TRA275 - Fuel Cell Systems 2024

Linear Optimization Model for Future Cost-effectiveness of Fuel Cells and Hydrogen in Maritime Transport

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INTRODUCTION & MOTIVATION

Maritime transport is one of the hard-to-abate sectors, mainly due to its energy density requirements. Focusing on **reducing greenhouse gas emissions**, this project employs linear modeling to assess scenarios and costs. The study delves into **global maritime transport,** and specific sectors like **short sea**, **container** and **ocean** transport, all of which are currently heavily dependent on fossil fuels. Application of alternative propulsion systems and fuels improves the **sustainability** aspects of maritime transport, providing advantages such as reduced emissions and increased energy efficiency. The emphasis is specifically on **fuel cells** and **hydrogen**, tailored for use in the shipping sector.

GET MODEL & GAMS

The model employed for linear cost optimization is the **Global Energy Transition** (GET) model developed in the program GAMS. Spanning the years **2030-2100**, the model operates in 10-year increments. The world is delineated into **10 regions** based on the IIASA´s global regional division with compiled energy costs yielding comprehensive global results. The model assumes stable technology costs throughout the entire period and posits the availability of all technologies in all regions. The GET model operates as a **cost-minimizing energy system model**. It determines an **optimal fuel and technology mix** to meet global energy demand within specified constraints at the lowest system cost.

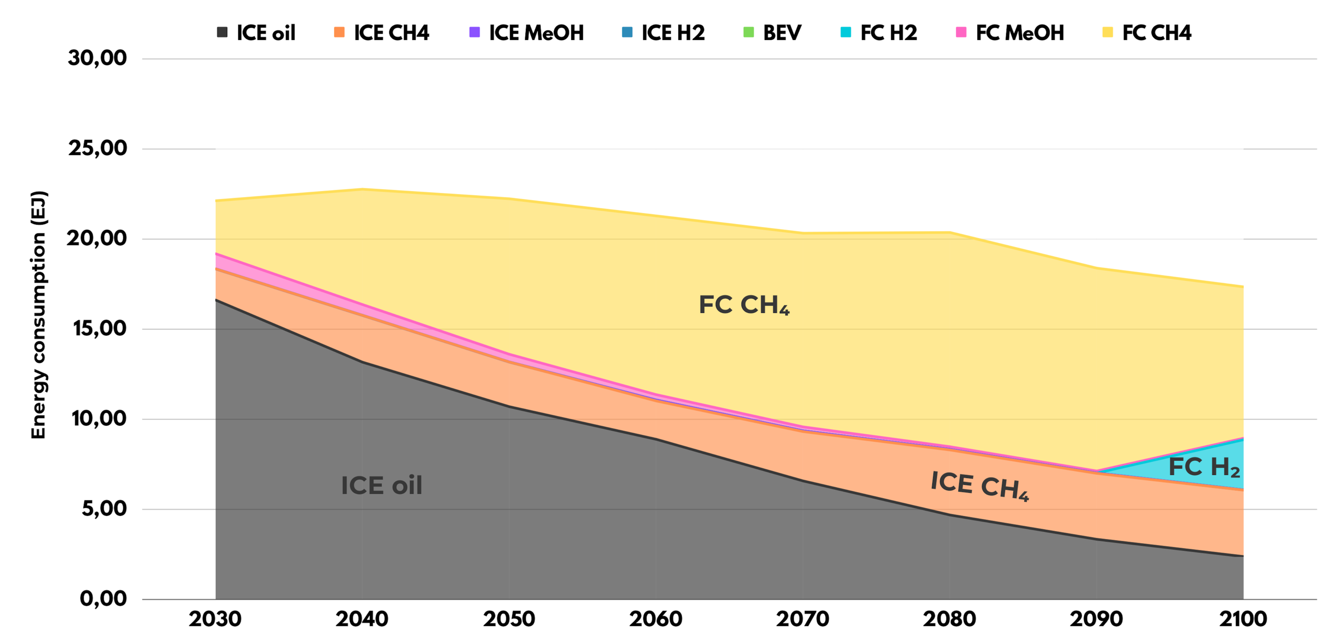
CLIMATE TARGETS FAILURE

In these scenarios, the model does not incorporate any restrictions for CO_2 emissions and concentration levels. This is a representation of the global energy system if **society fails to meet the climate targets**, while fulfilling the energy demand in all sectors.

