The Transformative Role of Floating Container Terminals in Sustainable Supply Chains and Climate Resilience

The Sea Tech Floating Terminal, developed by Sea Technology.

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Sea Technology

With over 75 years of experience in improving the maritime industry - our passion and knowledge is vast and strong. During the recent years, Sea Technology have been developing a new floating infrastructure with a strong sustainable approach - revolutionizing the Blue Ocean Economy, The Sea Tech Floating Terminal (The STFT). The STFT is a full-service floating container port & potential energy node with full automation – floating and ocean based. Strategic positions of the STFTs will serve as a HUBs assisting several ports in several regions in different countries. At the same time other industries such as busy with green energy transition can utilize the platform as an energy node.

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Partner Network

During the time for this research project, and also since the starting phase, a valuable partner network has been formed. Several stakeholders have participated in interviews and provided useful information for this project. In the partner network we have international ports representative, terminal operators, stakeholders in the green energy transition, and suppliers of intended equipment for a terminal.

Prior to the starting point of the research project, team Sea Technology had already a good base of partners. Just to mention a few there are the South Korean Shipyards like DSME, Kongsberg Maritime, Trelleborg, Aker Solution, Liebherr Cranes, Cargo Tech OY, Alfa Laval, Blykalla, Core Power, Terrestrial Energy, MAN Germany and Knud E. Hansen. They have been valuable in contributing to and validating findings in the project.

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Glossary

EMSA - European Maritime Safety Agency.

Energy Sector Stakeholders - Including renewable energy companies and infrastructure developers, involved due to FCTs acting as potential hubs for renewable energy (wind and wave energy).

Environmental Groups - Advocacy groups focused on minimizing pollution and habitat disruption from maritime operations, ensuring that Floating Container Terminals (FCTs) meet strict environmental standards.

FCT - Floating Container Terminal.

Feeder Vessel - Smaller ships that transport cargo between smaller ports and major ports.

FNPP - Floating Nuclear Power Plant.

Governments and Regulatory Bodies -These stakeholders are responsible for maritime safety, environmental regulations, and economic policies affecting international shipping and port operations. They play a critical role in licensing, regulatory approvals, and oversight of FCT operations.

IMO - International Maritime Organization.

Investors and Financial Institutions - Entities that fund the development and deployment of FCTs, including banks, investment groups, and public funding initiatives.

Local Communities - Stakeholders in terms of local employment, environmental impact, and economic benefits from port activities.

Maritime Companies - Include shipping companies, operators of floating platforms, and companies specializing in maritime infrastructure.

New Panamax - A ship sized to enter the new Panamax channel (51.25 m/168 ft).

Panamax- A ship that is sized to enter the old Panama channel (32.31 m/106 ft).

Port Authorities – Local and international authorities interested in integrating FCTs into existing port networks while balancing traditional operations.

Supply Chain and Logistics Companies - Companies that depend on efficient and reliable port operations and are impacted by FCTs in terms of operational strategies and cost structures.

TEU - Twenty-foot Equivalent Unit; standard container dimensions are 20ft x 8ft x 8ft, usually holding 9 to 11 pallets and weighing about 8,000 pounds.

Technology Development Partners and R&D Institutions - Research and development play a pivotal role in evolving the FCT concept into a viable logistical solution. Partnerships with academic institutions and research bodies are essential for continuous innovation and addressing technical challenges.

The Blue Ocean Economy - Refers to the oceans' contribution to economies, the need for environmental and ecological sustainability, and the ocean economy as a growth opportunity.

The STFT - Sea Technology Floating Terminal, a specific solution to FCT developed by Sea Technology with a 24/7 – continuity in supply of electricity 24 hours a day and seven days a week

The STFTe - A version of the STFT exclusively developed to handle electricity in large amounts with a 24/7 continuity in supply of electricity 24 hours a day and seven days a week

ULCV - Ultra Large Container Vessel, over 18000 TEU.

Executive Summary

In the 15th century the port of Rotterdam was a small fishing port. Today the Port of Rotterdam is number ten on the list of the few ports in the world that can take on the Ultra Large Container Vessels, the ULCVs. Trade is the backbone of many economies and the continues globalisation points to the fact the ULCVs are just in the beginning of demonstrating their huge potential. It is estimated that 80-90 % of global trade travels on the ocean. It is believed that the next generation of ULCVs will reach up to 30, 000 TEUs.

There are many advantages of using the ULCVs and cost savings is one of them, up to 30 % cost savings can be achieved by the efficiency of the modern ULCVs. However, this of course requires enough ports that can handle the depth, the technical requirements of long berths, cranes and the know-how plus the speedy services that these vessels require. During the summer of 2024, there was up to 30 days waiting to access port in Singapore, one of the largest trans-shipment ports in the world. This translates into massive costs both financially and environmentally. The lack of sufficient modern port infrastructure poses a big problem and just maintaining current operations comes at a high price – in many touchpoints. It is also so, that the ports of tomorrow needs to be able to play their role in the green energy transition.

A solution to the current locked in land-port infrastructure is to add capacity through a system of Floating Container Terminals (FCTs) such as the Sea Tech Floating Terminal (the STFT), to the supply chain. In April 2023 RISE and Sea Technology teamed up and were awarded funds by the Swedish transport administration (Trafikverket), to explore which role FCTs can play in future proofing global trade, the green energy transition, with special consideration to Swedish trade and the position that Sweden has in Northern Europe.

Timing is a crucial aspect when it comes to implementing new and innovative technology. After having deep dived in interviews with stakeholders we have unfolded many interesting aspects. It is our conclusion that the regulatory framework, the mitigation of risks in addition to the clear business opportunity combined with significant improved environmental footprint do point to the fact that the timing for FCTs is here taking into consideration both the challenges and opportunities. This report explores the maritime industry's interest and cautious optimism regarding FCTs, emphasizing potential benefits and challenges. A review of literature and interviews highlights key drivers—such as security, financial viability, and trust—and barriers to adoption.

Sweden, particularly the west coast, could benefit from FCTs to address Northern Europe’s logistical challenges. For instance, an FCT like the STFT in Kattegat could alleviate road transport congestion, increase capacity for the Port of Gothenburg without dredging, and optimize cargo movement with fully loaded ULCVs to transfer cargo to feeder ships. FCTs could thus potentially strengthen Nordic and Baltic supply chains, open new routes, and promote green initiatives, like offshore wind production.

In conclusion, the limitations of land-based ports, such as the port of Rotterdam and several others, combined with growing ULCV sizes, trade demands, population growth, and environmental regulations, underscore the need for transformative infrastructure. FCTs could play a critical role, offering a sustainable, flexible alternative and extension to traditional ports. With timing favourable and regulatory and environmental drivers in place, FCTs like the STFT present a viable solution to evolving supply chain needs.

Sammanfattning på svenska

Under 1400-talet var Rotterdams hamn en liten fiskehamn och Idag är Rotterdams hamn nummer tio på listan över de få hamnar i världen som kan ta emot Ultra Large Container Vessels (ULCVs), de allra största containerfartygen. Handel är ryggraden i många ekonomier och den fortsatta globaliseringen pekar på att ULCV:er bara är i början av sin utvecklingsresa.

Det uppskattas att ca 80–90 % av den globala handeln färdas över haven. Det förväntas att nästa generation av de stora containerfartygen kommer att nå upp till 30 000 TEU. Det finns många fördelar med att använda de riktigt stora containerfartygen och kostnadsbesparingar med upp till 30 % är en av dem som uppnås genom effektiviteten hos de moderna ULCV:er.

Detta kräver dock tillräckligt med hamnar som kan hantera det djup som fartygen behöver, som också kan leverera de tekniska kraven på långa kajplatser, samt erbjuda tillgängliga tjänster som dessa fartyg kräver. Under sommaren 2024 var det upp till 30 dagars väntetid för att få tillgång till hamn i Singapore, en av världens största omlastningshamnar. Detta översätts till enorma kostnader både finansiellt och miljömässigt.

Bristen på tillräcklig modern hamninfrastruktur utgör ett stort problem och bara att upprätthålla nuvarande verksamhet kommer till hög kostnad utifrån flera perspektiv. Det är också så att morgondagens hamnar måste kunna spela sin roll i övergången de nya kraven på fossilfria energilösningar. En lösning på den nuvarande inlåsta infrastrukturen med landfasta hamnar är att lägga till kapacitet genom ett system av flytande containerterminaler (FCT) med fokus på omlastning, såsom ”The Sea Tech Floating Terminal” (STFT), till försörjningskedjan. I april 2023 samarbetade RISE och Sea Technology och fick medel av Trafikverket för att utforska vilken roll FCT kan spela för att framtidssäkra global handel, den gröna energiövergången, med särskild hänsyn till svensk handel och Sveriges position i Nordeuropa. Tajming är en avgörande aspekt när det gäller att implementera ny och innovativ teknologi.

Efter att ha djupdykt i intervjuer med intressenter har vi upptäckt många intressanta aspekter. Vår slutsats är att regelverket, riskminimering i kombination med tydliga affärsmöjligheter samt ett betydligt förbättrat miljöavtryck pekar på att tiden för FCT är här, med tanke på både utmaningar och möjligheter. Denna rapport utforskar sjöfartsindustrins intresse och försiktiga optimism när det gäller FCT med betoning på potentiella fördelar och utmaningar. En genomgång av litteratur och intervjuer lyfter fram nyckelfaktorer som säkerhet, ekonomisk bärkraft och trovärdighet som exempel på hinder för genomförande. Sverige, särskilt västkusten, skulle kunna dra nytta av FCT för att hantera logistiska utmaningar i Nordeuropa.

Till exempel skulle en FCT som STFT i Kattegatt kunna mildra trängseln på vägtransporter, öka kapaciteten för Göteborgs hamn utan muddring och optimera godstransporter med fullt lastade ULCV:er för att överföra last till federfartyg. FCT skulle därmed potentiellt kunna stärka de nordiska och baltiska försörjningskedjorna, öppna nya rutter och främja gröna initiativ, som havsbaserad vindkraftsproduktion. Sammanfattningsvis, begränsningarna med landbaserade hamnar, såsom Rotterdams hamn och flera andra, i kombination med växande ULCV-storlekar, handelskrav, befolkningstillväxt och miljöregleringar, understryker behovet av transformativ infrastruktur. FCT skulle kunna spela en avgörande roll, och erbjuder ett hållbart, flexibelt alternativ och tillägg till traditionella landfasta hamnar.

Med gynnsam tajming med regelverk och miljömässiga drivkrafter på plats, presenterar FCT som STFT en genomförbar lösning för att möta utvecklande behov i försörjningskedjor.

Table of contents

1. Introduction

Global trade continues to expand, and a well-functioning transport system is essential for the movement of goods around the world. Shipping currently accounts for about 80-90 percent of all goods transported globally. To ensure cost-efficient and reliable global supply chains, well-functioning ports are needed for the efficient trans-shipment of goods. Large ports face several challenges, and this report will describe how strategically located floating container terminals at sea (FCT), used as trans-shipment hubs, can be used to potentially overcome a number of challenges and problems that ports and global shipping in general face today.

One of the key challenges for both individual ports and global port systems is port congestion. This problem is widespread, affecting many ports around the world. As container volumes continue to grow, many ports find themselves struggling to manage the increased traffic. Limited space for expansion makes it difficult for these ports to accommodate the rising demand. The congestion problem in ports causes delays, longer turnaround time for ships and higher costs. These are key factors for shipping lines in their port selection (Martínez Moya and Feo Valero, 2017), making ports less attractive. This problem will likely not decrease, as container volumes continue to increase.

Another significant issue is the negative environmental impact of shipping in port areas, which includes air and water pollution, ecosystem destruction, and the strain on land infrastructure, leading to increased particulate pollution and noise. There are increasing regulatory pressure for ports to adopt greener practices, mainly driven by regulations stipulated by the international maritime organisation (IMO) (Lam and Notteboom, 2014). While ports are implementing various initiatives to promote sustainability, the most effective way to minimize these impacts is by reducing traffic volumes.

Port authorities may face challenges, as ports are often located in areas where land is expensive and must contend with competing interests from both residential and commercial developments. With the increased urbanization and densification of cities, this competition is likely to intensify. Consequently, if ports are relocated to non-urban areas, the valuable land they once occupied can be repurposed for other uses.

As the size of mega vessels continue to grow, water depth becomes a significant challenge for ports. Insufficient depth can limit access for these large ships, necessitating costly dredging. This not only requires substantial financial investment, such as 270 million USD for port of Gothenburg dredging to enable them to unload the biggest container ships, but also raises environmental concerns regarding sediments and ecosystem impact.

One innovation that has the potential to address these challenges is a floating platform at sea, which can handle containers and serve additional purposes, such as functioning as an energy node. Deploying an FCT a few miles offshore could enable large ships to unload and trans-ship cargo to smaller feeder ships servicing smaller regional ports. From a systems perspective, this set-up could be cost-effective, subject to certain conditions such as density of transport network and local transport geography (Souravlias et al., 2020, Kurt et al., 2021, Baird and Rother, 2013, Kim and Morrison, 2012). Furthermore, an FCT may offer environmental benefits, as dredging can often cause significant environmental consequences and conventional emissions in port areas are reduced amongst several other aspects as particle pollution, risk of accidents and noise.

An FCT can potentially serve multiple functions beyond traditional shipping activities, including distribution, storage, and the production of green energy, e.g. act as an energy hub. This encompasses not only wave energy, wind energy, but could potentially also be suitable locations for small modular reactors (SMRs), contributing to energy production generation but also maintenance support for offshore wind farms, as well as aquaculture industries (Tamis et al., 2021, Flikkema and Waals, 2019). Ports are increasingly recognized as key energy nodes in the broader energy transition (Acciaro et al., 2014). Floating energy hubs could have the potential to facilitate intermediate storage and distribution of energy in various forms.

Over the last decade, the concept of FCT has gained interest in scientific literature and in large research projects like the Horizon-2020 funded Space@Sea (Flikkema and Waals, 2019). Additionally, besides being researched in the scientific literature, the topic FCT and different types of offshore ports has been investigated in several cases around the world over the last decade, for example, outside the USA, outside Italy, and in Bangladesh. Details regarding their initiation is stated in the grey literature, e.g. for Chittagong port development see Figdor et al (2020). However, all of these seem to have stalled, though the underlying reasons have not been officially reported.

