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From Concept to Market: Internationalization of Sustainable Methanol Piping Solutions for the Maritime Industry

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ABSTRACT:

The maritime industry is facing a significant transformation as regulatory pressure, technological advancement, and sustainability goals are pushing to accelerate the shift toward low-emission alternative fuels. Methanol, which has gained a lot of traction due to its compatibility with existing vessel infrastructures, manageability in a liquid state and the fact that it can provide substantial greenhouse gas reductions when produced through sustainable processes. In this highly regulatory environment, explaining how the firms that provide methanol-based solutions internationalize and come up with complex and safety-related solutions is of increasing importance.

To provide a more detailed insight into this changing landscape, the study investigates the internationalization paths, technical conceptualization, and sustainability implications involving high-pressure methanol piping systems. The paper uses a qualitative approach and a single case study, utilizing a set of semi-structured interviews with experts in the maritime industry. Through an analytical review, the study outlines the key considerations that will guide the internationalization efforts of these organizations, including regulatory requirements, the role of global networks, as well as the critical role of collaborative engineering in designing the compliant methanol solutions.

The findings show that internationalization in the maritime sector is inherently network-based, whereby companies rely on sustainable relationships to overcome market entry limitations and to achieve legitimacy. The study also indicates that conceptualization of methanol piping systems is informed by stringent safety regulations, regulatory interpretations, and inter-organizational alignment. Despite several barriers such as limited supply of green methanol and the underdeveloped global infrastructure remain a major challenge, methanol piping systems can already play a significant role in sustainable shipping and in achieving the goal of decarbonization offered by the International Maritime Organization.

Promoting and expanding existing global business models in the unique context of maritime decarbonization, this dissertation provides new empirical data that is relevant in the spheres of alternative fuels, network-based growth, and innovation in safety-related technologies. In addition, it also gives practical recommendations to policymakers and players in the industry who are keen on accelerating the adoption of methanol-based solutions. The paper concludes with a series of recommendations that future research should follow to enhance the academic understanding of the maritime energy transition and the technologies that support them.

KEYWORDS: (Internationalization, conceptualization, network theory, born global, methanol, sustainability)

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1 Introduction

This chapter introduces a comprehensive overview of the background and context of the thesis, explaining the research gap, research questions and objectives of the study. It also defines important terms and ideas to help readers understand key concepts and the topic. Furthermore, it covers the limitations of this research, making clear what this study will and will not cover. The thesis involves artificial intelligence for enhancing grammatical accuracy and maintaining academic writing style.

1.1 Background of the Thesis

The maritime industry, a mainframe of global trade and transportation, is facing a rapid and prodigious transformation. This shift is mainly driven by increasing awareness of environmental issues and the need to reduce greenhouse gas emissions (Sun et al., 2025). The international maritime organization (IMO) has set an ambitious target to reduce greenhouse gas emissions from shipping which led this industry to adapt and explore alternative fuels (IMO, 2023). This accelerates interest in fuels beyond traditional heavy fuel oil and marine gas oil, thereby creating an opening for innovative solutions in marine fuel handling systems.

Among these various alternatives, methanol is one of the most prominent candidates. Methanol is very significant in reducing both greenhouse gas emissions and sulfur oxide when produced from sustainable sources such as biomass or renewable energy(Tomos et al., 2024). Rather than Heavy Fuel Oil (HFO), methanol is sulfur free and can greatly contribute to improving air quality. Additionally, it is basically liquid at normal temperature, making it easier to handle and store compared to Liquified Natural Gas (LNG) and Hydrogen (Verhelst et al., 2019). These characteristics of methanol make it a viable option for transitioning towards a more sustainable maritime industry.

However, the transition to methanol as an alternative fuel is not without challenges. Methanol is highly flammable and toxic, requiring several safety guidelines while designing the shipping system to reduce potential risk to personnel and environment. It needs very reliable fuel handling systems capable of safely handling its hazardous nature(Jin, 2024a). Due to these concerns, a robust and efficient piping system which can withstand complex chemical and physical properties of methanol should be implemented while transporting methanol from storage tanks to engines. Additionally, it is required for many existing ships to be retrofitted as handling methanol needs additional elements which are absent from most of the existing ships.

As a result, these advances have unlocked new possibilities for technological innovation as well as international partnerships for those trying to supply maritime equipment. Firms that specialize in piping systems and fuel handling technology and safety components are playing an increasingly important role in helping to lead the way to low-emission fuels. But the success of these technologies coming into the world market relies on several critical elements, including compliances to global regulations, strategic partnerships, and the ability to adapt products according to customer and market demands.

Therefore, it is crucial to understand how maritime technology companies consider, develop, and scale their methanol-based products supporting the larger decarbonization journey of the industry. This paper explores the interplay between innovation, global market integration and sustainability in the shift to methanol-based shipping.

1.2 Research Gap

While there is growing interest in methanol as a fuel for shipping within both the academic and commercial sectors, there are several research gaps that need to be addressed, particularly concerning high-pressure piping systems.

Firstly, there is a major research gap in commercialization and product market. Even with all the discussion about methanol as a marine fuel, few studies aim to explain how innovative suppliers are translating their concepts into standardized piping systems that are ready for market around the world (Tomos et al., 2024). The maritime industry has various regional standards and requirements, so companies struggle to align their designs, certifications and manufacturing processes among multiple countries. There is a need for further research that how these technology service providers address these issues, and how they collaborate with global partners to ensure compliant and scalable products (IMO, 2023)

Secondly, a significant gap is between infrastructure and fuel emphasis. Most of the current literature makes the environmental benefits and the regulatory aspect of methanol more prominent, while the infrastructure (including fuel handling piping systems) is relegated into the background (Verhelst et al., 2019). But without them, methanol does not work safely and efficiently on ships. Technical development and creation of these pipes is still in its embryonic phase and the potential contributions of these engines to the decarbonization strategy for shipping have yet to be examined. The consequences of high-pressure piping on safety, performance, and sustainability are key if we are to achieve international emission targets (Jin, 2024).

The third gap is that of entry into foreign markets. Much of the existing research on going global focuses on manufacturing and service industries and rarely addresses the role of marine equipment suppliers in forming their networks and competing in the global shipbuilding arena (Brynolf et al., 2022). The industry is built on relationships, reputation and long-term collaborations, not mere head-to-head competition Most of the experience with building credibility in global supply chains is from large suppliers; still, there is a lack of empirical evidence of how smaller and medium suppliers overcome network dilemmas and gain credibility (Osobajo et al., 2021).

Lastly, another gap is the one related to technical implementation and safety. Methanol is a flammable and toxic fuel that calls for advanced fuel-handling solutions that remain in line with strict safety standards (OCIMF, 2020). However, there is a gap in research on engineering, verification and operational requirements for high pressure double walled piping as well as the way of tailoring such solutions for retrofitting and new-built vessels worldwide. These gaps need to be addressed, if knowledge is to be expanded and practiced being enriched in research as well as in industry.

This study seeks to bridge these gaps by examining the development, adaptation and globalization of high-pressure methanol pipeline technology by technology providers to connect these dynamics of technical innovation, safety and market integration in the shipping industry.

1.3 Research Question and Objectives

Based on these identified research gaps and according to the changing orientation of the maritime industry, this study formulates its research questions and aims on the joint intersection of technological conceptualization, market integration on an international scale, and sustainability. These themes capture key development areas where innovative engineering solutions, such as the design of high-pressure methanol piping systems, contribute to the global transition toward low-emission maritime technologies. So, the research questions are-

RQ 1. What are the key drivers and barriers affecting the internationalization of high-pressure methanol piping solutions in the maritime industry?

RQ 2. How do maritime equipment suppliers build and leverage networks to gain access to global shipbuilding markets?

RQ 3. How are the conceptualization and development of high-pressure methanol piping systems shaped by technical, regulatory, and collaborative factors in the maritime industry?

RQ 4. How can methanol piping solutions contribute to the maritime industry's decarbonization and compliance with IMO emission targets?

The main objective of this study is to have a deeper understanding of the way new maritime suppliers are helping bring methanol-powered tech to market, and making it more global, particularly when it comes to high-pressure methanol piping systems. By examining both what individual companies are doing as well as what the entire industry is doing, this study will provide some useful insights related to technology, organizational and relationship aspects which will affect the way firms enter international markets and grow in a sustainable manner. So, the objectives for this study are as follows-

- To analyze the productization and standardization processes of methanol piping systems for international markets.
- To evaluate the strategies and networks that enable maritime suppliers to integrate into global shipbuilding markets.
- To assess the role of methanol piping technologies in supporting the maritime industry's sustainability and compliance with IMO emission targets.

1.4 Delimitation of the study

The study concentrates on the internationalization of methanol-based maritime technologies, especially in high-pressure methanol piping systems. The maritime equipment supply market is the scope of the research which explores the conceptualization, development, and adjustment of market technologies by its suppliers to ensure they satisfy the needs of global markets that began to move in the direction of low-emission fuels.

The paper is a qualitative single-case study in which the researcher considers one Finland-based maritime technology firm to be the central case, supplemented by the reflections of a limited number of external stakeholders in the industry. Consequently, the results do not represent the experiences or the views of the whole maritime industry, but merely a few participants. As a result, the study will seek to offer an analytical and not a statistical generalization that adds to theoretical knowledge and not broad conclusions.

The study is geographically confined to the countries of Finland and Northern Europe, where the case company is located and the use of methanol is discussed as successful initiatives. The paper lacks a comparative investigation with other areas as well as other marine fuels like ammonia or hydrogen. Also, the study is based on organizational and strategic factors, i.e., conceptualization, network integration, and sustainability, not on a specific aspect of engineering or cost-efficiency evaluation. Lastly, the research will be focused on the initial phases of internationalization in an emerging market environment. It does not analyze the business performance in the long term of the methanol systems and the lifecycle of market expansion. These constraints enable the study to have a clear focus on the strategic and relationship aspects, which affect the internationalization of methanol piping solutions in the maritime industry.

1.5 Definition of Key concepts

Internationalization

Internationalization generally refers to businesses that are expanding their activities beyond their domestic base to engage in international business. According to Johanson & Vahlne (1977), it is an incremental process. Companies learn by experience in the foreign market and commit gradually. In this paper, internationalization is conceptualized as a strategic as well as relational strategic action whereby suppliers of maritime equipment integrate their technologies and services into global shipbuilding systems.

Conceptualization

In this study, conceptualization is defined as the process of converting interesting technical ideas into formalized, standardized, marketable solutions. It consists of the early phases of product design and development and technical validation, which ensures that all design requirements comply with the relevant regulations and safety standards. Conceptualization of methanol fuel systems includes design of high-pressure pipelines capable of dealing with the characteristics of methanol by fulfilling the international standards of maritime regulations (IMO, 2023).

Methanol as a Marine Fuel

Methanol is a promising marine low-emission fuel which can be synthesized from renewable resources such as biomass, biogas or captured CO2. It has environmental benefits when used in marine engines: low sulphur oxides (SOx), nitrogen oxides (NOx) and particulates as compared to conventional marine fuels. Because methanol remains a liquid at ambient temperatures, it is easier to store and distribute and is therefore a viable transitional fuel for shipping decarbonization. However, together with its high flammability and toxicity, this fact requires sophisticated fuel-handling systems, strong piping and good containment (Verhelst et al., 2019).