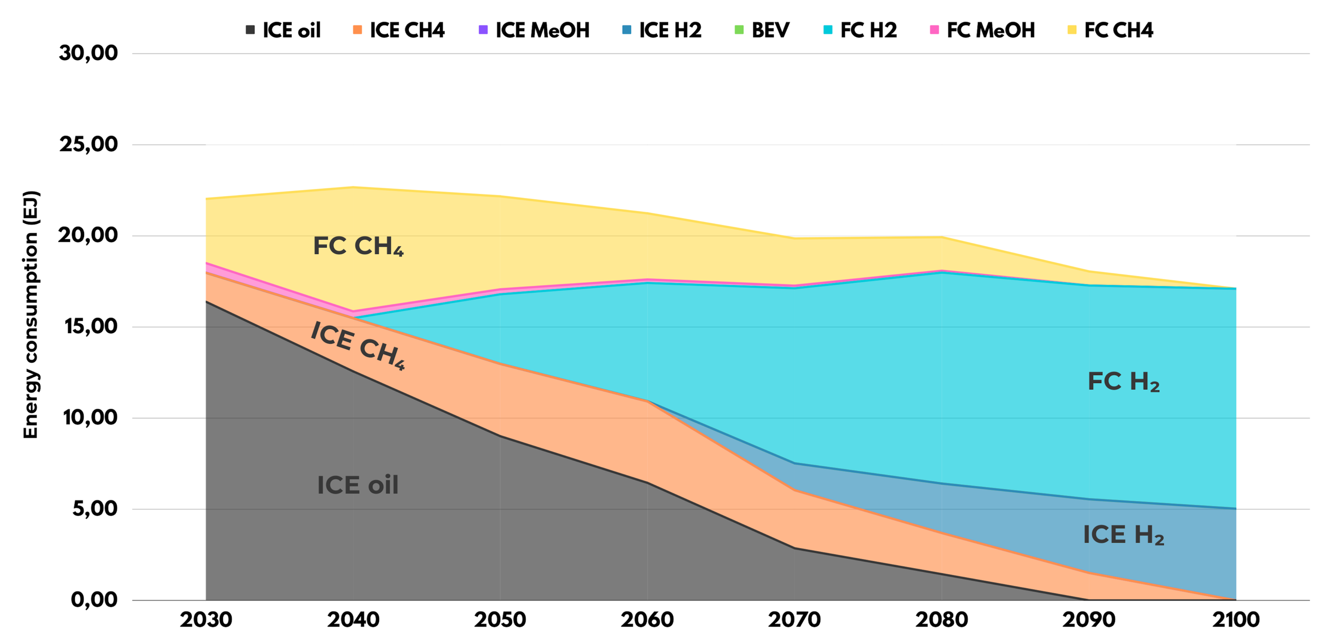
CLIMATE TARGETS ACHIEVEMENT

In these scenarios, the model incorporates a temporal reduction of CO_2 emissions to align with progressively stringent concentration targets. According to IPCC AR5, limitations on **CO_2** are **905 billion tons** for cumulative emissions (RCP 2.6 trajectory) and **450 ppm** for concentration in the atmosphere,

Baseline Scenario (Climate Targets Failure)



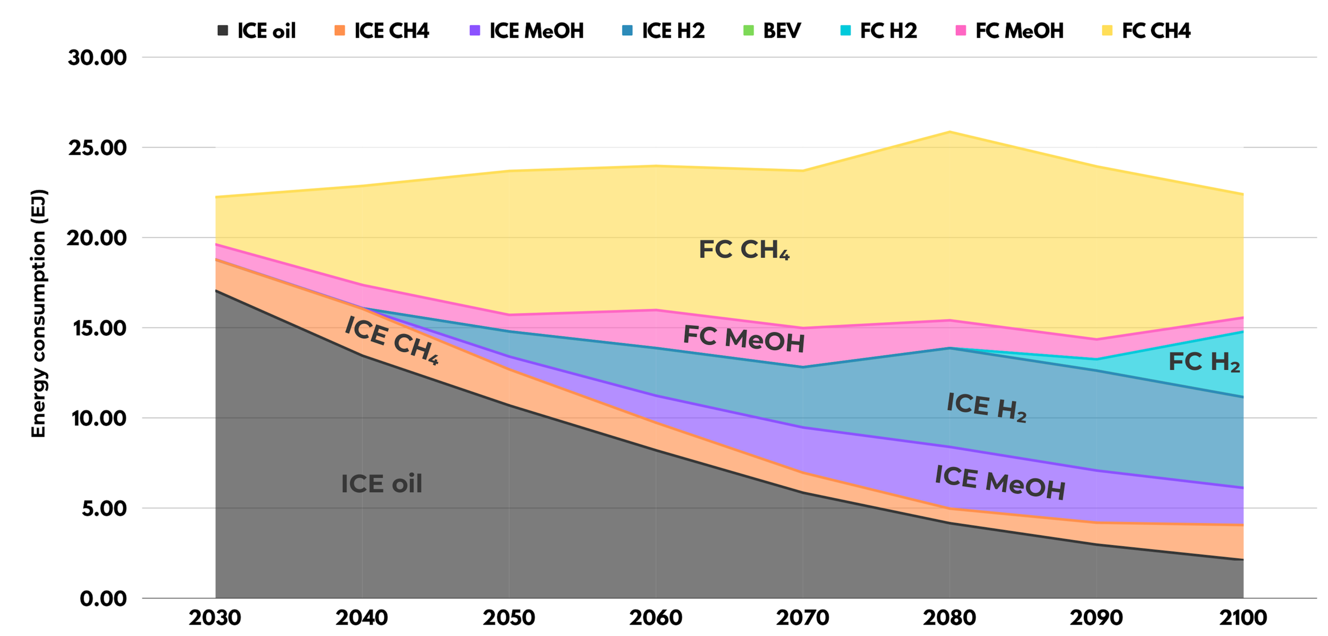
Baseline Scenario (Climate Targets Achievement)



