MARINE FUEL ALTERNATIVES FOR A LOW CARBON FUTURE – MARKET INFLUENCE ON THE PATHWAYS SELECTED

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ABSTRACT

Decrease in carbon dioxide emissions was not the driver when shipping started to investigate fuel alternatives to replace the traditional heavy fuel oil. Instead it was regulations of sulphur contents in fuel in sulphur emission control areas (SECA). The dominating driving forces for a ship-owner to change fuel are regulations and price. The result will thus be an economic based fuel choice among those fuels fulfilling present regulations rather than a long term sustainable alternative. A fuel change is usually also connected to a capital cost for conversion and infrastructure that has to be compensated by lower fuel price. Fuels used in SECA areas today are low sulphur marine gas oil (LSMGO), “hybrid fuels” (heavy fuel oils that has been blended to low sulphur contents), LNG or methanol. LNG and methanol in addition to fulfilling sulphur regulations also provide a pathway to renewable fuel and have low emissions of nitrogen oxides and particles. However, in the past years, the economic incentive has changed from a favourable situation for the “clean” fuels like LNG or methanol towards traditional fuels fulfilling only sulphur regulations. Decisions are today based entirely on the fast changing prices, providing a selection of fuels that fulfil only present regulations and excluding possible future regulations or customer demands. The long-term pathway towards sustainability with a change into fossil free fuel production is not taken into account.

In the paper, the relation between the many possible drivers as well as the implications of market changes for decrease of greenhouse gas emissions will be further discussed.

Keywords: Alternative marine fuels, Legislation, Emission control areas, ECA, SECA, Price, Regulation,

NOMENCLATURE

AIS Automatic Identification System
ECA Emission Control Area (defined by the IMO)
EEDI Energy Efficiency Design Index
EtOH Ethanol
HFO Heavy Fuel Oil
HVO Hydrotreated Vegetable Oil (= “biodiesel”)
IMO International Maritime Organisation
LBG Liquefied Bio Gas
LNG Liquefied Natural Gas
LSFO Low Sulphur Fuel Oil
MDO Marine Diesel Oil
MGO Marine Gas Oil
MRV Monitoring Reporting Verification
MT Metric tonne
RFO Residual Fuel Oil
RoPax Passenger and car ferry
SECA Sulphur Emission Control Area (not used by the IMO, but appears in public discussion)
ULSFO Ultra Low Sulphur Fuel Oi

1. INTRODUCTION

Shipping is traditionally regarded as an energy efficient means of transport and, since it is performed to a large degree in the oceans far from densely populated areas, it has not attracted as much attention in terms of decreasing emissions to air as has other, land-based, emission sources. However, this is not the whole picture. Transoceanic shipping is indeed large and a very important actor in international trade, but shipping is a large sector with many different sizes of ships and different purposes and a lot of the transport work occurs close to land and in densely populated areas.

The area in the Baltic Sea that is part of the European Emission Control Area (ECA) for sulphur emission is an area with large shipping activities. Figure 1 shows the annual traffic 2014 in some passages as well as the AIS (Automatic Identification System) tracks of all ships during one week in July. The large traffic through the Kattegat – Öresund area occurs in a region with around 8 million inhabitants close to the sea. The Baltic Sea is also pointed out as a Particularly Sensitive Sea Area (PSSA) by the International Maritime Organisation (IMO) (IMO, 2015a). A study in 2005 on behalf of the European Commission also concluded that NO_x emissions from shipping will be on par with the land based sources in Europe by 2020 if no new regulations are imposed for the marine sector (Cofala, 2007). Thus, there are strong driving forces to reduce emissions of sulphur and nitrogen oxides and particles from shipping in order to decrease local and regional impacts on health and natural environment. The demands on emission reduction has been started by different driving forces. National and regional initiatives aiming at reducing acidification of soil by sulphur and nitrogen oxides, as well of reducing nutrient flow to sensible waters like the Baltic Sea have been followed by worries of health impact by particle emissions and photochemical oxidants. In national waters and shipping is affected by this, but for the international regulations, the IMO (International Maritime Organisation) is the body where the development is performed

For ships entering ports and in national fairways, local and regional emission regulations or other means of decreasing emissions like reduced port or fairway fees are used. The regional and local regulations vary, but are mainly driven by a need for protecting health and local environment. It may also be worth noting that for inland shipping in Europe, as well as for small vessels in national traffic, different engines and fuels are used, and the regulations are mainly similar to those for land vehicles.

In the process of handling the health and local and regional environmental issues the discussion on reducing emissions of greenhouse gases from shipping has come to a late start. The IMO have the responsibility for handling shipping´s climate impact and are meeting this by a scheme for energy efficiency of new ships, EEDI (Energy Efficiency Design Index), in force from 2016.

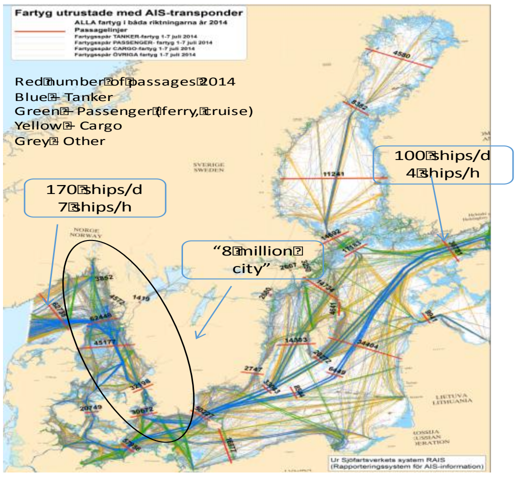

Figure 1: Ship passages in some locations of the Baltic Sea area during 2014. AIS ship tracks from one week (1^{st} to 7^{th}) in July included. Data from Swedish Maritime Administration.