Sustainability in the Maritime Sector

Sustainability is defined in this context as the development and application of technology and practices which will reduce environmental impact, increase energy efficiency, and achieve IMO decarbonizations. The transition of the maritime industry towards sustainability includes the use of alternative fuels, fuel efficiency, and the implementation of circular economy principles in ship design and operations (IMO, 2023). This study

explores sustainability not just in terms of an environmental regime goal but also as a catalyst for technical innovation and international competitiveness in business.

Network Theory

Network theory emphasizes the relationships, alliances and social connections between firms as important to internationalization (Johanson & Mattsson, 2015). It states that access to foreign markets is determined by one's position in the business network, and trust, reputation, and cooperation are key. In the global market of the maritime sector, which is characterized by long-term relationships and complex supply chains, relationships built with the shipyards/standards bodies and partners are a prerequisite for accessing the worldwide market (Johanson & Mattsson, 1988).

1.6 Structure of the study

This thesis will be divided into five key chapters, representing the phases of the research process and contributing to the final idea of the topic of the internationalization of methanol piping solutions in the maritime industry.

This chapter gives a summary of the research topic which includes the background, problem statement, research gaps and objectives. It also establishes the essential notions pertaining to the research and indicates the constraints. The chapter has ended with an explanation of the thesis structure so that the reader can follow the subsequent chapters.

The literature review focuses on theoretical backgrounds of internationalization and the Uppsala Model and Network Theory. It also examines the supporting views like the Born Global and Resource Dependency theories as a means of situating the study in the wider context of international business. Research on methanol as an alternative marine fuel is also discussed in the chapter with a focus on technological, regulatory, and sustainability

aspects pertinent to maritime innovation. The paper ends with the identification of the main research gaps that will be the focus of this study.

The methodology chapter describes the study of philosophical and methodological frameworks. It talks about interpretive methods of research, qualitative approach and the single-case study strategy. The specifics of the data collection procedure, such as the selection of the participants, interview design, and the ethical considerations are presented, and an explanation of the thematic data analysis approach is provided, as well as the steps undertaken to guarantee the research trustworthiness.

The findings chapter provides empirical results based on the semi-structured interviews with the internal company representatives and the external stakeholders in the maritime industry. The findings are structured in thematic themes on major issues like drivers and barriers to internationalization, the role of networks and collaboration, conceptualizing the methanol piping technologies, and sustainability prospectus in the maritime transition to methanol.

The discussion chapter is the interpretation of the findings in terms of theoretical framework and the available literature. It explains the theoretical and practical implications of the findings, especially in the field of maritime internationalization and sustainable innovation.

The conclusion chapter provides the summary of this research and recommends practical implementations. It also suggests future directions for further research in this area.

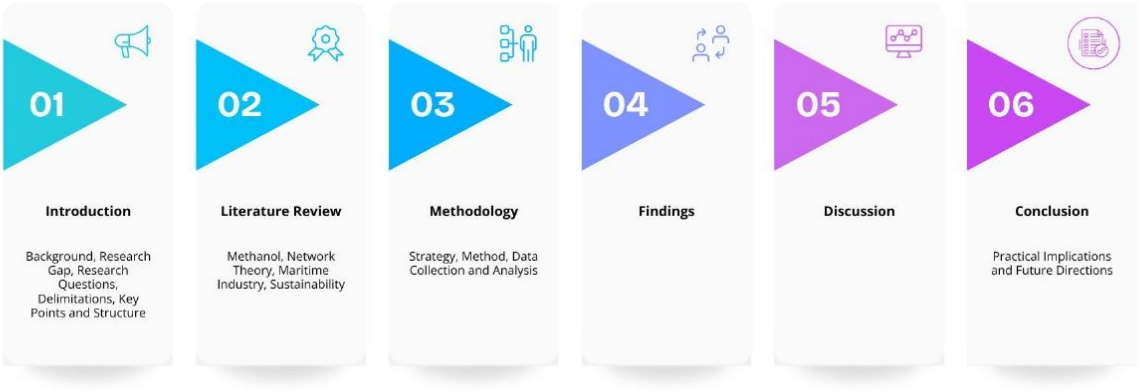

Figure 1:Structure of the Study

2 Literature Review

This chapter offers a broad overview of the literature surrounding the internationalization in the maritime industry, and the adoption of methanol-based solutions as part of the industry's shift towards sustainability. It starts with discussion of the concept and development of internationalization, the main theories used to understand how firms expand beyond their home markets. The following is a discussion which examines the Uppsala Model of Internationalization, focusing on the incremental learning process and its subsequent revision integrating the role of networks and knowledge in the process of reducing uncertainty. The chapter goes on to discuss the Network theory of internationalization which emphasizes the importance of inter-organizational relationships, trust and collaboration in enabling market entry and growth, as are particularly relevant to the maritime industry's interconnected supply chains. Additionally, the chapter includes the Born Global perspective to contrast the traditional gradual internationalization process to the rapid expansion of innovative firms entering multiple markets from inception.

2.1 The Concept of Internationalization

Internationalization is a process by which firms expand their business opportunities outside their country of origin. The process involves several activities, such as building relationships with suppliers and customers, as well as establishing physical units in foreign countries (Costa et al., 2018). Different researchers have interpreted internationalization from various perspectives. In their Uppsala model, Johanson and Vahlne (1977) suggest that firms gradually increase their international involvement as they gather knowledge regarding foreign markets and operations. In recent decades, literature has also introduced perspectives on born global firms, network-based internationalization, and resource-based views, reflecting the growing complexity of international markets.

Internationalization plays a significant role when it comes to the context of technical and industrial products, where firms often face unique challenges. Unlike consumer goods, technical products such as high-pressure piping solutions require adherence to strict

safety standards, performance specifications, and localized engineering regulations in different markets. Moreover, internationalization of industrial products often involves long sales cycles, relationship-based marketing, and after-sales service consideration, demanding strategic and operational adaptability (Bell et al., 2001). This research particularly focuses on the Uppsala model theory of internationalization for niche-oriented firms in the methanol piping solutions industry.

2.2 Uppsala Model Theory of Internationalization

The Uppsala Model of Internationalization, first articulated by Johanson and Vahlne (1977), proposes that firms intending to internationalize typically proceed incrementally. Initially, companies are involved with physically and geographically close markets through low-commitment entry modes such as exports, gradually acquiring experience, and lessening ambiguity before advancing to distant markets(Johanson & Vahlne, 1977). According to Cisneros-Reyes (2021), The Uppsala model identifies two core mechanisms: state variables, which include knowledge about foreign markets and resource commitments, and change variables, which refer to strategic decisions and processes of organizational learning that alter the firm's position over time. This model describes these elements as a cyclical process, where experiences influence future commitments and decisions, driving the firm's gradual progress towards internationalization.

However, this framework has been criticized for its linear, country-specific orientation, arguing that it is unable to capture the fast-changing nature of current global markets or the important role of business networks (Forsgren, 2002). Moreover, this model fails to explain the fast and sometimes non-incremental international growth shown by "Born Global" firms, which aim to compete in several markets right from the start, relying on existing global knowledge and networks rather than gradual learning. These criticisms highlight that partnerships, strategic alliances, and business networks can help fast international growth, challenging the original framework's step-by-step approach (Coviello & Munro, 1997).

In response to these criticisms, later revisions of the Uppsala model, most notably those of 2009 and 2017, added ideas from network theory and highlighted the role of managerial decisions and resource allocation in shaping the internationalization process. These updated models view market expansion not just as overcoming the “liability of foreignness” but also the “liability of outsidership”, which encompasses the disadvantages of being outside important business networks. In the updated view, a firm’s place in business networks and its ability to build and use relationships are central determinants of international success. The network-based approach argues that being an outsider to important networks creates more uncertainty than cultural differences or distance. Building trust, gaining knowledge, and identifying opportunities within these networks are necessary, as they enable firms to find new prospects and adapt their resource commitments more flexibly than the original model suggests (Johanson & Vahlne, 2009; Vahlne & Johanson, 1977).

2.3 Network Theory of Internationalization

Network theory, as applied to International Business, draws from the foundational work of Johanson and Mattsson (1988) and Håkansson and Snehota (1995), which explains that markets are not just single, separate deals, but rather a network of long-term relationships with interconnected systems. From this perspective, companies are part of a complex network consisting of suppliers, customers, competitors, industrial associations, and governmental agencies. The firm’s position in this network influences the opportunities and challenges it faces when trying to enter or expand into foreign markets.

The network-based perspective shifts the focus from which market the firm selects to whom the firm has established networks. This is particularly relevant in industries that involve large, customized projects that rely on trust and cooperation, such as engineering, shipbuilding, and industrial manufacturing. In these fields, strong relationships can be more decisive than market proximity in determining the sequence and speed of internationalization (Coviello, 2006).

Johanson and Mattsson (1988) argue that firms internationalize not just by learning incrementally, but also by using their existing relationships to reach new markets. For instance, a domestic supplier may introduce a firm to foreign buyers, a joint venture partner can assist in getting access to regulatory bodies, and a multinational client may initiate the firm's participation in overseas projects. In such cases, a firm's international expansion is less determined by geographic or cultural distances and more influenced by its capacity to leverage existing network connections (Guler & Guillén, 2009).

The revision of Uppsala model by Johanson and Vahlne (2009) introduced a significant change. The idea of "liability of foreignness" means that firms face disadvantages when they operate in a country with an unfamiliar culture and rules. However, a bigger challenge is the "liability of outsidership," which happens when firms are excluded from important business networks (Johanson & Vahlne, 2009). Without strong local connections, firms may struggle to secure contracts, comprehend the market, or tailor their products to meet local needs. Reframing how companies build knowledge is critical in fast-changing global markets, where opportunities can appear and disappear quickly. While learning through direct experience in foreign markets remains a pillar of this revised model, recent research shows that firms do not rely only on their operations. Knowledge can also be shared through relationships with partners, suppliers, and customers (Lavan et al., 2025).

Moreover, within the network-based framework of internationalization, three interrelated mechanisms emerge as particularly significant drivers of firms' international expansion. Building trust is important as it reduces transaction costs, decreases opportunistic behavior, and accelerates the exchange of sensitive information. In the industrial market, where projects take long lead times and high stakes, trust is a prerequisite to getting contracts (Zaheer et al., 1998). Acquiring and sharing knowledge through networks provides companies with access to both explicit information, such as market data and technical details, as well as tacit insights, like local business customs and informal decision-

making practices. This knowledge can substitute or complement learning from experience, enabling faster entry into foreign markets (Liu et al., 2017).

2.4 Internationalization in the Maritime Industry

The maritime industry is one of the most globally integrated sectors, in which shipping companies, shipowners, equipment suppliers, and regulatory bodies operate collaboratively across multiple continents (Stopford, 2009). Unlike most of the firms in the local market, maritime companies cannot limit their operations to the domestic market. The nature of shipping companies is multinational, connecting production and consumption hubs worldwide (UNCTAD, 2023). In the case of service providers or equipment manufacturers, the internationalization process is not an incremental growth strategy, but a necessity to follow regulatory requirements, shipowners' needs, and relationships with industry drivers (Lun et al., 2010). Understanding how firms in this industry expand internationally is important to design an effective market entry strategy for high-pressure methanol piping solutions.

