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PROSPECTS FOR ALTERNATIVE MARINE FUELS

Extended summary report from a project within the collaborative research program Renewable transportation fuels and systems (Förnybara drivmedel och system)

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THE SWEDISH KNOWLEDGE CENTRE
FOR RENEWABLE TRANSPORTATION FUELS

PREFACE

This report summarizes the results from a project that has been carried out within the collaborative research program *Renewable transportation fuels and systems* (Förnybara drivmedel och system), Project no. 42403-1. The project has been financed by the Swedish Energy Agency and f3 – Swedish Knowledge Centre for Renewable Transportation Fuels.

f3 Swedish Knowledge Centre for Renewable Transportation Fuels is a networking organization which focuses on development of environmentally, economically and socially sustainable renewable fuels, and

- Provides a broad, scientifically based and trustworthy source of knowledge for industry, governments and public authorities
- Carries through system oriented research related to the entire renewable fuels value chain
- Acts as national platform stimulating interaction nationally and internationally.

f3 partners include Sweden's most active universities and research institutes within the field, as well as a broad range of industry companies with high relevance. f3 has no political agenda and does not conduct lobbying activities for specific fuels or systems, nor for the f3 partners' respective areas of interest.

The f3 centre is financed jointly by the centre partners and the region of Västra Götaland. f3 also receives funding from Vinnova (Sweden's innovation agency) as a Swedish advocacy platform towards Horizon 2020. Chalmers Industriteknik (CIT) functions as the host of the f3 organization (see http://www.f3centre.se).

The project has been performed jointly by IVL Swedish Environmental Research Institute and Chalmers University of Technology. The project group has been supported by a reference group including Cecilia Andersson (Stena Line), Fredrik Backman (Preem), Martin von Sydow (Wallenius Marine), Fredrik Svensson, (Energigas Sverige), Toni Stojcevski (Wärtsilä), Magnus Lindgren (Trafikverket), Reidar Grundström (Sjöfartsverket), Jessica Hjerpe Olausson (Maritime Cluster of West Sweden, Region Västra Götaland), Rebecka Bergholtz and Markus Selin (Energimyndigheten), Joanne Ellis and Martin Svanberg (SSPA) and Olle Hådell (formerly at Trafikverket). The reference group has participated in the multi-criteria decision analysis and has provided valuable input to other parts of the project.

This report should be cited as:

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INTRODUCTION

There is a need to reduce the emissions from the shipping sector (Transport & Environment, 2017). According to a recent decision by the International Maritime Organization (IMO) the global greenhouse gas (GHG) emissions from shipping should be reduced by 50% by 2050 compared to 2008 (Transportstyrelsen, 2018). In order to drastically reduce the GHG emissions there is a need for low-emitting alternative fuels since other measures are not enough (Brynolf et al., 2014).Thus, the shipping sector is in a stage of searching for new energy carriers that can fulfil present regulations and also be a bridge to coming, discussed or foreseen demands and regulations. Besides targets for GHG emission reductions there are global regulations related to e.g. emissions of nitrogen oxides and sulphur oxides. The total fuel use for shipping globally is estimated to around 300 million tons/year (Smith et al., 2014). Replacing all fuel oil used today with non-fossil alternatives will likely involve many different alternatives.

The shipping sector is working under somewhat different boundary conditions compared to the automotive sector. Large part of the shipping takes place on a global market and with international regulations, but there are also different regulations and availability of fuel depending on geographical area. The global character of shipping makes the introduction of regulations slow. However, the global level may imply a positive effect since policies introduced globally may gain acceptance among actors since all countries are affected in the same way.

Ships are also usually designed and built in very small series compared to cars, although individual components like engines and technical systems are more generic. The size and function of a ship allows design with space for fuel, but this is always competing with cargo capacity. Shipping will compete with land transport and other energy sectors for energy carriers.

AIM

The overall aim of this project has been to make an initial assessment of the role of renewable fuels in the global shipping sector, and to contribute with scientifically based decision support for the choice of alternative marine fuels, to industry, policy makers and other stakeholders. The project includes

i. a synthesis of current knowledge on alternative marine fuels including on-going projects and initiatives for deep sea shipping and short sea shipping,
ii. an assessment of factors influencing the choice of marine fuels including technical, environmental and economic aspects and the possibility to estimate the cost for some of these factors, and
iii. a multi-criteria analysis of selected alternative marine fuels providing a structured assessment of different marine fuels.