Despite its potential benefits, implementing an FCT in the current maritime linear shipping networks is a huge challenge. The FCT both need to be financially viable, e.g. offer trans-shipment cost at a price that makes it attractive. Secondly, as the FCT will compete with existing ports, or integrated in existing port networks, port choice from the perspective of other actors needs to be understood, see e.g. Martínez Moya and Feo Valero (2017).

Despite significant interest in floating ports, the concept has yet to be fully realized. Therefore, a deeper analysis of FCT or floating structures as energy hubs from a supply chain perspective is necessary. In response, **the aim of this project is to further develop the concept of an FCT.**

The rest of this report is structured as follows:

Chapter 2 presents the background, summarizing key trends in global maritime supply chains that will influence the use of FCT. Furthermore, over the past decade, various authorities worldwide have shown interest in FCTs, and these cases are described. Additionally, the chapter introduces how the STFT historically has been developed by the company participating in the research project (Sea Technology). Finally, based on an extensive literature review, the chapter outlines the various drivers and barriers to the adoption of FCT.

Chapter 3 provides a brief overview of the main methodologies used in the project, including semi-structured interviews, functional analysis, quantitative analysis, the business model approach, and investigations into the integration of energy hubs within FCTs.

Chapter 4 presents a structured overview of how the FCT concept has been developed throughout the project. It begins with a functional analysis, identifying key requirements from various stakeholders. This is followed by a description of how the concept has been designed accordingly, including key technical specifications. Next, the chapter analyses the potential economic and environmental benefits of locating an FCT in the Kattegat. Finally, it presents a business model canvas analysis to outline the key aspects for an actor aiming to operate an FCT.

Chapter 5 further develops the concept by analysing how the FCT could also function as an energy hub. This includes exploring how the FCT can serve as a distribution hub for wind-generated energy and potentially as a site for (SMRs).

Chapter 6 contains a summarizing discussion of the report's findings, while chapter 7 presents conclusions and recommendations for further research.

This project has produced the following outputs. Appendix A provides a deeper functional analysis, while Appendix B presents a more comprehensive examination of the FCT as an energy hub. Additionally, two master's theses are part of the project, both supervised and extensively supported by the authors of this report. In their thesis, *"Drifting Into the Sea: A Qualitative Analysis on the Commercial Viability of a Floating Container Terminal"*, Halldén and Sanders (2024) analyzed industry perspectives on the FCT and assessed its commercial viability. In a forthcoming thesis, Muntahin and Palosari (2024) develops a facility location model to determine optimal locations for an FCT from a supply chain perspective, for example outside main ports in the North Sea or in Kattegat.

The project has also been presented at the Transportforum 2024 conference, entitled *"Flytande hamnar: en hållbar innovation till havs för hantering av container och förnyelsebar energi"*. Additionally, it was presented at the IAME 2024 conference with the title *"Analysing the Feasibility of Floating Container Ports in Maritime Supply Chains"*.

2. Background

Trends in worldwide shipping

The maritime industry is rapidly evolving due to several factors. Container shipping lines continue to build ever-larger vessels while striving to become more cost-efficient. Ports are also continuously innovating to remain attractive choices for container shipping lines and shippers of goods (De Martino et al., 2013). Additionally, a variety of environmental regulations have been implemented to reduce the maritime industry’s environmental impact, affecting both container shipping lines and ports. Furthermore, the maritime industry is influenced by several megatrends occurring outside the sector, such as urbanization. These ongoing changes and trends, both within and outside the maritime industry, have the potential to impact the attractiveness of FCTs, and are therefore explained below.

Already twenty-five years ago, Cullinane and Khanna (2000) noted that ships were rapidly growing in size due to economies of scale, both in terms of cost and energy efficiency of fuel use. This trend has continued, with ships tripling in size since then. Currently, several types of container vessels are available, each with distinct functions based on their size (see

Table 11 and Figure 11). ULCVs are designed for very long distances, such as routes from Asia to Europe. Their economies of scale make them advantageous, with lower fuel consumption per TEU and reduced crew and administrative costs. Recent studies show that it is economically justified for container shipping lines to increase ship sizes to 25,000 TEU in a short period (Ge et al., 2021). The main reason for this is that as ship sizes increase, the unit cost of fuel consumption, maintenance, and materials declines. However, this comes at a significant cost to ports, which have to spend enormous amounts of money dredging channels to accommodate larger vessels (Lian et al., 2019).Currently, only about 20 to 25 ports can handle the largest ships, depending on factors such as whether they are fully loaded. If the trend toward larger ships continues, ports will need to invest in costly and potentially environmentally harmful dredging of harbour areas.

Table 1 - Different types and sizes of container ships as referred to in literature

Type and capacity in TEU	Principal particulars – typical max LxBxT
Feeders less than 500 TEU	length and draft: 100x7.3 m
Feeders max 999 TEU	length and draft: 140x8.8 m
HANDY 1000 – 1999 TEU	length and draft: 190x11.4 m
SUB-PANAMX 2000 – 2999 TEU	length and draft: 227x12.0 m
PANAMX over 3000 TEU	length and draft: 294x12.6 m
POST-PANAMAX 3000 – 7999 TEU	LxBxT: 370x43x14.5 m
POST-PANAMAX+ 8000 – 9999 TEU	LxBxT: 350x45.6x14.6 m
SUPERPOST-PANAMX 10000 – 15000 TEU	LxBxT: 399x56.0x16.0 m
ULCV all above 15000 TEU	LxBxT: 399x60x17.5 m
*A large number of ULCV of 24.000 TEU were delivered during 2023	

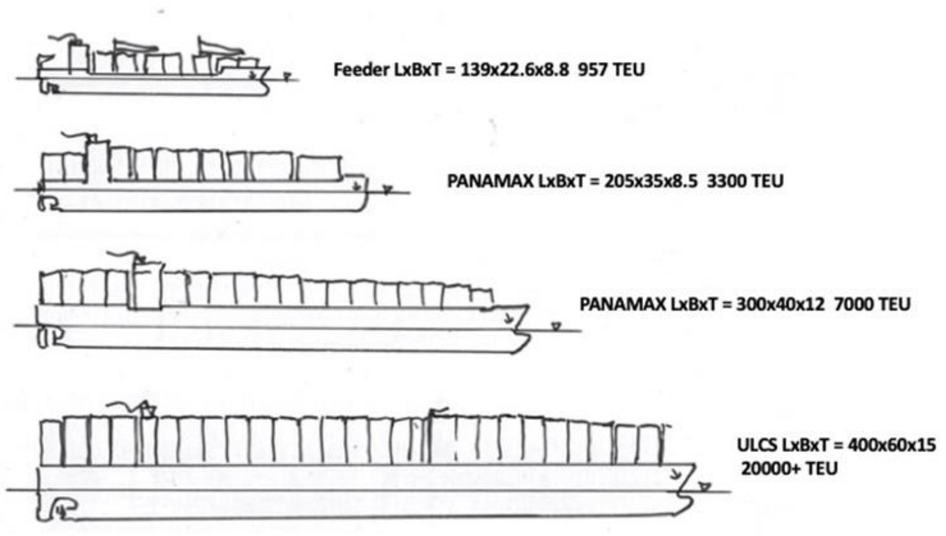

Figure 1 - Container ships of different size

Port congestion is a significant factor in determining a port's attractiveness, as high congestion leads to time and financial losses for customers (Meersman et al., 2012). The challenges of port congestion became especially evident during the COVID-19 pandemic, such as in the ports of Los Angeles and Long Beach (Liu et al., 2023). Additionally, as ships grow larger, complexity increases in ports, for instance, due to longer turnaround times, which can further contribute to congestion. As ships have increased in size, ports, terminals, and entire transport systems have had to upgrade to accommodate them, including major ports like Antwerp and Amsterdam. Although these ports have managed capacity expansions in a cost-efficient way (Ge et al., 2021), there may still be a need to reconsider whether it is worth continuing to expand existing ports, or if newly constructed mega ports, from the beginning adapted to the ultra large container vessels (ULCVs), either on land or offshore, such as floating ports, might be a more cost-efficient option in the long run.

Port choice has long been a well-researched area, with ongoing debate about whether shippers or shipping lines have the stronger influence in selecting ports (Martínez Moya and Feo Valero, 2017). Regardless, several factors are critical for a port to remain attractive. Martínez Moya and

Feo Valero (2017) in a literature review, identified three main categories: port location, port effectiveness, and port connectivity. Within these categories, key factors include location, port efficiency, port charges, frequency of service, and port infrastructure, among others. Furthermore, ports constantly need to innovate to remain competitive. In that respect, Yap and Ho (2023), in a literature review, identified ten different strategies that ports may adopt to develop and attract customers: shipping connectivity, cargo-handling technology and capacity, value derived by shipping lines as port users, efficiency of port operations (including safety and security), trans-shipment market, terminal capacity utilization, financial performance of port operations, environmental sustainability of port operations, port cluster development, and logistics hub development. Other studies have concluded that factors such as green measures to decarbonize ports, new physical and digital infrastructure for automated and connected vehicles and port terminals, and full digitalization to offer new services are essential (Garrido Salsas et al., 2021). Thus, a multitude of factors affect port strategy and development, many of which are related to the port's location and design. How ports accordingly develop, in turn, influence key factors such as cost, connectivity, the trans-shipment market, and overall efficiency. However, not only physical handling but also digital investments in appropriate forms will be key strategies for attracting customers.

Similar to other industries and transport sectors, maritime actors face an increasing number of regulations aimed at becoming more environmentally friendly. For example, the EU has introduced the Fit for 55 package, which aims to reduce carbon emissions and achieve carbon neutrality by 2050, having a significant impact on the maritime industry (Mallouppas et al., 2022). As part of this, the EU has implemented the Emissions Trading System (EU-ETS) to discourage GHG emissions. Additionally, the FuelEU Maritime proposal is designed to promote the production and adoption of sustainable alternative fuels. On a global scale, the International Maritime Organization (IMO) has established a strategy to reduce greenhouse gas emissions. Among the various measures, one of the most significant for logistics decisions is the Carbon Intensity Indicator (CII), which measures a ship's energy efficiency based on the distance travelled relative to its cargo-carrying capacity (Tadros et al., 2023). For ports, the main implications in relation to container shipping companies include the potential provision of renewable fuels and the impact of port location on overall shipping emissions. These factors will be key in making ports more attractive to shipping companies in the future.

The logistics of FCT and smaller trans-shipment platforms

A few scientific studies have investigated the logistics and costs of various sizes and designs of FCTs and smaller trans-shipment structures. The study in the literature that most closely resembles the FCT developed in this report is by Kurt et al. (2021). In this paper, a concept involving two offshore container ports located off the west coast of the USA was suggested. The existing supply chains were compared with potential trans-shipment via these ports, and it was shown that the offshore container port solution was economically advantageous, as larger ships could be used to supply the offshore ports compared to the existing ports on the east coast. However, it was noted that several assumptions were uncertain, and further studies were needed. Pachakis et al. (2017) compared the expansion of the Port of Venice in terms of an onshore terminal versus an offshore terminal. It was shown that the offshore terminal could be developed with a reasonable capacity, a smaller footprint, and at a reduced cost per TEU, including both capital and operational expenditures. Assbrock et al. (2020) conducted a simulation comparing two cases: a floating hub servicing a hinterland port via river-sea shipping versus a floating hub using short-sea shipping with trans-shipment at a port ashore, followed by inland waterway shipping to the hinterland port. The study concluded that direct river-sea shipping is more cost-effective, primarily due to the additional handling required at the port ashore.

A few studies have focused on much smaller offshore platforms compared to the previously mentioned articles. Cao et al. (2021) studied small offshore platforms for trans-shipment and in their scenarios, there was a trade-off: while higher capacity, in the form of more buffer space on the platform, increased loading efficiency and reduced ship throughput time, it also resulted in higher overall costs. Baird and Rother (2013) studied small trans-shipment platforms and assessed that they would cost approximately $50 million, which is only a third of the cost of equivalent land-based infrastructure. These platforms were relatively small, quick to deploy, and easy to relocate, which helps reduce the risks associated with such projects. Gurning et al. (2022) studied how smaller floating facilities can be used for trans-shipment to service remote islands in Indonesia. They concluded that under their assumptions, a floating logistics support facility, with a structure weighing between 10,000 and 30,000 tons, is viable as a hub for cargo, passengers, and fuel.

Outlook of previous conceptual cases

For a little over a decade, different types of floating and off-shore structures have been explored worldwide in a number of cases, with four specific examples reported below. These initiatives have not been driven by commercial interest; rather, they were conceptually initiated by authorities who believed that floating ports could offer environmental benefits, reduce congestion, and enhance security. However, all identified cases appear to have been cancelled or postponed. Finally, the Sea Technology floating port as a concept is presented. As a company, Sea Technology were involved in the Venice, the Italian case, but their conceptual design of a floating port has since been further developed and is therefore presented.

The Portunus project (USA)

The Portunus project was led and evaluated by the Lawrence Livermore National Laboratory (LLNL), whose mission is to strengthen U.S. security. The Portunus project primarily started due to increasing concerns and the vision that U.S. national safety could be enhanced if goods and ships were inspected offshore before entering U.S. ports (LLNL, 2014), see Figure 2. Furthermore, additional benefits were anticipated, such as less invasive species, less air pollution and minimized use of fossil fuel.

In 2010, following a national invitation to U.S. business schools, the project was evaluated by three top business schools in the country, which provided an assessment of the concept. According to one presentation, it was shown that 100% of all transoceanic vessels including containerized, bulk freight, and private craft could be inspected by six offshore ports located near Seattle, Oakland, Los Angeles-Long Beach, the Gulf of Mexico, Georgia, and New York (LLNL, 2014).

The investment cost was estimated at $60 billion (LLNL, 2014), with a payback period of 23 years. It was suggested that a public-private ownership partnership would be needed. Under the right circumstances, it could also become economically beneficial for actors in the supply chain. It was argued that an optimized offshore port could offload eight 18,000 TEU ships in 36 hours. A faster turnaround time would allow ships to spend more time at sea, thereby performing more round trips per year to increase their income (MarineLink, 2014).