The maritime industry is characterized by its unique set of features that make the internationalized process different from other sectors. It is highly regulated, with standards set by international bodies such as the International Maritime Organization (IMO) and classification societies (IMO, 2023). Due to these regulations, such as safety, emissions and energy efficiency influence technology adoption and supplier selection (Härkälä, 2022). Moreover, this industry is capital-intensive and involves long-term, project-based operations. Shipping construction or retrofitting requires large financial commitments and long lead times, as well as coordination between multiple stakeholders like shipyards, engine manufacturers, shipowners, and equipment suppliers (Rodrigue et al., 2016). This highlights the importance of trust and prior experience in supplier selection. Additionally, the market is network-driven, making it difficult to get contracts randomly. In most cases, contracts are rewarded through established relationships, referrals, and reputation. Being well-known in major maritime clusters helps firms to build relationships and capture opportunities (Stavroulakis et al., 2020).

Finally, Maritime markets tend to move in cycles and are closely tied to global trade and commodity prices. This makes them unpredictable, creating challenges for suppliers trying to grow internationally, since shipowners' and shipyards' investment decisions often rise and fall with changes in freight rates and fuel costs (UNCTAD, 2023).

2.4.1 Drivers in Maritime Industry

However, several factors are driving the maritime industry to expand its international presence. One of the most significant drivers is regulatory bodies, as globally enforced IMO rules on emissions and safety require suppliers to ensure that their technologies are certified and accessible worldwide. Having products and services aligned with these regulatory standards is a prerequisite for entering new markets. Additionally, customer satisfaction and service delivery are important business drivers. Shipowners and shipyards expect high-quality products, as well as reliable after-sales support, from their suppliers. Failing to provide adequate service can hamper credibility and future contracts. Another significant driver in the maritime industry is the presence of networks and clusters, where most decision-makers operate. Being merged with the major stakeholders in maritime hubs not only provides collaboration opportunities but also insider information on upcoming projects. Strategic partnerships and co-innovation are pushing suppliers to internationalize more aggressively. Collaborating with engine makers, shipyards, and fuel providers can accelerate the adoption of new solutions while reducing costs and risks.

2.4.2 Barriers in Maritime Industry

The Maritime Industry is facing several barriers while doing central to global trading. The barriers hamper innovation, sustainability and internationalization. It creates difficulties adopting new technologies in methanol fuel systems and sustainable piping solutions.
This sector functions under diverse international, national and local guidelines which are set by several organizations like IMO and other societies (Francisco, 2023). Though these

guidelines guarantee safety and environmental performance, there create costly delays in consistent international standards. Global expansion is being complicated as the methanol piping system needed re-approval which is certified in Europe. Diverting to low emission fuels like methanol needs wide retrofitting of ships and ports. It is needed advanced and double-walled piping system for Methanol's flammability and toxicity (Jin, 2024a). Larg scale deployment limits due to partial standardization and inadequate bunkering infrastructure (IMO, 2023; Tomos et al., 2024). In this sector, investment is discouraged due to high capital expenditure and price gap between conventional and green methanol. Financial organizations carefully handle the funding to unconfirmed technologies that lead to absence of incentives or subsidies, which further restricts adoption (Xuan et al., 2024).

It becomes difficult for newcomers in the industry like ship builders and engine ma-nufacturers, as the industrial network is built on trust and long-term relationship. As a result, smaller firms are being restricted from internationalizing their solutions (Johanson & Vahlne, 2009; Zaheer et al., 1998). It requires high safety measures, personnel training and maintenance systems for methanol's hazardous properties (Chen, 2021). It creates complications in further implementation for unreliable safety standards and inadequate training programs. In methanol system there exists a tra-ditional, risk-averse industry mindset and inadequate expertise, which leads to slow technology adoption. Knowledge transfer reduces due to poor collaboration among academia, suppliers and industry (Forsgren, 2002; Lavan et al., 2025). Methanol's sustainability largely depends on its source of production. Green methanol has lo-wer carbon footprint, but it is costly and lower in supply (Tomos et al., 2024). In smaller firms, innovation is restricted because of internal administration, partial coordination and shortage of resources. For maritime industry's entry to sustainable technology is restricted and constrained by complex regulations, investment risk, limited infrastructure and institutional.

2.5 Born global concept of internationalization

Born global concept explains rapid internationalization of technology-oriented companies in industrial sectors, including maritime engineering and alternative fuel systems. Conventionally Maritime industry extended globally in a steady and incremental manner. The industry follows step by step model of internationalization which was proposed by Johanson and Vahlne (1977). The industry is a developing, technology driven firm engaged in justifiable solutions such as methanol piping systems. These types of industries often deviate from their goal and path. These born global companies follow the quick development path. They want to internationalize quick after the product development. They don't follow the long process of progressive market entry (Cavusgil & Knight, 2010). In the methanol and maritime industry perspective, these firms are bound to implement global orientation from the beginning. The firm's core customers are shipowners, engine manufacturers, and shipyards which operate within a highly global framework. Global companies like Uwira, developed specialized double-walled methanol piping systems. Companies are not limited to the boundary of national market. According to the international standard, they design their products. These standards are established by the International Maritime Organization (IMO) and classification societies like DNV and Lloyd's Register. To gain international legitimacy and access to international projects, firms comply with these standards, that leads to their better global positioning at an initial stage (Knight & Liesch, 2016).

Besides, the born global firms are supported by innovation, specialization and the use of digital and cooperative platforms. Because of Technological advancement, digital platforms, innovative simulation tools, advanced design systems and online networks, these firms can reach the customers and partners worldwide within a very short time. This can facilitate rapid distribution of technological innovations. This behavior brings into line with the feature of born global firms as entities that leverage knowledge-intensive resources and international networks to compete globally from the outset (Oviatt & McDougall, 1994).

The global change to the low carbon fuels further increases the speed of this trend. Methanol Adoption is primarily driven by international regulations, sustainability goals and global alliance. For this reason, firms are introducing methanol-compatible fuel systems to remain competitive in global market. Firms avoid conventional market barriers by the technological advancement and innovation. As a result they can position themselves within the global maritime supply chain early in their life cycle. It is the operational necessity not a choice to follow born global behavior within the methanol and maritime industry. It reflects the industry's deep incorporation with international markets and its arrangement with the broader decarbonization agenda.

2.6 Methanol as a Marine Fuel

The Maritime industry produces about 3% of the world's greenhouse gas (GHG) emissions. It leads to global efforts to find cleaner, low-carbon fuels (International Maritime Organization (IMO, 2023). The IMO has set a new goal to reach net-zero GHG emissions from international shipping by around 2050. Among the possible options, methanol stands out as a strong candidate because it is environmentally friendly, flexible to use, and works well with current fuel systems (Brynolf et al., 2022; IMO, 2023).

Methanol can be made from green hydrogen, biomass, and carbon dioxide that has been collected. This means that it could be used for carbon-neutral shipping (Wissner et al., 2023). It burns properly and releases a lot less pollution into the air than heavy fuel oil because its chemical structure is simple (CH_3OH). Researchers have found that using methanol can cut emissions of sulfur oxide (SOx) by up to 99%, NOx by 30–60%, and PM by about 95% (Wärtsilä, 2023a). Black carbon is a big short-term climate pollutant, and it doesn't make much of it.

GHG Emission mainly depends on how methanol is being produced. Renewable or "green" methanol, made from captured CO_2 and hydrogen using renewable energy, can decrease total GHG emissions by up to 95%. On the other hand, methanol made from fossil fuels causes small reductions if carbon capture and storage (CCS) is used

(Ravikumar et al., 2020). Methanol stays in liquid form at normal temperature. It gives important benefits over very cold fuels like liquefied natural gas (LNG) or ammonia. It can be stored and used in regular fuel tanks with only small changes, which makes it easier to adapt existing ships. Methanol also does not need high-pressure storage or cooling, which makes the fuel system simpler (MAN Energy Solutions, 2025).

From a safety point of view, methanol is biodegradable and easily dissolves in water. It helps reduce environmental harm if a spill happens. Methanol has a low flash point (11°C), strict safety measures are needed, such as double containment and good ventilation (IMO, 2023). Big engine makers like Wärtsilä and MAN Energy Solutions are now developing dual-fuel engines that can run on both methanol and regular fuels. It shows that the technology is becoming more competitive (MAN Energy Solutions, 2016; Wärtsilä, 2023).

Most of the world's methanol infrastructure is currently used by the chemical industry. But it also offers a strong base for switching to marine fuel use. Methanol bunkering facilities are growing fast. For example, the Port of Singapore is building new facilities that can supply more than one million tons of low-carbon methanol each year by 2030. Similar projects are also being developed in major ports like Rotterdam, Shanghai, and several others (Safety4Sea, 2024). Ships that run on methanol need special safety systems, such as nitrogen blanketing, double-walled pipes, and advanced monitoring, to reduce the risk of fire (DNV, 2025). Even though these technical challenges exist, methanol's ability to work with current port and ship systems makes it a practical and appealing transition fuel while fully zero-carbon options continue to develop.

At present, green methanol is much more expensive than traditional marine fuels. Many studies predict that costs could become similar by 2030 as production increases, renewable energy becomes cheaper, and technology improves. The rising carbon price under the EU Emissions Trading System (ETS) and the FuelEU Maritime Regulation is also

expected to make methanol more competitive. Methanol becomes cost-effective when the carbon price goes above about €150 per ton of CO_2 (Moreno, 2025).

Major shipping companies are helping to speed up the shift toward methanol. A.P. Moller–Maersk, for example, has signed long-term deals to buy green methanol and ordered new methanol-powered ships to meet future decarbonization goals (Maersk, 2022). Investments in methanol production plants are also growing in Europe, China, and the Middle East (IMES, 2025). Although converting ships to use methanol can be costly at first, its compatibility with existing systems can save money over time and reduce operational disruptions (Tomos et al., 2024).

The main challenges to using methanol on a large scale include limited global refueling systema, safety risks, toxicity and flammability. Also, there is a lack of trained crew to handle it safely. Methanol also has a lower energy content (15.8 MJ/L) in comparison with heavy fuel oil (HFO) at 35 MJ/L. It means ships need larger fuel tanks, which can decrease the space available for cargo (Zhang et al., 2025).

According to Cui et al. (2025) renewable methanol production cannot be done as low-cost green hydrogen and sustainable carbon sources are not economically available. It is very important to use clear certification systems and proper life-cycle assessments to make sure it decreases emissions. To reduce the Investment risk and to build necessary infrastructure quicker, long-term purchase agreements and green fuel guarantees are needed.

Methanol suggests a real-world way to help the shipping industry decrease carbon emissions. It is easy to handle as a liquid, produces fewer pollutants. It works well with existing infrastructure, making it a realistic substitute for traditional fuels. Yet, using methanol widely will require faster growth in renewable methanol production, more refueling facilities, and strong rules to ensure safety and environmental sustainability.

