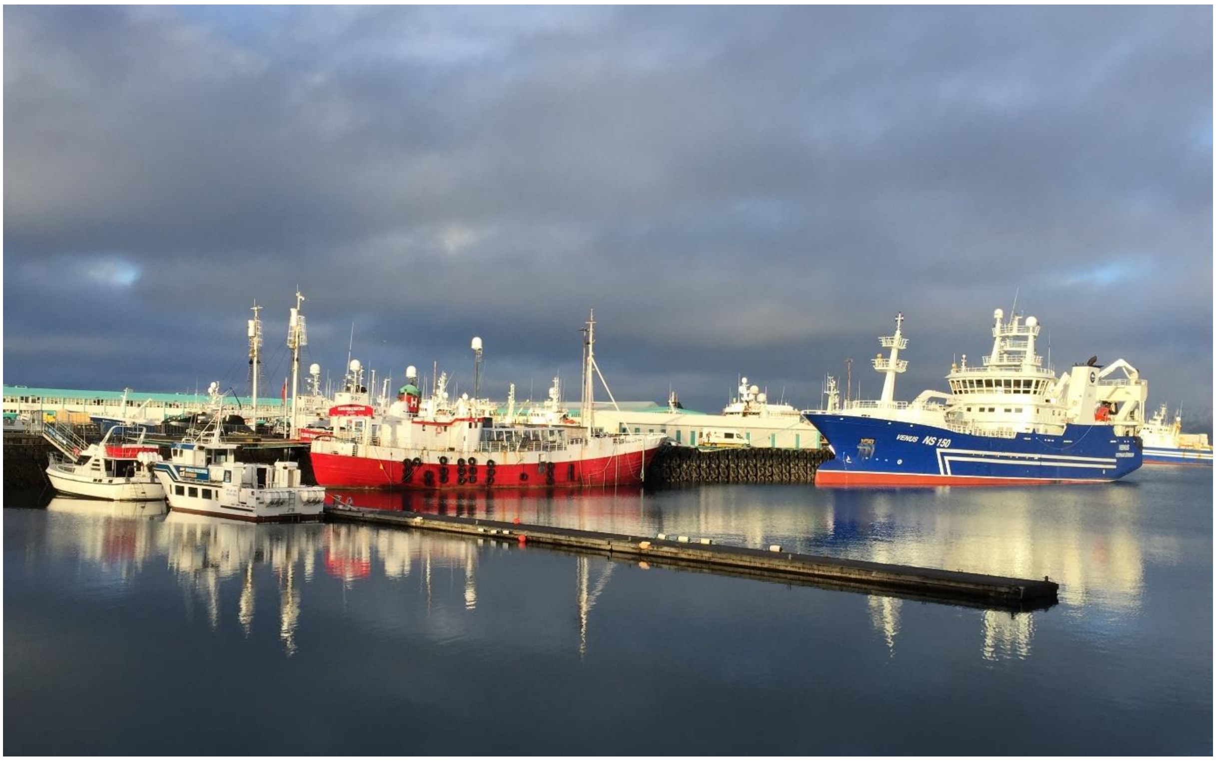

Best case practices in Nordic harbours for eco-friendly fuels
– Project report

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Icelandic New Energy

Hafið - Icelandic Centre of Excellence for Sustainable Use and Conservation of the Ocean

Nordic Marina

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1. Introduction

An immediate challenge is facing industry, policy makers and the wider global community to meet climate change objectives, deliver a cleaner environment and address local air quality concerns while serving increasing energy consumption and meeting human requirements for living.

The maritime industry has been making great efforts to develop and adopt measures to comply with Annex VI of MARPOL (International Convention for the Prevention of Pollution from Ships) which came into force on January 1, 2015 in the Baltic and North Seas. The main goal being the reduction of emissions, mainly of sulphur, scrubbing technology is an option as is adopting althernative fuels over conventional fossil fuels. Other important drivers include counteracting climate change and meeting general sustainability requirements which today are becoming the norm.

