL RISKS

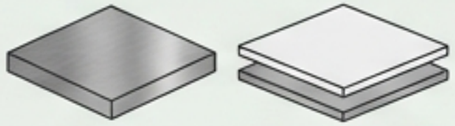
Titanium:

✔ **SAFE / GREEN LIGHT** ✔

Rubbers:

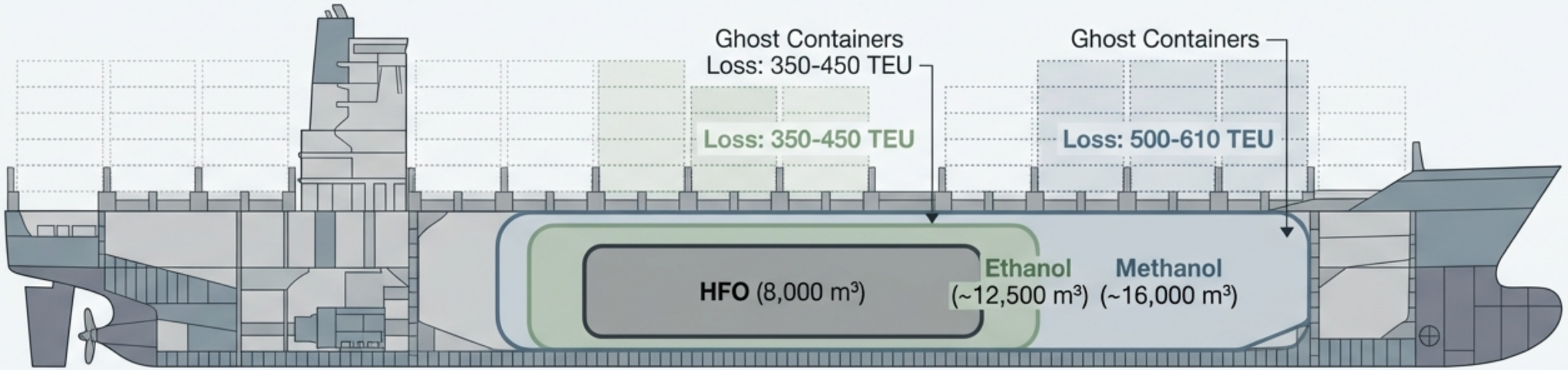
- PVC, Polyurethane (Red Light)
- Compatible: Buna-N, Viton (Green Light)

THE GOLD STANDARD



Stainless Steel & Teflon (PTFE).
Universal compatibility allows for multi-fuel flexibility.