With collaborative efforts between shipowners, fuel producers, and policymakers, methanol could become a central pillar of maritime decarbonization, bridging the industry toward fully carbon-neutral shipping by mid-century.

2.7 Conceptualizing Methanol Piping Solution

In business research, conceptualization states to turning abstract ideas into frameworks and practical models that can be Applied properly (Luft et al., 2022). In the maritime industry's methanol-piping solutions, conceptualization involves articulating a decarbonization ambition. It is within a strategic context giving importance to engineering, market strategy, business-model design, and ecosystem orchestration.

At the technical level, a clear concept must cover technical performance such as pressure ratings, material compatibility, leak-prevention protocols, and system integration with alternative fuels (Uwira and Elomatic, 2025). From a market-strategy viewpoint, conceptualization examines variables such as adoption readiness of ship-owners and yards, fuel-safety measures, engine-compatibility with methanol, and alignment with International Maritime Organization emission-targets and regulatory frameworks (Lloyd's Register, 2019).

Business-model conceptualization includes revenue mechanisms such as "piping ‑ system-as-a-service" (for piping), retrofit offerings, bunkering solutions, and close collaboration among ship-owners, engine-manufacturers, port authorities and fuel-suppliers. At the same time, the conceptualization of a methanol-piping system must consider the economic realities of implementing methanol solutions. Retrofitting vessels need high capital costs (Wu & Lin, 2025). On the other hand, since methanol is liquid at ambient conditions and can be managed through existing storage and handling systems with only modest customization, there are advantages. But its lower energy density demands larger storage volumes, influencing vessel design, cargo capacity and overall cost. Production cost of renewable ("green") methanol remains higher than conventional fuels,

which further impacts financial feasibility and underscores the importance of effective cost-management and potential subsidies (He et al., 2025).

Regulatory authorities significantly influence the conceptualization of methanol-based solutions. International policies like IMO guidelines and corresponding local initiatives provide foundational support for methanol adoption. It defines it as an acceptable low-flashpoint fuel and setting safety, emissions and bunkering standard. Compliance with such guidelines allows the design of strategic market positioning that meets emission-targets and minimizes regulatory risk. Studies show that regulatory support and financial incentives accelerate the pace of technical adoption and fuel transition within the maritime industry (Lloyd's Register, 2019).

2.8 Sustainable Development Goals (SDGs) and Methanol Solutions

Methanol Based marine fuel systems transition directly supports various United Nations Sustainable Development Goals (SDGs). These are related to clean energy, industry innovation, sustainable cities and climate actions. Several renewable sources such as biomass or captured carbon dioxide produce methanol. This methanol contributes to SDG 7 (Affordable and Clean Energy) that offers a feasible low-carbon energy carrier(Methanol Institute, 2025; Santasalo-Aarnio et al., 2020). The production process, which spans from renewable electricity to waste-derived feedstocks, is very flexible. The process enables a circular energy economy which integrates with national decarbonization strategies.

Methanol Piping and fuel systems adaptation raises revolution in shipping design, fuel handling and safety standards. This system creates new trade ecosystem around clean fuel technology (DNV, 2025). Methanol is properly compatible with the storage and distribution facilities. This network reduces the transition cost. The network also allows technological advancement without infrastructure failure.

Methanol Plays an important role in SDG 13 (Climate action). It minimizes the carbon footprint of worldwide shipping. Global shipping is about 3% responsible for total greenhouse gas releases worldwide (Bach & Hansen, 2023). Green methanol can be synthesized from renewable sources. It can reduce up to 7% CO_2 emission against conventional marine fuels. It also reduces quantity of sulfur oxides (SOx) and nitrogen oxides (NOx) from environment which improves air quality. It supports supporting SDG 3 (Good Health and Well-being), which significantly occurs in coastal and port (Wärtsilä, 2023; WEF, 2023). These indicate that transition to fuel is not only an economic and technical initiative but also strategic program toward sustainable maritime governance and global environmental control.

3 Methodology

This chapter gives a comprehensive report on the methodological framework that will be employed in this study and each of the steps will be described to ensure a strong and credible study design. It focuses on the justification of the decision of qualitative approach, in this case a single-case study, and how it fits the research questions and objectives of studying the internationalization of the sustainable methanol piping solutions in the maritime industry. Furthermore, the chapter explains the reasons why the single-case study approach is suitable. It further explains the data collection methods, especially the semi-structured interviews and secondary sources such as company websites and other related documents. The process of interpreting the collected qualitative data is explained in terms of analytical techniques such as deductive thematic analysis, which is guided by defined themes. There are also considerations of measures that ensure reliability and validity including elaborate interview processes, audio recording, transcription, and triangulating the findings with secondary data. In this systematic manner, the chapter explains the reasons and how every methodological decision makes the research findings robust, reliable, and relevant.

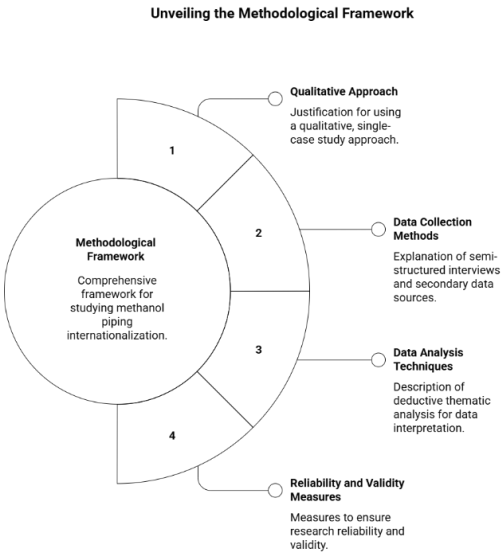

Figure 2: The Methodological Framework (Author's own)

3.1 Research Philosophy

A research philosophy is a set of beliefs and assumptions that guide the development and interpretation of knowledge. These assumptions influence a researcher's understanding of reality and the process of acquiring knowledge. In business and management research, acknowledging these philosophical foundations is essential, as they determine how different cases are conceptualized, explored, and explained (Saunders et al., 2019).

This study employs an interpretivist research approach, which posits that reality is constructed through human interaction, experiences, and interpretations, rather than being an objective, external fact. Interpretivism focuses on understanding complex social and organizational situations from the viewpoints of those directly involved. Researchers using this approach aim to discover the various, context-based ways individuals make sense of their surroundings, providing deeper insights into the dynamic and multifaceted nature of business realities (Creswell, 2014).

However, interpretivism reflects the idea that people and organizations can interpret the same situation in different ways. In this study, the internationalization of the maritime industry, particularly in methanol-based products, is viewed as a social process, shaped by how different stakeholders perceive, interact, and decide. Epistemologically, the study assumes that knowledge is seen as something developed together through conversation and interaction between the researcher and participants, rather than something objectively found. This view is consistent with Ponelis (2015), who notes that interpretivist research values the subjective meaning-making of participants and emphasizes understanding the situation from their perspectives.

Though interpretivism is ideal to explore subjective meanings and context-specific insights, it has its limitations. Some researchers argue that it may lack the objectivity and generalizability offered by positivist approaches. Critics also argue that the interpretivism approach may often lead to researcher bias, since the researcher's own view and interactions with the participants design the interpretation of the research (Bryman,

2016). In this study, as the central focus is on the perspective, strategies, and decision-making of maritime professionals, it is quite challenging to express the complexity of the internationalization process through quantitative methods. Although a positivist approach would be helpful to supplement such a study after the fact in terms of empirical tests, the interpretivist approach would be better suited to reveal more subtle, experience-related insights in this new and fast-changing industry (Saunders et al., 2019).

3.2 Research Method

Deciding the right research method is significantly important because it defines the shared understanding of how researchers view knowledge. Previously, most of the researchers used to select quantitative methods for international business studies. However, over time, qualitative methods have gained strong recognition in this field. Qualitative methods have shown that it can bring strong insights and help bring new theories into the IB field (Doz, 2011). An examination in recent studies reflects that 90% of studies published in international business journals employed qualitative methods, mainly interviews (Nielsen et al., 2020). This shows a growing interest in creative and flexible research designs that can capture complex and changing global business environment (Creswell, 2014).

This study follows a qualitative research method which perfectly aligns with interpretivist approach and exploratory purpose of this research. The aim of this study is to understand how maritime suppliers, particularly working with methanol-based technologies, can create and expand their business in international markets. A qualitative method is suitable as it helps explore complex social and business situations where people's view, experience, and other contexts are considered (Saunders et al., 2019).

3.3 Research Strategy

According to (Saunders et al., 2019), a research strategy is a plan of action which helps researchers to achieve a specific research goal. A strategy serves as a pathway to find answers to research questions. It connects the philosophical foundation of a study with the process of collecting and analyzing research data. Some well-known research strategies are experiments, case study, survey, ethnography, grounded theory, and narrative inquiry, each shaped by different research traditions (Creswell, 2014). Selection of a research strategy depends on various factors such as the nature of research questions and objectives, philosophy, purpose, and approach. Additionally, researchers should consider factors such as existing knowledge, time and resource limitation, access to data or participants (Bryman, 2016). Nonetheless, different strategies can complement each other in the same study.

Qualitative research can be conducted by several strategies, however, a popular strategy with qualitative research is a case study. This study employs a single case study strategy to understand how methanol-based solution providers conceptualize and internationalize their product or service in a fast-changing maritime industry. This research strategy is suitable for such interpretivist perspectives which helps us to understand detailed insights into complex organizational processes (Yin, 2018). This allows the researcher to explore perspectives, actual practices, and relationships between professionals and organizations engaged in developing methanol-based technologies for maritime industry.
According to Siggelkow (2007) and Stake (1995), single-case study as a research strategy can offer strong and persuasive evidence for testing theories when the selected case possesses unique features that aligns with the research objectives. In this study, the selected case represents a maritime supplier developing high pressure methanol piping systems, an emerging niche contributing to the industry's decarbonization goal. The case’s unique position within this evolving sector makes it particularly suitable for understanding the dynamics of innovation, market adaptation, and internationalization.

3.4 Data Collection Method

According to (Saunders et al., 2007), case study research can use several data collection techniques, including interviews, observations, document analysis, and questionnaires, and often benefits from combining them to strengthen the study's depth. Since this study is following single case study approach, the primary method of data collection will be interviews. An interview as a purposeful conversation between two or more individuals (Kvale & Brinkmann, 2009). The approach works well in identifying valid and reliable information that is direct, in connection with the research questions and objectives. Depending on the purpose of the research and the research strategy, interviews may occur in different types, that is, highly structured or unstructured. The right type will be based on its suitability to the research aim. The type of interviews employed in this study was semi-structured interview which is flexible but does not lose sight of the main themes (Bryman, 2016). This enables the researcher to delve deeper into the experiences and understanding of the participants and at the same time to make sure that these experiences are relevant to the goals of the study.

