



Prospects for renewable marine fuels

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CHALMERS



Shift

Sustainable Horizons in Future Transport

www.nordicenergy.org/flagship/project-shift/

Shift will inform smarter Nordic transport and energy policy

- By developing and applying tools that integrate modal shifts, fuel options, business models and consumer behaviour into scenario modelling and in-depth analysis



Nordic Energy Research
Nordic Council of Ministers

Possible marine fuels options



Diesel-quality fuels

Heavy fuel oil (HFO)
Low sulphur HFO (<1 wt. % S)
Low sulphur distillate fuels (<0.1 wt. % S)
Vegetable oils
Hydrotreated vegetable oil (HVO)
Pyrolysis oil
Biodiesel
Biomass-to-liquid (BTL)/synthetic biodiesel
Gas-to-liquid (GTL)/synthetic diesel (Fischer-Tropsch)

Gases

Liquefied natural gas (LNG)
Liquefied biogas (LBG)
Dimethyl ether (DME)
Liquefied petroleum gas (LPG)
Hydrogen/hydrogen with carbon capture and storage (CCS)

Alcohols

Methanol
Ethanol
Butanol
OBATE-fuel

Solid fuels

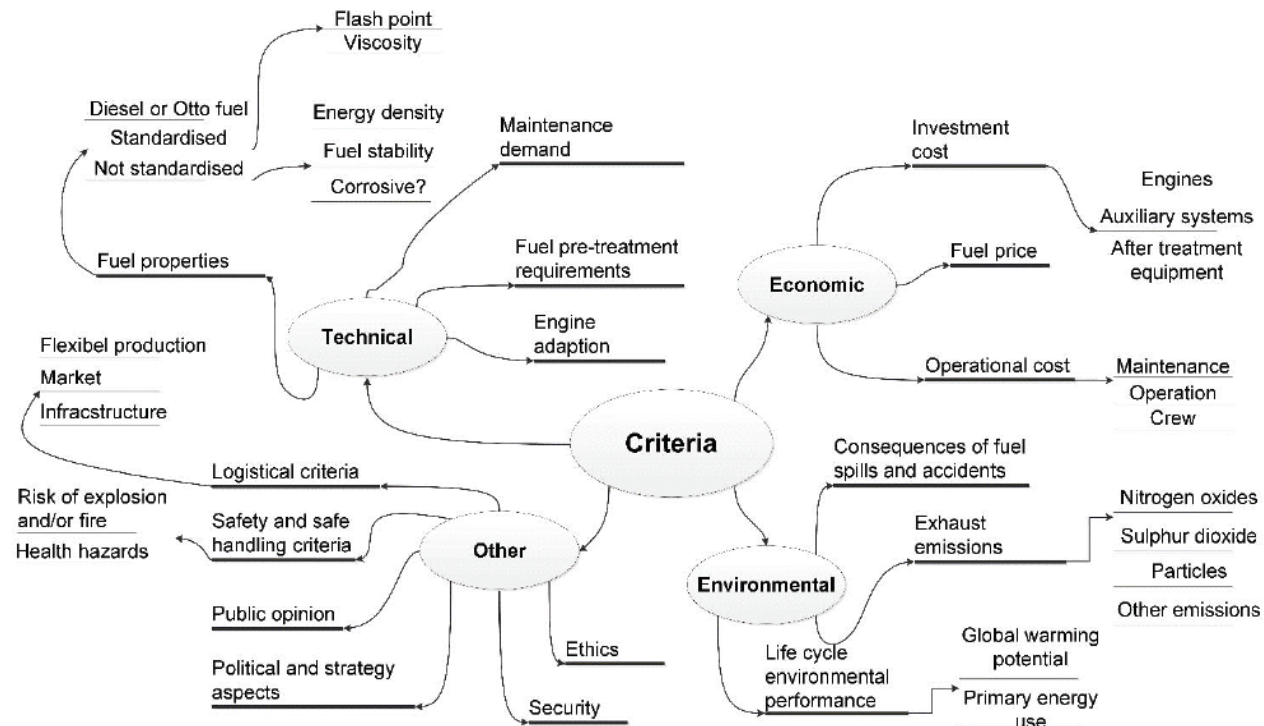
Uranium
Coal
Wood

Electricity

(Brynnolf, 2014)

Background

- Choice of fuel warrants an analysis of a range of different factors as price, availability, technology maturity level, safety, environmental impact, policies etc.



