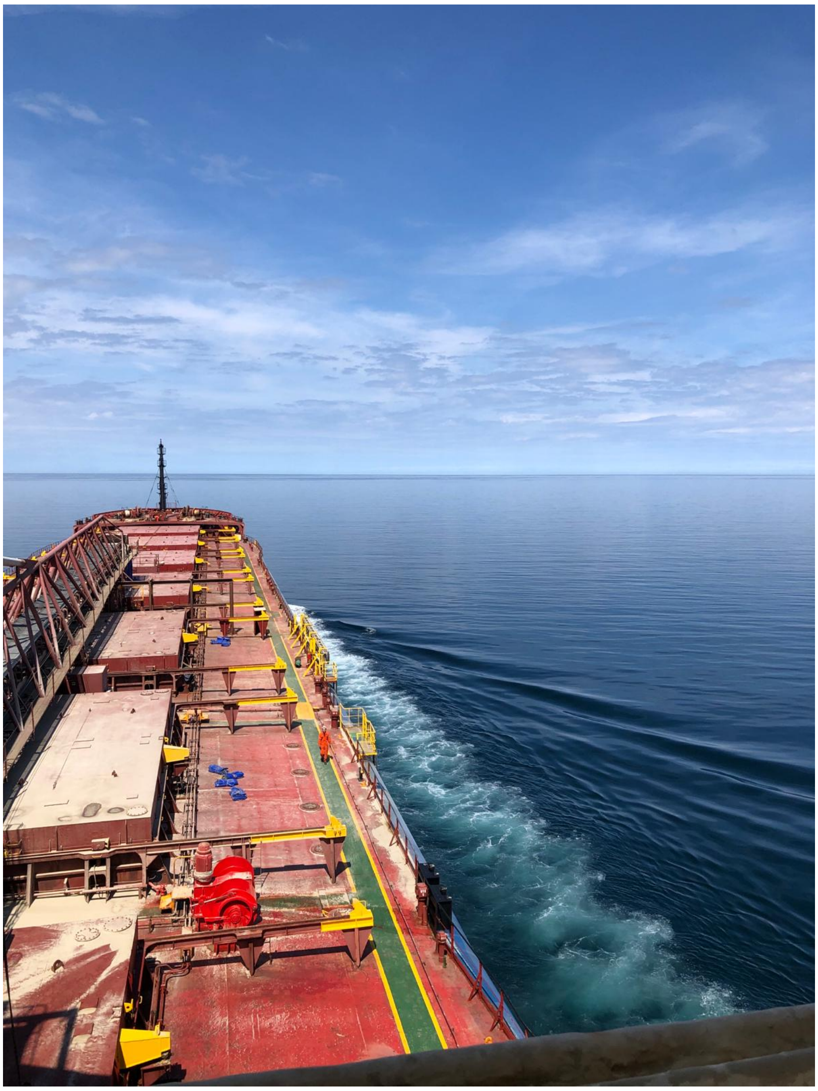
A radical transition framework for the maritime innovator

MSC MT Graduation assignment - Final report - Public version

Jurn Henderiks
Student number: 4733231



Marine technology
Graduation university: TU Delft
Graduation company: HydroFlexx International LTD
Country: Netherlands

Date: February 23, 2024

Thesis for the degree of MSc in Marine Technology in the specialization of
Maritime Operations and Management

A radical transition framework for the maritime innovator

By

Jurn Henderiks

Performed at

Sodaflexx

This thesis (**MT/34/24.023.M**) is classified as confidential in accordance with the general conditions for projects performed by the TUDelft.

11/03/2024

Company supervisors
Responsible supervisor: Elwin Koning
Daily Supervisor(s): *Elwin Koning*

Thesis exam committee
Chair/Responsible Professor: Jeroen Pruyn
Staff Member: Alessia Napoleone
Company Member: Elwin Koning

Author Details
Studynumber:4733231

Preface

I almost completed my master's degree in marine technology with a specialization in shipping management over the last two and a half years. Apart from shipping management, I have a keen interest in renewable fuels. As a part of my master's program, I conducted research on radical innovations.

I would like to express my gratitude to my supervisor Jeroen Pruyn from the University of Delft for guiding and supporting me throughout my research. Additionally, I would like to thank my company supervisor Elwin Koning from Sodaflexx for providing me with the necessary resources and support during this journey. Lastly, I would like to the technology developer and the shipowner for taking their time and effort in providing me with valuable insights through interviews which have been instrumental in completing my research.

Abstract

The European Union has recently revealed a plan called "Fit for 55." The plan aims to reduce carbon dioxide emissions by 55% before 2030. It includes FuelEU Maritime, which will introduce new emission regulations for ships over 5000 gross tonnages. The regulations will require shipowners to reduce their carbon footprint. The European Union has decided not to wait for the International Maritime Organisation's emission rules (IMO) and will enforce them for ships by 2024. By 2025, the rules will extend to offshore vessels with a gross tonnage of 400 or more and general cargo vessels carrying commercial goods between 400 and 5000 gross tonnages.

Efforts are being made to find a hydrogen carrier that closely resembles conventional oil-based products to comply with these regulations. All these fuels need to be produced with renewable energy sources, which have their efficiency losses. Renewable fuel production is only estimated to have a chemical efficiency of 50%. Innovation in the shipping sector is necessary to reduce energy losses. The shipping sector fits the rules of rural society, where incremental innovations are preferred over radical changes. However, radical change is necessary to accomplish the energy transition in shipping. According to the DOI theory, innovators are the first group of adopters. Innovators are eager to try new ideas and have a cosmopolitan (global) network. These innovators will play a critical role in the energy transition in the shipping sector.

The study's objective is to analyse if it is possible to influence a given adoption of the innovator. First, the research outlines the theoretical framework for the study. The literature search aims to determine a transition framework to answer the research sub-questions. The framework's scope will be refined to the innovator group and the maritime sector. A case study will be conducted to test the defined framework, and factors outside the scope may be included if needed. The literature collection approach involves determining the philosophical framework before researching the sociological framework. The mainstream innovation and inclusive innovation frameworks have been identified from a philosophical perspective. The mainstream innovation framework focusing on radical and technological typology is more appropriate for the research study. Rogers's sociological framework can be used to describe the adoption process. The Scopus search has been used to identify different theories, including spatial innovation frameworks, sectoral innovation systems (SIS), technological innovation systems (TIS), and path development. Finally, the study provides an overview of the innovation systems and their corresponding frameworks.

Then the study examines the transition framework for the shipping industry, specifically focusing on the Baltic area and the innovator group of Roger's diffusion of innovation framework. The study suggests using the technology innovation system (TIS) framework, which describes the influence on the system and is suitable for implementing radical innovation. This framework meets the objective and will help in the transition towards renewable fuels.

Additionally, the study provides a comprehensive overview of the actors and networks in the shipping sector, including shipbuilding, transport, customers, and institutions. The study highlights the primary players in each group, their roles, and their relationships with one another. The study further discusses the potential impact of these relationships on the transition to renewable fuels. For example, institutions can have a significant impact on the transition by exercising pressure on multiple levels. For example, EU Maritime regulations can pressure shipowners and shippers to adopt sustainable practices. Institutions can also pressure customers by increasing taxes and excise duty on harmful products.

In conclusion, the literature study has provided a comprehensive overview of the theoretical framework for the research study, specifically focusing on the transition framework for the shipping industry in the Baltic area. The TIS framework was selected as the most suitable framework for implementing radical innovation towards renewable fuels, in combination with path extension to describe the diffusion of knowledge within the TIS functions. Additionally, the study highlighted the importance of actors and networks in the shipping sector and the potential impact of relationships on the transition to renewable fuels. Institutions were identified as key players in exerting pressure on multiple levels to promote sustainable practices. Overall, the literature study provides insights into developing a transition framework towards renewable fuels in the shipping industry. This framework is tested in a case study.

The case study for the Technological Innovation System framework will examine the structure, functions, and motor of innovation. The technology used in the study is a solid hydrogen carrier, and the aim is to determine which TIS functions are the main drivers of innovation and whether actors can be influenced to adopt or reject a given innovation. The case study involves several actors, including Hydroflexx, H2-fuel, the technology developer, and a shipowner. The technology used in the case study, sodium borohydride, is explained in detail within the study.

The case study further discusses the motor of innovation in TIS. It explains the relationships between the structure and functions of TIS that are the main drivers of innovation. The case study additionally discusses the stages of innovation, starting with educating shipowners, yards, and naval architects about the technology to the start of market formation, fuel securing, and knowledge spread through media or marketing campaigns. It also emphasizes the importance of early adopters and innovators in the spread of knowledge and the formation of new innovator groups. Finally, it talks about the difficult phase of switching the business model between different stages of innovation.

Finally, the research has answered the main question. The main conclusion drawn from the study is that the development, dissemination, and diffusion of knowledge are the key functions that can influence a shipowner's decision to adopt a radical innovation in the maritime industry.

Contents

List of Figures

List of Tables

List of abbreviations

AFIF	Alternative Fuels Infrastructure Facility
B2B	Business-to-business
B2C	Business-to-customer
CEF	Connecting Europe Facility
DNV	Det Norske Veritas
DOI	Diffusion of Innovation
EEA	European economic area
ETD	Energy taxation directive
ETS	Emission trading system
EU	European Union
EUA	European Union Emission Trading Allowances
FC	Fuel cell
GT	Gross tonnage
HFO	Heavy Fuel Oil
ICE	Internal combustion engine
IFO380	Intermediate fuel oil 380
IMO	International Maritime Organisation
IS	Innovation system
LCV	Low caloric value
LNG	Liquefied natural gas
LOHC	Liquid organic hydrogen carrier
MARPOL	Marine Polution
MLP	Multi level perspective
Mta	Mega tons annually
NIS	National innovation system
ORIS	Open regional innovation system
R&D	Research and development
RBD	Risk based design
RIS	Regional innovation system
ROI	Return on investment
SECA	Sulphur emission control area
SIS	Sectoral innovation system
SME	Small-medium enterprise
TIS	Technological innovation system
upw	Ultra pure water
VLSFO	Very low sulphur fuel oil
WTP	Willingness to pay

Chapter 1

Introduction

Recently, the European Union unveiled a plan called "Fit for 55" with the aim of reducing carbon dioxide emissions by 55% before 2030 [1]. EU ETS and FuelEU Maritime are part of this plan. The current EU ETS system will be extended to the maritime industry [2]. These rules will be enforced in 2024, whereby an emission contract is needed for every ton of carbon equivalent emission by the shipowner, these rules have an implementation time of 3 years. Besides this, Fuel EU Maritime will introduce new emission regulations for vessels over 5000 gross tonnages [3], requiring shipowners to reduce their carbon intensity of the fuels, this regulation will enforce in 2025. The European Union has decided not to wait for the emission rules of the International Maritime Organisation (IMO) and will enforce them for ships by 2024. By 2025, the rules will be expanded to include offshore vessels with a gross tonnage of 400 or more and general cargo vessels carrying commercial goods between 400 and 5000 gross tonnages [4]. In addition to the EU regulations, the IMO MARPOL rules will expand the sulphur emission control areas (SECA) in 2024 [5], including the Mediterranean region. With the exception of the coastal regions of Portugal and a section of France, the SECA regulations apply to all other areas in Europe.

To deal with these regulations, efforts are being made to find a hydrogen carrier that closely resembles conventional oil-based products. When selecting a carrier, it is important to prioritize factors such as affordability, safety, and energy density similar to those of oil-based products. These carriers are hydrogen oil, ammonia, methanol or crystallized salt-based hydrogen [6]–[8]. No matter which fuel is chosen, all these fuels need to be produced with renewable energy sources, which have their own efficiency losses.