In this research, the primary data collection method will be semi-structured interviews, with the interview procedure being clear and consistent to guarantee high-quality and reliable information. The respondents included two members of Uwira Oy, Director, Energy solutions (U1) and Sales Director (U2), and two members of Wärtsila, Head of Product Development (W1) and an Engine Specialist (W2). The interviewees were selected based on their expertise in methanol-based solutions as well as knowledge and experience in maritime industry. Collectively, these stakeholders can offer complementary insights into the technical, regulatory, and business events, which influence the emergence of methanol as an alternative marine fuel. All participants will be informed about the purpose of the study, the conditions of confidentiality and consent before every interview. The interviews were conducted using a loose guide with pre-defined themes and open-ended questions formulated based on the research objectives (Creswell, 2014). Though these interviews were based on the same basic areas of discussion, follow-up questions can be tailored depending on the response of the participants to enable the

interview to proceed naturally and enable a deeper exploration. The interviews were held face to face or online depending on the time and preference of the interviewee. All interviews will be audio-taped with the consent of the participants to ensure accuracy and contextual detail as suggested by Saunders et al. (2007). These interviews were 40-45 minutes long and the tapes were transcribed later to produce the precise record of each conversation to enable a thematic analysis. The interview will be conducted in a systematic but flexible manner, balancing between the rigor of the methodology and the flexibility required to uncover the experiences and views of the participants on the internationalization of sustainable methanol piping technologies.

In addition to the primary data, secondary data will also be present in this study to add to the general knowledge about the research topic. The secondary sources were gathered through the websites of companies and publicly accessible materials connected with the organization of the case. According to Saunders et al. (2007), secondary data is the information that was initially collected in the context of another issue and application but is utilized here to supplement the primary results. Such data may contain both quantitative and qualitative material, starting with raw data with little processing to published summaries or reports that are analyzed and structured. The inclusion of secondary data assists in offering more context, aiding the triangulation of data and improving the validity of the research findings (Yin, 2018). Secondary data is frequently employed in business and management research, especially in case-based research, to construct a more detailed, more holistic image of the organizational and industrial environment.

Abbreviation in the text	**Company Name**	**Title**	**Duration of the Interview**
U1	**Uwira**	**Director, Energy Solutions**	**42 minutes**
U2	**Uwira**	**Sales Director**	**48 minutes**
W1	**Wartsila**	**Product Development Head**	**38 minutes**
W2	**Wartsila**	**Engine Specialist**	**40 minutes**

Table 1:Information on the companies and the interviewees

3.5 Data Analysis Method

According to (Saunders et al., 2007), qualitative data refers to all non-numerical data and unquantified data that can be the result of research strategy. The major characteristic of qualitative data is that it is expressed through words rather than numbers. Such data may be provided by casual responses to open-ended questions in a survey, or more elaborate sources, such as responses to interviews. To analyze the qualitative data properly to come up with their significance, the qualitative data must be analyzed in detail, which is accomplished by using the existing methods of qualitative data analysis. Such methods of analysis may be deductive or inductive. According to Bingham (2022), the deductive method is based on beginning with already identified themes and applying a top-down format to the analysis. Conversely, the inductive method is a bottom-up approach where the researcher lets patterns and themes emerge out of the data.

In this study, thematic analysis approaches will be applied to analyze the collected data as it is a common method of analyzing qualitative research and identifying, interpreting, and reporting patterns or themes of data (Braun & Clarke, 2006). Thematic analysis has a lot in common with interpretivist philosophy since it permits the researcher to understand how participants in the case of the maritime industry construct meaning around complex social and organizational processes, i.e. internationalization, innovation and sustainability. Once the interviews are transcribed word to word, the researcher will start with a familiarization process, which involves reading and re-reading the transcripts to have a rough idea of content and context. This shall be applied by open coding whereby meaningful statements, phrases or ideas pertaining to the research questions are sensitized and assigned preliminary codes. The codes will subsequently be considered and categorized into larger items to create initial themes, which will be repetitive thoughts or patterns that exist in the various interviews. The new themes will be continuously optimized in an iterative process, making sure that they reflect the views of the participants and are coherent with the theoretical framework identified in the literature review, specifically, the Uppsala Model and Network Theory of internationalization. It is

anticipated that the themes will be related to the following areas: drivers of internationalization, networks and role in technological innovation, and the use of methanol as an alternative fuel. To make sure that the analysis is credible and trustworthy, the concept of triangulation will be used by analyzing the results of the company participants and comparing them with the views of outside industry professionals (Yin, 2018). In addition, the analysis will be supported by reflective notes to recognize the interpretations of the researcher and possible prejudices. Lastly, the direct quotes of the participants of the interview will be included in the results section to verify the identified themes and add genuineness to the outcomes.

3.6 Validity and Reliability

The credibility of research findings largely depends on how accurate the study is planned and conducted (Saunders et al., 2007). Well-designed research can help decrease errors that turns the result more authentic. Reliability and Validity are two significant parts of a well-designed research.

Reliability means that the research process is dependable and if the research is conducted again similar result will be found. It also means the method of data gathering are steady and free from unfairness. Reliability can be affected by several factors such as participant's mood, unfairness in answers and errors conducted by researcher. To avoid the mistakes, most of the interviews are conducted in the middle of the week as the interviewees remain active and not too tired. The options to stay anonymous are given to interviewees to feel them free and to speak out honestly. To inspire normal and complete responses open ended questions are introduced. Additionally, data are examined carefully and supported by proper theories to make the results more reliable.

Validity measures how exactly the opinions of interviewees reflect. To ensure validity, there must be hard efforts related to environmental sustainability (ES). A guide for interview should be sent to the participants as they can prepare themselves according to their

knowledge and experience. After the interview session, the paper should be given to the interviewees for recheck their responses. If needed translation of interview question from one language to another, there should be taken more carefulness as it may change a little to the proper meaning.

Reliability and validity are discussed widely in qualitative research with a large concept called trustworthiness (Yvonna et al., 1985). Trustworthiness helps the research to rely on research as it is truthful, authentic and based real mark. It consists of four parts: credibility, transferability, dependability, and confirmability.

- Credibility: It means how much authentic the outcomes are. It can be improved by collection of data by internally and externally asking follow-up questions for authentication.
- Transferability: It states if the results can be applied to other similar studies. Readers can justify the relevance of the findings to different contexts based on the complete information such as internal and external provided to them.

- Dependability: It confirms the research is pure and others can follow it. Data organize to interpretation should be properly documented for further audit along with interview responses.

- Confirmability: it confirms that the outcomes are based on interviewees honest responses, not from researcher's point of view.

Overall, all the steps above make the research more trustworthy and confirm that the outcomes reflect the practical situation of internationalization and technological innovation in the maritime industry.

3.7 Case Company

Uwira Oy

Uwira Oy is a Finnish engineering firm involved in the production of high-quality piping systems, pressure equipment, and welded structures in the process and marine industries. Founded in 1993 and based in Vaasa, Finland, Uwira has accumulated a good reputation about its experience in providing customized high-pressure piping systems and precision welding. The company focuses on quality, safety, and adherence to the international standards of ISO and PED that are pivotal in the maritime and energy industry.

Uwira has also shifted its attention to sustainable marine technologies over the past few years, including assisting the switch to low-emission fuels including methanol. The fact that the company has devised high-pressure methanol pipe systems is an indication of the move by the firm to align with the decarbonization objectives of the global maritime industry and the emission reduction targets by the International Maritime Organization (IMO). Uwira solutions have engineering experience coupled with understanding of complex pressure systems, which qualify it to act as a technological facilitator to ship owners and engine manufactures that are switching to the use of methanol-based fuels. Uwira has also provided methanol piping systems to the world's first methanol fueled ship Stena Germanica (Leinolat Group, 2025).

The operations of the company also indicate the general trends in the maritime supply chain where companies are under increasing pressure to be innovative, network and work cross-boundaries and comply with changing environmental requirements. Being a middle-sized Finnish provider within a very specific niche, Uwira has its opportunities and threats in going international with its solutions. These are the necessity to be certified in new markets, establish strategic alliances, and be competitive in the new global market of alternative fuel systems.

To conduct this research, Uwira is used as an illustrative case of how suppliers of maritime technology are developing, adapting and internationalizing their product in reaction to the rising demand for sustainable fuel technologies. Through exploring the

experiences and strategies of Uwira, as well as the opinions of industry stakeholders more generally, the study aims to produce a more detailed understanding of how and why internationalization occurs in the changing methanol-powered shipping industry.

4 Findings

The empirical findings of the research are presented in this chapter and are based on four semi-structured interviews with the representatives of two key layers of the maritime value chain, including methanol technology suppliers and engine developers. The results will be presented as four thematic areas that reflect the main trends that occur throughout the interviews: (1) the drivers and barriers to the maritime shift to methanol; (2) the centrality of networks to internationalization; (3) the conceptualization and standardization of high-pressure methanol piping systems; and (4) the role of methanol in the sustainability of the maritime sector. These themes were obtained as a result of the iterative coding mechanism, where the constant ideas, experiences, and consistent opinions were coded into logical analysis categories. Throughout the chapter, direct quotes are used to show insights of the participants and keep the originality of their point of view.

4.1 Drivers and Barriers in the Maritime Shift to Methanol

The maritime sector is experiencing an unprecedented transition to low-emission and alternative fuels. The two interviewees pointed out that this change is more of policy pressure and global commitment to decarbonization, and not that of voluntary preference in the market. According to the Director at Uwira Oy, the international maritime organizations (IMO) greenhouse gas reduction goals have taken over to be the major determinant of technology adoption in the sector. Such rules force both shipowners and suppliers to seek an alternative fuel like methanol, which provides a direct avenue to compliance without requiring significant overhaul of the ship systems.

> *“There is a big drive now in the maritime side to go for zero carbon. This is the biggest driver right now. Regulations are setting the targets, and we must follow that. Methanol is very hot for the moment because it can help achieve these emission goals.” (U1)*

The familiarity and handling characteristics of methanol were cited as other factors that contributed to its rapid adoption. The physical and chemical properties of methanol like those of diesel make methanol a desirable transitional fuel to risk-averse or cost-conscious shipowners. Such compatibility also enables the existing systems, especially engines, storage, and piping, to be adjusted instead of being completely substitutable, thereby reducing the barrier to adoption.

> *"Methanol is a very similar fuel to the traditional ones, so familiarity is one of the key aspects. It can be handled with existing systems, which help a lot in adoption. And if it is produced with green energy, then it allows you to reduce carbon emissions, which are definitely a hot topic right now." (W1)*

However, the existing supply restrictions and high price of green methanol are also still important barriers. Although there is grey methanol (recycled fossil fuel), this does not help to achieve real decarbonization and can increase lifecycle emissions. The contradiction was explained by Wartsila's representative who alerted that in case of the lack of renewable production methods, methanol could not be considered a sustainable solution.

> *"Methanol is not available in the right quantities, especially if it is sourced from green energy. Grey methanol doesn't solve anything; it can even pollute more than diesel. So, it must be green methanol, and that's where the challenge is—availability and cost." (W1)*

> *"It's the infrastructure. So, the availability of methanol in ports… that I would say is the biggest challenge at the moment." (W2)*

The two interviewees noted that one of the core obstacles is economic feasibility. The cost of renewable methanol at present remains too expensive to rival traditional fuels, and even carbon tax penalties. Many shipowners will not be willing to commit to methanol conversions or newbuilds until the ratio of costs varies. Uwira Director further indicated that in the case of technology suppliers, the technology of handling fuel systems is difficult to invest in early due to the long development cycle of technology. Developing new high pressure, double-walled methanol piping solutions are associated with long

leads, expensive certifications, and the utilization of a substantial number of resources. This has created a special reluctance by small to medium sized companies to commit themselves to full scale production before demand stabilizes.