Although the evaluation of the concept involved a number of partners such as the University of California, Bechtel Engineering, the American Bureau of Shipping, RAND (an American research institute providing research and economic analysis for Portunus), and the National Oceanic and Atmospheric Administration, no information can be found regarding commercial interest in investing in the concept. It seems to have remained a vision.

Figure 2 – The Portunus project (Illustration: Mark McDaniel/LNLL)

Louisiana International Deep Water Gulf Transportation Terminal (USA)

The Louisiana International Gulf Transfer Terminal was conceived by the Port Authority Commission of Louisiana around 2013. The vision was to establish the terminal at the mouth of the Mississippi River to facilitate trans-shipment to smaller ports in America's heartland. The initial capacity was estimated at approximately 2 million TEUs, with potential for expansion to 3.5 million TEUs annually (Correcha, 2012). The total project cost was projected at $10 billion, which included plans for a multi-purpose port accommodating dry bulk, liquid bulk, and containers (Pachakis et al., 2017).

A significant motivation for the terminal was the increasing size of ships, as its design would eliminate the need for costly and labour-intensive dredging often required by traditional ports. This facility was expected to handle the largest vessels and facilitate trans-shipment to various smaller ships and potentially self-navigating barges, featuring a dedicated two-square-kilometre area for storage and trans-shipment, see Figure 3 (Correcha, 2012).

At that time, it was noted that America's inland waterways transported only 2 percent of the nation's cargo. The introduction of this terminal could encourage a partial modal shift from rail to sea, alleviating some pressure on the rail system. The Mississippi River and its tributaries extend through 32 states in the U.S. and into Canada, totalling 14,500 miles of inland waterways (Correcha, 2012).

Although Correcha (2012) indicated that the project had secured funding and pre-construction work was slated to begin in November 2013, it appears that the initiative has since stalled completely.

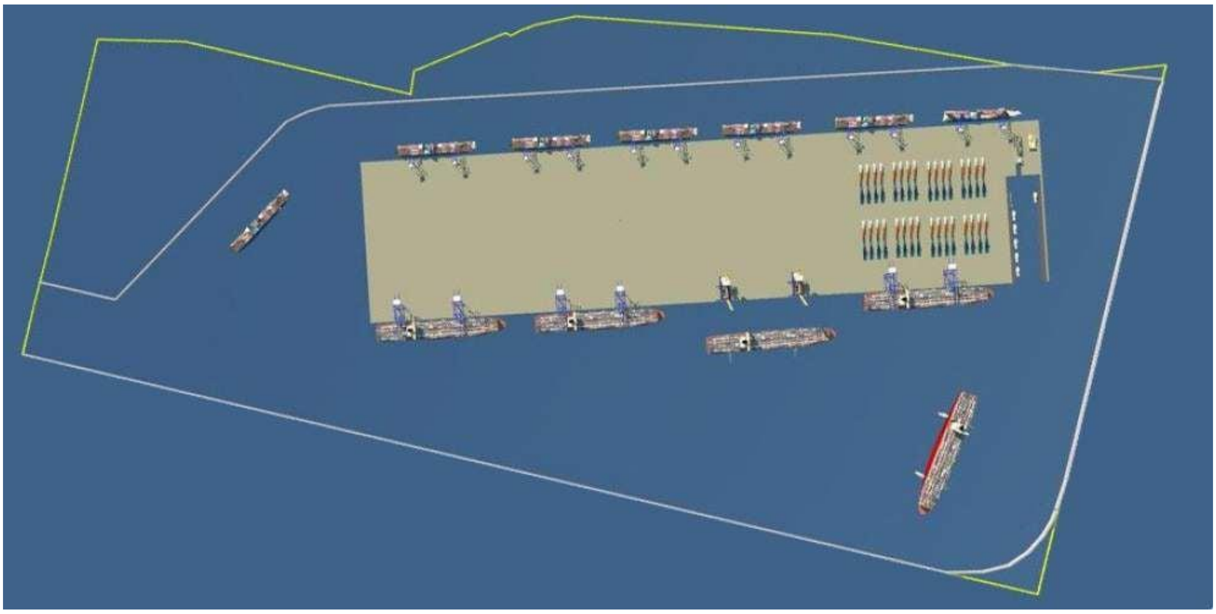

Figure 3 – The international Louisiana International Gulf Transfer Terminal (credits: www.ligtt.com)

Chittagong (Bangladesh)

Bangladesh authorities had expressed interest in developing a floating port to alleviate congestion at the Chittagong port, located outside Dhaka (Seaco, 2019). Chittagong port handled 2.3 million TEUs per year, significantly exceeding its designed capacity of 1.6 million TEUs, making conventional expansion challenging (RRR-Advice, 2019).

At least two feasibility studies have been conducted, each proposing different designs (PDA, 2019; Seaco, 20199. The design proposed by PDA (2019) features a floating port with a capacity of 1 million TEUs per year, see Figure 4. Its modular design allows for easy expansion to accommodate various types of cargo, including bulk goods.

Similar to other projects worldwide, it was argued that a floating port can be advantageous, as it do not require dredging or extensive land reclamation. Additional benefits include resilience to climate change impacts, such as rising sea levels (PDA, 2019). Furthermore, shippers in the Dhaka region could bypass highway congestion by trans-shipping through smaller ports and utilizing river routes, potentially leading to time and cost savings (RRR-Advice).

Officials indicated that if the studies confirmed the need and viability of a floating terminal, construction would proceed (Seaco, 2019). However, no official updates have been provided, and it appears the project has been abandoned or postponed.

Figure 4 – Floating port (Credits: Public domain architects)

Venice (Italy)

The Venice Port Authority's (VPA) had plans already in 2012 for a floating port installation as a part of a broader initiative to enhance the port's capacity and mitigate environmental impacts within the Venetian Lagoon. This project, known as the Venice Offshore Onshore Port System (VOOPS), aimed to address the challenges posed by large vessels and environmental constraints.

VOOPS envisioned a dual bottom structure (not floating) comprising both an energy terminal and a container terminal, located eight nautical miles offshore where the ocean depth is 20 meters. This location was strategically chosen to accommodate ULCVs that could not be handled by the existing port facilities due to their size. The project was designed to handle a significant amount of the port's traffic, aiming to transfer and process cargo between the offshore terminal and inland ports effectively.

The innovative design included a continuous conveyor belt system for moving containers to and from Porto Marghera and Porto Chioggia, utilizing automated technologies and semi-submersible vessels known as "Mama vessels." These vessels were designed to transport containers with minimal environmental impact, featuring systems that would generate waves less than 0.5 meters high to ensure safe navigation within the lagoon. There were also thoughts of a bridge connecting the platform with land.

The economic and strategic benefits anticipated from the VOOPS project were substantial. It was projected to create hundreds of jobs during both the construction and operational phases, significantly boost the local economy, and enhance the logistical capacity of the Northern Adriatic region as a gateway to central European markets.

The VOOPS project exemplifies a forward-thinking approach to maritime infrastructure, combining capacity enhancement with environmental stewardship. The initiative not only aimed to transform the Port of Venice but also served as a potential model for other ports worldwide facing similar challenges. The details of this ambitious project were documented and discussed in various forums, including presentations to the International Maritime Organization and publications in maritime industry reports

Figure 5 – Artist work for Maritime Reporter & Engineering News 2015

The offshore terminal, was positioned 8 nautical miles from the Porto di Malamocco, is designed to accommodate deep-drafted container vessels and is expected to handle a throughput of 3 million TEU annually, with 2.2 million TEUs transferred to onshore terminals and the remaining 0.8 million TEUs transhipped to other locations.

The preferred transportation between the offshore and onshore terminals involves the use of a "Mama Vessel" carrying unpowered barges, selected for its flexibility, environmental benefits, and cost-effectiveness. The terminal is also designed with a buffer storage capacity of 5000 TEU per berth. There were also plans on a potential bridge at a later stage.

The terminal had plans to feature modern, innovative infrastructure and state-of-the-art IT and communications systems to ensure rapid turnaround times, excellent safety, security, and a competitive cost structure.

One major concern was to limit dredging to minimize environmental impact and is geared to meet the throughput demands forecasted by the Venice Port Authority. The design also included provisions for handling environmental concerns such as tides, water levels, and extreme weather conditions, ensuring reliable and safe operations.

In late 2019 and early 2020, Team Sea Technology engaged with the Venice Port Authorities (VPA) to explore the feasibility of an FCT. The initial project was hindered by the potential for significant operational downtime due to adverse weather conditions and regulatory constraints, leading to its discontinuation.

The STFT first version (Asia – Rotterdam)

The initial concept of the STFT – The Sea Tech Floating Terminal, came about in 2015 as a result of extensive discussions and exchanges between the three parties, evolving from a separate concept developed by Sea Technology AB with the use of semi-submersible vessels, The Sea Horse.

- Sea Technology of Sweden was at that time headed by Bengt Lundquist, a semi-retired Naval Architect having extensive knowledge of offshore structures, car carriers and of various types of other merchant vessels. In addition, also one of the inventors behind of the RoRo technology. In addition, also a pioneer within Naval Architecture as Technical Director for Wallenius for 17 years where the first Container vessels were designed and build, the Atlantic Container Line.
- Earth Shipping International LLC is based in Florida, USA and is headed by Mike McCarthy who acts as a maritime consultant in various marine sectors.
- Clarkson's Platou is the world's biggest shipbroking and maritime services company.

The intentions and aims of the STFT concept, in its early days, were to simplify and make the global logistics chain more efficient - as far as it is related to container transport by ULVCs. In addition, the STFT could also solve the problem of the ULCV's being confined to one trade lane Asia/Europe. The STFT were (and still is) to be considered as a fully self-sustained, independent floating container terminal, designed for fully automated operations around the clock. According to the studies made then by the parties involved, the benefits of the ULCV's calling at an STFT, rather than to land-based ports, were considerable; in terms of time and money, in terms of the logistics chain as a whole and in terms of land-based port/terminal infrastructure and productivity. The studies were made by the management team of Clarkson's together with team Sea Technology and external consultants.

In the studies made, just as the considerations are today - The STFT can also realise the benefits of the cheapest container transportation costs to areas of the world not currently served by ULCV's. The STFT would allow the ULCV's to make a one-stop call in the required geographical area, fully laden, discharge cargo, reload and then sail back to the next area of operation also fully laden. Cargo is brought to the STFT by the ULCV's, discharged to the STFT, transferred across the Terminal Deck and then reloaded onto feeder vessels for carriage to land. Conversely, cargo is brought from land to the STFT by feeder vessels, discharged to the STFT, transferred across the Terminal Deck and reloaded to the ULCV vessels. The feeder vessels (back then and now) are the link from the STFT to the land-based ports. It is the link that the STFT provides, between the ULCV's and the shore that it is believed that the FCT's can fulfil the needs of several parties in the container supply chain in a more efficient, economical and environmentally friendly way. This was proven with several calculations, interviews and the efforts of the selective parties – although on a conceptual level.

At the time, the STFT, was not realized. The timing was not optimal. Hence the innovating company, Sea Technology, has since then further developed the logic, concept, partnerships with both MOU signed with Swedish company Blykalla and a LOI with DNV AS, the Norwegian internationally famous classification society, in addition to long list of partners.

Figure 6 - First version of The Sea Technology Floating Terminal, The STFT, Copyright Sea Technology.

Drivers for floating ports

An analysis of existing unrealized cases, along with scientific literature, shows that there are quite a few drivers for FCT, which can be categorized into financial, capacity-related, operational, environmental, and regulatory categories, see Table 2. It should be noted that some barriers are definitive; for instance, an FCT is not affected by factors that influence conventional ports, such as competition for land for other purposes onshore. However, some drivers are more potential in nature; for example, a FCT could be cost-efficient from a systems perspective, considering the advantages of using larger ships. Nevertheless, these advantages depend on local conditions and involve some uncertain assumptions.

Table 2- Drivers for floating ports

Category	Benefits/Drivers
Financial	• FCT are not affected by changes in land cost (Kurt, 2024, Lee et al., 2024) • FCT are not affected if land becomes scarcer (Kurt, 2024) • FCT have potentially lower initial investment cost in comparison to conventional ports (Kurt, 2024, Baird and Rother, 2013) • FCT have potentially lower operating costs (Baird and Rother, 2013) • FCT can be used in areas to facilitate economic growth, through trans-shipment of goods (Gurning et al., 2022) • FCT can host various activities at sea that may improve financial performance such as renewable energy and aquaculture (Flikkema et al., 2021a)
Capacity	• FCT can be used when there is a lack of capacity for storage of containers on shore (Souravlias et al., 2020) • FCT can be used when there is a lack of space for loading and unloading on shore (Souravlias et al., 2020)

	• From a system perspective, if the network of ports is congested, FCTs can alleviate that network (Kurt, 2024) • If a FCT has a modular design, expansion can be efficient (Kurt, 2024) • FCT can be located strategically when it is impossible to build large ports due to constrained geography (Kim and Morrison, 2012) • FCT can be used as a trans-shipment hub to reach remote islands (Gurning et al., 2022) • FCT can increase their capacity more rapidly than conventional ports (Baird and Rother, 2013)
Operational	• FCT are portable and can be relocated for various reasons, such as oceanic challenging situations (Kurt, 2024) • FCT can handle UKCVs, i.e. they do not face the same problems as conventional ports that may need dredging as ship sizes increases (Kurt et al., 2023) • FCT can be quickly deployed, removed, relocated and expanded (Kim and Morrison, 2012) • Planning operations is more easily done in FCT than in conventional terminals (Baird and Rother, 2013) • Information sharing at FCT may be more efficient compared to conventional ports (Lee et al., 2024)
Environmental	• Through policy, it may be easier to promote sustainability in an FCT than in conventional ports, through for example environmentally friendly fuels and sustainable logistics operations (Gurning et al., 2022) • Compared to artificial islands, FCT have lower environmental impact (Flikkema et al., 2021b, Flikkema and Waals, 2019) • Conventional ports may face challenges due to rising sea levels, which is not an issue for FCT (Flikkema and Waals, 2019) • FCT may be a hub for aquaculture and floating fish farms (Drummen and Olbert, 2021) • FCT can be used for offshore renewable energy to facilitate the energy transition (Drummen and Olbert, 2021) • As sea levels rise, FCT may be an option (Kurt, 2024)
Regulatory	• Environmental legislation may force ports to expand at sea to reduce environmental impact

Barriers

Given that FCTs have not been built yet, despite the clear drivers, several barriers act as obstacles for any actor willing to invest in an FCT. In Table 3Table 3 , these are structured in five categories: financial, capacity-related, operational, environmental and regulatory. Many of these barriers relate to uncertainty, particularly concerning design issues, such as the ability to withstand waves and manage long-term maintenance challenges. Additionally, similar to the drivers, there is uncertainty of various cost elements, such as equipment costs. However, many of these barriers could potentially be overcome through technical development, although this needs to be demonstrated before any actor is likely to invest in and operate an FCT.