2. PRESENT AND COMING REGULATIONS AFFECTING FUEL CHOICE

In general the process of developing a regulation within the IMO has been a time consuming process of searching consensus involving several actors. This has further delayed the start of regulations for shipping. As an example, the allowed concentration of sulphur in marine fuel in the North Sea and Baltic Sea ECAs from 2010 (1.0 %) was the same that entered in force for heating oil in Stockholm City from October 1969 (Landell, 1969).

In a recent Ph D thesis, Erik Svensson observes that in the regulation of sulphur contents in fuels "*scientific arguments and claims were used to justify views with underlying economic arguments, which were strengthened with legitimacy*" (Svensson, 2014) (abstract, page i). The regulatory work is thus influenced by economic considerations to a large degree.

After a long process, regulations on sulphur and nitrogen oxide emissions are step-wise being implemented and the ship-owners are looking for alternative fuels to fulfil these.

2.1 SULPHUR AND NITROGEN OXIDES

The heavy fuel oil (HFO) is known as a cost efficient marine fuel with a high energy-efficiency also from a well to propeller perspective. Adverse effects of acid rain on nature and culture heritage led to various national restrictions on sulphur contents in fuel for land based applications from the 1960´ies and on while shipping became the major user of high sulphur heavy oils. The International Maritime Organization has after a long process decided upon regulations related to sulphur contents in marine fuel in North America and the Caribbean, and in the Baltic and North Seas through ECAs. (IMO, 2015b). In the Sulphur Emissions Control Areas ("SECA") the maximum allowed sulphur content in marine fuels is 0.1% (weight), which entered in force from January 2015 (Figure 3). In the SECA areas, regulations also allow for sulphur exhaust emission abatement by use of scrubbers, instead of changing to a low sulphur fuel.

Further ECAs have been proposed in the Australia, Japan, the Mediterranean Sea and Mexico, as shown in Figure 2.

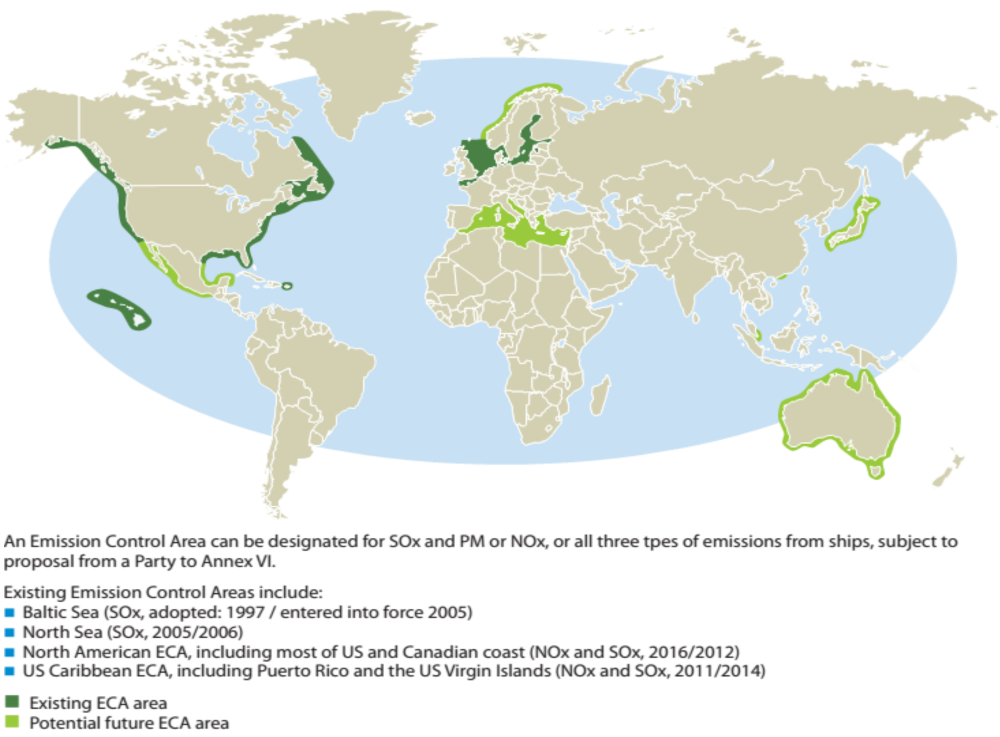

Figure 2: Existing and proposed Emission Control Areas (ECAs) globally (Source: IMO).

The first global regulations of NO_X emissions were introduced for engines produced after the year 2000 (Tier I engines). The Tier II standard applies to engines produced after 2011 and represents a decrease of approximately 20% in NO_X emissions compared to Tier I levels. In the existing NO_X ECAs, the North American ECA and the US Caribbean ECA, Tier III will be required for ships constructed from 2016, and will represent a decrease of approximately 80% in NO_X emissions compared to Tier I levels (Figure 4). Tier II has been proposed also for north Europe, but will not enter into force until 2020 or later.

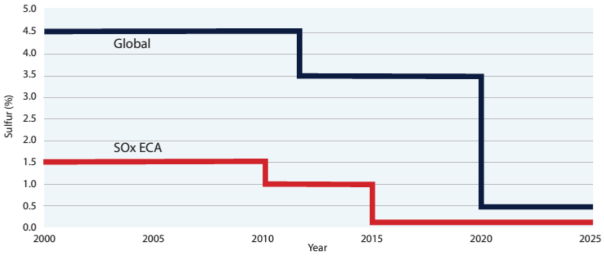

Figure 3: Levels of sulphur in marine fuel (weight %) in ECAs and globally. Note that 2020 is preliminary date for last step. (Source: IMO)

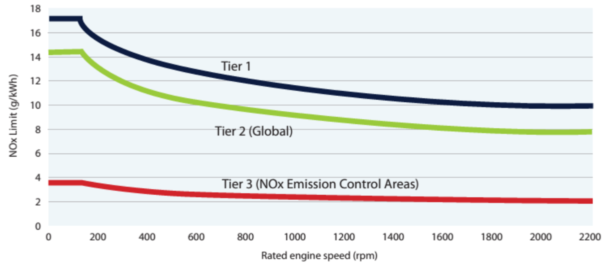

Figure 4: Regulations for NOx emissions. Tier III refers to ECA areas (Source: IMO)

Particulate emissions are connected with health and environmental impacts, but still there are no regulations of direct particulate emissions. However, the formation of secondary particulates is believed to decrease with decreasing sulphur contents in fuel and decreasing NO_x emissions. A specific category of particles is black carbon, which is of special focus due to climate effects and in the arctic area due to potential ice melting.