> *"It's still an economical issue. If the price of green methanol is higher than paying the emission penalties, then it doesn't make any sense for shipowners to switch. It has to become more convenient than paying for emissions." (W1)*

> *"From the design phase to final delivery, it takes one to two years to complete a high-pressure system. That's a long commitment before you see any return, especially for smaller suppliers like us." (U1)*

There was also the issue of infrastructure preparedness as discussed. The existing port and bunkering facilities have been designed mostly with heavy fuel oil and LNG in mind. Methanol is easier to store in liquid form compared to hydrogen or ammonia, but there are a small number of ports that still have pilot networks that supply methanol. There is still no infrastructure and that a mass adoption will demand a concerted effort on the part of manufacturers, terminal operators, and classification societies.

> *"Infrastructure is not in place yet, but some existing facilities can be adapted once supply grows. Still, it will take time before methanol is available in all major ports." (W1)*

Overall, the interviewees admitted that methanol is one of the top candidates in the decarbonization process of the maritime industry because of its familiarity, safety, and compatibility with current technology. Its success, however, depends on addressing several mutually sustaining issues: adequate production of green methanol, cost equality with fossil fuels, and global infrastructure distribution and bunkering. The results are representative of the tension in the maritime industry generally in between regulatory urgency and technological readiness and indicate a sector that is willing but not in full capacity to make the transition of methanol.

4.2 The Centrality of Networks for Internationalization

The second major theme that was found in the interview data relates to the centrality of networks and collaboration in the internationalization of maritime equipment suppliers. Participants continued to highlight that technological skills alone will not be enough to achieve success in entering global markets. Instead, relationship and trust with shipyards, engine manufacturers, classification societies, and shipowners will be the key factors of industry success. Both Uwira representatives clarified that global operations of the company require ongoing communication of all actors as they are all involved in the complex process of building and certifying ships.

> *"When you are talking about maritime projects, it is never only the end customer. We have to talk with shipyards, engine builders, classification societies, and even with the final shipowner. You need to be connected with everyone in the network, otherwise nothing moves forward." (U1)*

> *"It's a vital part that without networks and partnerships, one cannot do this alone. Understanding customer needs requires close collaboration with all involved actors." (U2)*

This network point of view is like the network theory of internationalization according to which the internationalization of firms is driven by inter-organizational relationships and not by sequential market entry (Johanson & Vahlne, 2009). The partnership with the known international players helps the smaller companies gain credibility and reach new markets much faster than they could by means of conventional step-by-step development. Such networks enabled the company to engage in innovative methanol projects in the past, where joint ventures or development joint ventures acted as a form of validation in new markets. Correspondingly, teamwork is invaluable in the new methanol market where no firm has the necessary expertise. He has pointed out that Wartsila's success in its development of methanol systems relies on tight collaboration with its component suppliers and certification agencies.

> *"The fact that we were part of a technical project about ten years ago is the reason why customers now trust us. That reference created credibility. It's a small industry, and people talk. If you have done it once, they know you can do it again." (U1)*

> *"We all need to collaborate. Wärtsilä is an engine maker, but we are not experts in piping or safety systems. We need suppliers like Uwira to make the pipes, and we need class societies to approve the designs. Everyone plays their part." (W1)*

The interviews also indicated how networks assist companies to go round the liability of outsidership, which is one of the concepts in the Revised Uppsala Model (Johanson and Vahlne, 2009). Smaller companies like Uwira experience problems of becoming visible in big and well-regulated markets dominated by other players present in the market. They may legitimize themselves by collaborating with well-known brands such as Wartsila and be able to reach new customer bases that would not have been available otherwise.

> *"It's difficult to be noticed if you are small. Partnering with a bigger company opens doors. It gives you a name and a reference that customers trust. If you go alone, nobody listens." (U1)*

Additionally, interviewees agreed that the aspect of geographical proximity to customers and projects is still relevant in the establishment of trust and after-sales services. It is important to be in close proximity to major shipbuilding centers including the ones in Asia to be able to receive timely technical support and to continue working together. He highlighted that a global presence would not only make partnerships stronger, but it would also help in building brand reputation in an industry where physical consistency and service continuity are the most important. Besides, interviewees spoke about the significance of reputation and relational capital in network-based sectors. Familiarity and previous performance are an informal but powerful tool towards drawing new business in. The reputation spreads through networks after a firm has proved to be reliable in challenging technical situations and will result in more contracts.

> *"Customers expect you to be close. If a ship is in Singapore or China, you need to be there when something happens. They might not have the expertise locally, so*

> *they need a solid partner on site. That's what makes international cooperation successful." (W1)*
>
> *"All of these—previous experience, trust, reputation—are factors that help someone recommend you. A successful project creates references that open doors to the next one." (U2)*

The findings are highly supportive of the theoretical argument that networks serve not only as mechanisms but also contexts of internationalization. Partnerships are used in high-technology industrial sectors like maritime engineering not only to access foreign markets faster but also to generate value by sharing specialized knowledge and resources. In the case of companies such as Uwira, developing relations with leaders in the world, classification authorities and shipyards is the best way to integrate into the international arena.

> *"You need technical knowledge and to know where the solutions are going. Understanding the market, opportunities, and creating your own network partnerships is very important." (U2)*

4.3 Conceptualizing and Standardizing High-Pressure Technology

The third significant theme is the technical complexity and standardization issues that surround high pressure methanol piping systems. Both interviewees reported that methanol technology is one of the places where specialized engineering knowledge is required, continuous innovation, and collaboration with the regulatory bodies. The toxicity, corrosiveness and flammability of methanol, unlike that of conventional fuels, make safety a rigid demand that manufacturers must meet by designing double-walled, high-pressure systems that can endure both physical and chemical challenges. Uwira representatives stated that the systems implemented in the company are specifically developed to address the properties of methanol, especially in the conditions of high-pressure injection. Such design factors extend way beyond the conventional fuel systems necessitating the use of superior materials, multiple layers of safety, and intensive verification steps.

> *"The challenge with methanol is the high-pressure injection and its chemical nature. The system must be able to withstand the pressure, corrosion, and temperature differences. It needs a double-wall construction and proper leak detection to make sure it's absolutely safe." (U1)*

> *"The challenge with methanol is understanding the system and creating a solution that overcomes these needs. The vibration issues on board taught us where the root cause was, and then we could make a better design." (U2)*

This focus on technical integrity highlights the engineering-based aspect of innovation in methanol handling systems. The case of Uwira shows that product conceptualization is closely connected with safety compliance and standardization. Design review, testing and approval of each new project is a long process which may require several external parties like classification societies, shipyards and engine manufacturers. The interviewees added that the existing methanol standards are still new. Such classification societies as DNV, LR and ABS are constantly revising their guidelines, however, interpretations vary between organizations. Such a dynamic landscape makes the cooperation of both the technology developers and certifying bodies a critical component of both the innovation and acceptance of the technology in the market.

> *"The class societies have their own interpretations of the IMO rules. Sometimes they differ, so you need to align your design with what each one expects. That's why we have continuous communication with them." (U1)*

> *"We are keeping close contact with stakeholders like engine manufacturers, classification societies, customers, and yards to ensure our designs meet all requirements." (U2)*

In the Wartsila's point of view, conceptualizations of methanol technology is a matter of technical development and partner validation. The product development head of the company elaborated that Wartsila and Uwira are collaborating on new piping solutions and are on the verge of official acceptance in principle by classification societies. This is not just to guarantee compliance but also to assist in setting up common industry standards to be adopted in the future. The interviews also indicate that the innovation and certification time is long-lasting. It can take more than a year between design and

delivery. To the smaller suppliers, this cycle is a big financial and operational investment. However, as pointed out by the Uwira director, this investment is necessary to keep the technical credibility and satisfy the global customers and classification bodies. Companies and regulators are together establishing what is considered to be a safe design of high-pressure methanol systems through shared experience, test results and documentation. This repeat cycle helps increase safety but reduces the barriers to entry of new suppliers later, which eventually leads to more people using methanol as a possible marine fuel.

> *"We have worked together with Uwira to develop this pipe design. Based on Wärtsilä's requirements, Uwira created a piping solution that fits our needs. Together, we are currently running an approval-in-principle process with DNV to ensure that the concept is safe, reliable, and ready for commercialization." (W1)*

> *"If the yard has not been doing any methanol system beforehand… they might ask what good companies would be to turn to." (W2)*

4.4 Methanol's Role in Maritime Sustainability

The potential of methanol as a non-polluting marine fuel and its strategic position in the decarbonization of the maritime industry is increasing rapidly. As pointed out by the interviewees, the transition to methanol is tightly connected with the overall sustainability strategy of the sector, which is imposed by international regulations, customer demands, and the pursuit of a long-term and cost-efficient fuel solution. To Uwira, sustainability is not only a reputational issue, but rather a strategic requirement that will outline the future of shipbuilding and supplier competitiveness. The director of the company has mentioned that the increasing knowledge of the industry concerning climate targets and environmental responsibility has increased the implementation of cleaner technologies, including the use of methanol fuel systems. The potential of methanol is especially promising since it is more aligned with the desire to decarbonize without causing significant

changes to the current vessel designs. It is an interim between the current systems that are fossil based and the zero-emission systems of the future (e.g., hydrogen or ammonia).

> *"There is a huge push from the regulatory side to go green. Shipowners are under pressure to reduce emissions, and that pressure passes down to suppliers like us. If we cannot provide solutions that help decarbonize, we are simply out of the game." (U1)*

> *"There's a huge need for methanol systems, but availability of green fuels is limited. Eventually, safety and sustainable operations will drive high demand globally." (U2)*

> *"Methanol is one of the hottest fuels at the moment because it offers a realistic way to reduce emissions with existing technology. It's a kind of bridge — you can retrofit existing engines and still get a significant cut in emissions if the methanol is produced sustainably." (W1)*

The sustainability attributes of methanol do rely solely on its production pathway. Green methanol is a renewable product based on biomass or captured CO2 coupled with green hydrogen, which has valuable reductions. Grey methanol, on the contrary, and is made from fossil fuels, contradicts the entire energy transition goal. This difference brings out a significant issue in the global energy shift, aligning environmental purpose with real fuel production activities. The Uwira director pointed out that operational safety and lifecycle dependability are also considered sustainability. The dangerous characteristics of methanol demand highly designed fuel-handling platforms, which avoid leakages, resist pressure, and safeguard communities and the environment. The challenge of developing these systems is not purely technical but also falls within the overall ethical issue of suppliers within a high-risk industrial sector.