Table 3 - Barriers towards FCT

Category	Barriers
Financial	• An FCT requires better technology compared to conventional ports and could imply a higher cost (Kurt, 2024) • An FCT requires better skilled personnel which implies higher salaries (Kurt, 2024) • The initial investment cost may be higher for FCT than for conventional ports (Drummen and Olbert, 2021) • The operating cost may be higher for an FCT than for conventional ports (Drummen and Olbert, 2021)
Capacity	• Overall design may be technically complicated, due to abilities to withstand harsh weather conditions in terms of wind and waves (Souravlias et al., 2020) • Based on design of an FCT, interaction between different parts of the construction need to be evaluated (Flikkema and Waals, 2019) • Designing an FCT for modularity to be able to scale up may be challenging (Souravlias et al., 2020)
Operational	• A FCT could add an extra step in the supply chain and may make coordination of logistics activities more complicated (Souravlias et al., 2020) • Long-term durability is unclear (Flikkema and Waals, 2019) • Maintenance due to corrosion and fatigue may be a challenge (Flikkema and Waals, 2019) • Waves can interrupt the operations leading to delays (Baird and Rother, 2013)
Environmental	• Climate conditions around the world may vary and need to be taken into account when designing the specific FCT (Souravlias et al., 2020) • Limited personnel facilities (Kurt, 2024) may lead to a lower quality of life for workers
Regulatory	• Unclear and undefined regulations regarding maritime and property law need to be overcome through definition of a floating port, flag state etc (Flikkema et al., 2021b)

3. Method and Models

To further develop the FCT concept, several methods were used in this project. This included a functional analysis to identify stakeholders, customers, and how the proposed Sea Technology STFT model could be designed to meet their needs. A quantitative cost model was created to estimate the operational costs of the port, and this was combined with a supply chain tool (Fluent Cargo) to evaluate the potential impact of the FCT from a supply chain perspective. Additionally, an environmental analysis was conducted to assess the FCT's potential environmental impact. A semi-structured interview study was carried out, presenting the STFT model to industry representatives, authorities, experts and academics to gather their insights. The final method, developing the business model, integrates findings from these studies through also using the business model canvas methodology. All these methods are briefly outlined below.

Functional analysis

The functional analysis aligns with Quality Function Deployment (QFD), see e.g. Chan and Wu (2002) in the way it identifies stakeholders and customers. The functional requirements of stakeholders and customers are determined through professional judgment, analysis of secondary data (e.g., stakeholder and customer documents, such as webpages), and a few supplementary interviews.

Quantitative cost model

A quantitative model has been developed to evaluate the cost of shipping goods via a floating port. Assuming a full-service port, all CAPEX and OPEX cost for the floating port have estimated through thorough work taking place of several years by Sea technology developing the STFT, the other participating parties - based on a design proposal validated with three separate shipyards.

Cost Model for the STFT and FCT in general

The STFT is estimated to cost approximately USD 2,5bn fully equipped as a trans-shipment container terminal. That includes construction, container cranes, power and towing. The construction part is estimated to be around 78 % of the total cost. A high-level perspective is presented below:

Table 4 - Cost structure of production

Indicative price from DSME (now HHI) P, Constr. Steel. Keel. Launching. Delivery	1950 USDm
22 STS super mega cranes. 10 very large for ULCVs and 12 for Feeders.	260 USDm
Deck stowage equipment. Owners' delivery and choice of system. Estimate	110 USDm
Anchoring equipment, 28 anchors with chains	30 USDm
Extra orders of items not included by yard's specified offer. Important items	50 USDm
Costs of Class approvals and certificates. SSPA model testing and calculations	20 USDm
Cost of towing the STFT from South Korea to the Mediterranean	80 USDm
Total approximate construction cost,	**2 500 USDm**

Our high level estimated is that the STFT would reach annual break-even at the following key values:

Table 5 – Revenue streams and throughput

Throughput of approx.	TEU # 800 000
Average charge per TEU	200 USD
Number of ULCVs port calls	#75
Port call charge, ULCVs	150 000 USD
Number of feeder vessels port calls	#250
Port call charge, feeder vessels	USD 12 000
Other service charges per year	50 USDm

Table 6 - Important input data

Interest rate	5 %
Depreciation time	60 years
Residual steel value	500 USDm
Shareholder equity	30%

The above calculations, based on the STFT case and indictive offers from the shipyards in South Korea, shows that the terminal can be profitable with a quite low throughput (800 000 TEU), this points to a possibility to also be financially attractive.

The FCT model proposes a transformative solution by implementing FCTs that facilitate the direct trans-shipment of containers between the ULCVs and feeder ships at sea. This supply chain design bypasses the congestion of traditional ports, potentially reducing waiting times from weeks to mere hours. Economically, this translates into cost savings. For example, the daily operational cost of a large container ship can range from $50,000 to $100,000. Reducing port waiting times from 30 days to 1 day could save approximately $1.45 million to $2.9 million per vessel per port call.

Figure 7 shows the economies of scale - from 10,000 TEU to ULCV sized vessels. It is estimated that using the ULCVs rather than smaller sized container ships, the cost savings could be as much as 30 %. Doubling the maximum container ship size over the last decade has reduced total vessel costs per transported container by roughly a third. This is another pointer to the effectiveness of using ULCVs and a strong reason to use larger and larger vessels.

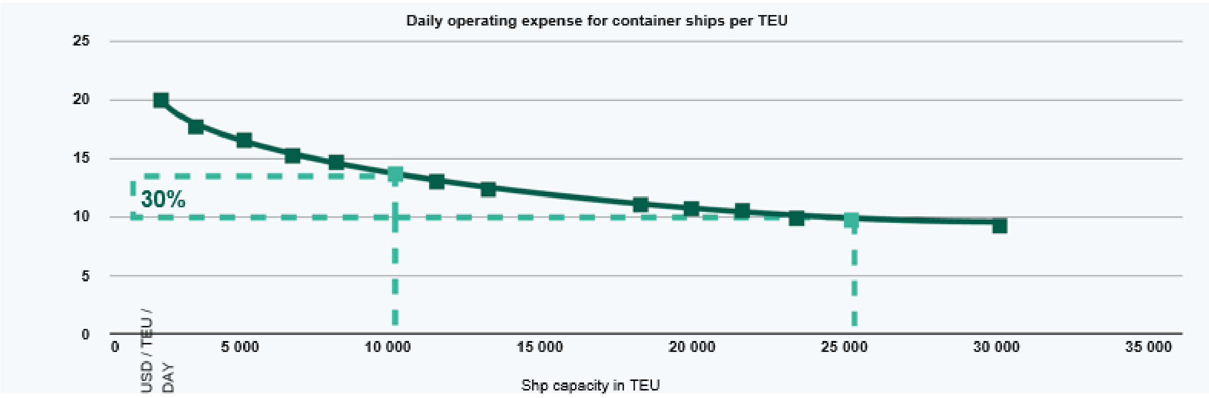

Figure 7 - Daily operating expenses for containerships per TEU, Source: A Ulfvarson based on Alphaliner

Financially, the implementation of the STFT is supported by a detailed cost model that underscores the viability. Initial estimates, which were calculated by the Clarkson's team, indicate that the capital and operational expenditures of the STFT are significantly lower than those required for expanding traditional ports. For instance, the cost of dredging and land preparation for a new port terminal can exceed $500 million, whereas setting up an FCT could reduce these costs by more than 50%, considering the modular and scalable nature of the floating platforms.

Supply chain analysis - Case Kattegat

The method used to identify the optimal location for an FCT in Northern Europe involved analysing transport geography, particularly considering the shipping fairways between ports and the depth limitations of passages to the Baltic Sea. Based on this analysis, locating an FCT in Kattegat was determined to be the best option. This was followed by a subsequent supply chain analysis, comparing this solution to a conventional supply chain.

Interview study

In order to evaluate the concept from different actors' perspectives, twenty interviews have been performed. These comprises industrial actors in terms of linear shipping companies, ports, port terminal operating companies and linear shipping agents. It also comprises maritime experts in terms of independent industry experts, renowned maritime professors as well as government experts. As the floating port concept is developed in Sweden and the research project is funded by the Swedish Road administration, most interviewees were from Scandinavia. However, to avoid a to narrow perspective, several interviewees were from abroad, including main Europe ports as well both North American port representatives and professors.

The interviews were divided into three parts and lasted approximately an hour each. The first part consisted of a presentation of the FCT by the interviewers, as developed by the entrepreneur, explaining its basic properties and how it would be integrated into international maritime supply chains, including a potential location in the North Sea. Thereafter, the interviewees were asked questions about the potential realization of a floating port. The final part covered a scenario assuming that an FCT was built in the near future, allowing the participants to reflect upon the impact on different stakeholders within a maritime linear network. The interviews followed a semi-structured format, delving into the perspectives of different actors, as well as examining the driving forces, obstacles, and key issues related to the implementation and usage of the FCT. All interviews have been transcribed and subsequently systematically coded in Nvivo1.7.

Business model canvas

Business Model Analysis is a widely applicable management tool that can be used in many ways. In this report, the very popular and useful Business Model Canvas approach developed by Osterwalder (2010) is applied. Scientifically based, yet very hands-on, this method has been used to study business models for countless companies in various industries. This method has been applied both within industry and academic research. In a maritime context, for example, it has been used to analyse modal shifts from road to sea (Williamsson et al., 2020) and to explore how to develop future ports (Salsas et al., 2022).

The Business Model Canvas is operationalized into four main parts: the offering, the customers, the infrastructure, and the finances, which are further divided into nine building blocks (Osterwalder, 2010), enumerated below. When adapted to a port (i.e. an FCT) context, these blocks focus on answering key questions:

1. **Customer Segments**: Who are the primary customers (such as container shipping companies, freight forwarders, and logistics service providers)? Are there different customer segments with specific needs for each?
2. **Value Proposition**: What value does the port offer to customers (e.g., trans-shipment, storage, strategic location)? How does the port differentiate itself from competing ports?
3. **Channels**: How are different customers reached (e.g., direct contacts, platforms, shipbrokers)?
4. **Customer Relationships**: What types of relationships does each customer segment require (e.g., long-term or short-term contracts)?
5. **Revenue Streams**: What will be the key revenue streams (e.g., traditional port fees, income from potentially being an energy hub)?
6. **Key Resources**: What physical resources are necessary (e.g., gantry cranes, straddle carriers)? What human resources are required (e.g., logistics personnel, port management)? What financial resources are needed for the construction and operation of the port?

7. **Key Activities**: What are the critical activities for operating the port (e.g., unloading, movement, storage, and loading of containers)?
8. **Key Partnerships**: Who are the key partners the port needs to build relationships with?
9. **Cost Structure**: What are the most important cost elements for both the construction and operation of the port?

4. Development of the concept of the floating port

Functional analysis and stakeholder analysis of needs

The functional analysis is conducted to identify what is of interest for investigation in interviews with key stakeholders in the maritime industry. A stakeholder is someone who has influence on the realization of the product without being the final customer. A stakeholder may be an individual, a group, or a legal entity, such as a state or port, who benefits or is harmed with direct or indirect economic consequences, such as taxpayers or neighbours. A customer is someone who pays for the entire product or for services. Table 2 lists the most relevant customers and stakeholders, along with their specific requirements identified in the analysis. A more detailed analysis of how these were derived can be found in Appendix A, which also lays the foundation for the interviews that were conducted.

Table 7 - Stakeholders and customers with their requirements and expectations

Stakeholder/customer	Description	Functional requirements and expectations (Voice of the customer)
Financiers	Contributors with money together with final owners of the STFT	The STFT should provide good business and give return to invested capital in accordance with agreement; solve port shortcomings
The STFT owner	The STFT owner may be the same as a nearby coastal port owner. The owner is responsible for the quality of long-term maintenance	The STFT should operate with low maintenance costs and without interruption to provide good business and give return to invested capital
Major port owner in the vicinity of the STFT location	The port owner is usually a municipal or a state who owns the land and the equipment installed to make it a port	The STFT is seen as a possible extension of the land-based port alternatively considers the platform a hostile investment by a competitor
The STFT operator	The STFT operator may be the same as a nearby coastal port operator	The STFT should operate without interruption to provide good business for the operator meaning that the STFT must provide # easy access to the platform for ships, supply ships, workboats and

		helicopters # quick and reliable mooring of ships coming and leaving # steady platform (very little motion of the platform in all directions) # good overview of operations on the platform # low conflict with fairways
Small and Medium-Sized Ports (SMSP) i.e. coastal container port owner	The port owner is most likely a municipality	The STFT should provide easy integration with ordinary business of the coastal port synergies with coastal ports
Coastal container operator of the SMSP	The operator may be a private company or the port owner	easy integration with ordinary operation of the coastal port synergies with coastal ports
Workers and workers union with the logistics	Most of the logistics will be handled by autonomous vehicles but some displacements may have to be handled "ad hoc".	The STFT should provide means of clear communication safety measures to avoid hazardous conflict with autonomous vehicles
IMO	Responsibility: Safe fairways in stationary operation and safe towing	The STFT must fulfil all international regulations of a floating platform through fulfilment of conditions required by Maritime authorities
National Maritime Authority	General safety for everyone in physical contact with the STFT Safe conditions for workers and subcontractors Deliver certificates on IMO-regulated safety measures that has been given status as law.	The STFT provides all by Maritime authority required information
Classification Society (DMV. LR, ABS...)	The purpose is to control and deliver certification of structural integrity and mechanical function in agreement with high standard in order for Insurance companies to accept risks.	The STFT interact with Classification Society and delivers required information. This information is listed in rule books.
Ship owners	Large Container (ULCV) ship owners Feeder vessel owners	In the end the STFT delivers the platform. A shipowner may want

		to participate in finalization of the concept
Ship brokers (ex. Clarkson)	Shipbrokers are specialist intermediaries/negotiators between shipowners and charterers	The STFT interacts with a mayor ship broker in order to pick up important information to make operation smooth
Newbuilding shipyard	Main shipyard and subcontractors	The STFT finalizes the technical specification and requires the final offer. Writes the contract together with shipowner and other financiers STFT follow up the construction work at the shipyard
Subcontractors to newbuilding shipyard	Delivers control systems, engines and pumps etc.	Together with the shipyard The STFT provides subcontractor with best information of subcontractors' contribution to the system
Repair yard/subcontractors on maintenance of the STFT under operation	The repair yard/sub-contractors have different knowledge, products and services -structure -machinery -IT (overall logistics and autonomy vehicles)	When required by the repair yard the STFT interacts with mayor subcontractors to provide the project with best offers (price and delivery times)
A nearby city in rural Africa or South America or other undeveloped countries	A town in within short distance by sea from the platform	Interested in buying fresh water or electricity from the STFT
The general public	Can be represented by NGO such as Confederation of Swedish Enterprise (Svenskt Näringsliv) Swedish Confederation of Professional Associations (SACO) Swedish Confederation of Professional Employees (TCO) Swedish Union of Clerical and Technical Employees in Industry (SIF) Swedish Trade Union Confederation (LO) Central Organisation of the Workers of Sweden (SAC) The general public will appear through newspaper and TV	Either direct or through relevant magazines and media inform the general public of new logistics for supply chains i.e. container transportation and energy supply