Initial results from a Multi-criteria Decision Analysis of Alternative Fuels for the Maritime Sector





Overall aim

- To assess the prospect of renewable fuels in the shipping sector by conducting a multi-criteria decision analysis of selected alternative fuels with a panel of shipping sector related stakeholders.
- The multi-criteria decision analysis model Analytic Hierarchy Process is used.
- Time perspective 2030



Objectives

- What are the relative economic, technical, environmental and social impacts of the selected alternative marine fuels?
- What are the relative importance of different criteria in the selection of alternative marine fuels according to stakeholders?
- What alternative marine fuel is most preferable considering the stakeholders' preferences?



Included marine fuels

- Liquefied natural gas (LNG)
- Methanol produced from natural gas (NG-MeOH)
- Methanol produced from biomass (Bio-MeOH)
- Hydrogen produced from electrolysis by wind power (Elec-H₂) with fuel cells

10 criteria (Economic, technical, environmental and social)

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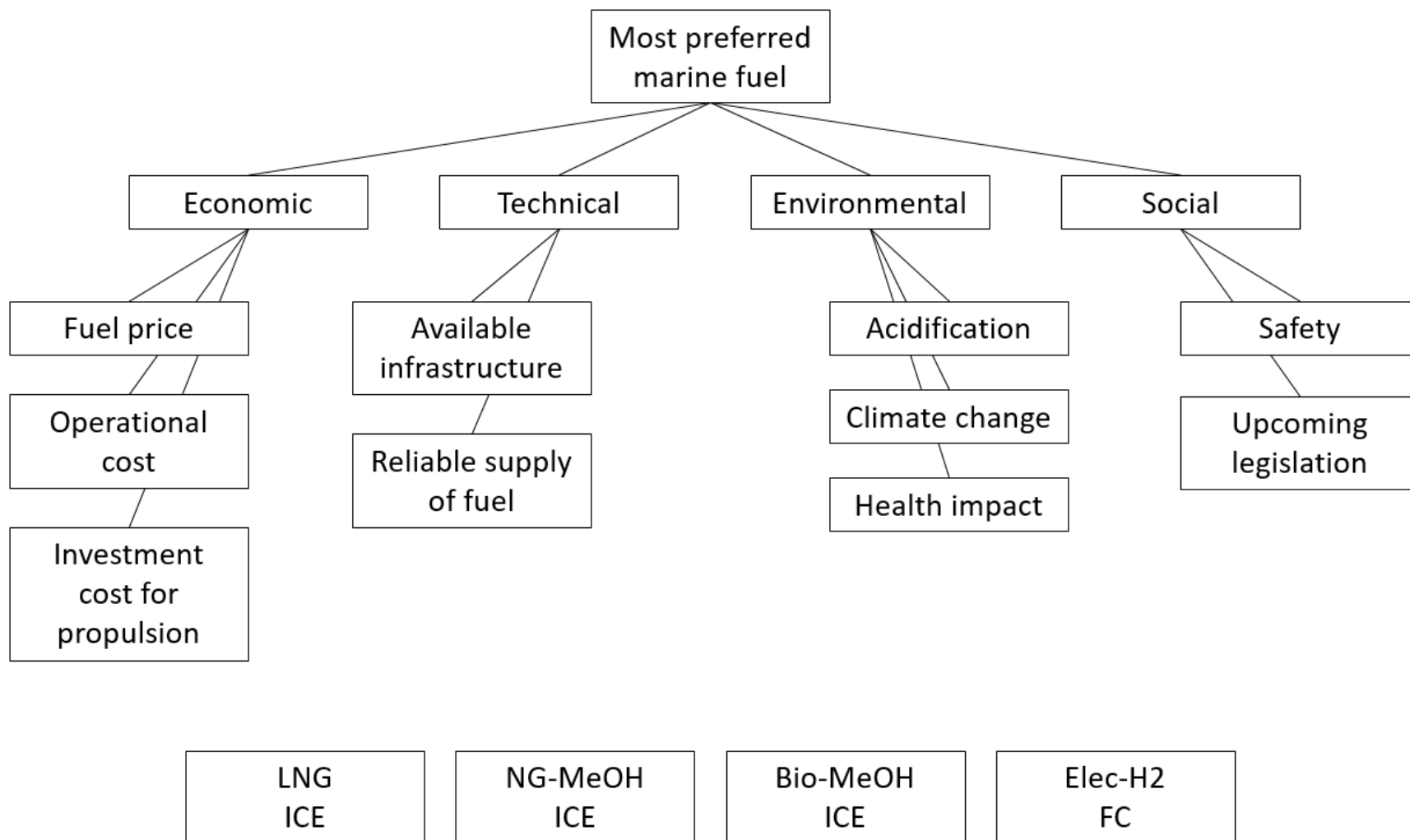
Multi-Criteria Decision Analysis