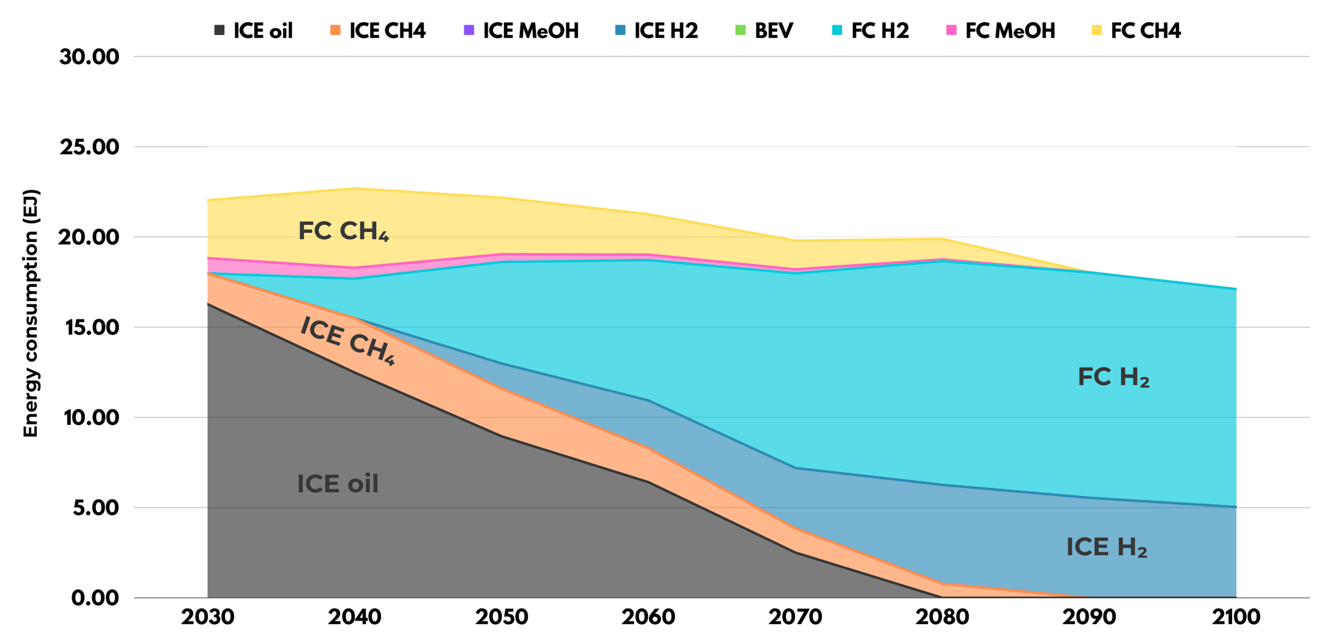
Electrolyser
maturity cost: 500 $/kW
efficiency: 80%
Fuel Cell Stack
cost: 890 $/kW
efficiency: 60%
Hydrogen Storage
cost for S, C: 225 $/GJ
cost for O: 300 $/GJ
Hydrogen ICE
cost for S, C: 600 $/kW
cost for O: 800 $/kW

S: short-sea, C: container, O: ocean

Market Penetration Scenario (Climate Targets Failure)