> *"Only green methanol makes sense from a sustainability point of view. If it's fossil-based, it can even make things worse. That's why availability of renewable methanol is the key issue right now." (W1)*

> *"When you design for methanol, you are designing for safety and sustainability at the same time. A leak-free system is not just a technical achievement — it's about protecting lives, the crew, and the environment. That's where our responsibility comes in." (U1)*

Interviewees also emphasized that the collaboration should be conducted at the industry-wide level to promote sustainability. It is necessary to make concerted efforts by the engine manufacturers, component suppliers, shipyards and classification societies to bring about measurable reduction in emissions. Wartsila's representative emphasized that this type of cooperation will enable the prompt standardization of technologies that are safer and cleaner, which will eventually be beneficial to the maritime ecosystem.

> *"It's a team effort. Engine makers, piping suppliers, class societies — everyone needs to pull in the same direction. If we all do our part, methanol can genuinely help the industry move towards zero-carbon operation." (W1)*

The interviews validate that methanol can make a considerable contribution to emission-reduction objectives when it is produced in a renewable manner and introduced with the help of safe and standardized technology. The results therefore confirm the explanation of methanol as a transitional enabler in the decarbonization process of shipping in the sea as it represents the possibilities and the undiscovered issues of sustainable innovation in international shipping.

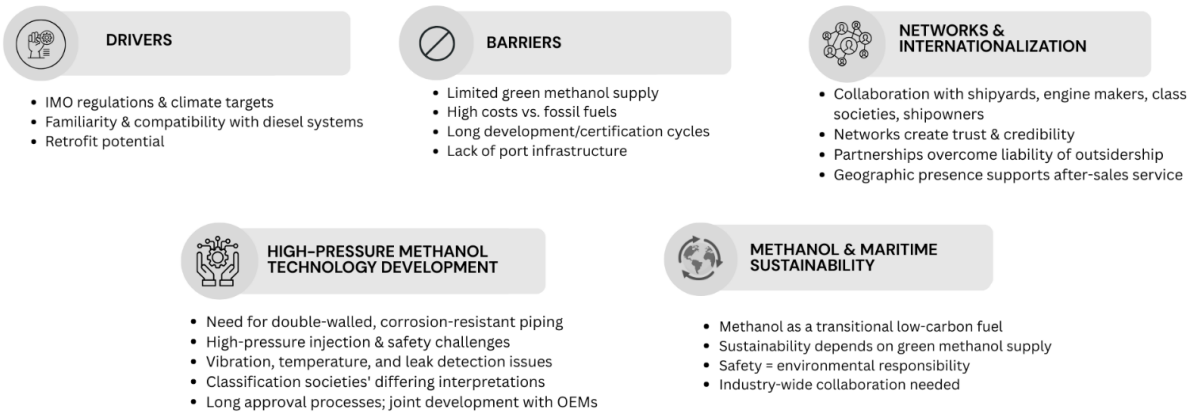

Figure 3: Findings of the study (Author's own)

5 Discussion

This chapter provides an academic reflection of the empirical results, placing them in the context of the available literature on internationalization, technological advancement, and maritime decarbonization. By having the analysis structured around the four research questions, brings together the realities of the development of the methanol system and the global market integration in a way that allows us to underpin our knowledge of how high-pressure methanol piping solutions are shaping the shift to cleaner fuels in the maritime industry.

RQ1. What are the key drivers and barriers affecting the internationalization of high-pressure methanol piping solutions in the maritime industry?

This study aims to identify the key drivers and barriers that enable or hinder the globalization of high-pressure methanol piping systems with specific respect to how regulatory requirements, market forces, and technology barriers all interact to promote their transnational adoption (See Fig. 4). The results indicate that regulatory pressure forms the strongest driver behind the move to methanol, which is consistent with the previous literature that highlights IMO decarbonization targets as the strongest driver defining fuel innovations (IMO, 2023; Sun et al., 2025). Interviewees constantly emphasized the idea that methanol is adopted because of the regulation and not by market forces. This finding is consistent with the view that maritime innovation is driven by institutional compulsions and not the industry's self-change. The familiarity and compatibility of methanol with current infrastructure, which have been reported in previous studies (Verhelst et al., 2019) only strengthens its status as a low-friction transition fuel.

However, the findings also reveal the key obstacles. The most pressing issue is the inaccessibility and high price of green methanol, something that reflects the problem by (Jin, 2024)that fuel supply chains are not ready to match technological advancement. This research offers a new dimension as it discloses that shipowners examine the investment in methanol compared to the price of emission penalties. In the case green methanol

remains more costly than the cost of carbon taxation, adoption will not happen, and this represents the economic behavior reported in the literature on incentives to green transition.

This is further slowed down by the lengthy development process of methanol piping systems which slows down internationalization. Uwira, smaller suppliers, face lengthy lead times (12 months-2 years), expensive certification processes, and unpredictable demand conditions, which align with the theory of innovation diffusion that demonstrates that complex technologies with high initial investment require consistent market feedback of scaling.

Overall, RQ1 demonstrates how regulatory momentum, technological familiarity and safety-based engineering influence the global spread of methanol, but it is negatively affected by the economic viability, the availability of fuel and the slowness of supporting infrastructure development. The findings validated and added to the previous research by recording barriers that were particular to high-pressure piping, a relatively unexplored field in the current literature.

Figure 4: Key drivers and barriers affecting the internationalization of high-pressure methanol piping solutions in the maritime industry (Author's own)

RQ2: How do maritime equipment suppliers build and leverage networks to gain access to global shipbuilding markets?

This research aims to understand how networks, partnerships, and relationships function in internationalization of specialized maritime technologies. The findings strongly support the network-based approach to internationalization, as per the Revised Uppsala Model by Johanson and Vahlne (2009). The respondents in the interview revealed that all maritime projects are collaborative and interdependent. The suppliers cannot act independently without continuous cooperation with shipyards, engine makers, classification agencies, and end users. These findings go in line with the argument by (Inkpen & Beamish (2015) that alliances help in sharing knowledge and reducing uncertainty in technologically demanding industries.

Despite the inherent transnationality of the maritime industry, it does not align with the concept of rapid and instant market entry as deemed by the Born Global theory, due to significant time and regulatory limitations. The results show that the technical development and certification of such systems is a long-term process, which takes one to two years on average, between design and delivery, creates a slower internationalization speed. Instead of immediate global access, suppliers must work out through a multi-actor, iterative, and regulation process in which the market entry is tightly controlled by the classification societies and requires gradual validation. Furthermore, the behavior of smaller suppliers is risk-averse, unwilling to invest in full-scale production until demand is more stable, which is better aligned with gradual resource commitment of the Uppsala model than the aggressive, fast growth common to Born Global companies (Knight & Cavusgil, 2004).

The interviews provide empirical evidence on how Uwira and similar suppliers overcome the liability of outsidership to the suppliers as advanced by Johanson and Vahlne (2009). In the case of smaller companies, market recognition in the global arena is achieved by

being affiliated with globally recognized enterprises like Wartsila. These joint arrangement systems act as a validating system, extending credit to the suppliers and gaining entry to foreign shipyards that would otherwise not be available.

Geographical proximity is also a strategic issue that is highlighted in the study. The participants confirmed that the physical proximity to the key shipbuilding clusters, especially those in China, significantly increased trust and problem-solving effectiveness. These findings reflect on previous literature that establishes industrial clusters as fast regarding knowledge transfer, reduced cost of coordination, and quick adjustment to project needs. Lastly, reputation emerged as one of the powerful intangible assets. The successful projects create some sort of references circulated informally in the maritime market, consequently strengthening trust and further penetration of the markets. Such results are in line with empirical observations that show in engineering markets with high risks, reputation and previous performance often outweigh marketing or pricing aspects.

Altogether, RQ2 confirms that the concept of internationalization in the methanol piping industry cannot take place outside of network arrangements. The results expand the current theoretical perspectives by clarifying how networks work in a tightly regulated, safety-critical field where technological interdependence and, thus, collaboration take an abnormally high form.

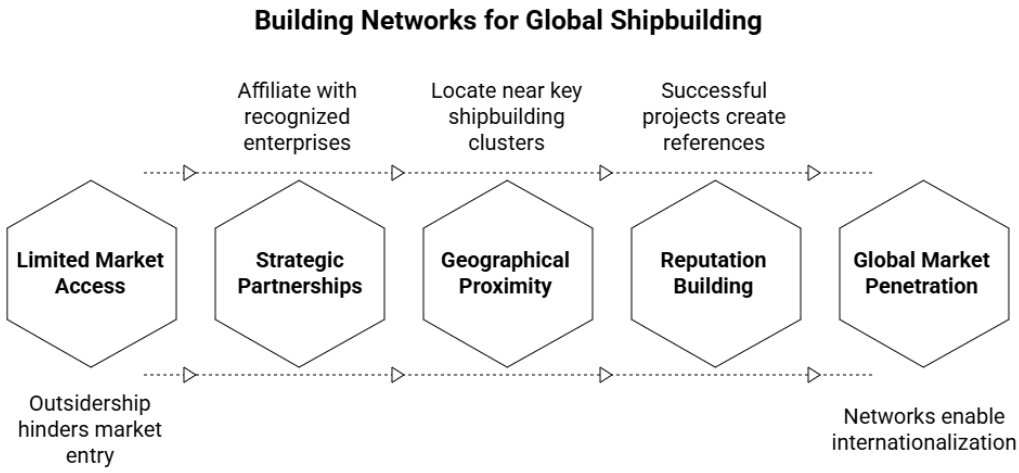

Figure 5: Building and leveraging networks to gain access to global shipbuilding markets (Author's own)

RQ3. How are the conceptualization and development of high-pressure methanol piping systems shaped by technical, regulatory, and collaborative factors in the maritime industry?

The purpose of the research question is to investigate the conceptualization and development of methanol piping solutions, specifically of high-pressure, two-walled piping solutions in the maritime industry. These include learning how suppliers perceive technical difficulties, how regulatory agencies define design opportunities, and how value chain coordination creates development trends of methanol-based technology. As the results show, conceptualization is not an extraordinary engineering process, but a multi-actor, iterative, and regulation-driven process of innovation, which is aligned with the views of the high-technology industrial literature (Baldwin & Clark, 2000; Teece, 2018).
As indicated by empirical evidence, conceptualization is largely driven by technical complexity as the catalyst. The flammability of Methanol, corrosive nature, and compatibility requirements are hazardous factors, which require specialized engineering solutions. According to the representatives of Uwira, the system was always explained by the necessity to survive under pressure which was extremely high and even control the vibration on board vessels and avoid the leakages due to the double-walls construction and

automatization. This makes the design process a reaction to the material characteristics of methanol instead of the actual adaptation of traditional fuel systems. This is consistent with the previous research that has indicated that alternative fuels present new mechanical and chemical industries that require new engineering paradigms (Stančin et al., 2020). The conceptualization of methanol piping is informed with the consciousness of failure modes and safety margins as opposed to the performance optimization concept.

Alongside the technical issues, the results reveal that design choices are subject to a determining impact of the regulatory frameworks. DNV, ABS, and LR among other classification societies along with IMO guidelines are developing a dynamic compliance environment. Interviewees explained that there are more interpretations of IMO rules by the classes and this creates uncertainties in the conceptual design phase. Firms need to develop their systems, i.e. with the rulebook open and regulatory negotiation is hence part and parcel of the design process. This is aligned with the idea that in highly controlled sectors, innovation should be developed in co-partnership with institutions to gain access to the market (Schiuma & Carlucci, 2018). The so-called approval -in-principle (AiP) procedure, where the representative of Wartsila referred to, serves as a risk-management tool and to standard setting. Therefore, controlling agencies influence the end approval, as well as the conceptual design of methanol piping systems.