An active participation of shipping related stakeholders and dissemination of the results have been important parts of the project.

The synthesis of knowledge on alternative marine fuels and the assessment of factors influencing the choice of marine fuels are based on a literature review and input from the reference group of the project. The multi-criteria decision analysis is based on the Analytic Hierarchy Process (AHP) approach (Saaty, 2008) and includes ten different criteria spanning over economic, technical, environmental and social aspects, e.g. fuel price, fuel supply, climate change, acidification and safety.

Seven alternative marine fuels are analyzed: liquefied natural gas (LNG), liquefied biogas (LBG), natural gas based methanol, biomass based methanol, hydrotreated vegetable oil (HVO), natural gas based hydrogen, and hydrogen produced with electricity from renewable energy sources. In the AHP method the included alternatives are ranked based on (i) the performance of the alternatives for the included criteria and (ii) the importance of the criteria. In our study the latter is based on input from the reference group of shipping related stakeholders, representing different stakeholder groups.

This report summarizes the main findings from the project. For more detailed information the readers are referred to the publications from the project (see below). Since the results from the multi-criteria decision analysis will be submitted for scientific publication, relatively little is presented here.

DELIVERABLES

The results from the project are documented in the following publications:

- Hansson, J., Grahn, M., (2016). The potential role of electrofuels as marine fuel: a cost-effective option for the future shipping sector? Proceedings of the International Conference on Shipping in Changing Climates (SCC) 2016, Newcastle, UK, 10-11 November 2016,
- Hansson, J., Grahn, M., Månsson, S., (2017). Assessment of the possibilities for selected alternative fuels for the maritime sector. Proceedings of the International Conference on Shipping in Changing Climates (SCC) 2017, London, UK, 4-5 September 2017,
- Månsson, S., (2017). Prospects for renewable marine fuels - A multi-criteria decision analysis of alternative fuels for the maritime sector, MSc thesis, June 2017, Chalmers University of Technology,
- Autade, A., (2017). Cost-effective fuel choices for the future shipping sector: the effect of different demand scenarios, MSc thesis, November 2017, Chalmers University of Technology,
- Hansson, J., Månsson, S., Grahn, M., (2017). Prospects for renewable marine fuels – the role of biofuels. Poster at the European Biomass Conference and Exhibition 2017, Stockholm, 12 June 2017,
- Hansson, J., Månsson, S., Brynolf, S., Grahn, M., (2018). Alternative Marine Fuels – the Prospects for Different Options based on a Multi-criteria Decision Analysis Approach. Manuscript to be submitted to scientific journal in June 2018.

The results have been presented for and discussed with the reference group of shipping related stakeholders (see preface for a list of participants) at two project specific workshops (27 April 2017 and 12 April 2018, both times at Chalmers).

In addition, the findings of the project have been presented by the project team at a range of conferences and seminars for primarily industry, authorities and other researchers.

SUMMARY OF PRESENT ACTIVITIES FOR ALTERNATIVE MARINE FUELS

There are many alternative marine fuels discussed in the literature and by the sector, including LNG, LBG, methanol, biodiesel and ammonia (see e.g., Andersson & Marquez Salazar, 2015; Bengtsson et al., 2012; Brynolf et al., 2014; Florentinus et al., 2012; Horvath et al., 2018;

OECD/ITF, 2018). Some can be used as fuel in diesel engines with minor or larger technical modifications, but there are also other alternative propulsive systems such as batteries, fuel cells, nuclear power, wind and solar energy (OECD/ITF, 2018). The different alternative fuel and propulsion solutions are currently at different maturity levels. Some are used commercially, like LNG, and/or used in special niches like batteries and electric hybrid propulsion and nuclear power. Some have been tested onboard ships in different pilot projects like methanol, biodiesel and vegetable oils. Some fuels have only been tested in testbeds or in smaller scale, or have not reached the stage beyond being discussed (e.g. hydrogen and ammonia).

Some recent initiatives for alternative marine fuels are listed below (for detailed information the reader is referred to the publications listed above).