- MCDA is a tool for managing complex decision problems
- Score alternatives and weight the criteria
- The alternative marine fuels are ranked based on how they perform with respect to the selected criteria and the relative importance of the criteria
- Possible to consider differing views





Hierarchy tree





Multi-Criteria Decision Analysis

- Pairwise comparisons
- Alternatives are scored based on how they perform with regard to a specific sub-criteria
- Criteria are given weights based on how important they are
- Results in ranking
- Intensities from 1-9 are used



Scoring of Alternative Marine Fuels

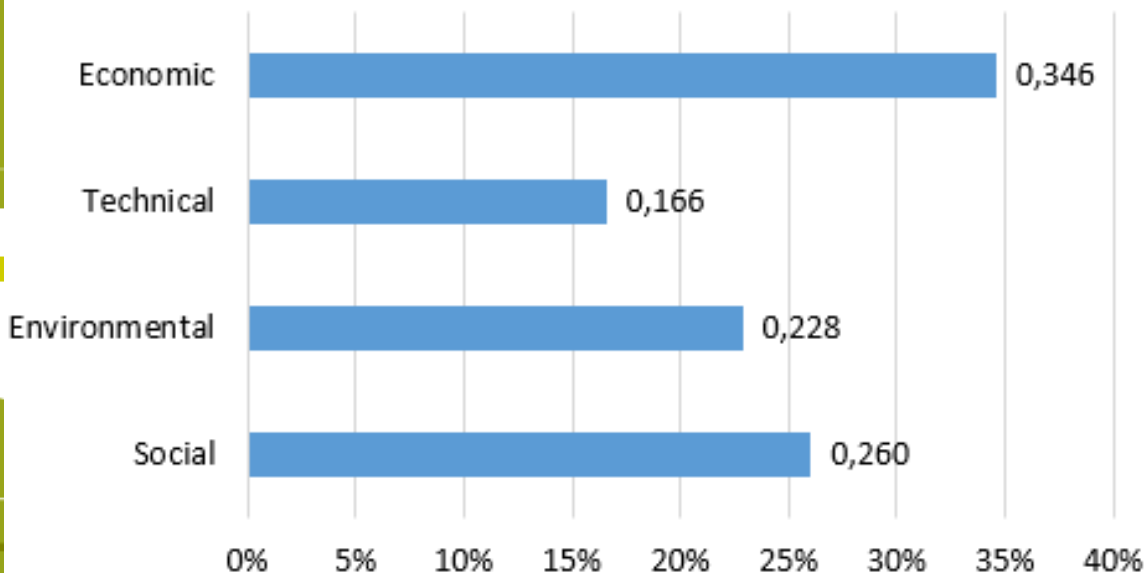
- LNG best in: Fuel price, Available infrastructure
- NG-MeOH best in: Investment cost, Operational cost, Safety
- Bio-MeOH best in: Investment cost, Operational cost, Safety
- Elec-H2 best in: Reliable supply of fuel, Acidification, Climate change, Health impact, Upcoming legislation





Relative Importance of Criteria for Joint Stakeholder Scoring

Criteria weights



Most important sub-criteria (for each group of criteria) are:

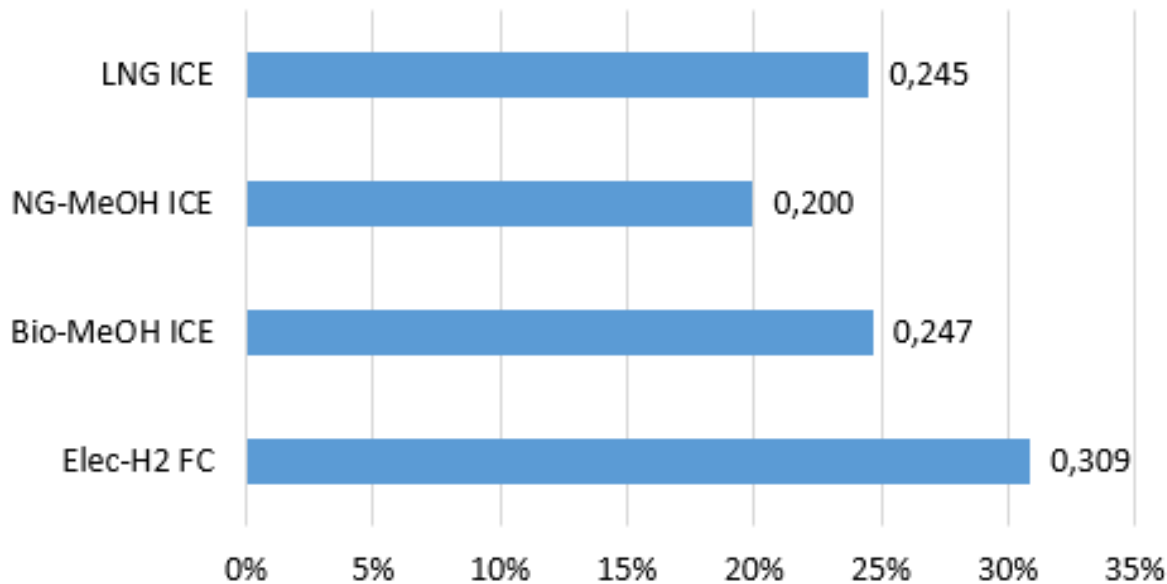
- Fuel price
- Reliable supply of fuel
- Climate change
- Upcoming legislation





Ranking Order of Alternative Marine Fuels for Joint Stakeholder Scoring

Ranking of alternative marine fuels



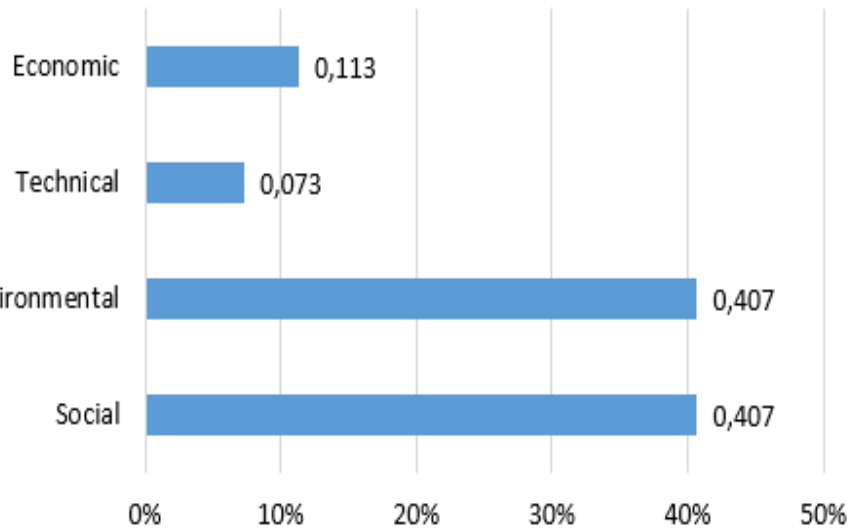
The ranking order of LNG and Bio-MeOH is sensitive to changes in criteria weights and perspectives used in scoring

Most “preferred” fuel: Hydrogen followed by bio-methanol and LNG (equally preferred)