With the aforementioned regulations to limit sulphur (SOx) emissions, various alternatives have been discussed as contenders such as low sulphur diesel oil, hydrogen, methanol, LNG, electric propulsion, biodiesel and more. Strategic planning to reach emission reductions is necessary but offering economically viable and socially beneficial solutions is equally important. Also, in order to emerge as a realistic and feasible marine fuel or energy carrier, the alternative requires infrastructure and bunkering in ports. The supply of clean fuels to ports in the North Atlantic must be considered as well.

Finally, for shipping to achieve carbon reduction strategy conforming to the Paris Agreement, zero emission vessels will probably need to enter the fleet in 2030 and make up a significant proportion of newbuilds from then on.

There are several alternatives to fossil fuels being implemented in the Nordic regions today. No one of those shows promise of substituting for all fossil fuel use as alternative fuels have different attributes with regard to; availability and infrastructure needs, energy content, storage requirements, security, safety as well as special training requirements for handlers and emergency responders.

This report provides a selection of best practice cases for several alternative marine fuel and energy solutions in the Nordic countries.

2. Methodology

Available networks were activated to gather information on alternative fuel implementation in the Nordic regions. Through this, best practice examples were chosen from the attainable project information. The focus was set on harbour infrastructure, fuel/energy supply and implementation on ships. The aim was to gather information on practical, hands-on solutions to put forward successful projects representing each of the chosen alternative fuel and energy solutions. Specialists were consulted and provided valuable input and information regarding their respective areas of expertise.

3. Alternative fuel types, energy and infrastructure

3.1. Methanol

Methanol is an alcohol, commonly used in industry and transported widely in the world. Methanol has been proven as a viable marine fuel with far less emissions of NOx and very little SOx and particulate matter. Methanol is a liquid fuel and thus, can be stored in conventional ship fuel tanks, with few modifications to the fuel piping and seals.

In the Nordic countries, Methanol is widely produced, mainly from biomass and natural gas but also from CO_2 capture and electricity, as with Carbon Recycling International in Iceland producing sustainable methanol – Vulcanol. Through a test project with cars running on methanol, a test pump delivering methanol to cars has been running well in Reykjavik, Iceland since early 2016.

Case: Pilot project for methanol as a marine fuel on ferry in Gothenburg

Methanol as a marine fuel has been tried and tested in praxis on board car and passenger ferry Stena Germanica which runs on the route between Gothenburg, Sweden and Kiel, Germany where each of the ship´s four Wärtsilä engines have been converted, one after the other, to run on methanol.

Figure 1 Methanol bunkering facilities for the Stena Germanica in Gothenburg

Project name: Stena Germanica
Location:Runs between Gothenburg, Sweden and Kiel, Germany
Operation date: Project launch March 2015 – ongoing
Project partners: Stena Lines, Methanex, Wärtsilä
Capacity: 4 x Wärtsilä eight cylinder engines of 24.000 kW propulsion power output[1]
Further information: https://www.stenalinefreight.com/news/Methanol-project

Methanol is being established as sensible choice for a marine fuel. The technology has been developed for larger engines and projects are working towards bringing methanol engines for small to medium sized ships to the market. Experience in transporting and handling methanol as a chemical needs to be passed on and implemented in relation to fuel bunkering and handling as fuel for ships. This has been done successfully for the Stena Germanica. Stena built a bunkering station with pumps that is supplied with methanol from trucks from a methanol terminal in Malmö in southern Sweden. Hopes are up for a methanol terminal in Gothenburg, which will be realistic as soon as at there is at least one additional ship bunkering methanol. All methanol bunkering infrastructure for the Stena project is in one place, at the Majnebbe harbour in Gothenburg[2].

Although not based in the Nordic countries, an important pioneer in establishing methanol as a marine fuel is Waterfront Shipping, a global shipping company transporting bulk chemicals and running 7, 50.000 dead weight tonne methanol tankers on methanol as all seven tankers have dual-methanol/oil engines. One year after the ship launch, Waterfront Shipping celebrated that by april 2017, 2 of its ships had run over 3000 hours on methanol as a fuel. This operation uses existing infrastructure and facilities already in place, for bunkering, with safety and security measures taken care of based on decades of experience in handling methanol as a chemical in transit[3].