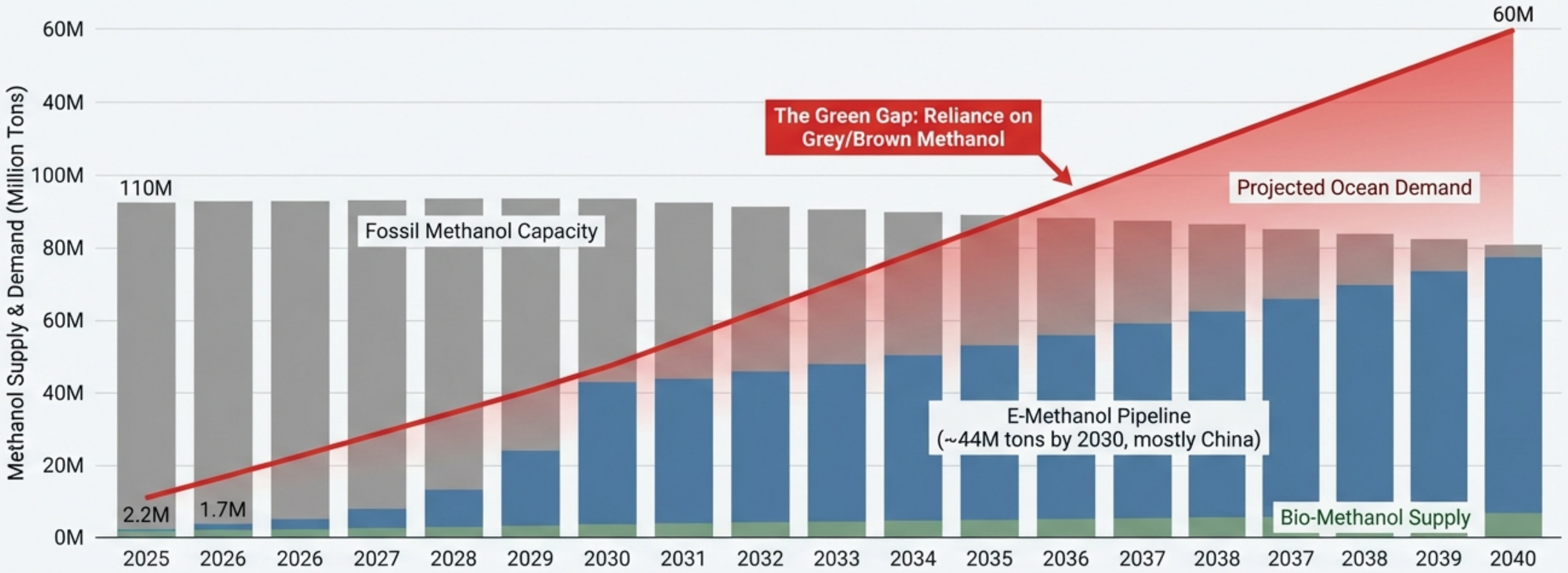
The Commercial Reality: Energy Density and Slot Loss



Key Metric