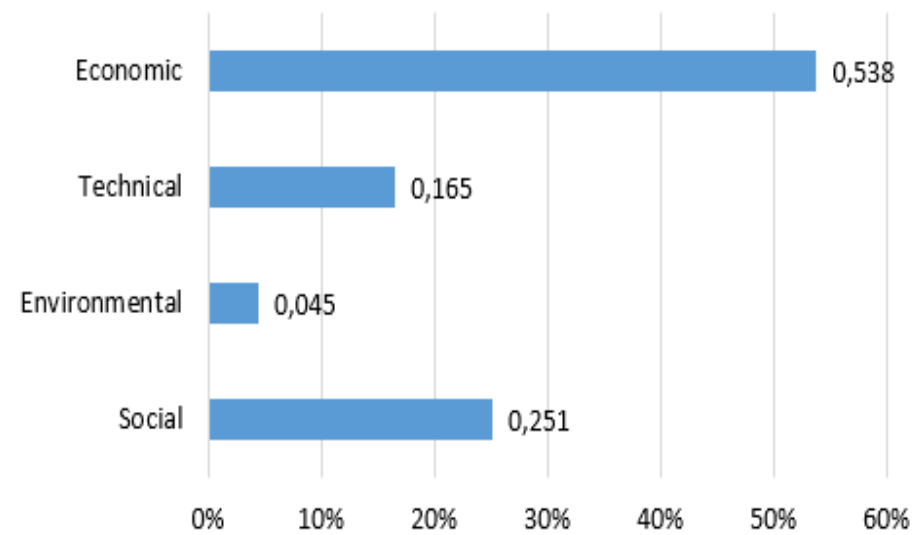


Fictional Authority and Ship-owner Weights

Authority role-play criteria weights



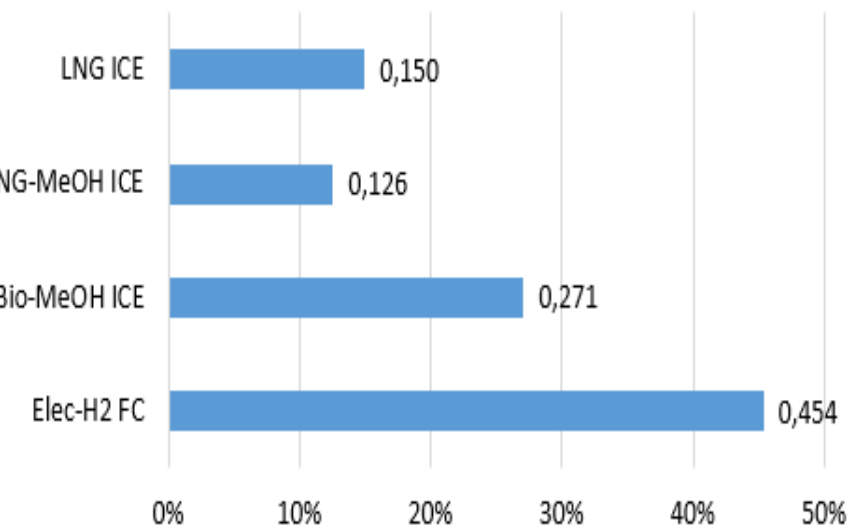
Shipowner role-play criteria weights





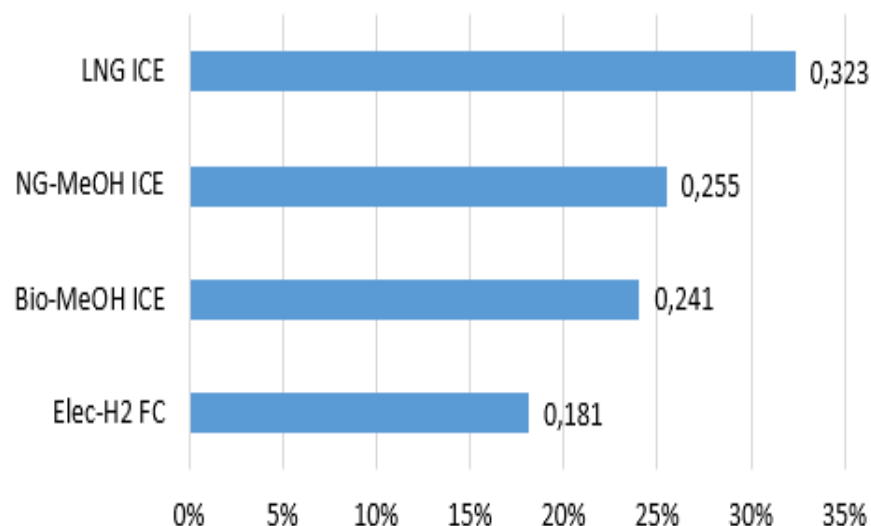
Fictional Authority and Ship-owner Ranking Orders