Lastly, the evidence suggests cooperation as an organizational requirement in the evolution of methanol systems. None of the actors have all the expertise to operate methanol safely: engine manufacturers must have piping suppliers; shipyards need engineering services; class societies issue certification; suppliers must depend on the market experience and technical needs of partner. Such interdependence is a strong contribution to the theoretical premises of the network strategy (Johanson and Vahlne, 2009) and the literature on innovation ecosystems (Adner, 2017) when the creation of technology is coordinated between several companies. The partnership development process involving Wartsila and Uwira is a good example of this process which mentions that the system

was not developed in isolation but through a series of discussions, integration of components and joint experiments.

Collectively, these results from RQ3 suggest that the conceptualization of high-pressure methanol piping system can manifest itself in the crossroad of the engineering capacity, negotiating regulatory authorities, and collaborating with multi-stakeholders. Technical properties of methanol determine design decisions made due to safety; class societies and IMO rules inform system architecture and documentation; and collaborative development facilitates the exchange of knowledge and eliminates system-level risks. Conceptualization thus does not so much involve the creation of a product as it involves maneuver within a technical-regulatory ecosystem where every participant has an important knowledge, legitimacy and resource to offer. This unified approach is necessary to make methanol a more widely used marine fuel, solidifying the fact that safe fuel-related infrastructure is the key to the decarbonization of the marine industry in the long-term.

Figure 6: Factors Shaping High-Pressure Methanol Piping Systems (Author's own)

RQ4: How can methanol piping solutions contribute to the maritime industry's decarbonization and compliance with IMO emission targets?

The purpose of this investigation is to evaluate the level to which methanol piping systems, and especially high-pressure, double-walled designs, contribute to the

transformation of the maritime sector in the direction of reduced emissions and facilitate the establishment of the International Maritime Organization decarbonization requirements. Despite the carbon intensity of maritime operations being determined by the fuel itself, the outcomes show that fuel-infrastructure is also necessary to enable the safe, scalable, and regulation-compliant adoption of methanol. As a result, the concept of methanol piping solutions is not only a technical component, but also a strategic facilitator of environmental change in the sector.

The results show that methanol piping systems contribute to decarbonization in the first place through the possibility of using methanol safely and reliably as a marine fuel, which is increasingly considered a viable option in the short term to reduce emissions. Methanol was repeatedly identified by the participants as being compatible with existing engine platforms and its liquid-like behavior, its ability to achieve significant CO2 and SOx reductions and thus emerge as an exciting transitional fuel. However, they noted that the emission credits would be subject to the condition that the fuel is green methanol made of renewable sources. This difference is consistent with the current scholarly and industrial standards that a sustainability effect of a methanol is essentially contingent on the process of its production (MAN Energy Solutions, 2016; Verhelst et al., 2019).

Additionally, methanol piping solutions inherently support adherence to IMO safety and environmental standards by mitigating risks and eliminating leakages, thus having implication on safety and environment. Due to the toxicity and flammability of methanol, double-walled construction, leak-detecting systems, and constant monitoring should be employed; all aspects that were singled out by suppliers like Uwira as core to design. These systems reduce risk through accidental releases and stable operation at high pressure, which is part of the overall goal of safe decarbonization that is adopted by the IMO. Pressure-free and leak-free piping also facilitates compliance with regulations not only through emission reduction, but also through the International Gas Fuel (IGF) Code and the expectations of the class society. This highlights the fact that sustainability in fuel

shifts cannot be narrowed down to carbon values; the safety of operations and the environment is also of high importance.

Furthermore, methanol piping solutions also help in decarbonization by acting as the key elements in the wider ecosystem of technology, hence one can easily ease the merging of methanol engines, storage tanks and bunkering infrastructure. The participants of Wartsila and Uwira described the technology as a bridge technology, allowing shipowners to upgrade their existing ships and thus hasten the transition without necessarily having to wait until fully zero-emission solutions like ammonia or hydrogen were available. This view is compatible with the academic notion of pathways of a transitional decarbonization (Geels, 2024) that industries are accommodated by intermediate technologies to achieve short- and medium-term sustainability goals.

Finally, the results highlight the need to coordinate the validation and standardization processes to enhance decarbonization across the industry. The piping suppliers contribute to the creation of common technical standards that reduce uncertainty and thereby enhance wider adoption through joint development programs with engine manufacturers, classification societies and shipyards. Standardization will also accelerate the process of spreading methanol technologies because it will provide clear instructions to designers, constructors, and analysts. This common standard-setting is crucial to scaling IMO targets because it helps reduce the fractured character of strategies that often hinder the adoption of green technology in the maritime sector (Larkin et al., 2017).

Figure 7: Role of Methanol Piping Systems in IMO Decarbonization (Author's own)

6 Conclusion

This paper examined the importance of high-pressure systems in methanol piping in context of the transition to cleaner propulsion fuels in the maritime industry. Using qualitative interviews with experts in both a piping manufacturing company and an engine development company, the study examined four key dimensions, namely the factors driving and hindering internationalization, how inter-organizational networks contributed to market entry, how the conceptualization of methanol piping technology, and how such systems contributed to the decarbonization policy of the International Maritime Organization (IMO).

The findings suggest that the implementation of methanol is largely driven by regulatory needs, the IMO emission abatement targets being one of them. The inherent properties of Methanol as a liquid and that it can be used in conjunction with retrofit solutions further support its suitability as an almost immediate alternative fuel. However, small quantity of green methanol, high cost of production and absence of full-fledged global bunkering system are major obstacles, which slow down the internationalization of methanol-based technologies.

The inter-organizational networks are seen to be critical in internationalization. An effective market entry into the international markets will require strong trust-relationship with engine manufacturers, shipyards, classification societies and shipowners. These networks make it easier to establish supplier credibility and reduce uncertainty, which is why it aligns with the current Uppsala model's interest in avoiding the liability of outsidership.

Technical and regulatory imperatives determine the conceptualization of high-pressure systems of methanol piping. The toxic nature of methanol requires the use of tough designs in the form of a double-wall, materials that are non-corrosive and reliable leakage sensors. Since the demands of the classes are constantly changing, the constant cooperation with industry participants will be an inalienable condition to keep the regulation

up to date, speed up the technological progress and promote the development of new standards.

Lastly, the study shows that methanol piping systems play a significant role in decarbonization of the maritime industry by facilitating safe and compliant use of methanol as a marine fuel. They have both technical and strategic effects, as they lead to a reduction in risk through engineering practices, and they enable retrofits and provide strength to the industry in terms of their confidence in methanol-based solutions. These systems form an important part of the infrastructure that needs to be in place to realize low-emission operations as the maritime industry seeks viable ways of meeting climate targets.

6.1 Practical Implications

This study provides some practical suggestions to the companies and regulatory players involved in the maritime transition to methanol. In the case of suppliers, more specifically the small and medium-sized enterprises, the results show that successful internationalization requires product shift to be replaced by network-based strategies. Since access to the international markets of shipping can depend on credibility, collaboration, and compliance, the partnership with the established engine manufacturers and system integrators can bring the most profit to SMEs. These alliances minimize the liability of outsidership and ease access to the foreign shipyards. Additionally, early certification is a good indicator of trustworthiness and supports market penetration.

In the engineering perspective, the result indicates the necessity of prioritizing standardization while conceptualizing methanol piping system. Modular and pre-certified designs can significantly reduce lead times, simplify retrofits, and enable more efficient scaling of high-pressure systems. Technical development should focus on safety measurements including corrosion resistance, robust double-walled constructions, and reliable leak detection. These features are essential to meet both regulatory compliance and customer expectations.

6.2 Limitation of the Study

Even though this study adds some significant information on the adoption and internationalization of methanol piping systems, it is necessary to note that there are several limitations. The empirical data is based on a reduced number of interviews with technical specialists. Though these views are relevant, they do not include the views of other key employees, including shipowners, port authorities, regulators, and classification societies, whose involvement can affect methanol adoption relatively. Moreover, the study was conducted in the context of ongoing technological and regulatory changes. The current findings might be revised as the industry becomes more mature with the advancement of methanol regulatory systems, bunkering systems, and engine technologies. Additionally, the analysis is heavily based on the views of European suppliers, which might not reflect the practicalities of major shipbuilding locations, e.g. China or South Korea. The use of solely qualitative data and information does not open the possibility of quantitative assessment of the costs, demand and long-term economic sustainability. Such restrictions do not diminish the interest of the results; it emphasizes the need to conduct a greater amount of empirical and comparative studies as the use of methanol grows.

6.3 Future Research Direction

There are several areas that offer potential future research possibilities. A relative evaluation of the infrastructure of methanol in contrast to other alternative fuels, including ammonia, hydrogen, and LNG, would provide a better understanding of the relative complexity, risks involved, and long-term competitiveness of different fuel options. More research on the economics of green methanol production and distribution is also urgently required since the availability and cost of fuel remain a decisive factor in large-scale adoption. Increasing the participation of stakeholders in future research would add both depth and validity to results. Inclusion of shipowners, classification societies, port operators, and regulatory authorities would provide a better overview of operational, legal and infrastructural issues surrounding the adoption of methanol. Long-term studies that

explore how supplier networks change over time would also be useful in illustrating how companies create and maintain an international market presence as the methanol projects continue to grow. Furthermore, experimental research of existing ships that run on methanol would prove helpful in terms of durability of the system, maintenance, emissions during the lifecycle, and safety of the crew. Studies to align the requirements of class society would also help clarify the process of alignment of the regulatory requirements in international markets.

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Appendices

Appendix 1. Interview Cover Letter

Hi,

I hope this message finds you well. I am reaching out to you as you have participated in a survey regarding methanol adoption in the maritime industry conducted by Uwira Oy.

My name is **Md Tashdeed Islam**, and I am currently pursuing my master's degree at the University of Vaasa. As part of my thesis with Uwira Oy, I am conducting a study titled:

"From Concept to Market: Internationalization of High-Pressure Methanol Piping Solutions in the Maritime Industry."

The purpose of this research is to investigate how maritime technology suppliers and industry stakeholders are contributing to the global transition toward sustainable marine fuels, particularly methanol, through innovation, collaboration, and international market integration.

To gain practical insights, I am conducting a series of **semi-structured interviews** with professionals involved in methanol or alternative fuel projects. I would be grateful if you could participate in an interview to share your perspectives and experiences. The discussion would take approximately **45–60 minutes** and can be conducted at your convenience, either **online or in person**.

All information collected will be used strictly for academic purposes, and your participation will remain **confidential and anonymized** in the final report unless you explicitly consent otherwise.

If you are available, I would be happy to arrange a meeting time that suits your schedule. Please let me know your availability, and I will gladly adjust to your convenience.

Thank you very much for considering this invitation. I sincerely appreciate your time and contribution to advancing the understanding of sustainable innovation in the maritime industry.

Kind regards,

Md Tashdeed Islam

Master's Student, International Business

University of Vaasa