	HFO	Renewable	Efficiency loses
Propeller output	1	1	
Propeller input	2	2	50%
Engine output	2.1	2.1	3%
Engine input	4.1	4.1	50%
Renewable production		8.2	50%
Renewable energy production capacity		33.0	75%*

Table 1.1: Example energy problem
*3MW Windmill producing 6500 MWh annually [9]

Table 1.1 provides a complete overview of a challenge faced by renewable energy based on standard vessel efficiency assumptions. It is important to note that renewable fuel production is only estimated to have a chemical efficiency of 50%. Additionally, a 33 kWh capacity windmill is required to produce 1 kWh output at the propeller every hour. The renewable system must significantly improve efficiency to reduce the need for renewable energy sources. The overall efficiency of renewable fuels is outside the scope of this research. However, it is an important factor. This should be considered in another research about the technology used in the case study to see if it is possible to use the technology on a large scale.

Besides energy efficiency, the storage condition of alternative fuels can be challenging. Some examples are pressurized hydrogen (high-pressure storage), liquid hydrogen (low-temperature storage), ammonia (poisonous hazard), or methanol (poisonous hazard). Another one of these renewable fuels is H2-fuel [8]. H2-fuel is a hydrogen carrier product made from salt-crystallized sodium borohydride. It is a fuel that can be stored in a chemical tank while filling the air voids with dry air or nitrogen to prevent a reaction with water. Apart from this, all other storage conditions are quite similar to diesel. This gives H2-fuel a significant advantage when compared to other types of fuels.

When the H2-fuel is transported from the tank to the reaction chamber, it is mixed with ultra-pure water (upw). The reaction chamber uses metal plates as an activator to speed up the release process. Two types of processes are available for this: batch processing and continuous processing. Batch processing has a peak flow and a lower extraction. The peak flow should be stored in a buffer, while a continuous process has a stable flow with a limited amount of storage required. The continuous process has a higher energy extraction because the fuel in the reactor can have a higher concentration of sodium borohydride. However, this process is still in an early stage of development. The result of these processes is hydrogen, which is released from both the sodium borohydride and the upw. In addition to the hydrogen, there is also a residual product left behind called sodium metaborate, which requires storage. The sodium metaborate contains lots of water. The water should be evaporated until the chemical mixture is $NaBO_2 + 2H_2O$ to store this product effectively. This will reduce the weight of storage for the residual product. Finally, the hydrogen produced during this reaction will be pressurized and used in a fuel cell or engine. The complete process is in figure 1.1.

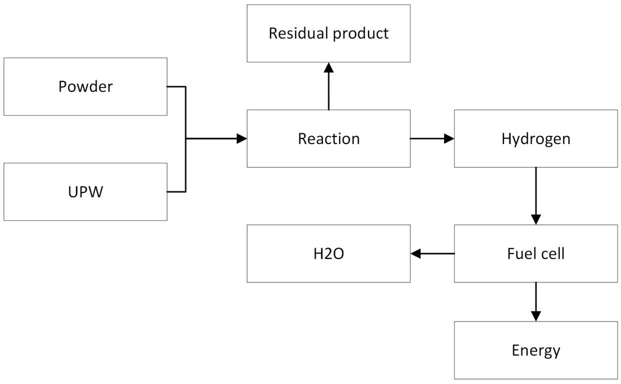


Figure 1.1: Simplified flow schema H2-fuel, detailed flow schema in figure 4.2

The sodium metaborate can be used to regenerate the sodium borohydride, which will reduce the cost of the fuel. According to the patent holder, the cost of regenerating and shipping one kilogram of released hydrogen from Saudi Arabia to Rotterdam is priced at 3.60 euros [8]. The price of the fuel will be higher in port, as multiple parties need to take a profit on the fuel. On the other hand, there is public demand for green products, which includes green shipping. As there is demand but limited supply in different categories, people are probably willing to pay extra for green products. According to a report by McKinsey [10], freight forwarders are willing to pay an additional 5 to 10 per cent for a green shipping line. Another study is about the willingness to pay for a t-shirt shipped using green fuel, whereby green fuel is described as an energy-efficient fuel. This study indicates a mean willingness to pay (WTP) of at least 30 per cent [11] for a green shipped t-shirt. The writer of this research has identified some points of criticism, specifically regarding the low price of the T-shirt. This challenges determining the WTP, as it could be 30 per cent or 3 dollars. To address this, the researchers should have conducted the same survey with different T-shirt prices. Additionally, informing customers that the T-shirt is shipped green sets certain expectations, implying that it is environmentally friendly. As such, it is important to provide a clear definition of what green means. While the research defines green as an energy-efficient fuel, this description is still vague. Without further elaboration, even marine diesel oil could be considered an energy-efficient fuel, which does not qualify as green.

Besides price, when implementing a new fuel, the main problem is the security of supply. There are two supply problems, the actual logistics ensuring the supply of the fuel in designated locations and the second on is the production of the new fuel. As H2-fuel will be a recycled product, logistics must be a two-way street. Also, on a small scale, the producer needs at least three times the product to keep up with demand. If the product scales, the producer can reduce the amount of fuel per active customer. As an example, if there is one vessel using the fuel. There is a batch of fuel on the ship, a batch in the harbour, and a batch at the recycling. If the recycling time is too long, an extra batch could be needed to fuel the vessel. When there are 100 ships, stock in harbours can decrease as a vessel only refuels every so often. This way, less than three batches per ship are needed. The larger the system, the lower the number of batches in the system per ship.

Implementing innovation in the shipping sector is necessary and could be difficult. The goal of this research is to learn how the decision to adopt or reject an innovation can be influenced. Therefore it is important to understand behaviour towards a given innovation for the industry. When conflicted with radical innovation shipowners will have a certain response. To gain insight into this behaviour of shipowners, the diffusion of innovation (DOI) transition framework [12] can be useful. It distinguishes two societies: rural and urban.

The rules of rural society and the shipping sector will be compared to identify similarities or differences. This comparison will help determine if the behaviour of rural society can also be expected in the shipping industry. In rural communities, people work alongside nature, allowing it to thrive on its own while they live and work in harmony with it. This sets rural society apart from urban society, where nature is often absent or heavily controlled by humans [13]. It can be argued that the shipping industry aligns with the characteristics of rural society, as vessels navigate in harmony with the ocean and are subject to unpredictable weather conditions at sea. Another key difference between rural and urban communities is the rate of change. Urban societies tend to adopt novelties fast and have constantly competing companies. Nonetheless, in rural areas, companies are also constantly competing. However, change happens more slowly in rural areas, and the community tends to resist radical innovation [14]. This behaviour is also described in studies about the shipping sector, which highlight the distinction between incremental and radical innovation in terms of behaviour [15][16]. Shipowners prefer incremental innovations, like improving fuel efficiency or updating current systems. Radical changes, such as switching to a different fuel type, tend to have more resistance. Therefore, the shipping sector fits the rules of rural society. It is difficult to achieve radical change, which is necessary to accomplish the energy transition in shipping. These are the rules of the innovation game in the shipping industry. Which have exceptions as someone has to be the first adopter of the novelty.

Different innovation theories and cultural differences can be used to describe this behaviour and the exceptions. There is the Multi-Level Perspective, which can be used to describe the change in market regime. The adoption theory describes the different types of first adopters and their importance. The description of cultural differences can be used to show that some countries or cultures are more likely to be first movers.

According to the DOI theory, the first group of adopters is called the innovators. The innovators are eager to try new ideas, have a cosmopolitan (global) network of peers, possess substantial resources and maintain high technological knowledge [17]. The innovators have the role of introducing new technologies outside the barriers of the social system. The innovators decide which ideas are introduced in the sector. In the shipping sector, some shipowners are often innovators regarding radical innovation. Scandinavian shipowners, for instance, tend to be more proactive and willing to take greater risks in pursuing radical changes [18]. Other research of ships sailing in the Baltic area shows similar behaviour towards innovation [19]. Also, according to a study on innovator behaviour in wireless services in Germany, Finland, and Greece. Finland was found to be the most innovative, while Greece was in the late majority category and Germany fell somewhere in between [20]. And in practice, the Danish company A.P. Moller-Maersk is often the innovator with the most recent choice to build 19 methanol-powered vessels [21]. This suggests that innovation is linked to national cultures, which is discussed by Gerard J. Tellas et al. [22]. They state that the drive of firms to innovate is based on religions, geographical locations and values of citizens. Besides culture, this behaviour can be a feeling of companies; they are willing to do better. However, it can also be explained as increasing pressure from the sectorial landscape on the technical regime, which forces the technical regime to introduce novelties to their designs. This behaviour is described in the multi-level perspective (MLP) [23]. The sectorial landscape is the political playing field, the technical regime is the current sector leaders, and a novelty is one idea within an innovation. As innovations tend to exist of multiple novelties. Some companies react early to new rules or expected rules to stay innovators. The increased pressure is from the European Union and IMO. The Baltic area is becoming one of the most restricted areas, including carbon taxing, reducing carbon intensity, and SECA. This could explain the different behaviour of shipping companies sailing in the Baltic area. Therefore, the Baltic area could be a suitable starting point for implementing renewable fuels in the fleet, like H2-fuel.

1.1 Problem definition

The shipping industry faces the challenge of transiting to using renewable fuel to comply with rules set by IMO and the EU. Safety, energy efficiency, and affordability are all essential criteria that must be considered. One of the challenges in utilizing renewable fuels is the implementation process for the innovators in the industry. Due to the innovative character of the industry and the potential security of supply risk, it presents a difficult choice for shipowners. It can be difficult to convince shipowners to innovate their vessels without knowledge of an innovator's decision process to adopt or disregard a radical innovation.

1.2 Objective

The overall objective is to understand what influences the decision of innovators to adopt or disregard a radical innovation. Without these innovators, the subsequent stages of adoption cannot proceed. The initial objective is to determine a general transition framework and subsequently focus on the innovator group and the maritime sector.

Research question
Main question
Can the adoption of a given radical innovation in the maritime industry be influenced?

To determine if the adoption of an innovation can be influenced, it should be clear which parameters are in place, what their function is, and if these can be influenced.

Sub questions for literature review

- Which innovation frameworks are most suitable for describing the adoption process of radical innovations?
- Which innovation framework can be used to describe the adoption process of radical innovations in the shipping industry for the innovators?

Sub question for case study

- Which TIS functions are the main drivers of the motor of innovation?

Definitions
Influence: Influence is the power an individual, group of individuals, company or institution has to change the innovation outcome by implying a specific action.

1.3 Scope & Research structure

The project will be scoped based on vessel type, sailing area and size of the vessels. The vessel type will be limited to container and bulk vessels, both vessels can be generalized in the final results. Ship types like yachts, cruise vessels or offshore vessels are case-specific and are difficult to compare. The sailing area will consider vessels in the shortsea shipping market, as the infrastructure has not started. Having ocean-going vessels at the start will cause difficulties in the security of supply. A suitable area will be the Baltic area, which is discussed in the introduction. The sizes of the vessels will also be limited, as the new rules from the EU apply to ships with a gross tonnage of 5000 or larger; the lower limit will be 5000 GT. To conclude, the project focuses on container and bulk vessels sailing in the Baltic area with a gross tonnage of 5000 or more.

Chapter 2

Theoretical framework

The objective of the literature study is to determine a transition framework to answer the first subquestion. After different frameworks have been identified, the framework will be scoped on the innovator group and then further refined to the maritime sector, to answer the second subquestion.

2.1 Introduction

The introduction will discuss the scope of the theoretical framework, the literature collection approach, the transition framework and the structure of the theoretical framework.

Scope

The literature search will define the transition framework. If the framework is clear, the scope will be refined to the innovator group and subsequently to the shipping sector. The defined framework will then be tested in a case study, which will be done after the literature study and if needed factors outside the scope will be included during or after the case study. An overview of the scope is in figure 2.2.