The STFT response to requirements

The STFT has been developed to meet stakeholder and customer requirements, see Table 8. The platform's size and capacity are designed to serve ULCVs, which currently have principal dimensions of LxBxT 399x61x17.5 m and a capacity of approximately 25,000 TEU. Future growth in vessel size is anticipated, and the STFT must be equipped to meet this demand. The annual throughput of the STFT is projected to be around 5–6 million TEU, sufficient to support two ULCV services operating simultaneously, i.e., two ULCV calls per week (Theoretically, the STFT could handle three ULCV services with an annual throughput of approximately 2.8 million TEU, though practical limitations, such as feeder capacity, may prevent this). For ease of reference, although the STFT is not a "ship" per se, this paper will refer to the accommodation block end as fore, the machinery end as aft, the ULCV side as port, and the feeder side as starboard.

Table 8 – Technical data of STFT to meet customer requirements

Item	Data
Outline Specification	STFT in-shore type Kattegat Terminal; April 2024
Principal particulars	LxBxD 600/700x360x30 m
Two extensions for superstructures:	Dimensions: 2 x 120 x 50 m
Draft and freeboard	17 meters draft and 13 meters freeboard = quay height
Displacement	at draft = 17 meters the displacement is 3.876.000 m^3
Container stowage capacity and payload	60.000 TEU
Weight of containers and consumables	1.000.000 tons
Ballast water capacity	3.300.000 tons
Services for ULCV and feeder ships	ULCV with 30.000 TEU
Platform for cargo	215.000 m^2
Handling equipment	Automated rubber-tired gantries (RTG)
Fresh water tank capacity	100.000 tons
Production of fresh water	Enough to service all ships and the crew of the platform
Diesel/Methanol oil capacity	100.000 tons

One side of the terminal will be served by ten fully automated, state-of-the-art ULCV ship-to-shore (STS) cranes with an outreach capable of serving up to 25 rows. The current generation of the largest ULCVs can carry containers 23–24 rows wide on deck. The extended outreach of these cranes allows for the "next generation" of ULCVs, around 24,000 TEU, to operate with the STFT. For example, the new Chinese vessel Chang Fan, with a length of 400 meters and a width of 61 meters, can load 23,992 containers.

The alternate side of the STFT, the "feeder side", can serve several feeder vessels simultaneously within the total available "quay" length of 600 meters. This side is equipped with 12 STS cranes, with an outreach capable of serving vessels up to 20 container rows wide. A 5,000 TEU Panamax container vessel is typically 13 rows wide, while the new generation of 5,000 TEU wide-beam vessels typically has 15 rows.

The STFT cranes are designed to accommodate any foreseeable future upsizing of feeder vessels. For container transitions and stacking on the terminal deck, whether side-to-side, along the ring line, or other stacking movements, 50 battery-operated mover-units will be installed. These units include rubber-tyred gantries, straddle carriers, stacking cranes, shuttle carriers, automatic guided vehicles, forklifts or equivalent equipment.

A fully automated system will be implemented for loading, discharging, moving, and stacking all containers, including movements to and from vessels, the terminal deck, and all onboard stacking operations. This system will be managed from the control and command centre.

The STFT has an operational draft of 18.0 meters, providing a "quay" height/freeboard of 17.0 meters. There will be five internal deck levels, from top to bottom: the terminal deck, three intermediate decks, and the bottom deck. The bottom deck and the double bottom will primarily house ballast water tanks.

The terminal deck has a total area of approximately 215,000 m^2 (about 22 hectares), providing storage for around 36,000 TEUs and a total load capacity of about 600,000 metric tons. The technical lifespan is estimated at 60 years.

The potential of an FCT - case Kattegat

To demonstrate the potential impact of an FCT from a supply chain perspective, we will analyse and compare different supply chains, both with and without an FCT. A more comprehensive analysis is available in Appendix A. This section begins with a visualization of fairways and key Northern European ports that could benefit from a floating terminal in the Kattegat , see Figure 8. A hypothetical potential route, the Transpolar Sea Route (TSR), is examined. The route, if ice-free, conditions were to develop, will potentially connect the Bering Strait to the Atlantic Ocean near Murmansk through the central Arctic.

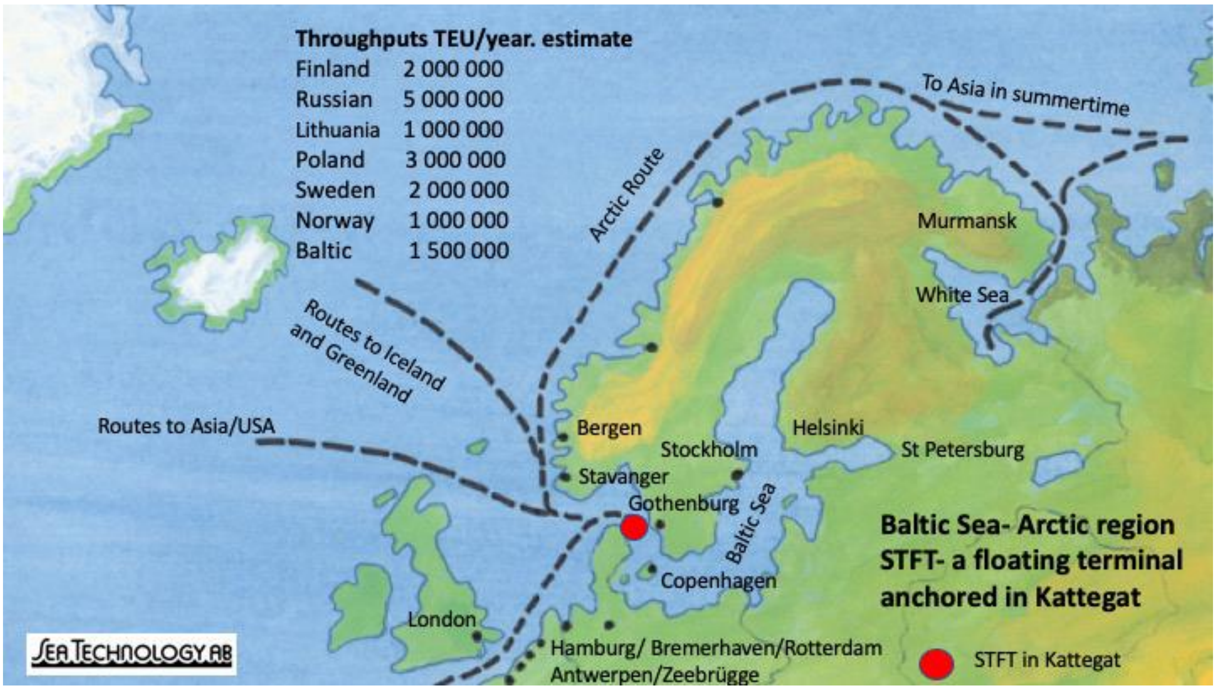

Figure 8 - Logistic map over North Europe with overview of fairways and container throughput

Current supply chains

The focus in this comparison is on supply chains from Shanghai to many ports of Northern Europe. Most containerised cargo is carried by ULCVs arriving at Rotterdam or Antwerp where reloading to feeder vessels or lorries take place. There are computer programs available to customers and brokers for analysis of supply chains. In this project we have made use of Fluent cargo, a comprehensive web-based program (www.fluentcargo.com). Most routes around the world were compared and a selection is documented in the report, Appendix A.

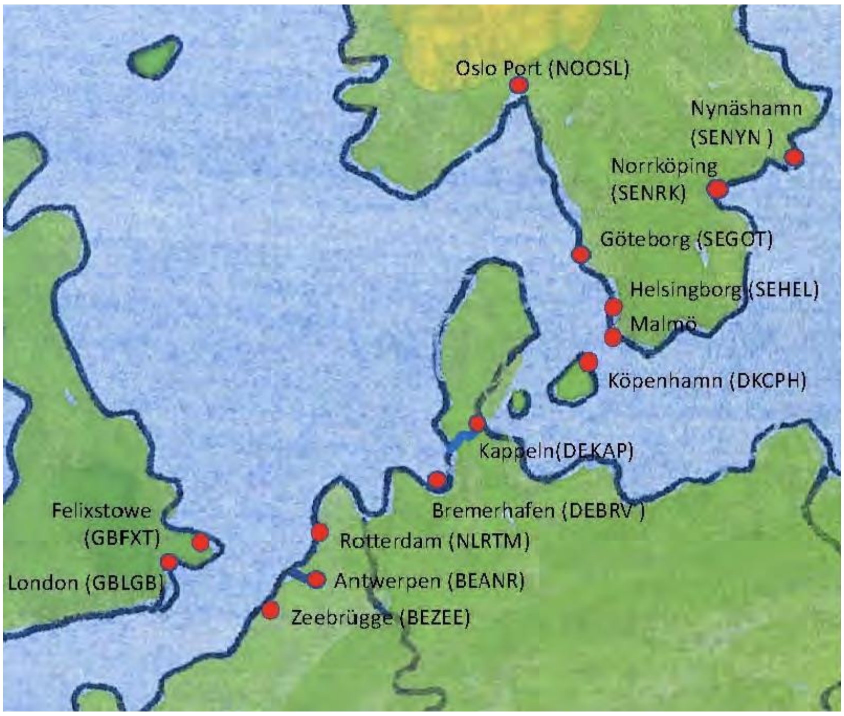

Figure 9 – A visualization of different ports in Northern Europe.

In Figure 9, a selection of major and smaller ports in Northern Europe is shown. ULCVs from Asia, for example, frequently arrive in Rotterdam, where trucks or feeder vessels take over distribution. By utilizing the Fluent Cargo tool, various potential routes can be identified based on availability. Fluent Cargo also provides data on distances between ports, and if trucks or trains are viable options, these are displayed as well. When using the webpage for a "port-to-port" request, at least ten routing options are generated, of which three are shown in Table 6, with travel distances and times provided. These routes are described to illustrate their complexity, as simpler options exist, such as direct shipments from Asia to Gothenburg on large vessels. However, Maersk recently announced the cancellation of that route.

Table 9 – Supply chains derived from using the program "Fluent Cargo".

Three options proposed by Fluent Cargo for the supply of containers between Shanghai and Gothenborg			
Option 1	**Leg number**	**Port to port**	**Distance/hours**
	1	Shanghai - Antwerp	10700 nm/745 h
	2	Antwerp - Norrkoping	800 nm/88 h
	3	Truck to Gothenburg	322 km/3.5 h
Option 2	**Leg number**	**Port to port**	**Distance/hours**
	1	Truck to Xiamen	1061 km/11 h
	2	Xiamen - Felixstowe	10.000 nm/632 h
	3	Felixstowe – Bremerhaven	307 nm/18 h
	4	Bremerhaven - Kristianstad	277 nm/20 h
	5	Truck to Gothenburg	487 km/7 h
Option 3	**Leg number**	**Port to port**	**Distance/hours**
	1	Shanghai - Antwerp	10.700 nm/745 h
	2	Antwerp - Oslo	607 nm/43 h
	3	Truck to Gothenburg	288 km/3.2 h
Remark: There will be cargo transfer between ships in ports along the route several times; Typically: Antwerp – Oslo will be with a feeder ship MSC ABIGAIL of 1 118 TEU			

To further illustrate the details and data retrieved from Fluent Cargo and used in subsequent analysis, Table 10 shows an example of a supply chain route for a shipment from Shanghai to Gothenburg via Felixstowe, Bremerhaven, Kristiansand, and then by truck to Gothenburg. Note that this is not the most common route— which previously has been direct shipment —but rather an example to demonstrate the data derived from Fluent Cargo. Instead, the complete analysis of a number of supply chains is found in Appendix A.

Table 10 - An example of supply chain from Shanghai to Gothenburg.

Ships from Shanghai to Gothenburg via Felixstowe, Bremerhaven, Kristiansand; truck to Gothenburg				
Leg number	**Port to port**	**Service ship/truck LxBxT m**	**Type of ship (number of TEU)**	**Distance/hours**
1	Shanghai – Felixstowe	ULCV: MSC CHINA (IMO 9936642 399x61x14.2 m	ULCV for 24.117 TEU	10700 nm/745 h
2	Felixstowe - Bremerhaven	MSC POH LIN (IMO 9279977) 294x31x10.9 m	Panamax (old) For 5.059 TEU	307 nm/18 h
3	Bremerhaven - Kristiansand	BENEDICT (IMO 9327578) 148x23x7.2	Feeder 1.100 TEU	277 nm/20 h
4	Kristiansand – Goteborg	Truck	Truck 4 TEU	288 km /3.2 h

The reshaping supply chains by the introduction of the STFT in Kattegat

If successful, future supply chains will be considerably influenced by the presence of an FCT in Kattegat. Through discussions with industrial actors, and assumed in subsequent calculation, there is a potential that about 20% of the cargo to Finland, Sweden, Norway, Denmark, Iceland, Poland and the Baltic states could be transferred over this FCT in Kattegat. Additionally, if feeders take over the regional distribution from trucks to minor ports this will save money and reduce emissions of carbon dioxide from fossil fuel. As a consequence, less road traffic around these minor ports will be seen to the benefit of local population.