Authority role-play ranking of alternative marine fuels



Most “preferred” fuel:
Hydrogen followed by
bio-methanol

Shipowner role-play ranking of alternative marine fuels

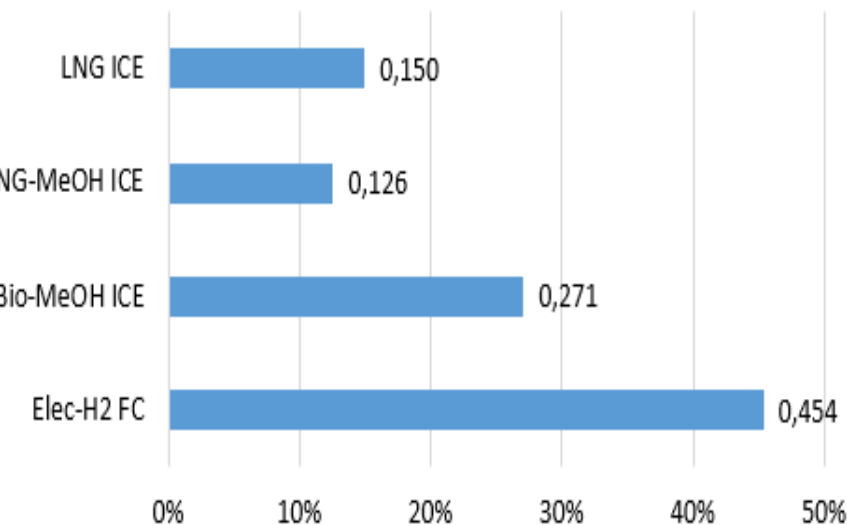


Most “preferred” fuel:
LNG followed by NG-
methanol

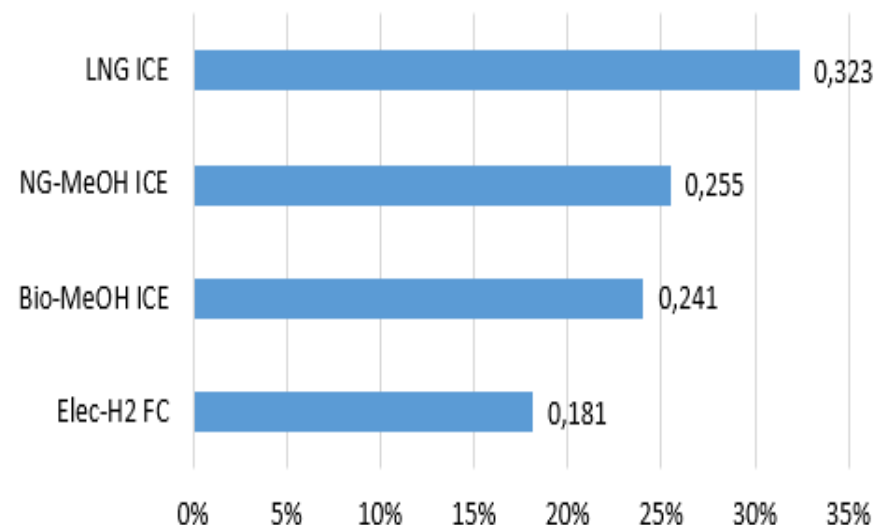


Fictional Authority and Ship-owner Ranking Orders

Authority role-play ranking of alternative marine fuels



Shipowner role-play ranking of alternative marine fuels



Result for fuel and engine manufacturer:
H2 or H2/LNG, LNG, bioMeOH, fossil MeOH



Stakeholders

- Stena Line
- Wallenius Marine
- Wärtsilä
- Preem
- Swedish Maritime Administration
- Swedish Transport Administration
- Energigas
- SSPA
- Environmental analysis Vehicles and Fuels
- Gothenburg University
- Chalmers University of Technology
- IVL Swedish Environmental Research Institute