Literature collection approach

For the literature collection approach, the first step is to determine the philosophical framework before researching the sociological framework. To determine the philosophical framework a keyword search has been done with the following input: Innovation & Philosophical. The result is two different tendencies in innovation frameworks from a philosophical perspective; Mainstream innovation and Inclusive innovation [24]–[26]. A further search on both terms has been done with keywords: Mainstream & Inclusive & Innovation.

Mainstream innovation has three different perspectives on innovation [25]:

1. Incremental innovation versus Radical innovation
2. Technological innovation versus Marketing innovation
3. Product innovation versus Process innovation

Suruso has identified characteristics for all mainstream innovation types, which are summarized in figure 2.1.

Mainstreams of Innovation Typology	Key Characteristics	Prominent Authors
Radical versus Incremental Innovation	- Radical innovation are the ones that are new to the world and are exceptionally different from existing products and services - Incremental Innovation involves revisions or alterations to existing products or service	Abrunhosa and E Sa (2008), Lin andChen (2007), Prajogo and Sohal (2003), Forsman and Temel (2011)
Technological versus Marketing innovation	- Technological innovation is the adoption of new technologies that are incorporated into processes or product - Marketing innovation is associated with internal processes supporting the delivery of a service or product	Rosenbusch (2011), Damanpour et al (2009), Auken et al (2008), Bon and Mustafa (2013)
Product versus process innovation	- Product innovation are creating a new or improved good or service - Process Innovation are focuses on improving the effectiveness and efficiency of production	Gunday et al (2011), Sigh and Smith (2004), Prajogo and Sohal (2006)

Figure 2.1: The Mainstreams of Innovation Typologies [25]

According to Heeks et al., inclusive innovation has six levels of including the poor in the innovation process [24][26], whereby level one is the lowest inclusion:

Level 1. Intention
Level 2. Consumption
Level 3. Impact
Level 4. Process
Level 5. Structure
Level 6. Post-structure

The intention level argues that there should be the intention to include the excluded groups in the innovation. However, no dialogue with the excluded group is made [26]. While the post-structure level fully includes the excluded groups in the innovation process, whereby all the key actors allow for the inclusion of the excluded [26].

As mentioned earlier, the innovation being discussed requires a significant amount of capital and expertise, thus fitting Rogers's definition of an innovator. However, this definition may not apply to inclusive innovation, which aims to involve those with limited resources. Due to the high cost of the innovation, it may exclude the poor in the initial stages, but they can be considered in the early adoption phase. Therefore, the mainstream innovation framework with a focus on radical and technological typology is more appropriate. For instance, the adoption of a new fuel in the shipping industry can be considered a radical innovation according to the philosophical typology in figure 2.1. Additionally, the technological innovation typology can be applied to the adoption process. Rogers's sociological framework [17] can be used to describe this, as it includes the adoption process.

For the sociological framework, the following keywords have been used in a Scopus search: radical OR technological OR product AND innovation AND sectoral. This resulted in 985 documents, to limit the search an additional criterion has been added. The total search has been limited to Social Science. This resulted in 287 papers, which were reduced based on title, abstract and availability to 31. The papers discuss different frameworks: spatial innovation frameworks, sectoral innovation systems (SIS), technological innovation systems (TIS), and path development. In the following section, an overview of the different theories is stated.

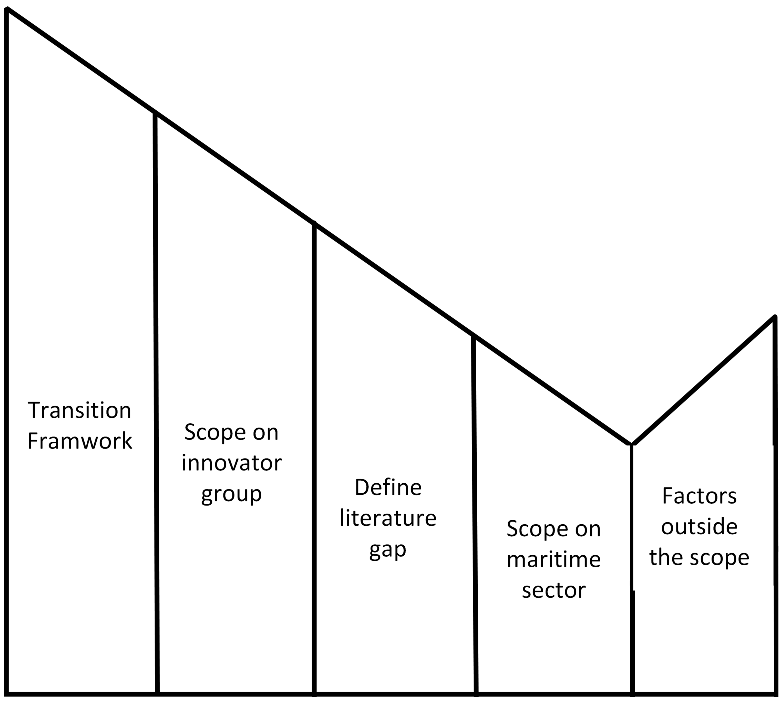


Figure 2.2: Scope

2.2 Systematic overview of theories

This section provides an overview of innovation systems and their corresponding frameworks. The overview given in this study has a review of the building blocks and system boundaries that form these frameworks. Furthermore, this literature research explains the diffusion hierarchy and draws attention to the differences between diffusion and dissemination and describes path development. The goal of this chapter is to gain a thorough understanding of the various components that constitute these innovation frameworks and the crucial role they play in the development and diffusion of innovations in innovation systems.

2.2.1 Building blocks

Spatial frameworks

Two different spatial frameworks are discussed in eight papers of the selected literature [27],[28],[29],[30],[31],[32],[33],[34]. Spatial frameworks are the spatial boundaries used in innovation systems. The approach characterizes innovation processes at different spatial levels and points out systemic failures that hinder implementation. Innovation policy should address these failures and spatial frameworks can support policymakers to identify these failures [30].

The first spatial framework is the local or regional innovation system (RIS). According to K. Kubeczko et al. [33], the RIS framework approach is based on a territorial approach for innovation; due to this focus, the framework can be applied to the development of rural areas. This aligns with the DOI theory of Rogers, which is used as a basic framework in this research and discussed in the introduction.
In the paper of K. Kubeczko et al. [33], three building blocks can be identified; knowledge, technology and network. Y.C. Chang et al. [32] identified two additional blocks; culture and financial capacity. I.P. Gomez et al. [30] identified three building blocks; knowledge application and exploitation, knowledge generation and diffusion, and regional policy. The building blocks of I.P. Gomez et al. [30] are defined by E. Autio [35] and M. Trippl [36]; both studies are added to the literature selection.
Knowledge application and exploitation
The subsystem responsible for the application and exploitation of knowledge has its main domain in commercial activities within the RIS. It describes the role of small-medium enterprises (SMEs) and large firms in gaining a position (of dominance) in the market [35].
Knowledge generation and diffusion
The subsystem responsible for generating and diffusion primarily involves industrial companies, while the latter includes various institutions involved in creating and diffusing knowledge [35].
Regional policy
The subsystem for regional policy has actors in the political playing field capable of influencing the direction of novelties and innovation on a regional level. The actors have a strong level of autonomy, meaning sufficient legal competencies and financial resources.[36]
Technology, finance, culture and networks
Technological change depends on the regional innovation culture; as discussed in the introduction, some areas are more likely to adopt radical innovations than others. The capacity to change depends on the type of innovation. According to Z.J. Acs and D.B. Audretsch [37]: *"Large firms innovate better in industries that are capital-intensive and highly unionized, whereas small firms have an advantage in industries that use a large share of skilled labour"* [28]. This means that the financial capacity needed depends on the type of novelty. To diffuse the novelty, a network of actors is needed. This creates path dependency, as multiple regional actors depend on each other to adopt the novelty [33].

The second spatial framework, known as the National Innovation Systems (NIS), is concentrated around novelties within a single nation [30]. However, since this study concentrates on the Baltic region, which contains multiple nations, the NIS framework will not be considered.

In conclusion, the selected literature discusses two spatial frameworks for innovation; the local or regional innovation system and the national innovation system. This section focused on the RIS framework, which is based on a territorial approach for innovation and can be applied to the development of rural areas. The RIS framework consists of building blocks such as knowledge application and exploitation, knowledge generation and diffusion, and regional policy, among others. It is important to note that technological change depends on the regional innovation culture and the financial capacity needed depends on the type of novelty. The NIS framework, which is concentrated around novelties within a single nation, will not be considered in this study as it focuses on the Baltic region, which contains multiple nations.

Sectoral innovation system

The sectoral innovation system (SIS) is discussed in nine papers of the selected literature [38],[32],[33],[39],[40],[41],[42],[34],[43]. The original paper of Malerba, which discusses the SIS framework will be included in the literature review [44]. Malerba defines SIS as [44]: *"A set of products and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products. A sectoral system has a specific knowledge base, technologies, inputs and demand. Agents are individuals and organizations at various levels of aggregation. They interact through the process of communication, exchange, cooperation, competition and command, and these interactions are shaped by institutions."* The SIS framework is dynamic and based on the evolution theory, allowing actors to influence the innovation process and map the innovation strength in a sector [44], [45]. In conclusion, a sectoral system is a complex network of agents, knowledge, technologies, and institutions that shape innovation processes and outcomes. The SIS framework provides a dynamic and comprehensive approach to mapping and analyzing innovation strength in various sectors.

S.M. Azad et al. [43], T. Nilsen et al. [38] and N. Gaponenko [42] identified three building blocks in the SIS framework; knowledge and technologies, actors and networks, and institutions.

Knowledge and technologies

The diffusion of knowledge is described in this building block. Knowledge can diffuse efficiently if there is great accessibility; however, this also means that competitors can effortlessly replicate the novelty. When information is not easily accessible, there can be a significant advantage for those already knowledgeable. However, the low diffusion of information makes it more challenging for customers to adopt novelties since limited knowledge is available [44]. Besides the diffusion of knowledge, there is the development of knowledge. For some sectors, novelties are only created if there are new rules and regulations or due to scientific breakthroughs at universities and research institutes. For other sectors, novelties are mostly driven by research and development (R&D) departments [44]. If knowledge is developed due to political or scientific advancements, it will be widely accessible. However, if the knowledge is gained through internal research and development, there will be less diffusion of that knowledge.

Actors and networks

Heterogeneous agents, such as firms, non-firm organizations, and individuals, are organized into networks, which can be at the national, regional, sectoral, or global levels. These networks create a path dependency, as multiple actors must collaborate to innovate the sector with distinctive novelties.[44],[42]

Institutions

Institutions such as standards, regulations, and norms play a crucial role in supporting innovation as these establish the rules of the game for it [44],[42].

Overall, the sectoral innovation system (SIS) framework is dynamic and takes into account the diffusion and development of knowledge, the role of actors and networks, and the importance of institutions. The three building blocks identified by Azad et al [43]., Nilsen et al. [38], and Gaponenko [42] are crucial to understanding the innovation strength of a sector.

Technological innovation system

The technological innovation system (TIS) is discussed in eight papers of the selected literature [32],[46],[47],[48],[49],[40],[41],[43]. The original paper of A. Bergek et al. [50] and a reaction on criticism of A. Bergek et al. [51] will be included in the literature review. According to Bergek et al. [50], TIS is primarily used to identify system failures and address them to policymakers. TIS frameworks can be part of a larger SIS framework or, if the technology is more general, multiple SIS frameworks. The seven-step approach of the TIS framework includes determining the starting point, identifying structural components (actors, networks, and institutions), functions (such as knowledge development and market formation), achieving a functional pattern, assessing functionality and setting process goals, inducement and blocking mechanisms, and key policy issues. The TIS framework helps identify system failures and address them to policymakers through a structured seven-step approach. It can be used for specific technologies or as part of a larger SIS framework.