There are also local regulations regarding sulphur content in fuel. One example is the California regulation valid 24 nautical miles of the California Baseline (California EPA, 2008) In contrast to the ECA regulations, the California regulation does not allow the use of exhaust cleaning techniques (scrubbers) in place of low sulphur fuels. The California Fuel regulation also requires that the fuel meets the specifications for distillate grade fuel, either Marine gas oil (MGO) or marine diesel oil (MDO), and not only that the sulphur percentage is fulfilled (California EPA, 2014). The local or regional regulations will set demands on flexibility in ships that are in use globally.

2.2 GREENHUSE GASES

International shipping is not included in these United Nations negotiations on climate change but is treated as a separate entity over which the IMO is held responsible for greenhouse gas reductions. The IMO have stated that "shipping industry will make its fair and proportionate contribution". Within the IMO work has led to a framework for fuel savings and energy efficiency by the Energy Efficiency Design Index (EEDI) for new built ships from 2016. However, an IMO report on shipping and greenhouse gas reduction concludes that "*all IPCC scenarios but one project emissions in 2050 to be higher than in 2012"* and "*improvements in efficiency are important but could not yield a downward trend"* (Smith et al., 2014).

Under the EU Monitoring, Reporting and Verification (MRV) rules, passed by the parliament in April 2015, ship owners will have to monitor CO_2 emissions for each ship on a per voyage and an annual basis (European Comission, 2015a); reporting is planned to start in 2018. The EU states that the EEDI is not sufficient and that there is a need for a system that covers also existing ships.

The EU white paper on transport from 2011 (European Comission, 2011) sets the goal of a 40 % reduction in CO_2 emissions from EU's maritime transportation as compared to 2005. The strategy from 2013 is to also integrate shipping in the EU's policy for reducing greenhouse gas emissions (European Comission, 2013).

2.3 OUTCOME OF THE SECA REGULATION

The process of introducing SECA regulation in North Europe has been associated with arguments stating both economical constraints and risk of lack of suitable fuel. When the regulations entered in force, the fuel prices had made the economical conditions different compared to the previous situation, although low sulphur fuel or scrubber installation still is more expensive than use of HFO.

At present, in October 2015, the introduction of low sulphur fuels seems to have been successful in terms of the immediate goal of decreasing sulphur emissions. The first indications of compliance are that a large majority of the ships fulfil the regulations (10 out of 300 ships investigated by remote measurements in Gothenburg were taken to a further investigation of fuel quality used, (Bergman, 2015)) and a large decrease of sulphur contents in the air in Denmark has been observed since the start of the regulation (ABS, 2015). This indicates that

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regulations really are driving the development in the direction intended. There are no statistics on how this was achieved, but according to shipping companies, there have been initial changes to low sulphur MGO and there is also a small, but growing number of ships with scrubbers. However, since the present regulation only covers the sulphur content in fuel, all fuels that have less than 0.1 % sulphur can be used to fulfil this (DNV GL, 2015). New fuel qualities have been introduced on the market, low sulphur fuel oil, LSFO, also called hybrid fuels, or ultra low sulphur fuel oil, ULSFO, made by blending refinery product streams that have not been used as marine fuels until now. This means that the fuels have specifications that do not fit in any of the “traditional” marine fuel definitions of MGO, MDO or residual fuel oil (RFO). Today there is a large number of fuel qualities that are more like HFO in all but the sulphur content. Their viscosity is more like HFO, the fuel needs heating and has higher flash points than MGO. They are aliphatic and can cause wax precipitation and also may need more lubrication (DNV GL, 2015, Lloyds register Marine, 2014) The trade names of the ULSFOs on the market are numerous. Some examples are: HDME 50, Fuel oil, DMB, ULSFO, RMD, Eco Marine (Lloyds register Marine, 2014).

In interviews with some shipping companies performed in 2014/15, it was obvious that the fuel price and technical conditions to use a fuel were determining the choice of new fuel or scrubber solution to fulfil demands on sulphur contents. It was also observed that none of the interviewed ship-owners did consider possible coming demands, but are waiting until new regulations are in force (Liao, 2015).

3. SOLUTIONS TO DECREASE EMISSIONS - ALTERNATIVE FUELS

The term “alternative fuels” points at the fact that there is a need for finding something that is performing in another way than the present. In the common discourse on transport fuels, the term also has come to be interpreted as non-fossil. For shipping, however, the demands on sulphur emission reduction and the regional restrictions in sulphur contents of marine fuel have made this a priority in searching for alternative fuels and the European Commission has included fossil alternatives like liquefied natural gas (LNG) for marine applications. It then is assumed that LNG can be replaced by liquefied biogas (LBG) with time in the same way that marine diesel is replaced by biodiesel.

3.1 EURPOEAN UNION VIEW ON ALTERNATIVE MARINE FUELS

The expert group on future transport fuels commissioned by the European Commission states: *“For road and waterborne (maritime and inland waterways) applications some possible alternatives exist, such as biomass, other renewables and nuclear power (via electricity and hydrogen production) and possibly for a transition period other fossil resources (e.g LNG and GTL). However, in the long term, most fuels would need to be of non fossil origin in order to secure a reduction in GHG emissions. For international maritime shipping, LNG can plan an important role as it is available in considerable amounts. ….Other alternatives are marine gas oil (MGO) and methanol”* (COWI, 2015) p 8.