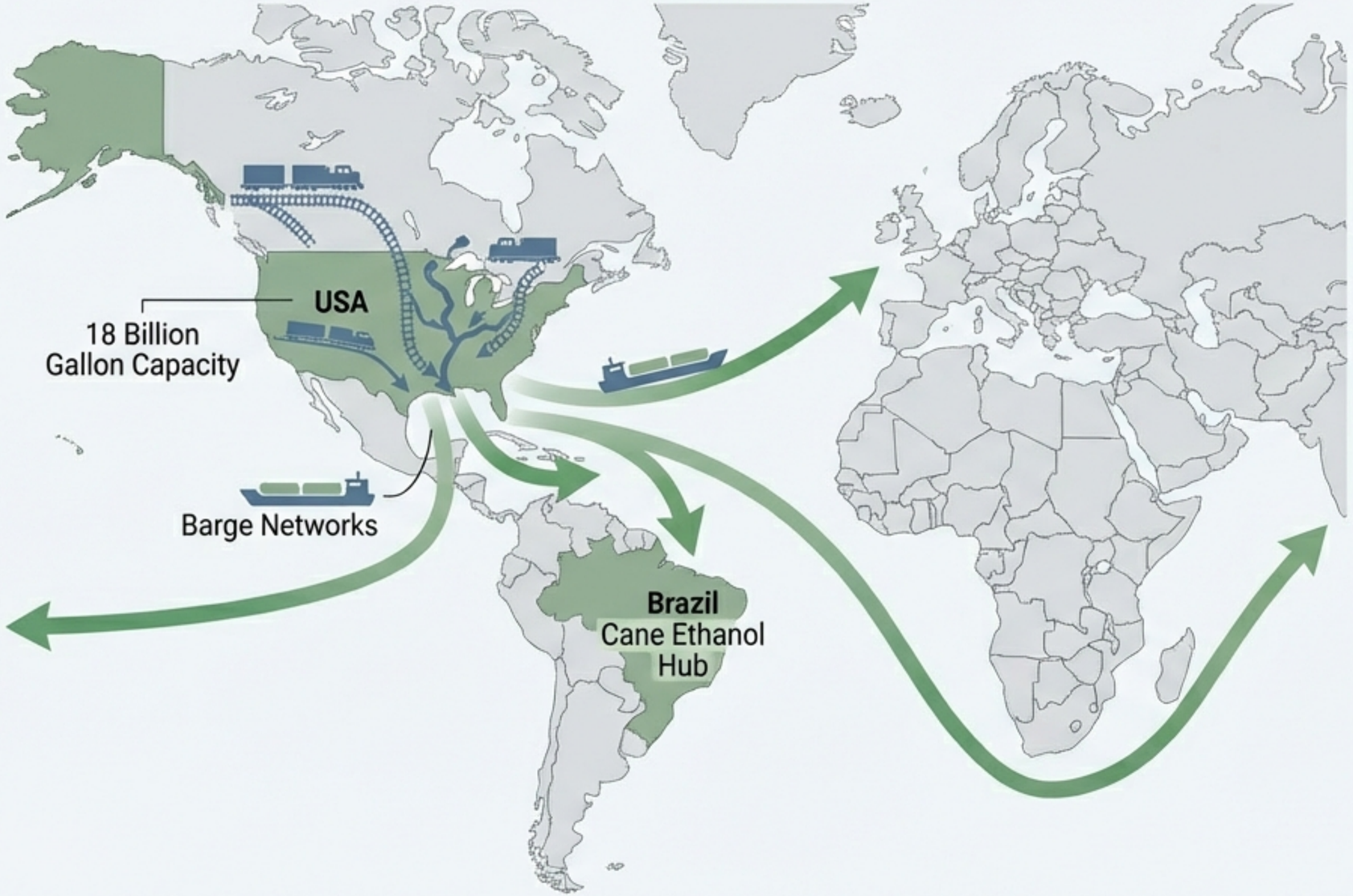
Energy Density Advantage: Ethanol (21.1 MJ/L) requires **~30%** less volume than Methanol (15.8 MJ/L).