S.M.Azad et al. [43] identified three building blocks for TIS; Structure, function, and motor.

Structure

The first building block is the structure which is defined by R.A.A. Suurs et al.[52] as; Elements that directly support or reject the development and the diffusion of novelties. These elements consist of actors, institutions and networks.

Function

The second building block is the functions of TIS, these functions can provide a dynamic perspective on the novelties. These system functions refer to system-level variables. They are types or sets of activities that influence the development of an innovation system. [52]

Motor

The third building block is the motor of innovation;*"Motors of innovation emerge from a configuration of structural factors and, in turn, rearrange that configuration."[52]*

The TIS framework has similarities with the SIS framework, as it is also based on evolutionary theory and has a dynamic framework [51]. There are similarities in the building blocks of both, as they utilize actors, networks, institutions, and knowledge development. According to Y.C. Chang et al. [32]:*"Both SIS and TIS stress the economic dynamics of technology development and the importance of inter-industry technology flows."*

In conclusion, the technological innovation system (TIS) framework consists of three building blocks: structure, function, and motor. The TIS framework has similarities with the SIS framework, and both stress the economic dynamics of technology development and the importance of inter-industry technology flows. The TIS framework is a comprehensive approach that includes steps such as setting process goals, assessing functionality, and identifying key policy issues. Overall, the TIS framework provides a dynamic perspective on the development and diffusion of novelties in innovation systems.

2.2.2 System boundaries

Three innovation systems (IS) have been discussed in the previous section. All three systems have similarities and differences on the system boundary level. Also, the RIS and TIS frameworks have different views within their framework, which changes the system boundaries. For RIS, there is an open regional innovation system (ORIS) [30]. A RIS framework has regional and firm boundaries. While ORIS includes regions and firms outside the RIS scope. There are two different ORIS systems [30]. The first focuses on small-medium technology diffusion, whereby the main goal is to generate more knowledge on the firm level with knowledge outside the region. The second focuses on high technology diffusion, establishing relationships outside the region to commercialise the novelty.

The TIS framework can be split into context TIS and focal TIS. Context TIS is defined by A.Bergek et al. [51] as: *"All other structures and relevant factors outside of the TIS"*. While focal TIS defines the system boundaries, which are based on analytical problems and spatial boundaries. Depending on the sector, the TIS framework can be limited to a national, regional, or global level. The complete TIS framework consists of both the context and focal TIS. The context TIS, described by Geels et al. [53] as the sociotechnical landscape, is a part of the focal TIS. The landscape encompasses disruptions outside of the TIS framework that influences the novelty described in TIS. In addition to contextual and focal TIS, there is also cross-sectoral TIS which refers to the extent of externalities resulting from innovation [54],[47]. Cross-sectoral TIS can indicate the strength of an innovation if it can be applied across multiple sectors. However, this can have either a positive or negative impact depending on the complexity and capacity of the innovations within the system.

The SIS framework has different spatial boundaries, depending on the sector and objective; the framework can be defined on a national, regional or global level [44]. The innovation can also exist in multiple SIS frameworks, as innovation can be used cross-sectoral [55]. For example, the energy transition, where the energy sector innovates to the use of renewable fuels and other sectors adopt this new energy carrier.

In conclusion, the RIS, TIS, and SIS frameworks all have different views on system boundaries, depending on the sector and objective. The RIS framework includes an open regional innovation system, while the TIS framework can be split into context and focal TIS. The SIS and TIS framework can exist on a national, regional, or global level, while RIS only exist on a regional level. Innovation can also be used cross-sectoral, as seen in the energy transition.

2.2.3 Diffusion hierarchy

The diffusion hierarchy distinguishes between frameworks that use a bottom-up approach and those that use a top-down approach to spread knowledge. Based on Rogers's DOI theory [17], a bottom-up knowledge spread is characterized by diffusion, which is uncontrolled and chaotic. In contrast, a top-down knowledge spread is called dissemination, a controlled form of diffusion where the information flow is fully managed.

In a RIS or ORIS framework, the knowledge is diffused, while SIS and TIS frameworks can either have knowledge diffused or disseminated [30]. Also, it can be argued that it is possible to have both, either at the same time when the dissemination of one company leads to the diffusion of knowledge in another company or the diffusion gets the attention of the leadership, which changes the direction of the innovation within a company and disseminates the knowledge in the complete company.

Overall, understanding the differences between diffusion and dissemination is crucial for spreading knowledge. Depending on the framework, both methods may be used, and they can have varying levels of control.

2.2.4 Conclusion

After reviewing various innovation frameworks, it is clear that innovation systems consist of building blocks and system boundaries that play a crucial role in the development and diffusion of innovations, an overview is given in table 2.1. The RIS framework has been discussed in detail, which is based on a territorial approach for innovation and can be applied to the development of rural areas. Additionally, the SIS and TIS frameworks have also been explored, which are dynamic and take into account the diffusion and development of knowledge, the role of actors and networks, and the importance of institutions.

While each framework has its own unique view on system boundaries, depending on the sector and objective, it is important to note that understanding the differences between diffusion and dissemination is crucial for spreading knowledge effectively. Depending on the framework, both methods may be used, and they can have varying levels of control. Overall, the selected literature provides a comprehensive understanding of how innovation frameworks work and the role they play in advancing technological innovation.

<table>
<tr><td rowspan="2"></td><td colspan="2">Regional innovation system</td><td rowspan="2">Sectoral innovation system</td><td colspan="3">Technological innovation system</td></tr>
<tr><td>RIS</td><td>ORIS</td><td>Context</td><td>Focal</td><td>Cross</td></tr>
<tr><td rowspan="4">Building blocks</td><td colspan="2">Knowledge application and exploitation</td><td>Knowledge and technologies</td><td colspan="3">Structure</td></tr>
<tr><td colspan="2">Knowledge generation and diffusion</td><td>Actors and networks</td><td colspan="3">Function</td></tr>
<tr><td colspan="2">Regional policy</td><td rowspan="2">Institutions</td><td colspan="3" rowspan="2">Motor</td></tr>
<tr><td colspan="2">Technology, finance, culture and networks</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td rowspan="3">System boundaries</td><td>Regional bounded</td><td>Outside region boundary</td><td rowspan="3">Spatial bounded</td><td rowspan="3">Outside of focal TIS</td><td>Spatial bounded</td><td rowspan="3">Include sectors outside of focal TIS</td></tr>
<tr><td rowspan="2">Firm bounded</td><td rowspan="2">Outside firm boundary</td><td>Analytical bounded</td></tr>
<tr><td>Firm bounded</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td>Diffusion hierachy</td><td colspan="2">Bottom up</td><td>Mixed</td><td colspan="3">Mixed</td></tr>
</table>

Table 2.1: Overview of innovation systems

2.3 Path development

2.3.1 Different paths

Besides RIS, SIS and TIS, the literature review describes innovation through path development. Two papers in the selected literature discuss path development [55],[38]; based on these papers, two papers will be added to the literature selection. Grillitsch et al.[56] discuss the regional industrial path development, and Trippl et al. [57] discuss different categories of path development. Both are based on the RIS framework and discuss path development based on regional boundaries, including cross-regional path development for knowledge diffusion. There are various categories for classifying path development: path development, path extension, path diversification, path emergence and path plasticity [55],[57],[38].

According to Grillitsch et al.[56]:*"Path development is described as growing existing industries."* According to Trippl et al.[57]:*"Future regional development paths are shaped by the past industrial development in the region."* To conclude, path development involves building on existing industries, while future regional development paths are influenced by past industrial development in the region. These findings suggest the importance of understanding the history and current state of industries in a region when planning for future development.

Path extension or upgrading is defined by Grillitsch et al.[56] and consists of large disruptions in existing industries. Path extensions can mean a change in technology, organization or even a change in the complete business model.

Path diversification defined by Grillitsch et al.[56]: *"A development from existing into new industries by applying existing knowledge in new industries or combining existing with unrelated knowledge."* So, path diversification refers to the expansion of existing knowledge into new industries or the combination of existing knowledge with unrelated knowledge.

Path emergence defined by Grillitisch et al.[56]: *"Emergence can either refer to the rise of a completely new industry often based on a technological breakthrough or the importation of already existing industries by drawing heavily on extra-regional knowledge and resources"*. So, emergence can occur through either the creation of new industries or the integration of existing industries with external knowledge and resources.

Path plasticity is defined by A.Butzin et al.[55]: *"The corridor in which change happens without causing radical transformation"*. Or in other words, the moment when an innovation shifts from incremental to radical. If this happens, the innovating industry will experience plastic deformation and be forced to change.

According to Grillitsch et al.[56], path development can be split into two different regions; the peripheral and the metropolitan region. The peripheral region is defined as the rural area, and the metropolitan region as the urban area. In the introduction of this research has been argued that the shipping sector fits the rules of the rural area. Therefore, the metropolitan region will not be considered.
The peripheral area can exclude path diversification if there is no critical mass in any specialization. Assuming this is the case, only path extension and emergence are suitable options. Also, in rural areas, the main challenge is not to adopt novel technologies but to shape the technology in the correct local conditions, making it suitable for adoption.

In conclusion, path development, extension, diversification, emergence, and plasticity are key concepts in regional industrial path development. Understanding the past and current state of industries in a region is crucial when planning for future development. Additionally, path development can be split into two different regions, the peripheral and metropolitan regions, whereby the peripheral regions are considered in this research, which includes the use of path extension and emergence to describe path development.

2.3.2 Connections

The objective and main question defined in the introduction of this study use the innovator group of the diffusion of innovation. To meet this requirement, a connection between path extension, path plasticity, path emergence and the diffusion of innovation will be defined. Without connections, the path development will not be suitable for this research.

First, the connection between path extension and plasticity. The path extension creates large disruptions in existing industries; as the disruptions are large, it aligns with the definition of path plasticity, and therefore path extension will create radical innovation. Path extensions can mean a change in technology, organization or business model.

Secondly, according to M.Grillitsch et al. [56]: *"It is thinkable that regions have developed a certain scale in a green industry but focus on low-skill manufacturing while the high-value and knowledge-intensive activities are located elsewhere. For such regions, path upgrading in the sense of increasing knowledge intensity in the industry and attracting higher-value-added activities to the region could potentially play an important role."* This definition can also be applied to the shipping industry. According to Craig Eason [58]: *"Not many shipowners take an active role in developing the technologies that they eventually need, relying on (cleantech) firms to do the R&D."* This means the shipowners wait until the technology is ready before taking an interest in new technologies. Non-ship-owning firms develop the innovations, while the shipowners focus on their normal business and only adopt the innovation if it is ready and will improve their competitiveness in the region. Also, in the previous section, it was mentioned that path extension occurs in peripheral areas. So, path extension describes radical innovation within the peripheral area and can describe the same behaviour described in the introduction with Roger's DOI Framework. To conclude, path extension can describe path development within the maritime industry.

From Rogers's DOI framework, the focus in this paragraph will be on innovators, early adopters and majority adopters. As discussed in the introduction: The innovators are eager to try new ideas, have a cosmopolitan (global) network of peers, possess substantial resources and maintain high technological knowledge [17]. The innovators have the role of introducing new technologies outside the barriers of the social system. The innovators decide which ideas are introduced in the sector. The early adopters are part of the local system and often have no cosmopolitan network of peers. The early adopters are important for the majority of adoptions. The early adopters are used to confirm the novelties for the majority [17]. Within the early adopters, it is possible to have overlap between different industries, as they have a regional network of peers.