Discussion

The results depend on:

- The alternative marine fuels included (aim to include more biomass based options)
- Selected criteria
- Perspectives used in scoring (will be improved)
- Mix of stakeholders
- More sensitivity analyses

Result may change





Contact

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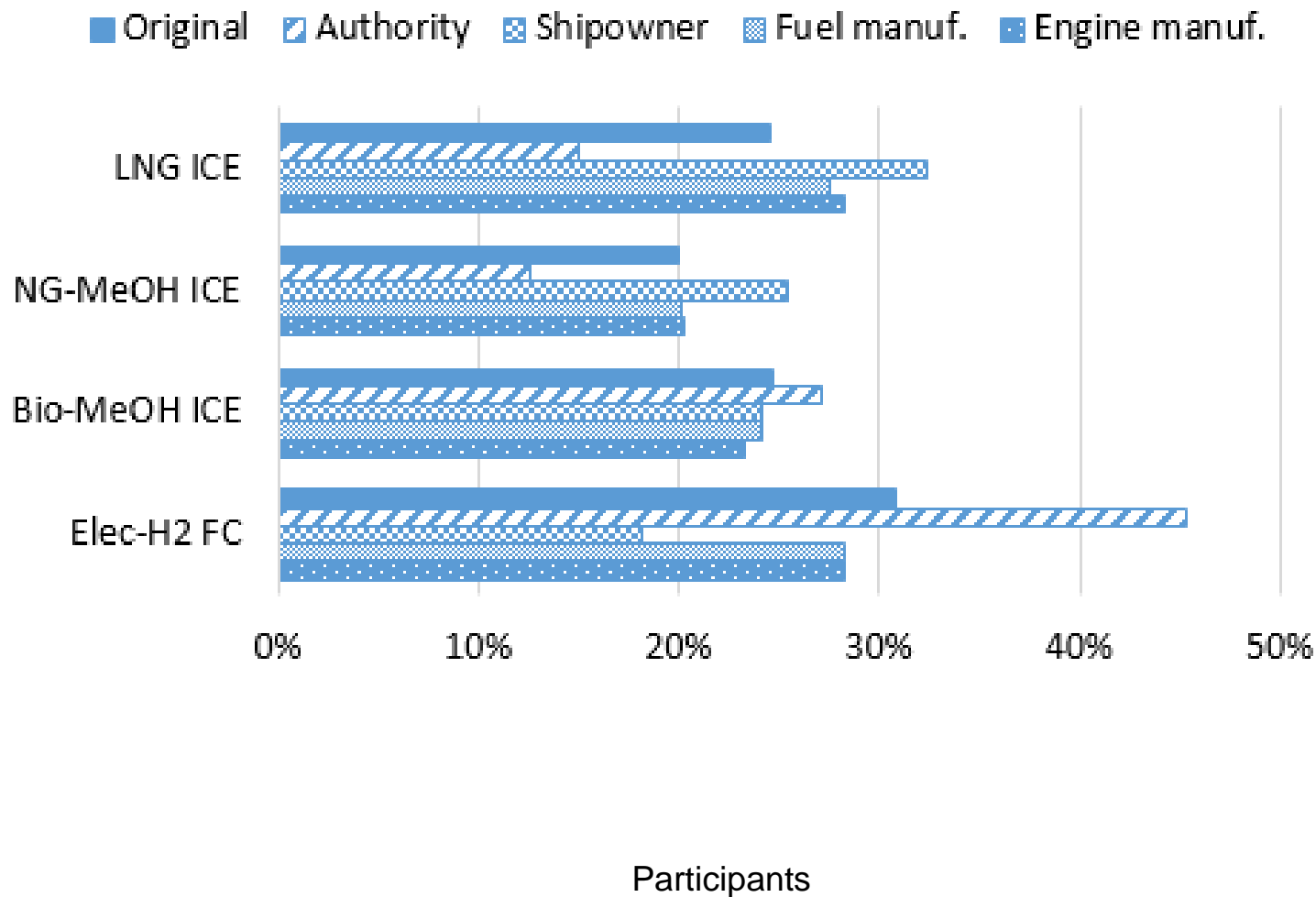
Thank you!