Methanol Supply: The Green Gap Challenge



Cost Hurdle: E-methanol (RFNBO) projected at $250–$630/t by 2050. Requires massive Direct Air Capture (DAC) infrastructure.

Ethanol Supply: The Infrastructure Advantage



The Logistics Edge:

- "Drop-in" capable via existing chemical terminals.
- No cryogenic infrastructure needed.
- Faster bunkering speeds.

The Regulatory Hurdle:

- ILUC (Indirect Land Use Change).
- Requires robust 'Proof of Sustainability' (PoS) to certify as Green Fuel under IMO/EU rules.

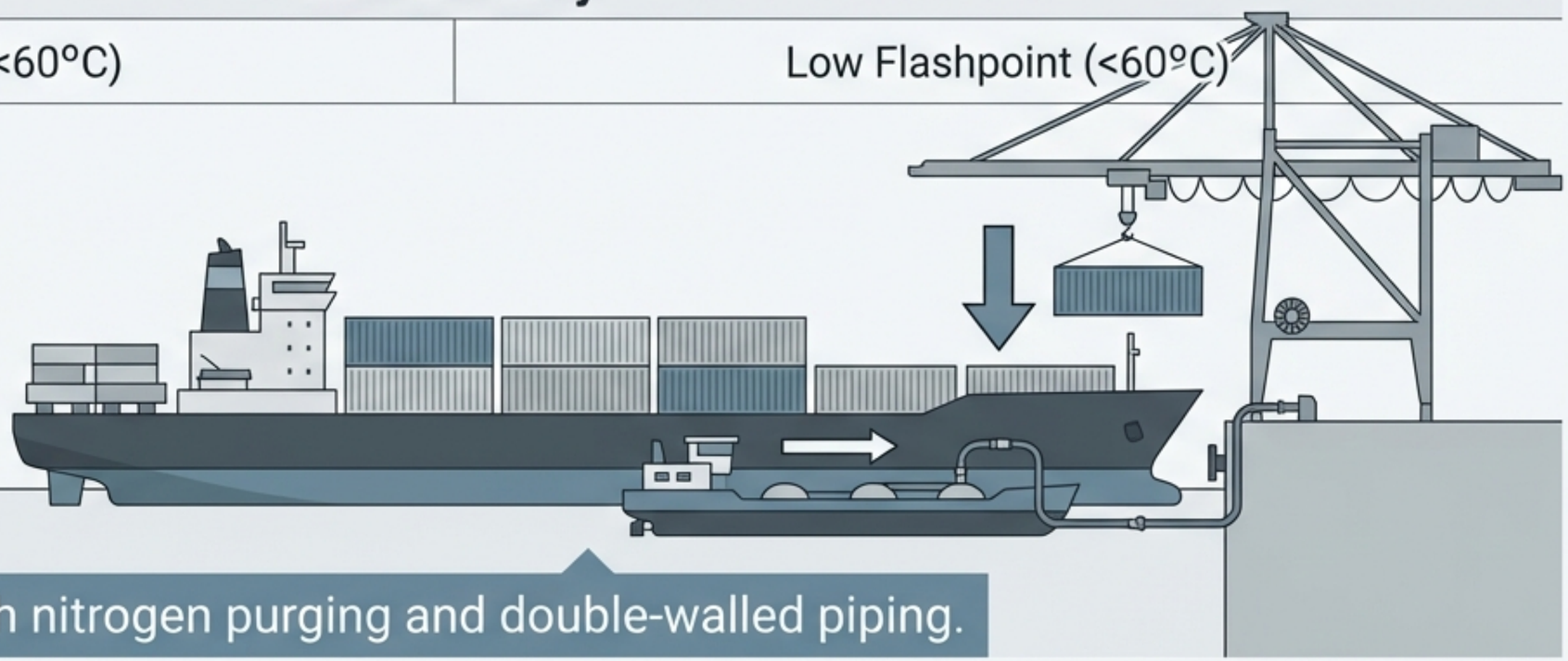
Operational Safety & Bunkering Protocols

Handling Comparison

Toxicity	
Methanol. High Toxicity. Fatal if ingested/contact.	**Ethanol.** Lower Risk. Lower Risk. Denatured product.
Flammability	
Low Flashpoint (<60°C)	Low Flashpoint (<60°C)