According to the writer of this research, path emergence can only happen after path extension as the technology first needs to be introduced in existing industries before new industries can occur. A link between path extension, path emergence, innovators, early adopters and majority adopters is shown in figure 2.3:

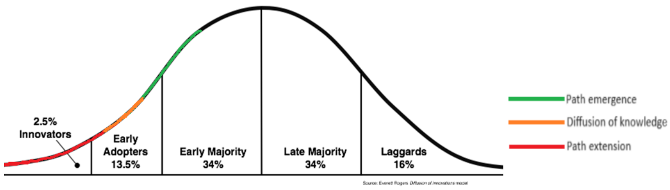


Figure 2.3: Path development within Rogers diffusion of innovation [17]

The red line represents the path extension and the green line path emergence. The orange line represents the diffusion of knowledge, which creates a transition between path extension and path emergence.

To summarize, this section defines the connections between path extension, path plasticity, path emergence and the diffusion of innovation. The concept of path extension is crucial for creating radical innovation in existing industries. Innovators play a critical role in introducing new technologies outside the barriers of the social system, while early adopters confirm the novelties for the majority. Path emergence can only occur after path extension, and the diffusion of knowledge facilitates the transition between path extension and path emergence. Overall, this section provides a framework for understanding the path development of novelties in industries, including the maritime industry.

2.4 Literature gap

In this study, three innovation systems and path development have been explored. However, there is a gap between the objective of this study and the existing innovation systems. While all innovation systems discuss knowledge development within their systems, the first group of innovators is not explicitly included in any of these systems. To address this gap, the researcher proposes a framework.

In order to describe the progress of knowledge development among innovators, the concept of path extension will be utilized. In Roger's framework, path extension is deemed suitable for innovators. Although there is no clear distinction between path development and knowledge development in literature, three papers [59]–[61] suggest that path development is a function of knowledge development. Therefore, it can be assumed that path development is a function of knowledge development. As path extension describes the change in a firm, the function is firm-based. Path emergence describes the change in an industry and, therefore, within a sector. It will be assumed that path extension can happen in focal TIS and RIS, as both are firm-based. Path emergence occurs within RIS, SIS, context TIS and cross-sectoral TIS, as all can describe changes within sectors. This connection is important because the success of the innovation systems depends on the development of knowledge about the innovation. Without knowledge, adoption of the innovation cannot take place, as no one is knowledgeable.

2.5 Conclusion

Studying innovation systems and their frameworks is essential to understanding the dynamics of technological change and the diffusion of knowledge. The literature presented two main frameworks, the RIS and NIS, where the former is based on a territorial approach and can be applied to the development of rural areas, while the latter focuses on novelties within a single nation, which is not used as it did not fit the objective of this study. Additionally, the SIS and TIS frameworks were introduced, which are more dynamic and consider the role of actors and networks and the importance of institutions. The RIS, TIS, and SIS frameworks have different views on system boundaries, depending on the sector and objective. RIS only exists on a regional level, while the TIS and SIS frameworks can exist on a national, regional, or global level. Besides these system boundaries, understanding the different diffusion hierarchies is crucial for spreading knowledge. Depending on the framework, diffusion and dissemination may be used, and both can have varying levels of control.

Also, the study highlighted the importance of path development, extension, diversification, emergence, and plasticity in regional industrial path development. Understanding the past and current state of industries in a region is crucial when planning for future development. Additionally, path development can be split into two different regions, the peripheral and metropolitan regions, whereby the peripheral regions are considered in this research, which includes the use of path extension and emergence to describe path development.

Furthermore, this study has explored the connections between path extension, path plasticity, path emergence, and the diffusion of innovation. Through this exploration, it has been established that path extension is critical for creating radical innovation in existing industries. The role of innovators and early adopters in introducing and confirming new technologies has also been highlighted. Additionally, it has been established that path emergence can only occur after path extension and the diffusion of knowledge facilitates the transition between the two. This framework provides insights into the path development of novelties in different industries, including the maritime industry. By understanding these connections, policymakers and industry players can develop effective strategies for driving innovation and creating competitive advantages in their respective fields.

Finally, a gap in the literature has been defined and the writer of this research has suggested a connection between different factors. A summary of all theories has been given in table 2.2:

	Regional innovation system		Sectoral innovation system	Technological innovation system		
	RIS	ORIS		Context	Focal	Cross
Building blocks	Knowledge application and exploitation		Knowledge and technologies	Structure		
	Knowledge generation and diffusion		Actors and networks	Function		
	Regional policy		Institutions	Motor		
	Technology, finance, culture and networks					
System boundaries	Regional bounded	Outside region boundary	Spatial bounded	Outside of focal TIS	Spatial bounded	Include sectors outside of focal TIS
	Firm bounded	Outside firm boundary			Analytical bounded	
					Firm bounded	
Diffusion hierachy	Bottom up		Mixed	Mixed		
Path development	Path extension		Path emergence	Path emergence	Path extension	Path emergence
	Path emergence					
Diffusion groups	Innovators		Majority	Majority	Innovators	Majority
	Majority					

Table 2.2: Overview of theories

To answer the first subquestion: Which transition frameworks are most suitable for describing the adoption process of radical innovations?

Different transition frameworks combined with path development and Rogers' DOI groups are defined. It is possible to combine innovators with TIS and (O)RIS along with path extension. Alternatively, a combination of SIS, TIS, (O)RIS, and path emergence can also prove to be effective. All combinations are suitable for describing radical innovations. Utilizing these frameworks supports the objective and describes the influence that developers have on innovators.

Chapter 3

Shipping industry

This chapter will discuss the different frameworks found in the last chapter for the shipping industry. First, a transition framework will be suggested and secondly, this will be discussed for the shipping sector.

3.1 Transition framework

The scope and objective of this research have been discussed. The area considered will be the Baltic area, and the main focus group is the innovator group of Roger's diffusion of innovation framework. This means that two options remain: focal TIS and (O)RIS. The SIS framework can be used for the Majority group, which is outside the scope of this research.

The RIS framework is a static framework, while TIS is a dynamic framework, as discussed in the literature study. Because TIS is a dynamic framework, it is preferred over RIS. As a dynamic framework is more realistic, in practice, a lot of things happen similarly. Also, TIS has a function describing the influence of search, which can define part of the answer to the main question of this research. At last, a Scopus search has been done using the following keywords: Maritime OR Shipping AND Innovation AND TIS OR RIS. The results are summarized in table 3.1.

Framework	Number of papers	Number of citations
TIS	7	173
RIS	4	9

Table 3.1: Result Scopus search

TIS papers are highly cited for the maritime industry, while RIS papers are not. Because TIS is dynamic, describes influence and is more used in the maritime industry. The transition framework will use focal TIS with a path extension route. If needed, external effects can be discussed within context TIS. As cross-sectoral has a path emergence route, this effect will also be outside of the scope, as the innovator group first needs to introduce the innovation in any sector before path emergence can occur.

3.2 TIS framework

The TIS framework has three steps; the first step is the structure of TIS. The structure of TIS consists of three things: actors, networks and institutions. The actors within the framework are mapped, and the networks between those actors are determined. Relevant institutions are identified, like governments, NGOs and universities. The second step is to define all seven TIS functions. This chapter will explain the functions in more detail, and the case study will apply the functions. The last step within TIS is defining the motor of innovation; this is the conclusion of the framework and combines the different functions with the actors, networks and institutions to give a complete overview of the innovation system.

3.2.1 Structure of TIS

The shipping sector has lots of actors. Figure 3.1 gives an overview of actors and networks. Two groups are within the actors and networks: ship-building and institutions. Other groups like transport and customers are outside the scope of this research.

Shipbuilding involves five key players: the shipowner, the shipyard, the ship designer, the manufacturer, and the fuel supplier. The fuel supplier typically doesn't participate in the shipbuilding process since engine manufacturers already have enough data on fuel oil to support ship design and construction. However, if new fuels are introduced, the supplier plays a significant role in ensuring that the ship design suits the new fuel type. The new fuel supplier must have a strong network with the other players since knowledge diffusion is essential to keep everyone updated with the new technology. The shipyards, ship designers and manufacturers need the knowledge to convince the shipowner of the new solution and prove its technological viability. Finally, the fuel supplier must notify ports in advance about the new technology to allow implementation in the harbour infrastructure if a certain consumption threshold is reached.

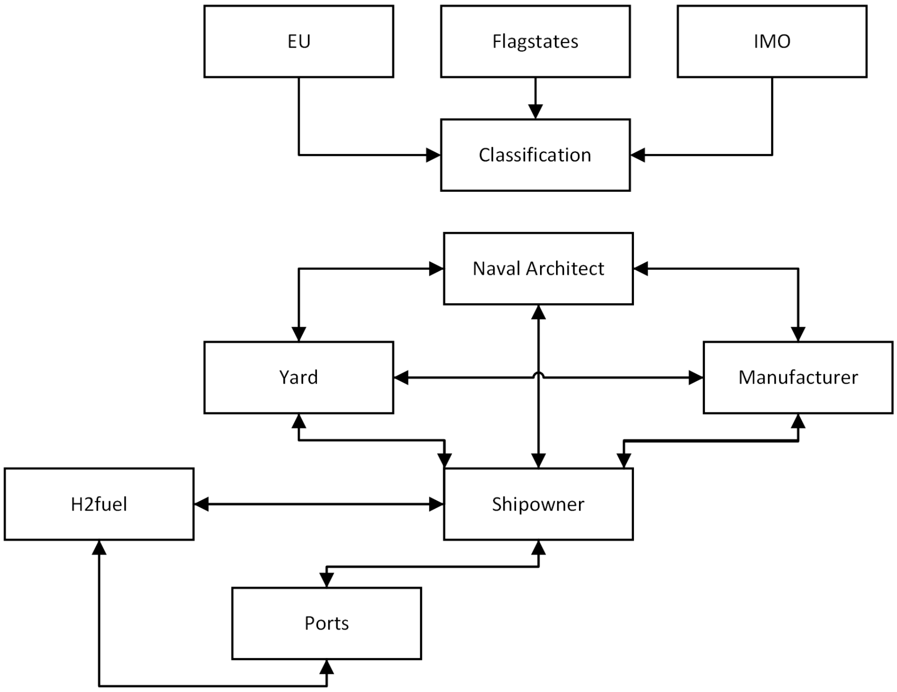


Figure 3.1: Overview of actor and networks

Institutions can exert pressure on multiple levels; this research includes pressure from the IMO and EU and excludes pressure from flagstates (governments) as this is a study in itself due to all the different local rules one ship can encounter on route. For example, EU Maritime regulations discussed in the introduction can put pressure on shipowners and shippers. Within the shipping sector, most of these regulations are checked by classification bureaus, which communicate with yards, naval architects, manufacturers and shipowners and give a certificate for the vessel. This can be used to enter ports, get insurance and prove the vessel is within the rules.

In conclusion, the shipping sector involves various actors and networks, including shipbuilding and institutions. The shipbuilding process involves five key players, and the fuel supplier plays a significant role in ensuring that the ship design suits the new fuel type. Institutions can pressure the system on multiple levels.

3.2.2 Functions

Knowledge development

The development of knowledge can be defined as a function of path extension, as discussed in Section 2.3.2. According to this concept, intensive knowledge development is necessary to gain customers. However, in the maritime industry, this phase is only effective after the product design is completed. Therefore, the diffusion or dissemination of knowledge should start only after the product design is completed. This will initiate the adoption process, and the innovators will decide whether the product is accepted or rejected. This makes radical product development a high risk in the maritime sector, as there is only interest after the complete design.

Market formation

The introduction of new fuels into the market can be a challenging process. One of the main obstacles is the delay in adoption by shipowners, who may be waiting for adequate infrastructure to be put in place. On the other hand, infrastructure builders may wait for vessels that can use the new fuel before investing in infrastructure. This creates a lock-in situation where each party waits for the other to act first, resulting in a delay in the adoption of the new fuel. To overcome this lock-in mechanism, a case study must explore strategies that can encourage both parties to act in a coordinated manner. By doing so, market formation can be accelerated, and new fuels can be introduced into the market more efficiently.