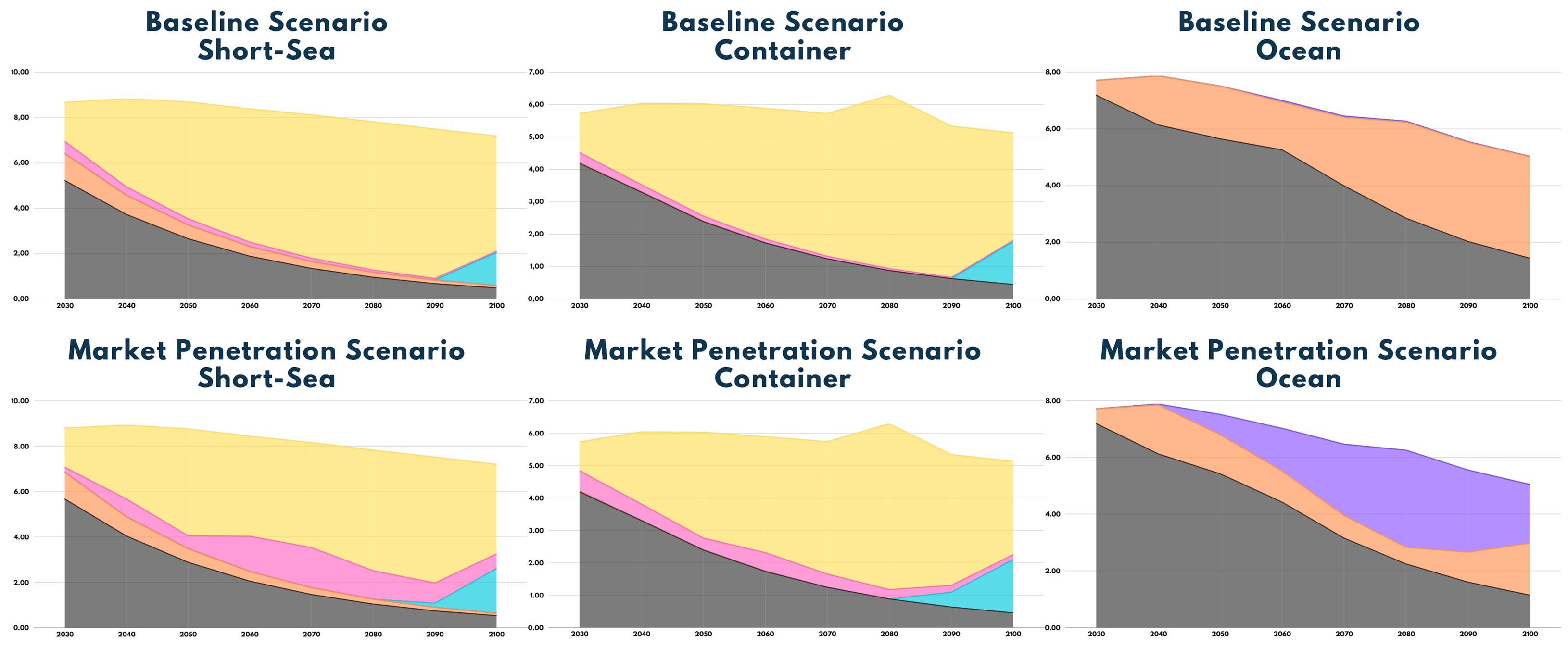


Market Penetration Scenario (Climate Targets Achievement)