Thus a large focus is still on the use of fossil fuels is anticipated in coming years. Recently, methanol has been included as a liquid fuel alternative. Methanol is today based on natural gas, but is foreseen to be replaced by methanol from renewable sources.

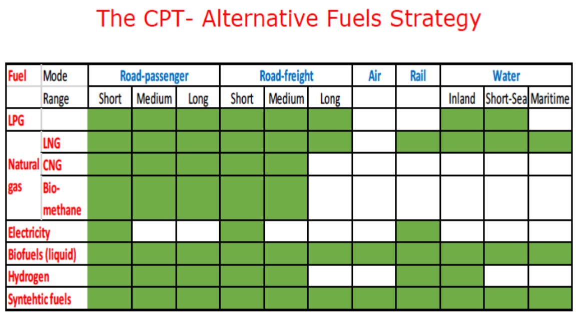

Figure 5: Fuels and applications according to the EC Directive on Alternative Fuels (Tricas Aizpun, 2015)

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Regarding methanol, recital 6 of the Directive of alternative fuels states *"…Methanol can also be used for inland navigation and short-sea shipping. Synthetic and paraffinic fuels have a potential to reduce the use of oil sources in the energy supply to transpor*t" (Tricas Aizpun, 2015, European Parliament and European Council, 2014). The fuels included in the Alternative Fuels Strategy are summarised in Figure 5.

3.2 CRITERIA FOR FUEL SELECTION

Change of fuel in a sea transport system is a long term choice that is determined by a number of parameters. First, ships have a long life time, a nominal life of 15 to 30 years with a large spread depending on ship type, use, market etc (Stopford, 2008) and the power train, including fuel system and engine type is a part that is not very easy to change in a large retrofit. However, the large marine diesel engines are quite flexible in terms of fuel, thus opening some possibilities for various degree of retrofit.

The fuel type is one of the choices – diesel engines can run on a wide variety of fuel qualities, and in dual fuel mode, change between two fuel types – diesel or gas or diesel or an alcohol - can be handled. Dedicated gas engines are also a useful alternative as illustrated in Figure 6. Retrofit of engines and fuel system is possible for many engines and for new built engines an initial fuel/technology choice can be made. In general, the investment in new-build or retrofit is higher for gas systems, and have to be compensated by lower fuel prices.

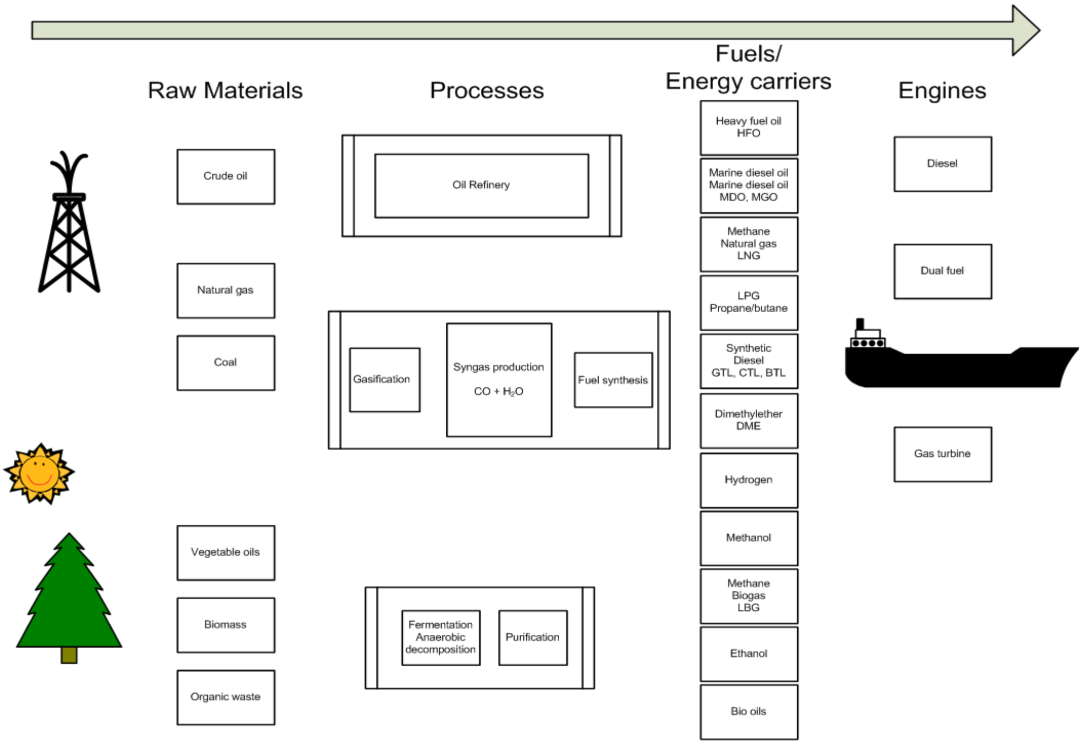

Figure 6: Marine fuel pathways from source to engine.

In order to make a new fuel work, there are a number of criteria that have to be fulfilled. This has been summarised by Brynolf et al. (2014) based on a workshop on multi criteria analysis of marine fuel properties with expertise from different competence fields. A general observation is that within each area of expertise, the criteria relating to that group were regarded as central. The general view that there is an initial need to first identify all necessary conditions for use of the fuel, before searching a suitable trade-off situation between criteria was a common insight during the exercise. In short – there is not one "best fuel" but there may be fuels that fulfil more of the demands for a specific ship or operation. Examples of criteria categories are illustrated in Figure 7.

From the discussion above, some principal pathways that have to be decided upon for fuel selection evolve. One important parameter is the physical state of the fuel – gas or liquid (solid fuels are not considered here), see Figure 8. The infrastructure and the fuel handling systems on board are dependent on the choice and it is

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associated with costs to retrofit between these alternatives. Dual fuel engines provide some flexibility, but require double fuel systems. Methanol fuel represents a combination of liquid fuel that can be handled in a dual fuel engine.