3.2. Liquid natural gas - LNG

LNG as a fuel is a proven, commercial solution for marine transport. In 2015, 150 ships LNG fuelled ships were in operation or on order[4] and presently, the fuel is used by ferries, coastal vessels and container ships alike. LNG is believed to be a strong contender to replace conventional oil-based fuels due to its significant contribution to the reduction in local air pollution, by eliminating sulfur (SOx) and particulate (PM) emissions, and reducing CO_2 by 20-25% and nitrogen oxides (NOx) by 75-90%.

[1] http://www.ship-technology.com/projects/stena-germanica-ropax-ferry/

[2] Per Stefenson, Stena Teknik, 2017, electronic communication

[3] https://www.methanex.com/sites/default/files/news/1YearOfMethanolVessels.pdf

[4] http://production.presstogo.com/fileroot7/gallery/dnvgl/files/original/124feddb807045969b3071a55f73c80b/124feddb807045969b3071a55f73c80b_low.pdf

According to the International Gas Union, Europe had a liquefaction capacity of 4,76 Mmty (millions metric tonnes, per year) with a planned capacity of 19,1 in 2014 (planned projects till 2023)[5], corresponding to 1,6% and 1,75% of the global capacity, respectively. Europe's reserves are estimated to be 2% of the global total proven reserves of natural gas[6]. Global natural gas resources are abundant and increasingly geographically diverse though for conventional gas resources, they are concentrated in Eurasia and the middle east. It is estimated that there are sufficient technically recoverable natural gas resources to last for at least the next 235 years relative to current production levels. Infrastructure is widely available, in the form of a well developed network of transmission pipelines, over 2.8 million km globally, allowing for transport from production regions to markets and consumers.

Case: Pilot project to promote the use of LNG fuel in Hirtshals, Denmark

The case selected to highlight for supply of LNG as a marine fuel is the port of Hirtshals in Denmark. This is Denmark's first LNG tank and bunkering facility. Its main customer for the fuel is Fjord Line, a Norwegian shipping company operating two ferries, MS Stavangerfjord and MS Bergensfjord, across the Skagerrak strait to Norway. The ferries are also able to bunker in Risavika on the western Norwegian coast. The ferries were the first cruise ferries in the world to run exclusively on liquified natural gas. The impetus for the project was the 2015 MARPOL Annex VI 0.1% limit on sulphur levels in maritime fuels and the goal to impact shipping throughout Scandinavia. Hirtshals was already a major transport hub for shipping in the Baltic region, optimally located at the top of the Jutland peninsula of Denmark. An estimated 100,000 vessels pass through the strait on an annual basis.

Figure 2 LNG bunkering station in Hirtshals

©https://www.lngworldnews.com/denmarks-first-lng-bunkering-facility-opens/

[5] https://www.igu.org/sites/default/files/Part%203%28Oct14%29-%20LNG.pdf

[6] https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf

Project name: Pilot project to promote the use of LNG fuel: Installation of 200 tonne LNG tank and filling facility at the port of Hirtshals, Denmark for fuelling of passenger/cargo vessels with a view to later establishment of a larger tank at the port Location: Hirtshals, Denmark Operation date: July 2015 Project partners: Port of Hirtshals, HMN Gashandel A/S and Fjord Line AS Design and construction: Liquiline LNG, with Intergas AS as project managers along with HMU A/S and Rambøll A/S as consulting engineers Capacity: 500 m^3 of LNG, 200 m^3/hr Financial support: MEUR 1.3 from EU TEN-T program Further information: https://ec.europa.eu/inea/ten-t/ten-t-projects/projects-by-country/denmark/2013-dk-92060-s

The LNG bunker facilities in Hirtshals consist of a 200 ton LNG storage tank and equipment. The tank can be filled from either LNG tanker trucks or from LNG tanker ships. LNG fuel is transported from Norway but it is also available from the GATE terminal in Rotterdam.

Feasibly, this facility will lead to an LNG installation on a larger scale in the Hirtshals region. This may also allow the port to become an important link for LNG transport from major production facilities within the region and evolve into a Scandinavian logistics centre.