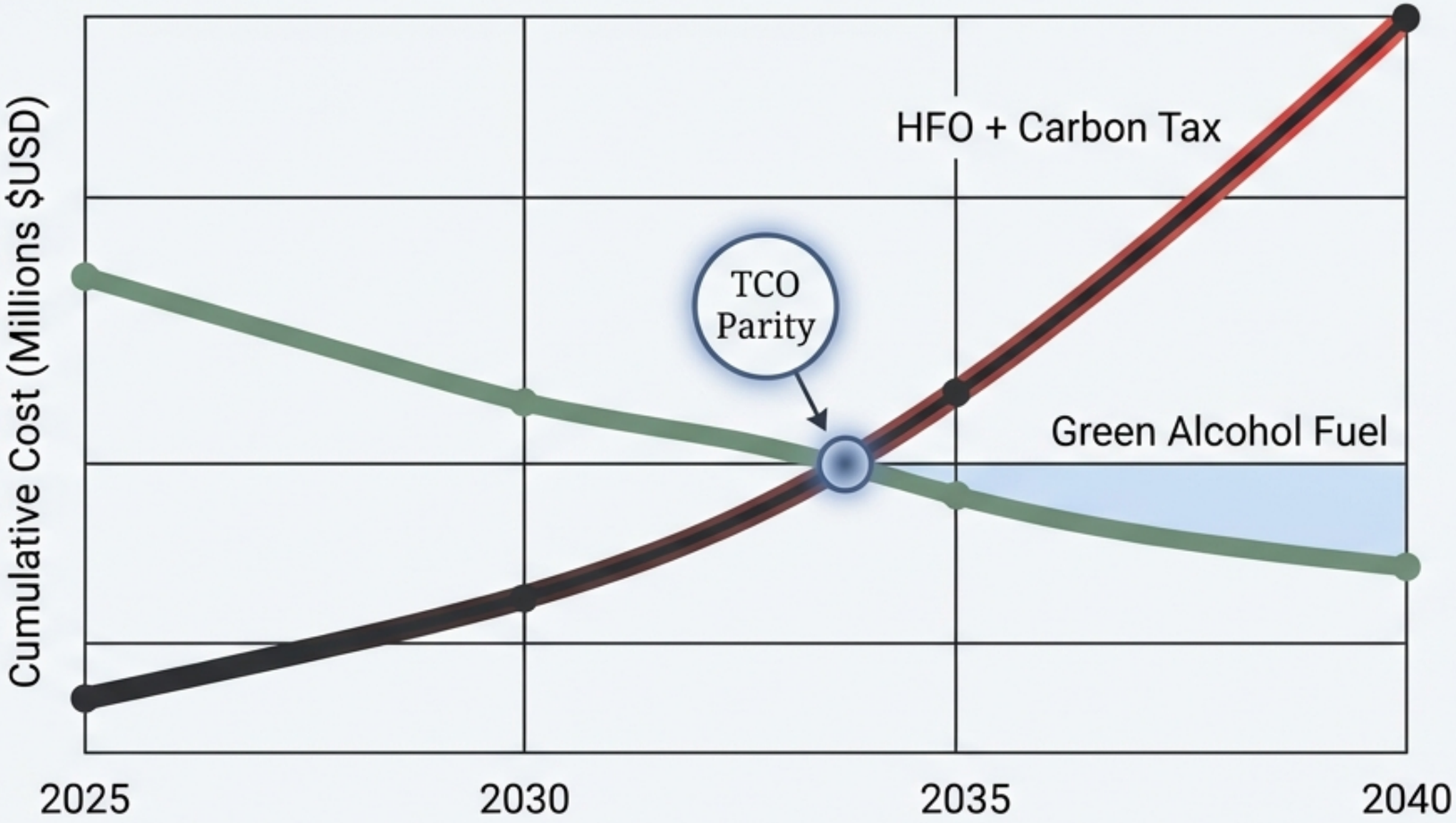
SIMOPS Diagram

SIMOPS
(Simultaneous Operations)



Maersk Proven: Feasible with nitrogen purging and double-walled piping.

The Financial Equation: CAPEX vs. OPEX



KEY METRICS: CAPEX

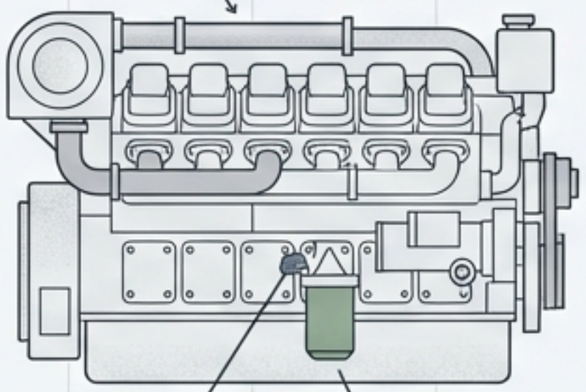
- Newbuild Premium: +10-15%
- Retrofit Time: ~2 Weeks (Drydock)

KEY METRICS: OPEX

- Fuel Multiplier: Green Methanol currently 2.5x - 4x cost of fossil fuel.