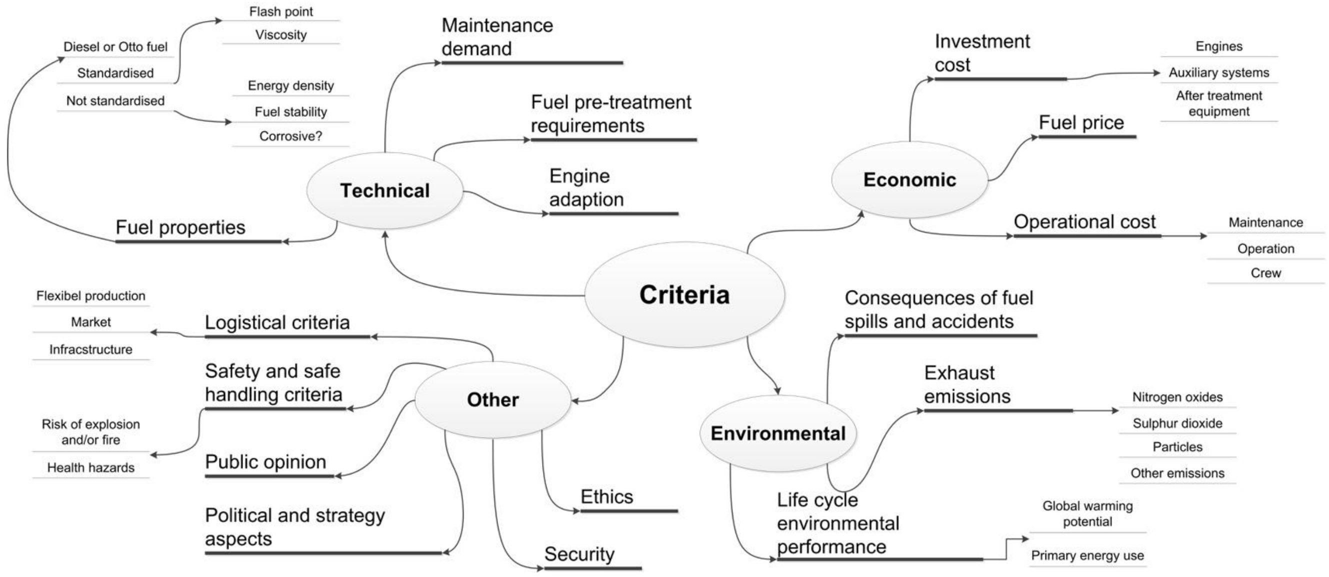

Figure 7: Criteria for decision on alternative fuel (Brynolf, 2014)

The pathways indicated in Figure 8 have all the possibility to lead to non fossil fuel without retrofit, meaning that a retrofit to methanol or LNG will prepare for non fossil fuels but also point out a specific fuel. This lead to the future challenge to find a pathway leading to an economically and sustainable future, non fossil fuel.

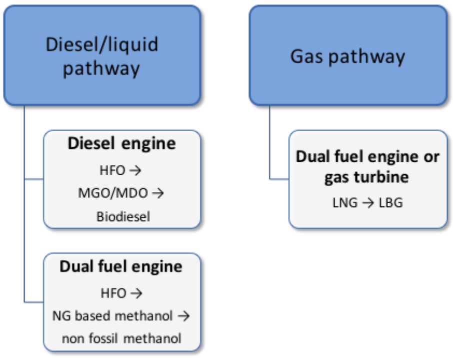

Figure 8: Pathways to non-fossil fuel

4. ENERGY MARKET

Predicting future prices of energy is not possible, although there are many attempts to do so. The development of the energy market in recent years shows that predictions on stable prices or of continuing increase in price have not been fulfilled.

The crude oil price and, following that, the price of most commonly used fuels, was stable for a long period during the 1990´ies. After that the price situation has been more difficult to predict. See Figure 9 where marine

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fuels (Europe Brent Spot price, HFO, MGO and natural gas) are compared[1]. The price difference between fuels was increasing during a period from year 2000, and the relative prices changed. Natural gas has in recent years become more economically attractive. LNG is at present being forwarded as an alternative marine fuel by the European Commission, (European Parliament and European Council, 2014). However, the lack of infrastructure for distribution and bunkering of LNG in many ports in North Europe as well as high cost of retrofitting of ships and building up distribution systems made the shipping industry look at methanol as a fuel alternative, being "natural gas converted to a more easily handled and widely available liquid". For some years from about 2011 to 2013, the methanol spot price was at a level that made it a sulphur free liquid fuel that was cheaper than low sulphur MGO in terms of energy contents (see Figure 10).

Several pilot projects on retrofit of ships to methanol propulsion were started, the largest is the retrofit of the RoPax ferry Stena Germanica, supported by the European Commission in a Ten-t project (European Comission, 2015b). The retrofit started in spring 2015 with retrofit of one engine, and the retrofit of all four 6 MW main engines will be complete in end of the year. The retrofit was economically feasible when the project was started, but today, the fuel prices makes MGO or ULSFO a more attractive alternative from economical point of view.