To illustrate the challenges of current supply chains and the potential of an FCT, the Port of Antwerp serves as a case in point. With a throughput of 10 MTEU, a maximum water depth of 12.2 meters, and a maximum ship length of approximately 150 meters (500 feet), Antwerp cannot accommodate ULCVs. Although there is currently a temporary decline in activity, as global industry and trade rebound, ULCVs will likely become standard for shipping between major ports in Asia, such as Shanghai, and Europe. In such cases, these vessels will favour deeper ports, making an FCT increasingly competitive.

A few supply chains are described in Appendix A to demonstrate the impact of an STFT in the Kattegat. The assumption is that sufficient cargo arrives in Northern Europe to fully utilize the platform, allowing an STFT throughput of 5–6 million TEU per year. This is equivalent to 250 fully loaded ULCVs or 365 ULCVs at 70% capacity, approximately one ULCV per day. A 24-hour turnaround time at the port is considered realistic, with container cranes operating simultaneously.

Maritime shipping is highly sensitive (elastic) to bunker fuel costs, which account for 45–50% of operating expenses, with limited opportunities for reduction aside from slow steaming. However, from a comparative perspective, maritime shipping is less sensitive to fuel price fluctuations than trucking or rail. This implies that higher energy prices are likely to encourage routing options with port calls as close as possible to shipment destinations

To provide a comparison, two supply chains are illustrated below as examples (additional comprehensive details are available in Appendix A). A fuel use comparison as a part of the financial comparison is made.

Case 1. A fully loaded ULCV (24,000 TEU) arrives at the STFT, transferring 2,000 TEU to a fully loaded feeder vessel for transport to Oslo, see Figure 10
Case 2. In comparison, a less efficient “traditional” supply chain involves a fully loaded ULCV transferring a TEU to a truck, which then drives the entire route to Oslo, see Figure 11Figure 11

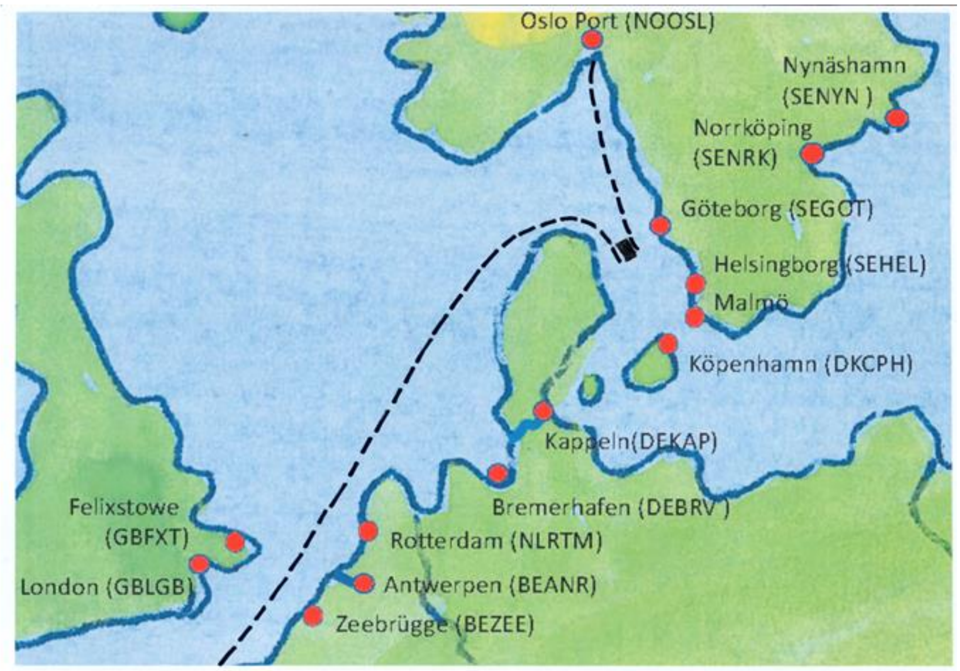

Figure 10 - The STFT hypothetically located in Kattegat, exact location needs to be determined.

The distance from Shanghai to the STFT in the Kattegat is 11,130 nautical miles, resulting in an operating cost for a ULCV (25,000 TEU) of approximately $0.007 per TEU per nautical mile, totalling $78 per TEU. For a ULCV, fuel consumption accounts for about 50% of total operating costs at sea, depending on fluctuating bunker oil prices. The feeder distance from the FCT to Oslo is 273 nautical miles, resulting in a fuel consumption of 117 litres.

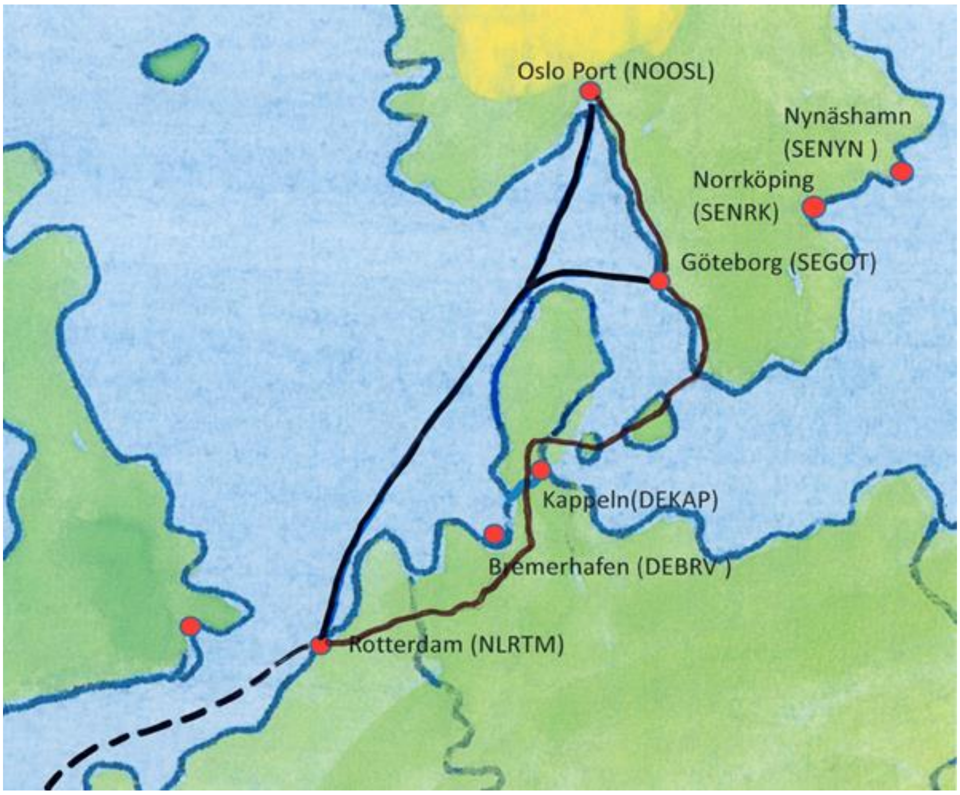

Figure 11 – A less efficient traditional supply chain

By utilizing Fluent Cargo, common transport routes for a ULCV that docks in Rotterdam and then transfers cargo via feeders to Oslo or trucks overland via Gothenburg to Oslo are identified. Details on distances and fuel consumption are presented in *Table 11 -* Trucks or feeders from Rotterdam to Oslo*Table 11*.

Table 11 - Trucks or feeders from Rotterdam to Oslo

Specification of carrier and port to port	**Distance [km]**	**fuel consumption [litres]**
Truck distance Rotterdam – Gothenburg – Oslo	1576	630
Truck distance Gothenburg – Oslo	294	117 (part of above)
Distance for feeder (4000 TEU) from Rotterdam to Oslo	1000	40

When comparing the supply chain with an FCT located in the Kattegat (Case 1) to a traditional supply chain (Case 2), the fuel savings amount to approximately 630 – 40 = 590 litres per FEU. This represents a significant reduction in both cost and environmental impact. Figure 12 illustrates these supply chains from a global perspective, and additional details can be found in Appendix A.

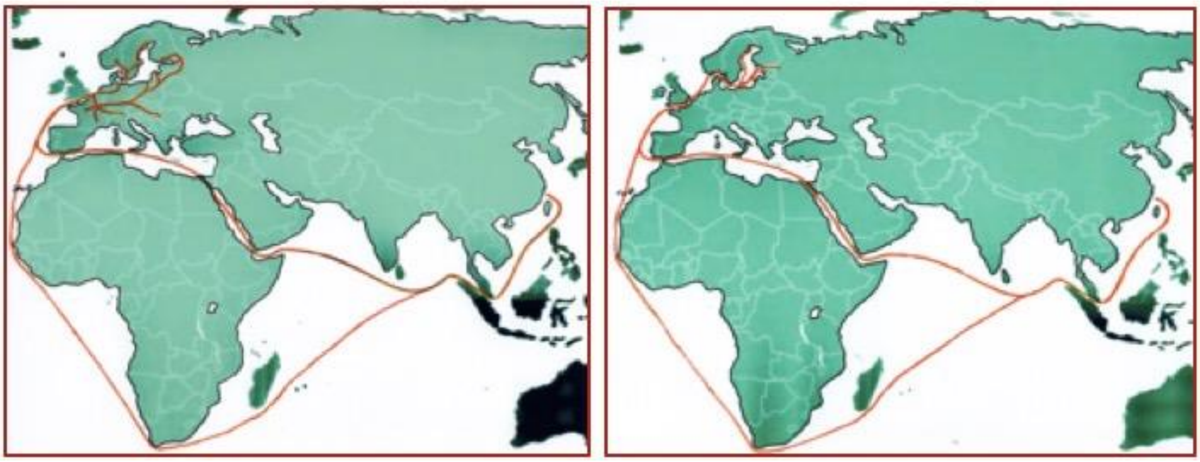

Figure 12 - The figure to the left shows common supply chains from Asia (Shanghai) to Europe and the Baltic states. To right are the more favourable routes when fuel consumption and CO_2-emissions are considered.

Environmental potential of an FCT

Together with 2050 (https://2050.se/), Sea Technology has within the project conducted a scenario mapping regarding CO2 emissions, using the Avoided emissions framework (here labelled the SeaTech scenario). These calculation compares two scenarios from transports to target ports in the Nordics and Baltics. In the baseline scenario, goods arrive at Rotterdam by ULCV and is distributed by a mix of modes to target ports. In the SeaTech scenario the introduction of a SeaTech platform is assumed to facilitate a modal switch for a share of these transports, from road to feeder vessel. The assumed share of goods that can be rerouted from road to feeder vessel in the SeaTech scenario is explained below. For these specific transports, the emissions are calculated as road transport in the baseline and by feeder vessel in the SeaTech scenario.

Key Assumptions:

- Calculation is made for the top 10 ports in the Nordics and Baltics, assuming the traffic from Rotterdam/SeaTech is distributed proportionally to the share of throughput per port.
- Port locations, distances and throughput defined by SeaTech
- Port/platform operations assumed to be roughly equal in both scenarios (Baseline vs SeaTech), emissions from operations are therefore excluded
- Emissions from transports are calculated using emission factors from the Global Logistics Emissions Council (GLEC), Framework 3.0.
- Emissions from road transports are calculated using a GLEC end user emission factor for road transport: "Artic truck up to 40-ton, Container"
- Emissions from sea transport with feeder vessels is calculated using GLEC end user emission factor for shipping: "Intra North Europe, Dry container"
- Emissions from Transport with ULCV is calculated using GLEC end user emission factor for shipping: "Asia to-from North Europe"
- Emissions from construction of the SeaTech platform is roughly estimated based on the LCA Emissions for a Panamax tanker, which is scaled up in proportion to the ratio between the proposed measurements of the platform and a Panamax tanker.

In this calculation, it is shown that the STFT solution cuts emissions by 75% over 10 years, reducing CO_2 from 27 million to 7 million tons, with 1.5 million tons from construction of the platform. Transport emissions are reduced by 80%, achieving climate break-even in less than a year, see Figure 13.

Figure 13 - Diagram developed together with 2050 and team from Sea Technology showing the STFT solution versus baseline scenario in tons of CO2

Furthermore, research on emissions from large vessels shows that an idle container ship typically burns 80 to 100 metric tons of heavy fuel oil per day, depending on size and operational conditions. Each metric ton of heavy fuel oil burned produces about 3.15 metric tons of CO_2. The environmental data are frequently cited in reports by the International Maritime Organization (IMO) and studies from environmental organizations like the International Council on Clean Transportation (ICCT). A FCT has the potential to reduce this by adding capacity into the supply chain and by doing so reduce the downtime for the ULCVs. Emissions per Day: The European Maritime Safety Agency (EMSA) and IMO also highlight that waiting in port areas results in significant emissions of CO_2, sulphur oxides (SO_x), and nitrogen oxides (NO_x), contributing to pollution and environmental damage. Hence, an FCT located away from land has the potential to reduce these emissions in sensitive port areas, where people live and ecosystems and fauna is especially sensitive, by also mooring with shut down engines, collaboration with carbon capture companies and the exposure

Sustainability evaluation – current port traffic and the potential of FCTs

Current Sustainability Issues and impacts from ship traffic in land-based port are quite significant. There is room for mitigation of such issues and improvements with new technologies and understanding of ecosystems. In land-based ports there are problems such as (Transport and environment(a), 2022, Transport and environment(b), 20229 but not limited to.