LNG and LBG

Methane in the form of LNG is introduced as marine fuel. In March 2018, the in-service and on-order fleet of LNG-powered seagoing ships has reached 200 (LNG World Shipping, 2017). The fleet of LNG-fuelled vessels that are not LNG carriers amounts to 103 ships in service and 97 on order (LNG World Shipping, 2017). Also retrofitting of ships to LNG fuel (usually dual fuel) is tested. LNG being a fossil fuel will not lead to reduced GHG emissions from shipping (Brynolf et al., 2014) but could be replaced partly or totally by LBG but so far no example of LBG sold to shipping has been found (Tybirk et al., 2018).

Methanol

Methanol has been tested as marine fuel. This includes tests with conversion of four engines to dual fuel methanol on board the Stena Germanica ferry that runs between Gothenburg, Sweden, and Kiel, Germany, one conversion of a pilot boat to methanol, and seven new built dual fuel chemical tankers transporting methanol with the possibility to use the cargo as fuel (Green Pilot, 2018; Waterfront Shipping, 2013).

Biodiesel

Biodiesel (FAME, HVO etc.) can be used for blending in fossil fuels for shipping but can also be used as neat fuel. Some ongoing initiatives include:

- The company GoodFuels is making biofuel available in ports, starting with Port of Amsterdam 2016 and continuing in Singapore 2017 (GoodFuels, 2018).
- Heineken and GoodFuels demonstrate drop-in marine fuel on board an inland transport barge (GoodFuels, 2018).
- Royal Caribbean Cruises has tested biodiesel on one vessel (Florentinus et al., 2012).
- A Canadian cargo ship has tested a mix with animal fat and cooking oil (20%) (Florentinus et al., 2012).
- Maersk Line has tested biodiesel mixtures on board one containership (Jivén et al., 2016]

Electricity

Some initiatives to apply electric propulsion in shipping include (Hägg et al., 2018):

- The HH ferries between Helsingborg (Sweden) and Helsingör (Denmark) are operating on electricity with charging in port.

- Stena Line is testing battery power on board Stena Jutlandica (a ferry with the capacity of 1500 passengers and vehicles running between Göteborg, Sweden, and Fredrikshavn, Denmark) initially starting with battery power to bow thrusters and maneuvering in port (Stena Line, 2018). Later the battery power will be connected to the propellers, enabling navigation for short distances.
- In Norway, Color-Line has announced that they, together with the shipbuilder Ulstein Verft, are in the process of building the world's largest plug-in hybrid ship with a capacity of 2000 passengers and 500 cars (Color-Line, 2018) and there are also other initiatives.
- In Stockholm, Sweden, one ship for public transport (E/S Sjövägen) has electric (battery) power.
- The Swedish Traffic Administration (Trafikverket) is converting short distance road ferries to electric propulsion with a land connected cable and is planning for battery ferries for longer distances.

Hydrogen/Fuel cell

There are several maritime fuel cell initiatives (Tronstad et al., 2017). For example, in Norway a fuel cell powered ferry using hydrogen will be built (Slinn, 2017). The ferry will be a pilot version of a hybrid hydrogen/battery powered ferry and will be operational in 2020. The hydrogen production company Greenstat hydrogen AS also aims to demonstrate hydrogen for the maritime sector and Statoil has several maritime projects in pipe-line.

KEY FINDINGS AND CONCLUSIONS

The initial assessment of the role of renewable fuels in the shipping sector performed in this project can be summarized in the following key findings and conclusion.

There has been an increased interest in alternative marine fuels in recent years. A range of different options with different characteristics are discussed, where some perform better in terms of environmental performance and others in terms of economy, infrastructure, availability and volume. This implies that performing an overall comparison considering various factors is a complex task.

There are many initiatives in progress for use as well as for production of alternative marine fuels (including fossil fuel based options). Except for the case of LNG and electric propulsion in short sea shipping, most of the initiatives and activities that this project has studied are at pilot or test scale. Besides LNG and electricity there are projects for methanol, biodiesel and hydrogen. LBG, electrofuels (fuels produced from carbon dioxide, water and electricity) and ammonia as well as other biofuels are also discussed. It is still a quite long way to implementation of economically feasible alternative marine fuels, in particular for deep sea shipping. There is also a lack of sustainability evaluation for some alternatives, like ammonia.