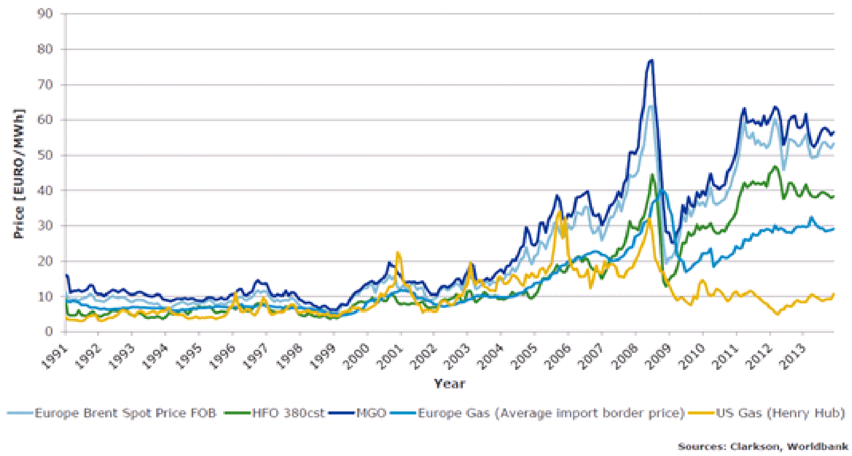

Figure 9: Development of fuel prices from 1991 and on. (World Ports Climate Initiative, 2015)

The economic calculations on ship retrofit and fuel change to fulfil sulphur regulations in SECA areas have thus been challenged by very shifting boundary conditions. The decrease in price of crude oil has made the diesel prices fall, but the methanol price has not followed that development. When making a snapshot on the fuel prices in end of October 2015, See Figure 11, the low sulphur fuel that is the cheapest is ultra low sulphur fuel oil (ULSFO, also marketed as low sulphur fuel oil LSFO), which is 5 to 12 % cheaper than MGO.

The oil prices in Figure 10 can be compared to the methanol spot price. Methanol today is mainly sold as a chemical, with somewhat different prices in Europe, Asia and North America. Only in China there is a wide spread use of methanol as a vehicle fuel (Su et al., 2013). The European price for autumn 2015 is 295 €/MT (MT= metric tonne) corresponding to around 42 €/MWh (Methanex, 2015). The methanol price has been falling in recent months and is approaching the MGO price. When looking at the production cost, there still seems to be a margin for making cheaper methanol (Andersson, 2015).

[1] The Europe Brent spot price is a price benchmark relating to a light crude oil

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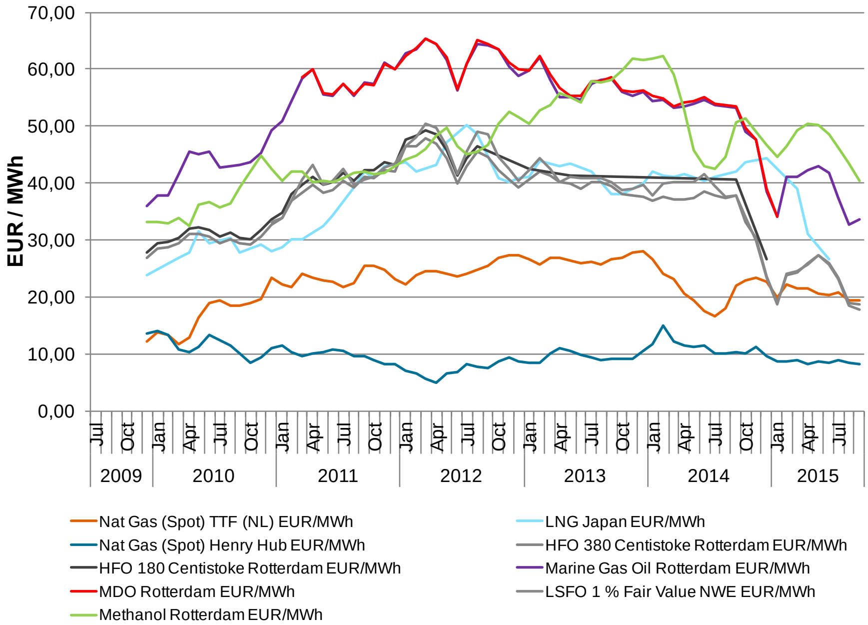

Figure 10: Fuel price development from 2009 to September 2015. All data converted to €/MWh (Data compiled by T Stojcevski, Wärtsilä)

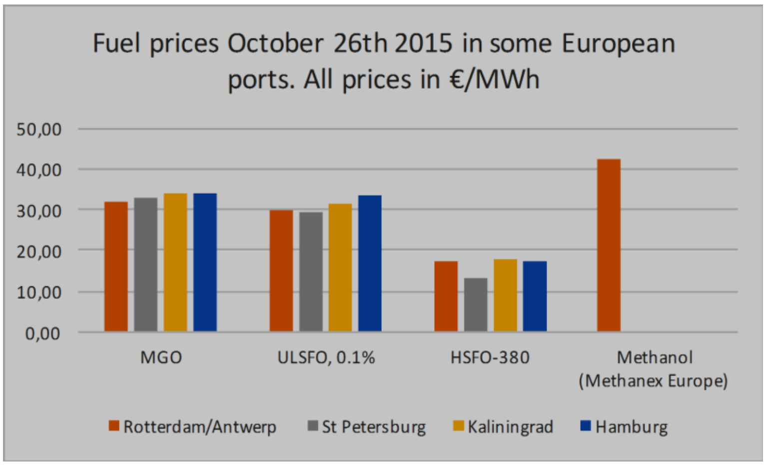

Figure 11: Snapshot of marine fuel prices per 26th October 2015 (Petrol Bunkering and Trading, 2015). Compared to Methanex Europe price (Methanex, 2015)

For renewable fuels the marine fuel market is not well developed or even existing. These fuels may be produced from biomass or vegetable oils, but can also be produced directly from carbon dioxide and renewable electricity, “electrofuel”. The availability of biomass for fuel production is limited, and the avoidance of this step for fuel production may be an interesting alternative. The price of biofuel is difficult to estimate, although there are different blends made for land transport. The cost of production may give an indication of the potential price. An attempt to assess the production cost for some biofuels, ethanol as well as different biodiesel qualities has been made (Festel et al., 2014). Some of the results, (recalculated to €/MWh in order to allow comparison) are shown in Figure 12. The results shown are for an oil price of 50 €/barrel in 2015 cost and technology level. The cost may decrease when technology is more mature and more process information is available. The production cost of non fossil fuels is usually higher than for fossil,, mainly due “upstream costs” for biomass or other carbon sources but the conversion process to fuel may also be costly which is obvious also for these fuels. The data are only examples, and raw material acquisition costs as well as fuel production costs may vary and have a potential do decrease when technology matures.