- Significant amount of air emissions (e.g. sulphur oxides SOx, nitrogen oxides NOx, carbon dioxide CO2, particulate matter PM) from mooring vessels impacting receptors and in for instance Venice where residential houses adjacent to the Stazione Marittima port and, in case of the cargo port Porto Marghera, the situation is already heavily impacted with limited margins.
- "The port of Rotterdam is associated with almost 14 million tonnes of CO2 each year, putting it on a par with Europe's fifth biggest industrial polluter – the Weisweiler coal power plant in Germany" - according to a study made by Transport & Environment, T&E, in 2022.
- Risk for accidents with releases of hazardous substances in the proximity of land, people due to heavily trafficked and congested port inlets (e.g. oil, sanitary wastewater)
- Environmental noise and impact on the shore and sea bottom in the port and inlet areas (e.g. erosion from the ship traffic)
- Dredging often results in hazardous chemicals imbedded in the sea bottom from dumping, being released and there are not enough studies to understand how that actually impacts ecosystems and the water quality.
- Health impact from air emissions (e.g. PMs) on exposed population.
- Exposure to electromagnetic fields from radar systems.
- Sludge created by erosion and traffic destroys engines and significantly impacts water quality

A high-level study was made by Sustainability advisor of Sea Technology, Christina Brodin, which has identified that relocation n of the port traffic to FCTs has the potential to reduce impact on:

- Exposure of air emissions to sensitive receptors
- Environmental noise impact to sensitive receptors
- Incident & accidents risk due to congested inlets and ports
- Prevention of erosion on sea bottom and shores.
- Reduction of net air emissions due to mooring with shut-off engines and local energy supply by using tugboats, auto moor system based on vacuum and the possibility to develop easier access to cleaner fuels and energy - read more in our appendix about the STFT as an energy node.
- Local waste handling and freshwater production

Business model

In this section, the business model for an FCT is developed. This is partly based on the concept developed by Sea Technology, the STFT, including their design and cost estimates. However, it is also underpinned by an analysis of the semi-structured interviews conducted throughout the project with individuals from the industry, academia, and authorities. Thus, in the business model canvas, the concept of the FCT is discussed more broadly, rather than being limited to only Sea Technology's specific design. Also, both academic and grey literature are used to address the questions posed in the Business Model Canvas. Since no FCT has been built yet, not only the aspects necessary for it to remain competitive with other ports once operational are addressed, but also key aspects required for the FCT to actually reach the implementation phase are covered.

1. **Customer Segments**:

Compared to conventional ports, the FCT will focus primarily on the efficient trans-shipment of containers. To achieve the necessary volume for profitability, for the STFT case break-even is at around 800 000 TEU with a max capacity at 5-6 million TEU annually, connectivity with the customers is very important. According to project calculations, the most critical customer segment will be global container shipping companies. Around 7-10 major firms control roughly 80% of the global container market, operating ULCVs that will unload at the FCT. Securing commitments from these companies will be essential for the project's success, whether through signed letters of intent, volume commitments, or even direct investment in the FCT as it approaches commercialization.

While not as important as the global container shipping companies, smaller feeder vessel operators, which will service secondary ports, e.g. in the Baltic Sea, will also be an important customer segment to secure trans-shipment to smaller ports and subsequently reach the destinations of transport buyers. Also, logistics service providers or ship brokers are important customers, who contribute to the connectivity of a port, which is one of the most important competitive factors for any port as a trans-shipment hub (Yap and Ho, 2023).

If the FCT is developed to include an energy hub, for which the project has identified several alternatives, see appendix 2, additional revenue streams can be generated. However, this will require collaboration with a new group of customers involved in the production and distribution of energy. Appendix 2 provides a summary of key customers and stakeholder in energy generation, including wind power and SMRs.

2. **Value Proposition**:

There are several key components of the value proposition for customers of the FCT. Based on the interviews, the most important is the strategic location along current shipping routes, aligning with the large flows of containerized goods. This strategic positioning not only reduces transport distances and fuel costs but also has the potential to lower trans-shipment costs and lead times overall. The project has shown that in the North Sea context, one viable location could be in the Kattegat. If located elsewhere, interviewees pointed to areas off the North American west coast and in Southeast Asia, where there are large trade flows, as suitable locations from a global perspective.

Another important aspect is the FCT's potential superior trans-shipment efficiency compared to conventional ports. As a newly constructed facility, it is specifically designed to handle the increasing size of modern ships, ensuring efficient loading and unloading processes. These benefits enhance the value proposition for both shippers and shipping companies within global maritime supply chains.

One interviewee from a shipping company highlighted that operating a ULCV costs about $50,000 per day. Conventional ports are often not positioned to minimize travel distance and are affected by congestion and long wait times. Therefore, significant savings can be achieved if ships can transport goods more efficiently, avoiding congested ports and unnecessary transport distances. Given the number of days that can be saved for each ship, this could amount to substantial amounts for the largest container shipping companies operating hundreds of ships.

Environmental benefits also play an integral role in the value proposition. The maritime shipping industry faces growing pressure to reduce emissions, and shorter routes enabled by a FCT will help achieve this goal. Container shipping companies can use such efficiencies gained to meet regulatory requirements such as the Carbon Intensity Indicator (CII). Thus, enhanced environmental performance can become an attractive part of the value proposition for potential customers. Hence, in sum, all of these aspects contribute to the value proposition of the FCT, which is to lower costs and environmental footprints for container shipping companies.

Finally, if the FCT functions as a green energy hub, producing renewable maritime fuel, this could be an important part of the value proposition for container shipping companies. It has been argued that renewable energy production could become a key service offered by ports in the future (Díaz and Soares, 2023).

3. **Channels**:

The channels of communication with customers, such as container shipping companies and feeder companies, do not need to be unique for the FCT compared to conventional ports once the terminal is operational. Instead, it is crucial that the operator of the FCT aligns with industry trends, such as following trends on “smart ports”, c.f. Belmoukari et al. (2023), particularly the use of digital platforms for container booking and tracking.

The real challenge lies in marketing the FCT before it has been implemented. To effectively reach potential customers, various channels should be employed throughout different stages of the marketing process. At an early stage, traditional channels such as maritime industry conferences, trade shows, and advertisements in industry-specific media will help create awareness. So far, both the focal company behind the report (Sea Technology) and other floating platform concepts and companies have received some media coverage in the maritime transport sector media. However, significantly more exposure will likely be needed to attract enough stakeholders and build the momentum required. Once initial traction is gained, direct engagement with major containers shipping companies through in-person meetings, networking events, and strategic partnerships will be crucial. The investor or operator could also use online customer acquisition tools, including content marketing, whitepapers, and case studies, to demonstrate the value of the FCT and attract early customers. Subsequently, the potential operator will need also to rely on conventional marketing channels to attract the first customers, mainly container shipping companies, who must commit volumes for the FCT to be constructed

4. **Customer Relationships**:

Given that long-term volume commitments were identified by interviewees as very important, this need should be reflected in long-term relationships with major container shipping companies. Inevitably, these relationships will likely need to be formalized in contracts, especially before the FCT is constructed, to secure the necessary investments.

Interviewees also suggested that disruptions could impact the FCT differently from conventional ports, which may experience issues related to hinterland infrastructure. Instead, the FCT may face more frequent closures due to weather conditions. Therefore, it is crucial to incorporate strategies for managing unforeseen disruptions into customer relationships, using various flexibility measures. In fact, flexible and resilient contracts to address such disruptions have been highlighted as a key competitive advantage for ports in the future (Salsas et al., 2022).

If the FCT operates as a bunkering hub, key relationships will include those with bunkering companies. However, the bunkering market is relatively mature, and long-term relationships may not be necessary for conventional bunkering services

5. **Revenue Streams**:

For container trans-shipment, the revenue streams are relatively straightforward, primarily consisting of container handling fees, storage fees, berthing fees, and trans-shipment fees. The space on FCT is more limited compared to conventional ports, which may reduce the presence of certain actors, such as stuffing companies and providers of value-added services like container repair. However, this limitation can streamline operations, allowing the FCT to focus on its core business, trans-shipment of containers, and optimize trans-shipment activities to maximize the related primary revenue streams, as they represent the largest share of income.

If the FCT also functions as an energy hub for renewable maritime fuel, additional significant revenue streams will come from the storage and distribution of fuel to key customers. These revenue streams can be substantial, particularly if renewable fuel is developed early on the FCT in relation to the maritime industry in general.

6. **Key Resources**:

Several interviewees indicated that the most suitable operator for the FCT would be a larger global terminal operator that already manages multiple large-scale terminals worldwide, as they possess the capabilities necessary to operate a facility of this scale (5-6 million TEUs).

The key resources will include all loading and unloading cranes, as well as the vehicles used for container movement on the FCT. This project has concluded that the goal is to achieve a high level of automation for these vehicles, enabling efficient handling and making the FCT an attractive choice for customers. Efficient container handling is widely recognized as a crucial strategy for ports (Martínez Moya and Feo Valero, 2017), and there is a growing trend towards more autonomous operations among the world's leading ports. Given that the FCT will have the capacity to invest in the latest equipment, pursuing a high level of automation is a logical choice, which is very true for the case of the STFT. Additionally, implementing automation could be justified, as it would reduce the need for personnel on the platform. Inevitably, personnel will be needed to be transported to and from the FCT by boat, or helicopters, which can be costly, so minimizing these trips is essential. As mentioned by the terminal operators interviewed, skilled personnel will be a key resource, as the FCT will require more highly skilled workers than conventional ports due to the complexity of its operations. However, much of the physical work can likely be controlled remotely, allowing some personnel to work from a distance. Similarly, management and customer relations can be handled from onshore locations to further minimize transportation needs to the FCT and facilitate efficient use of the key resources.

7. **Key Activities**:

Compared to conventional ports, storage will be less important at the FCT as the focus will be on efficient and quick trans-shipment. Other activities, such as customs, are likely to take place elsewhere, but doesn't have to be. Customs can be an integrated activity, this will depend on geographical location and customers. Interviewees emphasized that the most critical aspect of operations is the unloading and loading of ships. Essentially, the FCT serves as a trans-shipment hub, where efficiency in these processes is paramount. Given that the FCT is newly built, its design and scale can be adapted to accommodate the latest generations and trends in ship size. Equipment, such as gantry cranes, can be tailored to the technological needs of ULCVs, ensuring that loading and unloading activities are as efficient as possible. Additionally, interviewees favoured the concept of having unloaded on one side of the platform and loading feeder vessels on the other, allowing for streamlined container movement in one direction

Two interconnected key activities that must take place eventually are inspection and maintenance. One interviewee pointed out that there is no dry dock capable of accommodating an FCT of the intended size. Therefore, it will either need to be modularly constructed or inspections will need to be conducted at sea. In the case of the STFT, this has been studied together with Aker solutions and systems of underwater robots that cleans on a regular basis (Lindholm, 2021). There was no expected need in the case of the STFT to move the terminal to any dock for maintenance purposes.

The FCT could thus go for different options here, and other projects have more clearly investigated the modular design, such as the Space@sea project (Flikkema and Waals, 2019). Regardless, a plan must be developed before FCT can be implemented, and the design of the FCT will affect how different activities can be managed.

8. **Key Partnerships**:

Given that multiple interviewees pointed out that the maritime industry is very conservative, risk-averse, and prefers to see proven solutions before trying them out, key partnerships are needed to demonstrate that a FCT is a reliable solution if it is to reach the implementation phase. This will include relationships with actors such as classification societies and insurance companies that can verify the trustworthiness of the solution. Additionally, various types of research partnerships with universities or research institutes may be necessary. Interviewees expressed scepticism regarding the FCT's ability to function under harsh weather conditions, such as high winds and waves. These conditions can be tested through simulation studies, which can then be verified by building small-scale FCT models for testing in basins capable of creating real-life wind and wave scenarios. A few such tests were conducted in the Space@Sea project (Flikkema et al., 2021a), but further research with key partners is needed to understand the impact of harsh conditions worldwide and how they must be managed through appropriate FCT design accordingly.

A key partnership to facilitate both implementation and the ongoing attraction of volumes could involve one of the largest container shipping companies as an investor or key partner for the FCT. According to interviewees, these companies may see a strategic advantage in vertically integrating an FCT into their business. Companies like Maersk, for instance, have clearly articulated strategies to integrate ports and other logistics activities into their operations (Paridaens and Notteboom, 2022). A company with this strategy could serve as a potential key partner for the FCT. Furthermore, the willingness of various container shipping companies to invest in the FCT will likely depend on its location, as some are more rooted in specific regions of the world than others

9. **Cost Structure**: What are the most important cost elements for both the construction and operation of the port?

The construction costs are estimated to account for approximately 78% of the total budget of 2,500 MUSD for the STFT. Once operational, the trans-shipment costs are comparable to those of large ports in Europe. Cost calculations indicate that the STFT reaches break-even at an annual volume of 800,000 TEU, though a volume of 5-6 million TEU would yield stronger financial performance.

To sum up, the business model analysis shows that all the important elements of a business models can be established. However, convincing both a potential owner as well as operators remains significant challenges, though they can be overcome through demonstrations in small scale and by extensive research work. Attracting initial customers to commit large volumes of containers will be very important to get the project going.

5. The STFT as energy node

The core idea of the FCT is to function as a trans-shipment hub for containers (see Figure 14). However, during the project, it has also been explored whether the STFT could serve as an energy hub. By accommodating multiple functions, the platform can achieve economies of scope and generate additional revenue streams. This multipurpose setup could also accelerate the transition to renewable fuels from the ocean, enhancing its overall sustainability impact.

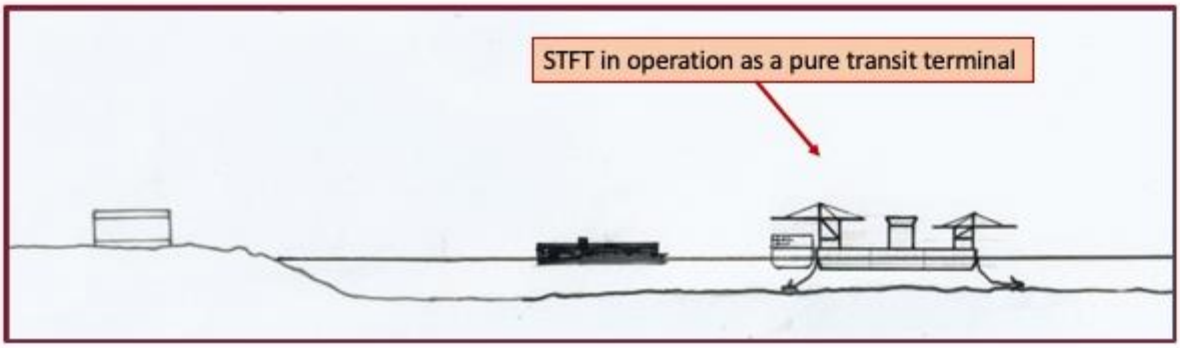

Figure 14 - The STFT in operation as a transit terminal for container shipping

To achieve the EU's climate-neutral target outlined in the European Commission's 2020 Strategy, an increased production of renewable energy at sea is essential. The strategic goal is to expand offshore wind power capacity from around 12 gigawatts to 300 gigawatts by 2050. Offshore wind power offers significantly greater electricity production potential than land-based wind power, as wind conditions at sea are stronger and experience less turbulence. Additionally, larger projects can be undertaken at sea due to fewer restrictions compared to land-based projects. The Baltic Sea, for instance, holds enormous potential for offshore wind development.