The fast development of use of electric propulsion represents an interesting option, especially for use in ports and fairways, where health issues are important. Electricity as marine fuel is also mainly of interest for relatively short distances. Due to limits and/or difference in availability, biofuels are currently primarily of interest for minor applications in short sea shipping and for public transport. However, some biofuels (LBG, HVO, and biomass based methanol) could also be blended to some extent in fossil marine fuels used for other applications. The development of biofuel production pathways from e.g. forest residues and sea-based resources may increase the total availability of biofuels.

In general, electro-fuels seem promising, given that the potential to produce biofuels in a scale that is required to cover a substantial share of the shipping sector is limited. Hydrogen may also be an interesting option for the future shipping sector. The potential for these options requires further assessments.

There is a limited number of studies analyzing the additional costs associated with using alternative fuels. There are some estimates for e.g. the cost of lost cargo capacity due to that some alternative marine fuels require more space onboard (Horvath et al., 2018) but the more important cost factor will likely be the price of the fuel itself.

The factors that influence the choice of marine fuels the most are, according to the project's reference group of shipping related stakeholders, the climate impact of the fuel, reliable supply of fuel, fuel price, safety, investment cost and acidification impact. To what extent different marine fuels are better suited for different kinds of shipping depend on several factors associated with the ship type such as maximum power requirement, area and type of operation, operational profile and if cargo capacity is limited by volume and/or weight.

According to the multi-criteria decision analysis of selected alternative marine fuels performed within the project, overall economic criteria are considered more important than technical, environmental and social factors for the choice of marine fuels for the stakeholders. However, different stakeholder groups in our study (ship owners, authorities, engine manufactures and fuel producers) weigh the criteria differently, resulting in different fuels turning out as the most interesting option. Preliminary findings from the multi-criteria decision analysis indicate that e.g. LNG is the option that is ranked highest for ship owners, while for Swedish authorities, renewable marine fuels are ranked higher. However, additional sensitivity assessments will be performed before the final result is confirmed and published in full.

KORT SVENSK SAMMANFATTNING

Sjöfarten behöver införa alternativa drivmedel för att minska sin miljö- och klimatpåverkan både på kort och lång sikt. Det övergripande syftet med detta projekt har varit att analysera de förnybara drivmedlens roll inom sjöfartssektorn och bidra med beslutsunderlag kring val av förnybara bränslen till berörd industri, politiker, myndigheter och andra intressenter. Projektet inkluderar

i. en kunskapssammanställning kring alternativa marina drivmedel och olika aktörers pågående satsningar,
ii. en övergripande analys av faktorer som påverkar val av drivmedel inom sjöfarten inkluderande tekniska, miljömässiga, ekonomiska och sociala kriterier och
iii. en multikriterieanalys av utvalda alternativa marina drivmedel som ger en strukturerad bild av för- och nackdelar med olika bränslen. Multikriterieanalysen inkluderar tio kriterier t ex bränslepris, tillgång, klimatpåverkan och säkerhet och sju drivmedel (LNG, LBG, metanol baserad på biomassa respektive naturgas, HVO, samt naturgasbaserad och förnybart framställd vätgas).

Kunskapssammanställningen visar att intresset för alternativa marina drivmedel har ökat betydligt på senare år och det finns många initiativ kring användningen av alternativa marina drivmedel. Med undantag för LNG och eldrift på kortare sträckor är de flesta projekten på pilot- eller testskala. Utöver LNG och el finns projekt framför allt för metanol, biodiesel och vätgas. Men även elektrobränslen, LBG, ammoniak och andra biodrivmedel diskuteras.

De faktorer som enligt tillfrågade sjöfartsaktörer påverkar valet av drivmedel på sjöfartssidan mest är drivmedlets klimatpåverkan, om tillgången på bränslet är pålitlig, bränslepris, säkerhet, investeringskostnad och påverkan på försurning. Sammantaget väger ekonomiska faktorer tyngre än tekniska, miljömässiga och sociala faktorer vid val av marina drivmedel för sjöfartsaktörerna. Olika aktörsgrupper som redare, bränsletillverkare, motortillverkare och myndigheter viktar dock olika kriterier olika, vilket påverkar resultatet. Multikriterieanalysen visar preliminärt att redare t.ex. rankar det alternativa drivmedlet LNG högst, medan svenska myndigheter anser att förnybara drivmedel är mer intressanta. Ytterligare känslighetsanalyser kommer dock utföras innan dessa resultat kan verifieras och publiceras i sin helhet.

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