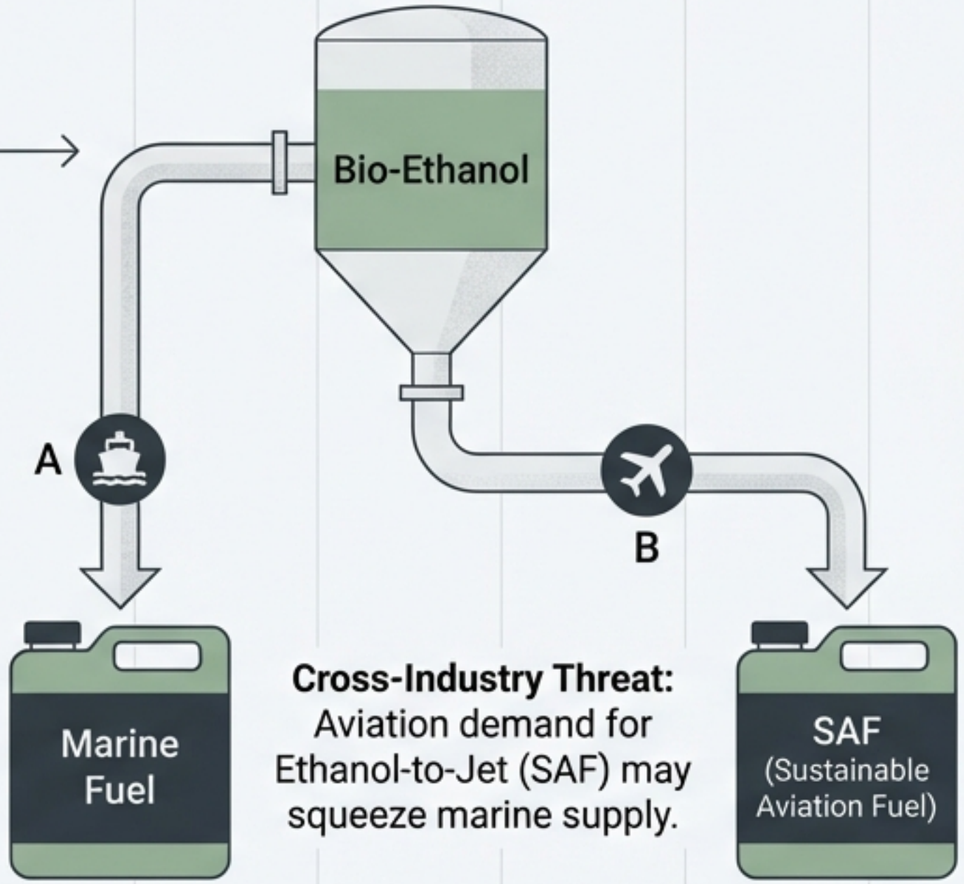
Future Outlook: Convergence and Competition

Trend 1: The “Omni-Alcohol” Engine



Fuel Agnostic
(Methanol **OR** Ethanol)

Trend 2: The Green Molecule War



Cross-Industry Threat:
Aviation demand for Ethanol-to-Jet (SAF) may squeeze marine supply.

Strategic Recommendations

For Shipowners

Materials First Strategy

Specialize vessels for "Alcohol Readiness." Specify Ethanol-compatible seals and Methanol-compatible metals (No Titanium) to ensure 100% asset flexibility.

For Regulators

Codify the Standards

Fast-track Ethanol inclusion in the *IGF Code*. Move from interim guidelines to fully codified standards to unlock insurance and financing.

For Investors

Back the Aggregators

Focus on suppliers capable of sourcing both molecules and utilizing "Book-and-Claim" digital systems to balance green credits across regions.

References & Source Data

MAN Energy Solutions (ME-LGIM Performance Data, 2025)

WinGD (X-DF-M & Ethanol Roadmap, 2024/2026)

DNV & Lloyd's Register (Fuel Readiness Reports)

Maersk (Operational Feedback on SIMOPS)

IRENA (Renewable Methanol Cost Projections)

European Union (FuelEU Maritime Regulation Texts)

U.S. Grains Council (Ethanol Marine Fuel Studies)

Journal of Marine Science (Combustion & Emissions Analysis)