For production of “electrofuel” from electricity and $CO_{2,}$ cost estimates range from125-340 €/MWh depending on electricity price and process (Taljegård, 2015).

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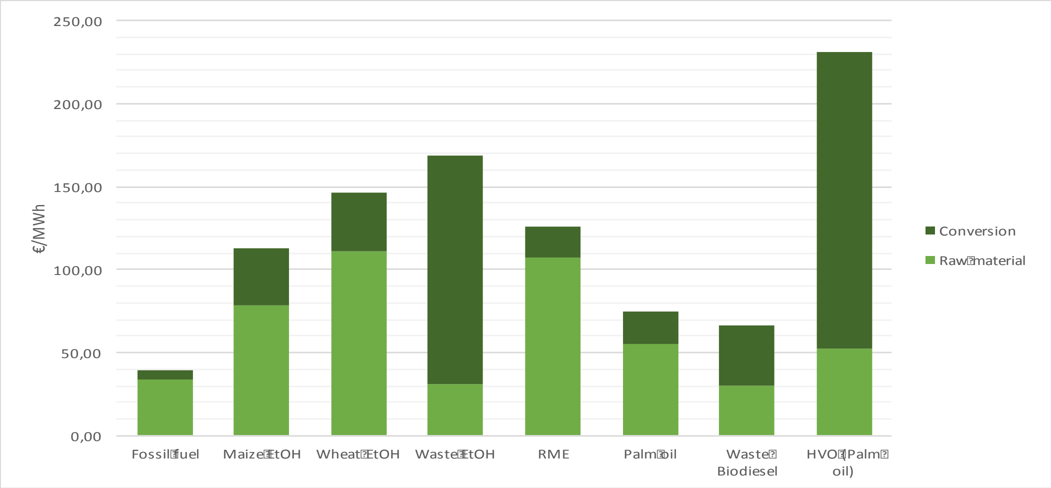

Figure 12: Cost of production for some biofuels. Based on data from Festel et al. (EtOH = Ethanol, HVO = hydrotreated vegetable oil)

5. ANALYSIS

What are then the drivers for a fuel change that would make a start of the pathway to change to non-fossil fuel?

As mentioned, when talking to ship-owners that have ordered new ships or retrofit to other fuel, as well as class societies and consultants, it is very obvious that the only thing that can induce a fuel change from HFO to an alternative is a regulation. When the regulation is there the fuel with lowest price and cost of operation will be selected without special regard to possible future regulations or demands. This is clearly visible from the wide use of "hybrid fuels" to fulfil SECA regulations. The hybrid fuels (LSFO) are cheaper than MGO, today by 5 to 10 %, and are thus a natural choice. The limitations of these fuels due to mixing constraints given by risk of precipitation are more and more avoided and many ship-owners use these fuels. Today there are no measurements of operational emissions of NO_x and particles from use of hybrid fuel available in literature, but due to the chemical similarity with HFO, the decrease in these, non regulated properties, is expected to be small. If so, one of the expectations with the SECA regulation, that particle emission would decrease when abandoning HFO in favour of MGO is limited.

When transferring conclusions from the SECA outcome to decrease of GHG emissions from shipping, also here regulations would be the driving force. Since the present regulations with EEDI for new ships will not be sufficient to decease GHG emissions from shipping to the needed extent, and the EU MRV directive for reporting CO_2 emissions from ships is only about reporting today, the shipping sector needs to do more. In order to make ship-owners change fuel into a non-fossil or "low carbon" alternative, there is need for regulations that can start the process. A regulation can also provide a long term stability in conditions from policy point of view that is needed in the decision.

The SECA example has also shown that a support for test platforms for new fuels is feasible. The first ship is running on methanol on one engine and will be fully converted in the end of 2015. This would not have been possible to fulfil without financial support.

The oil price situation has made the decision situation more complex. The possibility to negotiate a price of alternative fuel set in relation to the price of for example MGO would enhance the possibility to make an economic evaluation.

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6. CONCLUDING REMARKS

In this paper we have reviewed the present marine fuels regulations, and drivers and costs or some of the alternative fuels that can comply with SECA regulations. This experience give some hints for the conditions needed for a large scale introduction of non fossil marine fuels. The following observations are made:

- Experience from the result of the sulphur regulations in SECA areas shows that when regulations are in place, there is a large degree of compliance
- Interviews with ship-owners indicate that only regulations will start a fuel/technology change and the cheapest solution at the time is mainly selected.
- There is still little interest in a long term strategy including future demands on marine fuels among ship-owners

Concerning the introduction of non-fossil fuel, it may be concluded that:

- The present tools (EEDI and MRV) will not lead to any significant decrease of GHG emissions from shipping
- A large scale change to non fossil fuels is not likely to occur without regulations and long term policy from government and policy makers.
- The availability of biomass for fuel production is limited, and fuels based on renewable energy and CO_2, e. g. as “electrofuel” may be of interest
- The present European strategy for marine fuels is not enough to make shipping fulfil the goals in the EU White paper.
- There is a need for support for test platforms and pilot projects to change technical systems and convert to fuels not earlier used
- There is an need for support for development of the market for non-fossil marine fuel, not only for LNG
- The fossil free alternative fuel that will be the “fuel of the future” has to have a potential to be produced at a competitive cost among the non fossil alternatives. The potential for this should be further evaluated when selecting pathway to future fuel types and development of cost and energy efficient fuel production is needed. Also the upstream cost and energy input in the fuel has to be included.

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REFERENCES

ABS. 2015. *Sulfur in Danish air halved since ship fuel limits imposed* [Online]. Available: http://www.marinelog.com/index.php?option=com_k2&view=item&id=9857:sulfur-in-danish-air-cut-by-half-since-ship-fuel-limits-imposed&Itemid=230 [Accessed 7th October 2015.