This may be only the first step for the port of Hirtshals. Following the success of the installation of the bunkering facilities, Fjord Line hopes to set in motion its follow up steps in a five year green strategy, to install an LNG liquifaction plant. This would allow for easy access to the fuel in a growing market and bring the price down.

3.3. Biodiesel

Biodiesel is generally processed from renewable soybean or rapeseed oil and other vegetable oils or recycled cooking oil through a simple refining process. The potential for oils and fats has been tested by the automotive sector for a number of years and some types of biodiesel have been tested in marine applications, mostly as a blending component in for marine diesel oil.

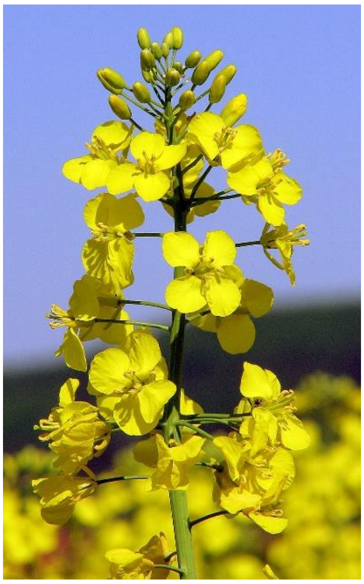

Figure 3 Rapeseed

©https://en.wikipedia.org/wiki/Rapeseed#/media/File:Brassica_napus_2.jpg

Biodiesel is essentially free of sulphur and aromatic compounds, and this is its greatest environmental benefit. It may, however, increase NOx emissions, depending on the type, design and age of engines used. Little or no modifications are required prior to running an existing diesel propulsion system on biodiesel or a blend thereof, making it a good candidate as an alternative marine fuel. Biodiesel has been most commonly used in blends of up to 5 or 20% but the main limits for its use remain cost and availability.

There are however characteristics of biodiesel that potentially affect safety in marine applications. These concerns include inconsistent quality, impact on engine seals, disadvantageous hydrophilic properties, cold weather flow drawbacks, and imperfect storage qualities in a marine environment over a period of time. Still, the properties of finished biodiesel depend heavily on the feedstock used. These properties can include Cetane number, cold flow, and stability.

Case: Ecocoaster

In 2016 Meriaura Group and partners Foreship Ltd and Aker Arctic Technology Inc. designed and had a new ship concept built. The VG EcoCoaster^{TM} is an energy efficient dry cargo carrier, capable of running on alternative fuels. The objective of the project was to design a vessel meeting all the upcoming maritime environmental regulations, including Annex VI of MARPOL, and halving the fuel consumption compared to conventional short sea cargo vessels of similar type and size.

Project name: VG Ecocoaster^{TM}

Location: Turku, Finland

Operation date: October, 2016

Project partners: Meriaura Ltd., Foreship Ltd., Aker Arctic Technology Inc and VG-Shipping

Capacity: 5000 DWT

Further information: http://www.meriaura.fi/en/company/vg_ecocoaster

In October 2016, the first of two EcoCoasters ships was delivered, the second followed a few weeks later. The ship's engines are suitable for marine gas oil and biofuel but run on a proprietary biofuel known as VG Marine EcoFuel. It is produced using solely bio and recycled oils based on local waste materials, in the Uusikaupunki refinery in Finland, owned by VG-Shipping. Currently, the Meriaura fleet consumes the entire production but in the long term, the EcoFuel product will be made available to other vessel operators. As for Meriaura's short term plan, the goal is for 50% of its fleet to be made up of the fuel efficient and low emission EcoCoasters by 2020, a veritable and ambitious target.

3.4. Electricity

Shore power infrastructure for small to medium sized ships has been established widely in the Nordic countries and there is no technical barrier in this. The main obstacles to be tackled are the power grid strengthand power availability at each location, infrastructure for shore power connections and electricity sales in harbour both for port stay periods for conventional ships but also charging facilities for electrical and hybrid ships. A concensus has not been reached on a single connection technology which may pose a problem for ships sailing worldwide or between areas as investing in an on-board installation for shore power connections that will not fit as a universal plug. Harbour regulations are though, in different areas, pushing for no combustion when ships are in port with price incentives, preferred pier areas, faster service and partly by obliging ships to connect where connections are available and fitting.