Legitimation
The legitimation process is important for implementing new fuels in the shipping industry. Most of the legitimation process will be rule-based, created by the IMO. Without rules, an expensive and complicated risk-based design process with a classification bureau should be done to prove the vessel's safety. If the vessels do not comply with the standards, the vessel cannot be insured. Also, if there are no standards, it can become difficult to fuel the vessel at different places as there are no standardisation rules for this part. This makes the role of the innovators important, as they decide which standards are in place.

Resource mobilization
Resource mobilization is important; it funds research, R&D, test cases, adoption phase, etc. Different things can cause resource mobilization in innovation. The resource mobilization for methanol in the shipping industry rose when Maersk announced the building of 20 methanol-powered vessels [21]. Meaning that a large company can influence the direction of resource mobilization. Besides large companies, strong local clusters can get momentum and raise more money for the research and adoption of their innovation.

Influence on the direction of search
Influence on the direction of search can be caused by any TIS function. A strong legitimation process can influence firms to start experimentation, mobilise their resources and change their direction of innovation. Also, creating new markets can cause a change in direction, and knowledge development can cause entrepreneurs to change their direction. To conclude, every TIS function has the ability to change the influence of search for a sector.

Entrepreneurial experimentation
Entrepreneurial experimentation is one of the most important factors for implementing innovation. Experiments can lower the risk, as it is often small-scale and gives the entrepreneur a learning curve and, therefore, knowledge development. This will make the implementation process easier and less risky as the entrepreneur already has experience.

Development of external economies
The development of external economies uses a path emergence, discussing the emergence of different economies [50]. This is outside the scope of this research.

3.2.3 Motor

The motor of innovation is a combination of structures of TIS and functions of TIS and will describe the path extension. Motors of innovation also describe the dynamic behaviour of the innovation within TIS. The motor of innovation can be identified if the structure and function are clearly defined for the researched innovation. The motor of innovation will discuss the influence on the direction of search, as all functions can influence someone's interest in a topic.

3.3 Case study plan

The different functions of TIS will be tested in a case study. The goal of the case study is to identify if shipowners can be influenced to convert the power train of their vessels to sodium-borohydride. The case study will have an analytical approach supported by three interviews. The case study will be split into three parts. First, the structure of TIS is discussed, followed by the functions, and lastly, the motor of innovation is defined.

The interviews will be conducted with the technology developer, the graduation company of the researcher of this research and a shipowner. The shipowner will be selected based on the following criteria:

- Active sailing route in the Baltic area
- Vessel size $\geq$ 5000 GT
- Innovative history

The vessel sizes of the shipowner should be large enough, so the owner has to comply with the new rules. Also they should have an innovative history, so the company is more likely to adopt other radical innovations in an early stage.

After a shipowner has been selected the interviews will be conducted, including a financial comparison between current fuels and the alternative proposed in this case study.

All these interviews should focus on the different TIS functions and identify which functions are the main drivers of the innovation. Finally, the case study result can be used to answer the main question of this research.

3.4 Conclusion and Discussion

This chapter focuses on the Baltic area and the innovator group of Roger's diffusion of innovation framework. As the TIS framework has a dynamic approach and a function to describe influence, it is preferred over the RIS framework, which has a static approach. The TIS framework's functions describe the influence on the system, especially the direction of search. The shipping sector involves various actors, networks and institutions. The TIS framework, with its structure and functions, can describe the dynamics within these actors and networks. Therefore, it provides a suitable theoretical framework for this research.

The TIS framework highlights that the maritime industry faces significant challenges in adopting new fuels due to the lock-in mechanism and regulatory constraints. However, exploring strategies that encourage coordinated action can accelerate market formation and meet emissions targets.

In addition, the legitimation process plays a crucial role in implementing new fuels in the shipping industry. Without rules, an expensive and complicated risk-based design process is required to prove the vessel's safety. Therefore, the role of innovators is critical in deciding which standards are in place.

Also, resource mobilization is important in innovation, as it funds research, development, test cases, and the adoption phase. Large companies and strong local clusters can influence the direction of resource mobilization, and entrepreneurial experimentation is essential for implementing innovation. Experiments can lower the risk as they are often small-scale and give entrepreneurs a learning curve and, therefore, knowledge development.

To conclude, maritime industry developers must diffuse knowledge to gain customers. The diffusion or dissemination of knowledge should start only after the product design is completed to initiate the adoption process. By exploring strategies that encourage coordinated action, considering different fuel options, and considering the roles of innovators, resource mobilization, and entrepreneurial experimentation, the maritime industry can successfully transition to a new fuel mix in a sustainable and efficient manner.

At last, the second subquestion of this research can be answered:
Which transition framework can be used to describe the adoption process of radical innovations in the shipping industry for the innovators?

The combination of the focal TIS framework and path extensions is a suitable approach for describing radical innovation within the shipping industry. The path extensions focus specifically on the innovator group. In case external effects occur that are important for the case study, context TIS can be used to map these effects. In a case study about sodium-borohydride, this framework will be applied to identify which TIS functions can influence the shipowners' decision.

Chapter 4

Case study

A case study will be conducted to test the Technological Innovation System framework from the literature review. The case study will examine the structure, functions, and motor of innovation, all three combined is the TIS framework. The technology used in the study will be a solid hydrogen carrier. Three semi-structured interviews will be conducted to gather data on the actors involved, and this will be combined with data analyses of public sources and articles. The aim of this study is to determine which TIS functions are the main drivers of innovation and support the main research question, which is whether actors can be influenced to adopt or reject a given innovation.

4.1 Structure

The actors, networks and institutions for the case study will be discussed in this section. The interviews conducted with different actors are in appendix 6; the transcripts of the interview are a confidential appendix.

4.1.1 Actors

In this section, the different actors within the case study will be introduced.

H2-fuel

H2-fuel is the patent owner of the technology. The company has a relationship with the technology developer. H2-fuel, as a company, is working on promoting the technology. Finding partners for the scale-up of the technology. The main focus is to start the production of sodium borohydride. The company is not a part of this research; it plays an important role and, therefore, is introduced as an actor.

Technology developer

The technology developer creates the application for the extraction of hydrogen from sodium borohydride. The technology developer has a licence deal with H2-fuel. The developer will only focus on technology development while outsourcing sales and production.

Hydroflexx

Hydroflexx is the graduation company of the researcher of this research. Their goal of this research is to determine if a solid hydrogen carrier is suitable for shipowners. In a previous innovation project, named Sodaflexx the company sold a new way to clean engine exhaust gasses. Unfortunately, although the novelty is an improvement compared to other scrubber systems, selling the new technology to shipowners is difficult. Within this case study, the company wants to learn how companies get knowledgeable and which parameters are of influence on their decisions. Besides this, the company also wants to determine the viability of the hydrogen carrier in this case study.

Shipowner

The shipowner is a client of Sodaflexx, an entity of Hydroflexx. The shipowner is active within the bulker market and has routes between Spain, Scotland and Norway. The shipowner was the first to implement the Sodaflexx system and, therefore, can be considered to be an innovator. The shipowner has a sailing area in the Baltic Sea. As the shipowner is an innovator and sails in the Baltic, the shipowner fits the research profile.

Scientists

Scientists from various universities conduct research on theories related to different technologies. As most of the research work is funded by governments or the EU, scientists can easily share data with each other, which helps prevent duplication of efforts and leads to a more efficient research process.

Yards and Naval architects

To ensure that shipowners are properly supported, it is essential that both yards and naval architects are well-informed about new technology. This will enable them to perform their respective roles effectively. By involving these actors, the shipowner can benefit from their expertise and ensure that the project is completed to the highest standards. Therefore, it is crucial to recognize the importance of their involvement in the process.

Ports

Ports should invest in building fueling infrastructure to meet the growing demand for fuel in the industry. This can help them keep up with the changing needs of their customers and create a sustainable future for the shipping industry. By investing in this development, ports can also support their own growth and ensure that they remain competitive in the market.

4.1.2 Networks

This section gives an overview of the network relations between the parties included in the case study.

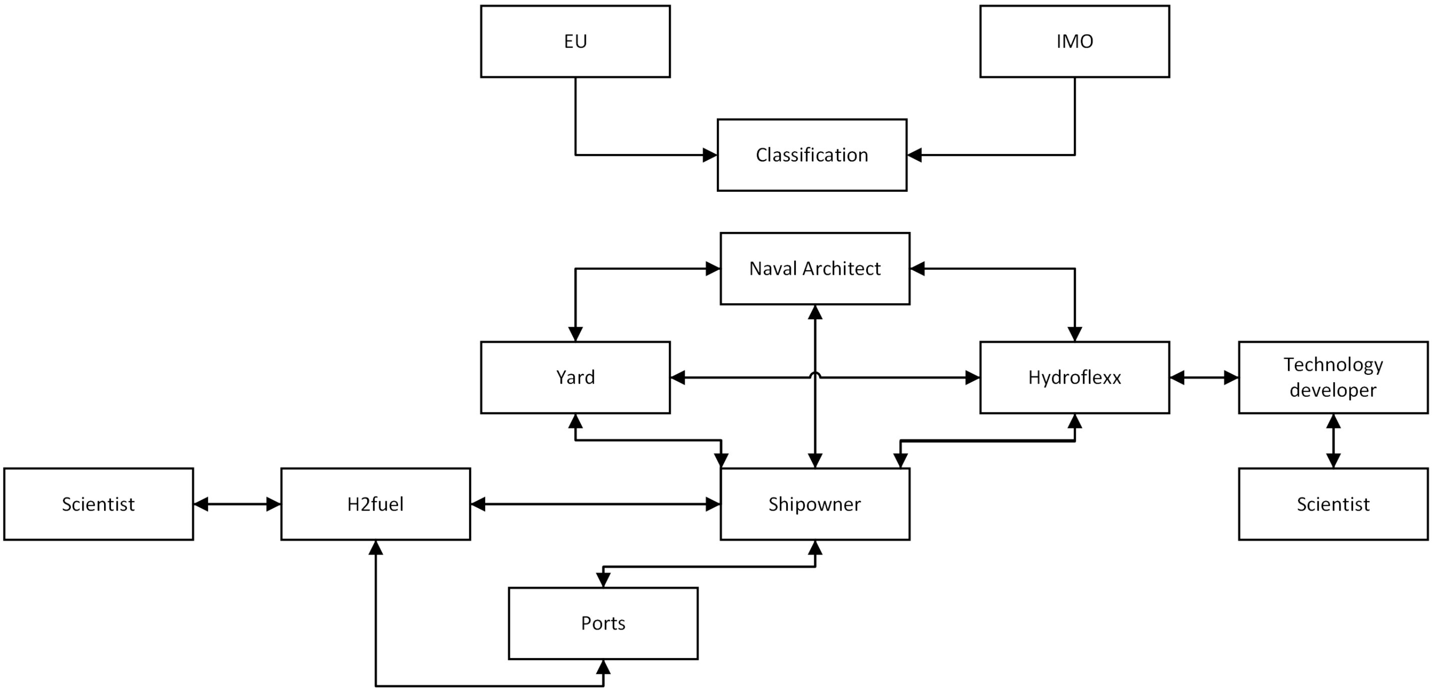


Figure 4.1: Network overview case study

4.1.3 Institutions

For the case study, the Fuel EU maritime rules and ETS rules will be described in more detail. Whereby a focus will be on the cost of the rules. Within these rules, there are costs for EUA contracts, compliance balance and energy taxation directives. Besides these new rules, regulations and protocols of the IMO and Classification for the use of hydrogen will be discussed. All regulations are discussed in the legitimation function.