Extra material

Participants

Comparison of ranking order





Intensities for scoring and weighting

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience or judgement slightly favour one element over another
5	Strong importance	Experience or judgement strongly favour one element over another
7	Very strong importance	One element is favoured very strongly over another
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation
2, 4, 6, and 8 can be used when the difference is less pronounced than the above explanations		

Saaty's table: The fundamental Scale for Pairwise Comparisons (Saaty, 2008)



A complete and correct pairwise comparison matrix

	(Economic)	(Technical)	(Environmental)	(Social)
Economic	○ 1	○ 5	3	4
Technical	1/5	1	1/3	1/2
Environmental	○ 1/3	3	1	2
Social	1/4	2	1/2	1

Note: The method includes a consistency check to make sure the scores are consistent. Being consistent means that if **Economic** is strongly favoured over (Technical), and slightly favoured over (Environmental), it follows that **Environmental** must be slightly favoured over (Technical).



Economic impacts

Table 4.1: Impact matrix for included economic criteria

<i>Alternatives</i>	<i>Investment cost</i> <i>[kEuro[*]/Ship]</i>	<i>Operational cost</i> <i>[Euro[*]/MWh]</i>	<i>Fuel price</i> <i>[Euro[*]/GJ]</i>
LNG ICE	124 800 ^a	3.90-4.40 ^b	8 ^d
NG-MeOH ICE	117 500 ^a	3.25-3.50 ^b	17 ^e
Bio-MeOH ICE	117 500 ^a	3.25-3.50 ^b	28 ^f
Elec-H ₂ FC	206 200 ^a	<i>Slightly higher^c</i>	52 ^g



Technical impacts

Table 4.2: Impact matrix for included technical criteria

<i>Alternatives</i>	<i>Available infrastructure</i>	<i>Reliable supply of fuel</i>
LNG ICE	+ ^a	--- ^b
NG-MeOH ICE	- ^c	--- ^d
Bio-MeOH ICE	--- ^e	- ^f
Elec-H ₂ FC	--- ^g	+ + ^h



Environmental impacts

Table 4.3: Impact matrix for included environmental criteria

<i>Alternatives</i>	<i>Acidification potential</i> <i>[mole H⁺ eq/t km]</i>	<i>GWP₁₀₀</i> <i>[g CO₂eq/t km]</i>	<i>DALY</i> <i>[yr/t km]</i>
LNG ICE	0.05 ^a	0.9 ^a	4.2×10 ^{-9b}
NG-MeOH ICE	0.10 ^a	1.1 ^a	10.4×10 ^{-9b}
Bio-MeOH ICE	0.15 ^a	0.2 ^a	13.3×10 ^{-9b}
Elec-H ₂ FC	0 ^c	0 ^c	0 ^c



Social impacts

Table 4.4: Impact matrix for included social criteria

<i>Alternatives</i>	<i>Safety</i>	<i>Upcoming legislation</i>
LNG ICE	+ ^{a,b}	- ^f
NG-MeOH ICE	+ + ^{a,c}	- - ^f
Bio-MeOH ICE	+ + ^{a,c}	+ + ^f
Elec-H ₂ FC	- ^{d,f}	+ + + ^g



Referensgrupp knyts till projektet

- Följande aktörer har hittills visat intresse för att delta:
 - Stena Line
 - Laurin Maritime,
 - Sjöfartsverket,
 - Västra Götalandsregionen,
 - Preem,
 - Trafikverket,
 - Energimyndigheten
 - Miljöanalys Fordon och bränslen
- **Vill ni vara med? Varmt välkomna!**