The growing interest in large-scale offshore wind farms to generate electric energy will increase the need for offshore energy hubs, such as HVDC substations. Naturally, if FCTs are constructed, the STFT could serve as a potential location for these substations. This analysis, further detailed in Appendix B, is driven by the need to fully understand the societal expectations and business environment that the STFT and STFTe concepts will encounter as they are developed to contribute to transition to renewable energy.

A key challenge is to achieve a continuous flow of electrical energy 24/7, making full use of the energy available from wind and solar radiation without any wastage. This requires a system that can store energy in batteries, methanol, hydrogen, or other concentrated, storable energy carriers. Numerous research and development projects are currently underway, many of which provide detailed overviews of potential solutions (see Appendix B for a summary and references to ongoing industry initiatives). The STFT and STFTe could play roles as energy hubs within these concepts.

The initial version of the trans-shipping terminal (STFT) is equipped with 20 diesel-driven generator sets, each providing 100 MW of electric power, sufficient to operate all container cranes and water pumps. In the future, demand may increase as feeder ships adopt battery-powered electric propulsion, which will require charging infrastructure. This additional charging capacity would require another 100 MW.

The STFT as a hub for wind power parks

In shallow waters, specifically at depths of 50 to 70 meters, existing solutions with bottom-founded transformation hubs are mature and already perfectly dimensioned. Rather, it is in deeper waters that the STFTe could be competitive when used to include a substation (see Figure 15), with more comprehensive details provided in Appendix B. To enable safe navigation for ships, a safe distance of about one nautical mile should be established between the STFT and wind farms, see Figure 15. An inter-array cable from a wind farm to an offshore HVDC substation over a distance of one nautical mile is not a problem.

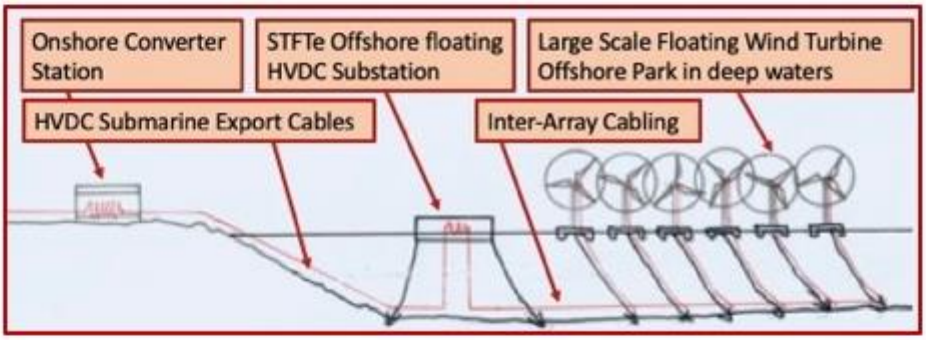

Figure 15 - STFTe as HVDC substation for a large floating wind park

For its own needs, the trans-shipment platform of the STFT will be powered by electricity from gensets, initially using MDO and later transitioning to green diesel fuel when it becomes available in sufficient quantities. When electricity is inexpensive due to continuous winds and solar radiation compared to customer demand, the surplus energy in these systems will either be used to charge batteries or to produce hydrogen for storage or conversion into green energy carriers in fluid form, such as methanol or ammonia

This version currently represents the most likely use of the STFTe as an energy hub. The reason is that, although the upcoming SMRs are promising, there is currently a lack of experience, and safety protocols need to be established. However, after the necessary regulatory developments regarding the work environment, the STFTe could also include SMRs on the same platform, as described in the next section.

The STFTe as energy hub with SMR

By the early 2030s, prototypes of SMRs may be ready for serial production, with demand expected to grow. For safety reasons, installation on floating barges and pontoons may be prioritized. In this project, a technical specification has been prepared (see Appendix B), indicating that the STFTe could potentially become one of the first large-scale floating nuclear energy sources in Scandinavia. This dedicated floating terminal would produce, collect, and distribute energy, supplying the trans-shipment platform with electricity from SMRs. From a cost-efficiency perspective, it may be beneficial to install surplus capacity for delivering electricity to nearby coastal areas. Additionally, if wind or wave farms are nearby, the STFTe could serve as a central energy hub, efficiently distributing electricity to consumers via transformation equipment. However, to ensure economic viability, careful planning will be necessary to fully utilize invested capital without unnecessary delays.

Floating barges for electric energy production from SMRs are an established concept. At an IAEA symposium on floating nuclear power plants held from November 14-15, 2023, in Vienna, legal experts, nuclear and maritime regulators, and industry leaders discussed the benefits and challenges of FNPPs, as well as the potential role they could play in combating climate change and supporting the transition to Net Zero. During this symposium, IAEA Deputy Director Lydie Evrard emphasized that the IAEA is collaborating with member states to ensure the safety of floating nuclear power plants.

During the project, Sea Technology initiated cooperation with Blykalla, a producer of SMRs, to assess the feasibility of using SMRs. Together, Sea Technology and Blykalla developed a technical specification, as detailed in Appendix B. Given uncertainties about radiation from the reactors, the project team concluded that a separate floating unit would be a more suitable option for an SMR application, at least for the time being.

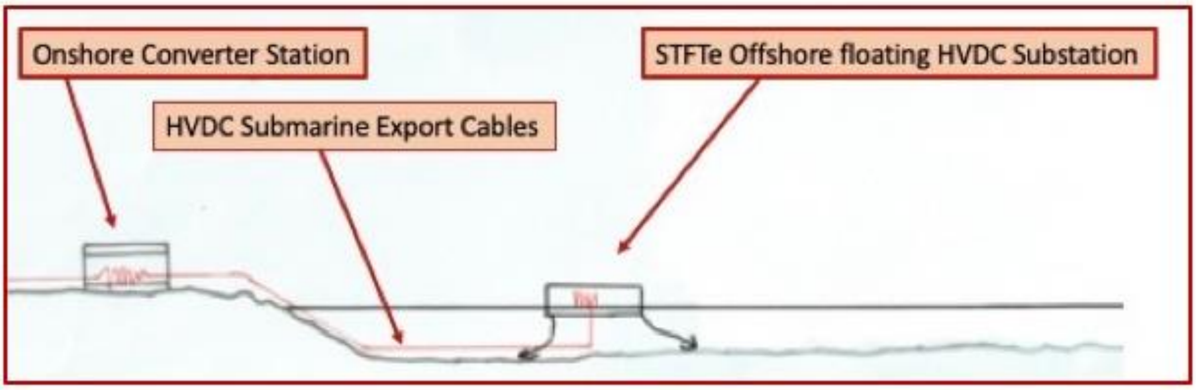

Figure 16 - The STFTe with several SMR installed

In reasonably shallow waters close to the coast, a floating hub containing several SMRs will generate electric power for the grid. The SMRs will produce steam to drive turbines, generating electricity. This electricity will be transformed to the optimal voltage for transmission to shore, most likely high-voltage DC. The offshore SMR hub is a safe solution, as it does not require large surrounding land areas for safety purposes. A key advantage is its flexibility in location; it can be positioned anywhere along the coast where the grid requires increased supply, helping to avoid costly investments in high-voltage infrastructure on-shore.

For many years to come, it is likely that energy from SMRs will be produced on standalone barges or pontoons, like the STFTe, separate from the dedicated trans-shipment platform, the STFT (see Figure 16). In the longer term, combined platforms may become feasible as experience with SMRs grows and the radiation risk levels are confirmed to be low, allowing for a defined safety zone around the reactor. This assumption is supported by experience with nuclear submarines.

6. Discussion

This report shows that the maritime industry is tentatively curious and optimistic of the concept of an FCT and praises the potential benefits. The review of both grey literature and scientific literature in combination with the analysis of the interviews rendered theoretical categories in terms of both drivers and barriers. Among the most frequently raised issues were security, finance, and trust.

Security may be a driver as containers can be screened on the FCT before reaching shore and large ships do not need to navigate in dense port areas. However, security has other dimensions and perspectives. For example, the current geopolitical tensions may lead to strong opposition from governments in Europe who may not want floating structures close to their boarders which they may not have jurisdiction over and potentially can be used for other purposes than handling containers.

Trust in the concept is a key issue. Many interviewees raised scepticism towards the concept of an FCT, wondering if ships safety can berth at the FCT and if technical issues regarding autonomous handling can be resolved. When the interviewees were presented with the information that the STF already had received offers from three capable and well-known shipyards, trust become stronger. Paradoxically, the concept is perceived as both innovative and not innovative within the industry, reflecting divergent viewpoints among stakeholders. From a technical perspective, a floating metal structure is not a radical innovation, but from a supply chain perspective it may be seen as radical as it from the viewpoints of interviewees is perceived as a completely new type of node in the supply chain. Additionally, it is suggested that the concept may need to undergo initial validation on a smaller scale before being perceived as reliable. One approach is to identify niche markets where slightly smaller versions of an FCT can be constructed, with factors beyond cost potentially justifying the investment. For instance, governments in certain regions may require port capacity expansion in challenging areas, such as the case with Chittagong port in Bangladesh. Furthermore, the development of a scalable terminal capable of continuous expansion may be necessary.

When it comes to the financial factors, an in-depth analysis both by the Clarkson's team and the Sea Technology team, prove that the STFT solution can be profitable already at throughput of 800 000 TEU. Of course, it’s a volatile market, but some certain macro key indicators that are important. The population growth is estimated to continue until 2060, and then stabilise, and a large part of that comes from developing regions like West Africa with Nigeria taking the lead. These are regions where finance can be secured through infrastructure funds and consortium. Both a reliable grid and port capacity are vital for a stable economic and societal growth. An FCT that can act as an energy node will be favourable. By providing clean, renewable energy and the potential to connect with feeder vessels powered by batteries or alternative fuels, the STFT can reduce dependency on traditional, polluting energy sources. This also opens up opportunities for regional industries—from fishing to waste management—to integrate and benefit from a shared, multifunctional hub that supports both maritime and onshore activities.

Sweden is strategically positioned, and especially the west coast, when it comes to increasing trade and stabilising supply chains in Northern Europe. When cargo analysis was applied to Northen Europe it was evident that many supply chains included rather long-distance road transportation by trucks from e.g. Port of Rotterdam to end users. This gives opportunities for a

FCT, like the STFT, in Kattegat to contribute with a transformative solution to the capacity and energy challenges faced. A strong case to save fuel and costs is indicated by using fully loaded ULCVs to a FCT in Kattegat for transfer of cargo to feeder ships. The case also presents an opportunity for increased throughput volumes for the Port of Gothenburg without having to dredge to increase depth.

From a Swedish perspective and Nordic including the Baltic, the usage of an STFT located in Kattegat, could protect supply chains and also enable the opening up of new container routes, like the Northeast passage route. With the stability provided, comes the possibility of more accurate budgeting and economic growth paired with reduction of emissions. Could it event pave the way for other green transitions like the decarbonization of steel or the growth of offshore wind energy production by providing the missing link?

Seventeen stakeholders that will play a role in executing on making a system of FCTs a reality in the near future have been identified. Their perspective has been valuable for understanding how to address concerns in how to break through the status que. Their requirements are met by a description of the equipment and procedures of the STFT and also with a detailed technical specification used by the Korean shipyards who offered to build the STFT. The function analysis report was useful for the preparation of the interviews with stakeholders.

While the concept remains visionary, its implementation has the potential to profoundly alter the landscape of linear shipping networks. If proven successful and if made more cost-efficient than conventional ports, major linear shipping companies some of which aspire for greater vertical integration of the supply chain may express interest in investing in an FCT like the STFT. However, a challenge is that the FCT is a trans-shipment hub with the lack of conventional port hinterland connections. Thus, future research needs to show how it can co-exist with major and minor regional ports, both from a linear network perspective as well as a business model perspective.

7. Conclusion and future outlook

The locked in structures of land-based ports has reached its max capacity and Sea Technology believe that there are indicators from many angles pointing towards a future where FCTs are part of the supply chain, infrastructure landscape and the green energy transition.

The ULCVs are still growing in size, trade is increasing, and the population is still growing. Regulatory framework is imposed on the shipping industry and the consequences of climate change are beginning to show. We also see disturbing trends that large green industrial projects are put on pause due to many factors – like timeline, funding, uncertainties. Based on discussions with industrial partners in green energy, Sea Technology believe that a system of FCTs have a big role to play in also enabling the missing link.

It is the conviction of Sea Technology, and many of the stakeholders and interviewees from the industry, that we have approached a time where FCTs can both be financed and in the case of the STFT also technically enough validated to take the first steps to adding floating capacity for both existing trade routes and enabling new trade routes. There are also enough indicators that the STFT as a solution also is a more sustainable version of port compared to the land-based transshipment ports we have today.

When introducing a new technology timing is important. The modern ports of today are a heritage from a time when globalisation, trade and population was not at the level we have today nor expect to have in the future. The port of Rotterdam started as a fishing port in the 15th century and turned into a commercial port in the 19th century. It is nr 10 in size when it comes to container handling. Today the port is heavily integrated with the city of Rotterdam – the ports have become cities, and the cities have become ports. Is that really what we want? Or is there another way where the land that these very large ports possess could be used for greater good, like housing, green areas and restored harmed ecosystems?

It is plausible to conclude that the regulatory framework and the mitigation of risks in addition to the clear business opportunity combined with significant improved environmental footprint do point at the fact that the timing for FCT is here given the challenges and opportunities.

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