4.2 Technology

Sodium Borohydride, referred to as H2-fuel, has been introduced in the introduction of this research. In this section, a more extensive explanation will be given.

Sodium Borohydride ($NaBH_4$) is used as an example fuel for the case study. Figure 4.2 gives a more detailed overview of the product using a continuous system. The $NaBH_4$ is mixed with ultra-pure water (UPW) and pumped into the reaction chamber. In the reaction chamber, a metal catalyst is used to speed up the reaction. In the first 30 minutes, 80 % of the hydrogen is released; as the system is continuous, the rest of the hydrogen will be released over time, and continuous extra fuel is added to the reactor creating a stable hydrogen flow. Half of the hydrogen flow will come from the $NaBH_4$ and the other half from the water according to the following reaction:

$$NaBH_4 + (6 + x)H_2O > NaBO_2 \cdot 4H_2O + 4H_2 + xH_2O \tag{4.1}$$

The hydrogen will be compressed, either with a compressor or by the speed of the hydrogen molecule and stored in a buffer tank. The hydrogen can be used in an ICE or FC, which creates energy output. Besides this part of the process, the reaction chamber also has a fixed amount of water, noted as x in the equation, and a residual product. The residual product, sodium metaborate tetrahydrate ($NaBO_2 \cdot 4H_2O$), will crystallize in the reaction chamber and be collected to be stored in the bunker. Depending on the recycling process of the fuel, the fuel should be dried to reduce the water molecules or stay as is.

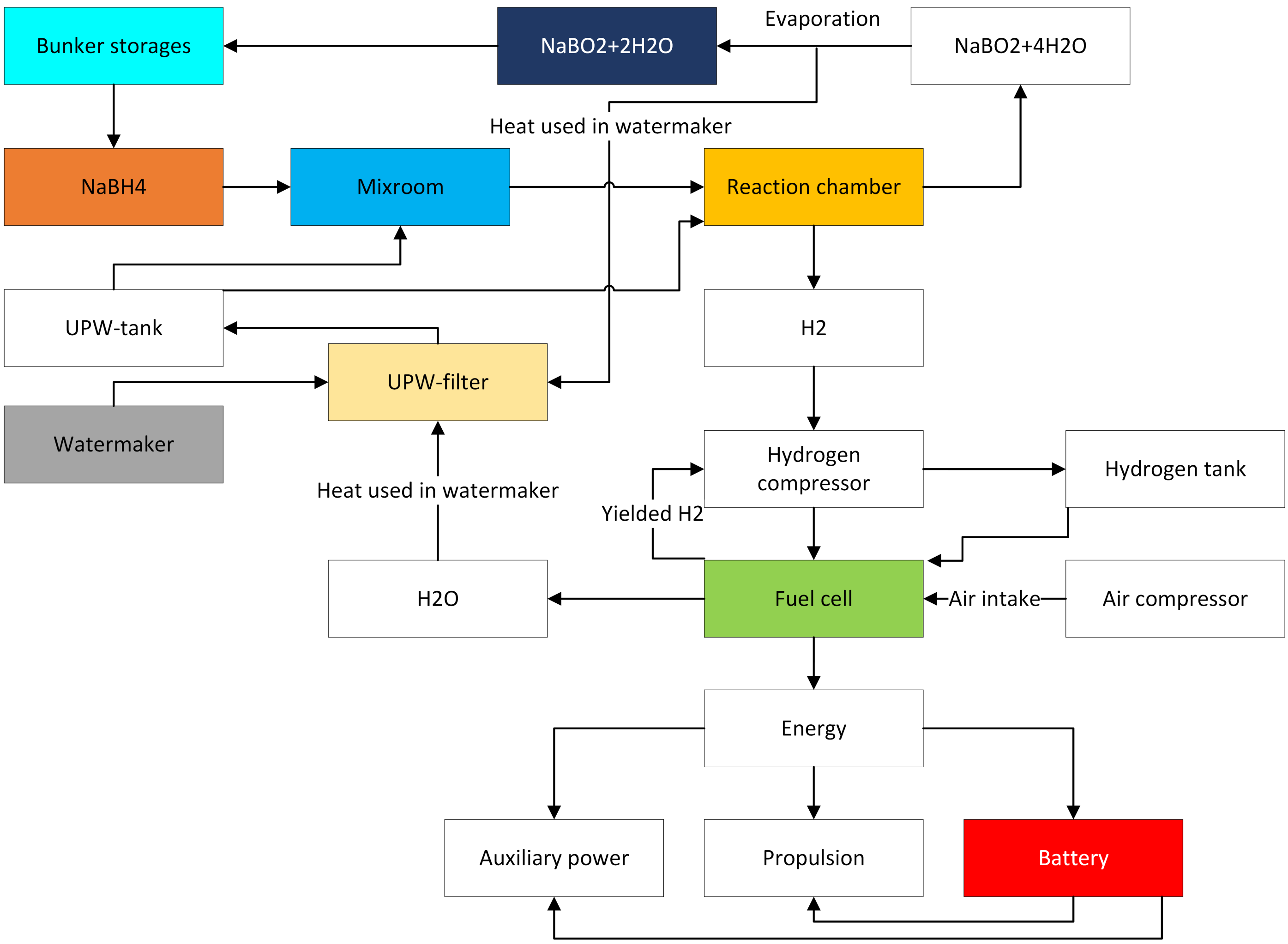


Figure 4.2: Detailed overview H2-fuel

4.3 Functions

The different functions of TIS will be discussed in this section. First, knowledge development will be discussed, followed by resource mobilization, legitimation and, at last, market formation. The TIS function Influence on the direction of search and Entrepreneurial experimentation will be taken into account in the last section 4.4 Motor of innovation.

4.3.1 Knowledge development

The interview with the shipowner gave insight into knowledge development from their side. The shipowner stated that most of his new knowledge is from general media. Interesting articles are spread between a select group of the company. This group works on alternative solutions to improve their fleet and make them future-proof. Besides this small group, knowledge diffusion is not performed on a large scale.

To compare knowledge development and diffusion of different alternative fuels in general media. A Nexis search has been done. Nexis is an article database software which uses a keyword search to find articles all over the world. The search has been done using the following keyword input: "Fuel" AND "Vessel" OR "Ship", extra filters were added: Maritime AND transport. The results are in figure 4.3.

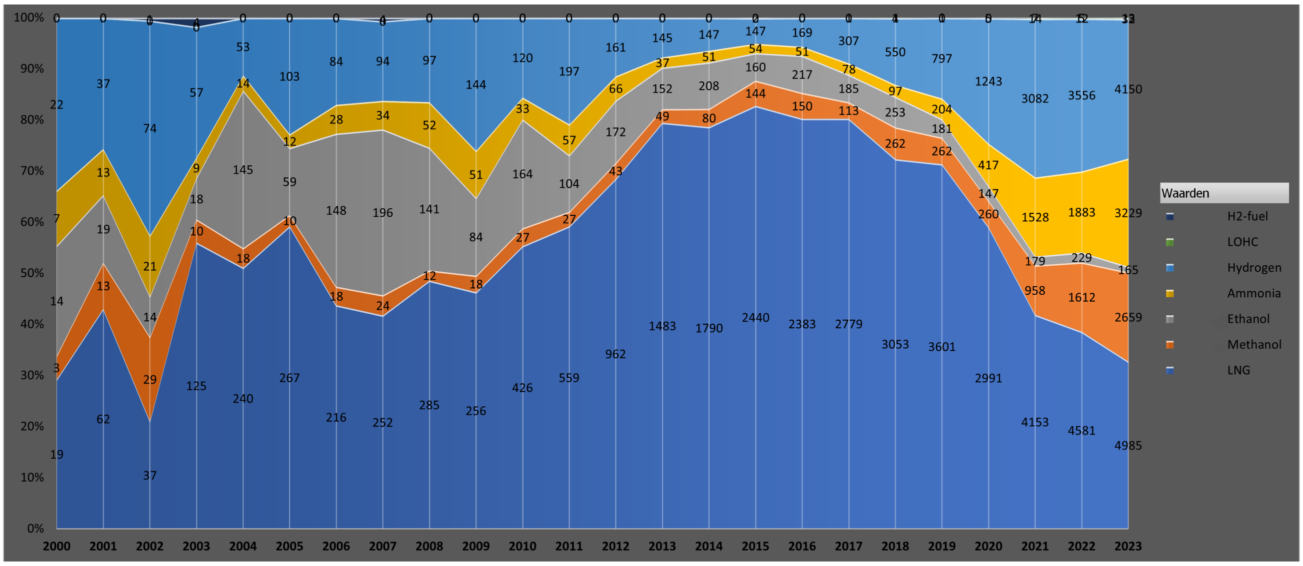


Figure 4.3: Nexis search results

The graph shows the different attention between fuels and the number of publications per year. For a long time ethanol and LNG had the largest part of publications. Most articles published on ethanol were due to a large accident in 2004 [62]. LNG was more popular due to LNG carriers and when the first vessels used LNG as a fuel for shipping in 2012 the attention of LNG rose to a high [63], [64]. More than 70 per cent of all articles published were about LNG. In 2021 Maersk announced the build of methanol-powered vessels [65]. The share and number of articles increased fast. In 2019, ammonia research published positive results [66] also increasing attention to this fuel and in 2021 the first pilot projects were announced [67]. Besides these fuels, hydrogen is gaining popularity as well, whereby the launch of the Energy Observer in 2017 [68] started the increase in articles. Powdered hydrogen, referred to as H2-fuel and liquid organic hydrogen carriers (LOHC) are relatively new fuels and need a breakthrough in the number of articles to raise awareness about these options.

The technology developer stated in his interview that the diffusion of knowledge was limited until the previous climate top in Dubai [69]. The top was in 2023 and the owners of H2-fuel have spoken to lots of people. At the end of the top, a group of political people know about solid hydrogen carriers. Secondly, he stated that a lot of noise is needed to spread the knowledge. He gave the example of the Neo Orbis [70], which is a pilot project using the solid hydrogen carrier.

Hydroflexx stated in the interview that shipowners do not want to learn new technologies. Although they need alternative fuels to comply with the regulations. Shipowners are still in denial. This matches the behaviour of the shipowner described in the literature study. According to Hydroflexx, shipowners first need to be convinced of using alternative fuels before being introduced to the product.

Based on the literature study, it was found that shipowners are not easy to persuade. However, spreading knowledge through word of mouth could be an effective way to convince people about the new technology. Combining this with publishing articles in the general media can inform all shipowners about this innovation. However, from the technology developer interview, it also became clear that the main focus is to gain interest on a political level. Also, Hydroflexx stated that shipowners do not want to learn new technologies. Meaning there is a gap between the three actors on how to diffuse knowledge between each other. Communicating this way might lead to miscommunication among actors, slowing down or even preventing innovation.

4.3.2 Resource mobilization

Resource mobilization is split into three categories: grants, company capital and private investments. The first two will be discussed in this case study; private investments are outside the scope.

Grants

Different grants have been identified with the sustainable maritime shipping support options tool of the Dutch government [71]:

- Fuel EU maritime
  The revenue from Fuel EU maritime will be used for the energy transition in the shipping industry. As the regulation is new and not active at this point, it is currently unclear how to access grants from this regulation. Therefore, the grants for fuel EU maritime are outside the scope.

- Transition loans
  Transition loans are special loans for the energy transition, companies can loan money from banks who get grants on the interest rate [72]. The grant can be used to lower the interest rate making the transition more affordable. This type of loan is available for the shipowner.

- LIFE
  LIFE [73], the EU's funding instrument for environment and climate action, has allocated 1 billion euros to support SMEs in the energy transition. The project aims to develop a policy framework at national, regional and local levels for clean energy, accelerate the deployment of new technologies, and attract private finance.