Shore power availabiltiy has a direct effect on emissions in harbour and thus also on local air quality. Traditional harbours tend to be centrally located in cities which emphasizes the importance of minimizing emissions.

Norway has been leading in relation to shore power connections, both with regard to infrastructure buildup and general implementation of connections for shore power on board ships[7]. Bergen harbour has been active in connection buildup and collaboration with ships with regular berthing time in the harbour such as oil rig supply ships and passenger ships.[8] Bergen harbour and Hurtigruten, a daily passenger and freight shipping service on Norway's coast that also offers Explorer voyages in the Arctic and Antarctica, have signed an aggreement of intent with Bergen harbour to enable Hurtigruten's

Figure 4 Bergen harbour ©Bergen havn

7 http://www.ksbedrift.no/media/1537/undersoekelse-om-markedsgrunnlaget-for-landstroem-oed-enova-dnv-gl.pdf
8 http://bergenhavn.no/onshore-power-supply-ops/

ships, that stay at berth in Bergen for 8 hours every day during winter time and 5 ½ hours in summer to connect to shore power. Hurtigruten's ships will be equipped with connections for shore power and Bergen harbour will aim to supply the power.
Hurtigruten is also encouraging other ports to follow Bergen's lead on shore power connections[9]. Furthermore Hurtigruten has commissioned two new explorer cruise ships with hybrid electric power, see case below.

Case: Hurtigruten hybrid-electric explorer cruise ships

Early in 2016, Hurtigruten explorer cruise company announced its plans to modify several of its vessels for shore power connections and in October 2016 announced the construction of two new hybrid electric powered expedition ships to be delivered in 2018 and 2019. These first ships will be able to sail for 15 – 30 minutes on electric propulsion, thus leaving harbour with minimal emissions. This electric propulsion time is expected to increase with new ships to follow[10].

Project name:Hurtigruten MV „Roald Amundsen" (2018) and MV „Fridtjof Nansen" (2019)
Location: Norway, adapted for sailing the Norwegian fjords and in Arctic and Antarctic waters
Operation date: Project announcement October 2016, estimated launch of first ship in 2018
Project partners: Hurtigruten
Design and construction: Rolls Royce, Espen Öino and Kleven Yards
Capacity: 530 passengers, 140 meters
Estimated emissions gain: Cutting fuel consumption and CO_2 emissions by 20%
Further information: https://www.hurtigruten.com/about-us/news/new-hybrid-explorer-ships/

3.5. Hydrogen

As an alternative fuels option for shipping, fuel cells and hydrogen are a promising technology, especially within the framework of zero emission and clean power sustainability. Hydrogen can be produced from (renewable) electricity and from carbon abated fossil fuels. The deployment of fuel cell power production is a means by which to eliminate NOx, SOx and particle emissions (PM), greatly reduce CO_2 emissions (when derived from carbon fuels) or even provide zero carbon emission ships (using hydrogen generated from renewables).

The world produces and consumes over 55 Mt of hydrogen on an annual basis in a range of industrial processes. Hydrogen has, however, not been widely used as a marine fuel but various developments are currently available and several research and pilot projects have been ongoing over the past 10-15

[9] https://www.hurtigruten.com/about-us/news/hurtigruten-modify-ships-for-shore-power/
[10] https://www.hurtigruten.com/about-us/news/new-hybrid-explorer-ships/

years. Many of these have revealed a strong potential for further implementation and scaling up. The technology itself is not a large business and thus expensive. Aside from the technological aspect, the availability is also an issue, as liquid hydrogen is not produced on a large scale in Europe and the demand is waiting for the infrastructure. Here policy shifts and instruments may prove to play important roles in giving the push needed to solve this problem.

Case: Zemships

To date, the Nordic countries have seen few projects demonstrating fuel cells as a source for propulsion, either along side diesel or LNG but no vessel running solely on hydrogen though numerous projects are underway (see next page for examples).