ANDERSSON, K., MARQUEZ SALAZAR, C, 2015. Methanol as a marine fuel. London: FCBI Energy.

BERGMAN, A. 2015. Få bryter mot SECA [Few violations of SECA regulation]. *Sjöfartstidningen, Gothenburg, Sweden,,* 26 August 2015.

BRYNOLF, S. 2014. *Environmental assessment of present and future marine fuels. .* PhD, Chalmers University of Technology.

BRYNOLF, S., FRIDELL, E. & ANDERSSON, K. 2014. Environmental assessment of marine fuels: liquefied natural gas, liquefied biogas, methanol and bio-methanol. *Journal of Cleaner Production,* 74**,** 86-95.

.

CALIFORNIA EPA 2008. Fuel sulfur and other operational requirements for ocean-going vesseil within the California waters and 24 nautical miles of the California baseline. *In:* CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY (ed.).

CALIFORNIA EPA 2014. Guidance for Complying with the California Ocan-GOing Vessel Fuel Regulation Durin the Air Resourxes Board Sunset Review Process. *In:* CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY - CALIFORNIA AIR RESOURCES BOARD (ed.) *Marine notice 2014-1.*

COFALA, J., AMANN, M, HEYES, C, WAGNER, F, KLIMONT, , POSCH, M, SCHÖPP, W, TARASSON, L, JONSON, JE, WIHALL, C, STVRAKAKI, A 2007. Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive. IIASA, Laxenburg.

COWI 2015. State of the Art on Alternative Fuels Transport Systems in the European Union. Final report.: DG MOVE - Expert group on future transport fuels,.

DNV GL 2015. Notice for low-sulphur "hybrid" fuel operation. Hamburg.

EUROPEAN COMISSION 2011. WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. Brussels.

EUROPEAN COMISSION 2013. Integrating maritime transport emissions in the EU´s greenhouse gas reduciton policies. *In:* EU (ed.) *COM(2013)479 final.*

EUROPEAN COMISSION. 2015a. *Reducing emisisons from the shipping sector* [Online]. Available: http://ec.europa.eu/clima/policies/transport/shipping/index_en.htm.

EUROPEAN COMISSION. 2015b. *TEN-T project: EU to co-fund pilot action on methanol for maritime transport* [Online]. Available: http://ec.europa.eu/transport/newsletters/2013/11-29/articles/ten-t-maritime_en.htm [Accessed june 7 2015].

EUROPEAN PARLIAMENT AND EUROPEAN COUNCIL 2014. Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alterntive fuels infrastructure. *In:* OFFICIAL JOURNAL OF THE EUROPEAN UNION, L. (ed.).

FESTEL, G., WÜRMSEHER, M., RAMMER, C., BOLES, E. & BELLOF, M. 2014. Modelling production cost scenarios for biofuels and fossil fuels in Europe. *Journal of Cleaner Production,* 66**,** 242-253.

IMO. 2015a. *Particularly Sensitive Areas PSSA* [Online]. Available: http://www.imo.org/MediaCentre/HotTopics/PSSA/Pages/default.aspx.

IMO. 2015b. *Prevention of Air Pollution from Ships* [Online]. Available: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx [Accessed 20 May 2015 2015].

LANDELL, N.-E. 1969. *Välfärd till döds ?(Wellfare to death?),* Stockholm, Bonniers.

LIAO, C., CARLSSON, CHRISTOFFER. 2015. *Oljeprisets påverkan vid val av system for att möte SECA kraven (The influence of oil price in selection of system to meet SECA demands).* Marine Engineer B Sc thesis, Chalmers University of Technology.

LLOYDS REGISTER MARINE 2014. Using hybrid fuels for ECA-SOx compliance. Operational guidance for shipowners and operators.

METHANEX. 2015. *Methanex posts regional contract methanol prices for North America, Europe and Asia* [Online]. Available: https://www.methanex.com/our-business/pricing [Accessed 27 October 2015.

.

PETROL BUNKERING AND TRADING. 2015. *Price information* [Online]. Available: http://www.petrolbunkering.com/price-information/ [Accessed 26 October 2015.

SMITH, T. W. P. J., J. P.; ANDERSON, B. A.;, CORBETT, J. J. F., J.; HANAYAMA, S.; O'KEEFFE, E.; PARKER, S.; JOHANSSON, L.; ALDOUS, L.;, RAUCCI, C. T., M.; ETTINGER, S.; NELISSEN, D.; LEE, D. S.; NG, S.; AGRAWAL, A.; WINEBRAKE, J. & J.; HOEN, M. C., S.; PANDEY, A. 2014. Third IMO GHG Study 2014. London, UK: International Maritime Organisation (IMO).

STOPFORD, M. 2008. *Maritime economics, 2nd ed.,* London, Routledge.

SU, L.-W., LI, X.-R. & SUN, Z.-Y. 2013. The consumption, production and transportation of methanol in China: A review. *Energy Policy,* 63**,** 130-138.

SVENSSON, E. 2014. *Sulphur Regulations for Shipping - Why a Regional approach?: Scientific and Economic Arguments in IMO Documents 1988-1997.* Doctor of Philosophy Doctoral thesis, Chalmers University of Technology.

TALJEGÅRD, M., BRYNOLF, S, HANSSON, J, HACKL, R, GRAHN, M, ANDERSSON, K 2015. Electrofuels - a possibility for shipping in a low carbon future. *SCC- Low Carbon Shipping.* Glasgow.

TRICAS AIZPUN, A. 2015. Clean power for transport initiative. The 2030 energy and climate policy framework. The directive on the deployment of alternative fuels infrastructure. *Methanol Policy Forum Europe 2015.* Brusseles: EC.

WORLD PORTS CLIMATE INITIATIVE. 2015. *LNG fuelled vessels - LNG prices* [Online]. Available: http://www.lngbunkering.org/lng/business-case/lng-pricing [Accessed 20 October 2015.