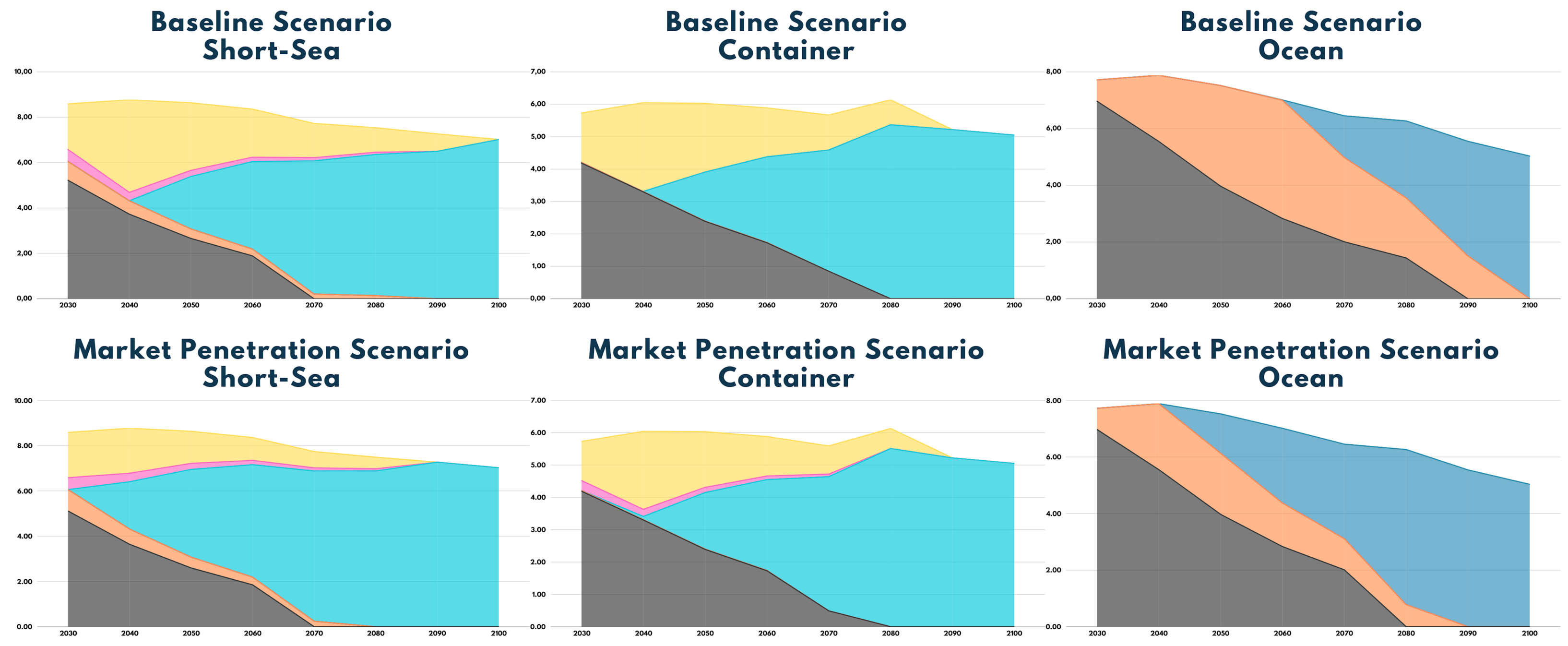


Electrolyser
maturity cost: 103 $/kW [1]
efficiency: 80%
Fuel Cell Stack
cost: 868 $/kW [2]
efficiency: 65% [3]
Hydrogen Storage
cost for S, C: 107 $/GJ [2]
cost for O: 145 $/GJ [2]
Hydrogen ICE
cost for S, C: 480 $/kW [2]
cost for O: 740 $/kW [2]

Pessimistic scenarios for single maritime sector



Optimistic scenarios for single maritime sector



RESULTS & DISCUSSION

The **fuel cell technology is set to grow** at similar rate in all 4 scenarios (12-13 EJ in 2100), with big differences in the fuel choice. In the **"Failure" Baseline Scenario,** CH_4 is dominating (50% market share in 2070), while in the **Market Penetration** one there is a growth of MeOH (up to 9% in 2070) and H_2 coming into the market only in 2080. Both fuels are being used more for ICE (13% and 21% in 2080). The **implementation of CO_2 limitations** results in the earliest phase-out of oil-based fuels in the **"Achievement" Market Penetration Scenario**, already in 2080. The most prominent fuel in this case is H_2 (90% in 2080), with the implementation of fuel cells already from 2030 and a good share of usage also for ICE, mainly in the ocean sector.

KEY FINDINGS

- Faster oil phase out in Market Penetration (10 years with CO_2 limitations)
- H_2 leading fuel with CO_2 limitations, CH_4 and MeOH otherwise
- FC implemented in short-sea and containers, ICE in ocean

RECCOMENDATIONS

- Stricter policies for CO_2 emission targets
- Reduced costs for H_2 technology
- Larger R&D investments (e.g. electrolysis)

Chemical Formulas

H_2	Hydrogen
CO_2	Carbon Dioxide
CH_4	Methane (including e-methane)
MeOH	Methanol (including e-methanol)

Acronyms

FC	Fuel Cell
ICE	Internal Combustion Engine
BEV	Battery Electric Vehicle

[1] Krishnan S., Koning V., et al. (2023), Present and future cost of alkaline and PEM electrolyser stacks. International Journal of Hydrogen Energy, 48, 83, 32313-32330.
[2] European Maritime Safety Agency (2023), Potential of Hydrogen as Fuel for Shipping. EMSA, Lisbon.
[3] Department of Energy (2019), Hydrogen Class 8 Long Haul Truck Targets. DOE Hydrogen and Fuel Cell Technologies Program Record.