In Hamburg, the FCS Alsterwasser, a tourist boat powered by two 48 kw fuel cell systems sailed the Alster, an inland lake, from 2008-2013. It was the world‘s first hydrogen inland passenger vessel, providing a noiseless, pollutionless tour for 100 passengers over the Alster and surrounding channels. It stored up to 50 kg gaseous hydrogen at 350 bar, a supply sufficient for three days of transport, in addition to an alternative power source if needed, a 560 V lead-gel battery[11].

Project name: Zemships
Location: Hamburg, Germany
Operation date: August 2008
Project partners: ATG Alster Touristik, Germanischer Lloyd, Hamburg University of Applied Sciences, HOCHBAHN, hySOLUTIONS, Linde Group, Proton Motor, UJV Nuclear Research Institute
Design and construction: Liquiline LNG, with Intergas AS as project managers along with HMU A/S and Rambøll A/S as consulting engineers
Capacity: 48 kW fuel cell, 50 kg gaseous H_2 in twelve 350 bar tanks
Financial support: MEUR 2.4 from EU LIFE06 program
Further information: https://ec.europa.eu/inea/ten-t/ten-t-projects/projects-by-country/denmark/2013-dk-92060-s

A hydrogen refuelling station (HRS) for the boat was built at a depot of Hamburg‘s public transport company Hochbahn, near Hamburg‘s city centre, with hydrogen being taken directly from a liquid hydrogen storage tank. Transit of the Alsterwasser from its mooring location to the refuelling station required about 30 minutes. The FCS Alsterwasser was retired when its HRS closed due to economic reasons in 2013.

[11] http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=Zemships_Brochure_EN.pdf

Figure 5 FCS Alsterwasser
©http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=Zemships_Brochure_EN.pdf

This is a clear example of the complications involving infrastructure for alternative fuels. In this case, the HRS was built and used only by the FCS Alsterwasser, a venture clearly not economical, serving one customer every three days. Government support required as project funding is generally limited to the project timeline.

Moreover, though this refuelling arrangement was useful for this small demonstration boat, deep sea vessels would face a challenge with regard to refuelling and availability of infrastructure.

There are several larger scale projects underway involving hydrogen fuel cell technology to power marine vessels.

- Viking Cruises plans to build the world‘s first cruise ship fueled by hydrogen, accommodating more than 900 passengers and 500 crew. Discussions are ongoing with fellow Norwegian company Statoil to produce the hydrogen the vessel requires.
- Norway‘s Fiskerstrand Holding AS has set a goal of delivering a hydrogen powered ferry by 2020 as part of a wider project, HYBRIDShips.
- Royal Caribbean Cruises is working to integrate a fuel cell module on one of its Icon-class vessels, the first fuel cell system piloted on a cruise ship. The 100 kW device will be used to cover the vessel‘s hotel load during port calls. The long term goal remains using a fuel cell as the main propulsion application.
- In late 2016, Royal Carribbean Cruises announced plans for two newbuilds powered by LNG and fuel cell technology. These are set for delivery from shipbuilder Meyer Turku in 2022 and 2024.

4.Discussions

Encouraging development is underway with regard to alternative fuels and fuel infrastructure in harbours in the Nordic countries. This development relies heavily on the private sector and available funding programs. Government initiatives are vital to ensure further implementation and strengthen the use of alternative fuel and energy solutions for the shipping sector. This is important for society on several levels as reducing emissions in general is an essential task as well as ensuring safe air quality in harbour communities and to contribute to the sustainability of global shipping. A common concern among the different players is the call for collective action in infrastructure build up, investment in technology and fuel availability as well as clarification of the regulatory framework and coordination of responsibility of government bodies.

Work on this project of *Best Practices in Nordic Harbours for Eco – Friendly Fuels* has been encouraging as there are numerous successful projects as well as promising development towards the future. Several technologies are at, or on the brink of, commercialization and with the aforementioned means of support and government action, those will provide much needed mitigation options. With collaboration the Nordic countries will remain at the forefront in the development and adoption of alternative energy and fuel initiatives as we approach significant milestones for regional and global emission reduction commitments.