- CEF
  The Connecting Europe Facility (CEF) [74] is a funding program that supports infrastructure projects such as rail, inland waterways, and maritime. It has a budget of 25 billion euros, out of which 14 billion euros are reserved for EU companies. CEF grants can cover between 30% to 50% of the project costs. Within CEF, there is the Alternative Fuels Infrastructure Facility (AFIF). AFIF is a call for proposals that aim to decarbonize transport along the network by supporting the deployment of alternative fuel supply infrastructure. The AFIF has a total budget of 1.5 billion euros and provides financial support through a combination of CEF grants and financial institutions. This grant can be used for building a recycling facility.

- Horizon Europe
  Horizon Europe [75] is the primary funding program for research and innovation in the European Union. It has a budget of €95.5 billion and aims to tackle climate change, achieve the Sustainable Development Goals set by the United Nations, and enhance the EU's competitiveness and growth. The program encourages collaboration, strengthens the impact of research and innovation, and supports EU policies while addressing global challenges. It also generates employment opportunities, engages the EU's talent pool, promotes economic growth and industrial competitiveness, and optimizes investment impact within a strengthened European Research Area. Legal entities from the EU and associated countries are eligible to participate. Within the framework of Horizon Europe, €15 billion is reserved for the energy transition,

and grants ranging from €4 to €15 million can be awarded. These grants can be utilized for the design of, for instance, recycling facilities.

- The European Hydrogen Bank
  The European Hydrogen Bank [76] is an initiative for subsidizing fuels. The bank offers grants of up to 5 euros per kilogram of hydrogen, but the grants will be awarded through an auction system. The more hydrogen a company can produce with fewer subsidies, the more grant money it will receive. For example, if one company can produce 8 billion kilograms of hydrogen with a subsidy of 10 cents and another company can produce 800 million kilograms of hydrogen with a subsidy of 1 euro per kilogram, the full grant will go to the first company.

There are various subsidies available for different aspects of innovation and different actors. During an interview, Hydroflexx was asked about the use of subsidies and they stated that it is challenging for small companies to access these large subsidies. In addition to the expenses required to obtain them, these grants are often awarded to consortia consisting of various companies in different countries. This makes it difficult for startups to acquire these grants, and often, during the process, Hydroflexx stated that they abandoned the procedure due to its complexity and cost.

Company investments

The interview with the shipowner and Hydroflexx gave insight into company investments. The shipowner stated the willingness to invest in a new system, if the system has a return on investment. Meaning that the shipowner will only invest in a carbon saving technology if this results in more profit. The writer of this research suggests that this could mean that the rules are not an incentive for the shipowner to innovate the fleet if this would increase costs. Tax regulations to give the shipowner more incentive are discussed in the next TIS function, legitimation.

Hydroflexx stated in the interview that the cost for the first new system could be split or completely covered by them. This would solve the return on investment of the shipowner. However, Hydroflexx also stated not to cover the operating expenses of the system. The question remains if the shipowner will use the system if this results in an increase in operating costs.

In conclusion, there are various subsidies available to facilitate the transition to a new fuel. Shipowners can benefit from transition loans that offer reduced interest rates. Additionally, there are several subsidies available for technology and infrastructure. However, as mentioned by Hydroflexx in an interview, these subsidies may not be easily accessible for small companies. It can be an expensive and challenging process to secure these grants, often requiring collaboration with an international consortium. This can be a difficult task for small companies, as it requires a significant amount of time from employees, which may be limited.

4.3.3 Legitimation

Legitimation will consist of two parts; the first part is the discussion about the development of new rules for ships. Focuses on design and protocol development. The second part will discuss the EU rules.

Guidelines, handbooks and protocol development

Alternative fuel regulations are presently being developed for vessel design. The International Maritime Organization (IMO) will release the next set of guidelines in December 2024 called MSC 109 [77]. This will mark the beginning of regulatory formation by the IMO, as the guidelines will serve as the foundation for future regulations.

As IMO regulations are taking longer than shipowners are willing to wait, class societies are also developing guidelines. Det Norske Veritas (DNV) has created the hydrogen handbook [2]. Along with a risk-based design (RBD) approach, the class society will provide approval for the vessel to be constructed and active.

The interview discussed the role of the shipowner within these rules. The shipowner was not familiar with a RBD approach. However, he was open to any regulatory approach for the design phase of the vessel. The shipowner was also asked questions about protocol development for new systems on the vessel. As the crew needs training and guidelines for sailing need developing as well. The shipowner said that crew training and raising are necessary. As long as there is an ROI, the shipowner is willing to support developing protocols and training. During the interview with Hydroflexx, they also stated that the development of protocols, guidelines, and training is necessary since the system is new. Their response is similar to the shipowner's response, indicating that they could work together to resolve this issue.

Taxes

The rules define three different taxes. The EU Allowances, the Fuel EU Maritime compliance balance and the energy taxation directive. All three rules will be discussed and the costs for different fuels or general fleet impact are summarized in tables.

1. EUA contracts

The first rules are European Union Emission Trading Allowances (EUA); for every ton of carbon dioxide equivalent emission, a single EUA needs to be acquired. An EUA can be bought at an auction, from a verification company or traded on the secondary market. The price of a single EUA will be 90 Euro, and for every EUA short, a fine of 100 Euro applies. The fine will increase if a pool does not comply for two or more years and the vessel(s) within the pool could be banned from the European Economic Area (EEA).

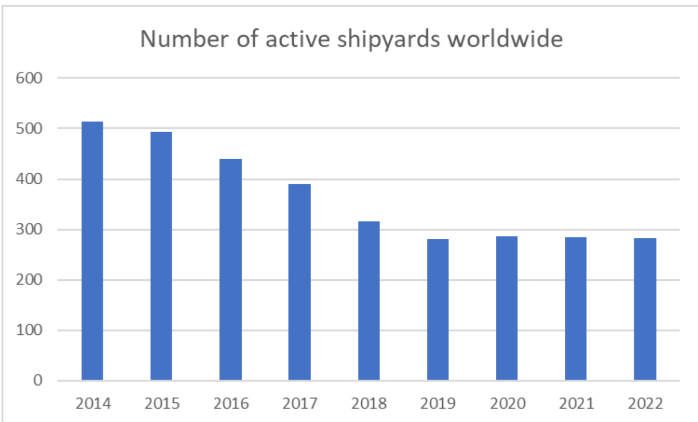


Figure 4.4: Number of shipyards worldwide [78]

Focal TIS is not suitable to describe the effects that occur on the EUA's price; therefore, context TIS is used to describe factors that can influence the price of the EUA's. The price of the EUA is expected to rise in the upcoming decades, which will make carbon-rich fuels economically unfeasible. Also, if there is a shortage on the market the prices at auctions and on the secondary market will rise as well. This can happen in the first year, if there is a lack of options to lower the carbon emissions in the maritime sector. Even if the sector wants to change, there will be a shortage of yard capacity and knowledge to install solutions. Figure 4.4 shows that the number of yards worldwide has decreased for years and stabilized in the last couple of years. This is also indicated in the Engine Retrofit Report by Lloyd's register [79]. A number of articles refer to this report [80]–[83], and all state that there is a lack of knowledge and capacity to retrofit a part of the worldwide fleet. Besides this, new builds are, for example, methanol-ready. However, this often still means that a conversion is necessary and it is currently unclear how ready these new builds are. It is unclear how much yard time is needed for these vessels and what knowledge should be taught to the workers at the yard to enable them to perform these conversions. Besides this alternative fuels are currently low in production and lack infrastructure. Even if owners are ready to convert their vessels to sailing on alternative fuels, the lack of infrastructure will delay this process. Prices of the EUA can rise in the upcoming years as the number of allowances in the pool will be reduced. Also, as the allowances are sold on auction, the spot market price in the secondary market will be an important indicator for auction prices.

Table 4.1 gives an overview of the cost for different fuels per ton of fuel. This shows that without taking any efficiencies and energies into account, HFO is the most expensive fuel. Sodium borohydride has zero tanks to wake, as the fuel does not have any carbon, and therefore, no EUAs are needed for this fuel.

Fuel	TTW CO2e	Costs EUA	
HFO	3.1	279	€/ton
LNG	2.8	252	€/ton
Methanol	1.38	124	€/ton
NaBH4	0	0	€/ton

Table 4.1: Overview cost EUA's per ton of fuel

2. Compliance balance

Besides having enough EUAs, the carbon intensity has to be within the limits. To check if all vessels within the pool together comply with the rules. The compliance balance has to be calculated, if the balance is positive the pool is within the rules. If the balance is negative, a fine has to be paid. The fine will equal 16.8% of the EUA's cost if the vessel uses heavy fuel oil and the price of one EUA equals 90 Euro. To prevent paying the fine, vessels can pool together. Either from a single shipowner or with multiple shipowners. The fine will increase if a pool does not comply for two or more years and the vessel(s) within the pool could be banned from the European Economic Area (EEA). This gives a "Green" shipowner the opportunity to sell the room on the compliance balance. According to the shipowner from the interview, the amount he is willing to pay depends on the consequences and the amount of man-hours needed to enter another pool.

Year	Fine
2025	€ 1,000,000
2026	€ 1,100,000
2027	€ 1,210,000
2028	€ 1,331,000
2029	€ 1,464,100
2030	€ 4,831,530

Table 4.2: Example of fines compliance balance, for not meeting the regulations for multiple years

The fine will increase with 10% annually, table 4.2 gives an example of the increase of the fine. As in 2030 the rules become thither, a reduction of 6% in total is needed to prevent the fine in that year, the fine will increase fast if the shipowner did not take action to prevent this in the last five years. The extra fine in 2030 is more than 1.8 million euros.

3. Energy taxation directive

The last tax is the energy taxation directive (ETD) [84], this tax is charged on fuels bought in EU ports. The tax depends on the fuel type [85]. An overview of the taxes per ton of fuel is given in table 4.3. Two different rates are in the table; depending on the source, the tax on HFO, for instance, is 0.90 €/GJ [3] or 10.75 €/GJ [85]. As the ETD for shipping is currently in the voting stage at the EU parliament, the rest of the report will use the higher tax rates.

Taxes HFO	36-434	€/ton
Taxes LNG	50-369	€/ton
Taxes Methanol	21-124	€/ton
Taxes NaBH4	5-27	€/ton

Table 4.3: Energy taxation directive costs

Total potential increase of cost

An overview of the total potential tax cost is given in table 4.4. Especially carbon-rich fuels, like HFO and LNG, can become financially unattractive due to the increase in cost. These tax costs are further taken into account in the TIS function market formation.

Fuel	Total	
HFO	760	€/ton
LNG	621	€/ton
Methanol	248	€/ton
NaBH4	5	€/ton

Table 4.4: Total taxes cost per ton of fuel

4.3.4 Market formation

The market formation will be split into different subjects. First, the current size and prices of the market will be given. A comparison between different fuels will be made, followed by an analysis of the shipowner of an H2fuel support system. At last, the current state of recycling will be discussed.

Market size and prices

The market size of the sodium borohydride market has been researched. Unfortunately, no public sources were available and reports about the market size were expensive. Two vague sources have been found and used, in combination with the prices given by different producers a rough estimate of the market size in MTa (Mega tons per annual) has been made. The residual product also has a market size, however no data at all has been found about this. Prices have also been given by different producers and are referred to as personal communication. An overview of all data is in table 4.5.

	2022	2023
Sodium Borohydride		
Value (Million €)	664-1230	900-2090
Price (€/kg)	15-50	15-50
Size (Mta)	13-82	18-140
Sodium metaborate tetrahydrate		
Value (Million €)	Unknown	
Price (€/kg)	20-65	Unknown
Size (Mta)	Unknown	

Table 4.5: Market size source:[86], [87] , Price sources: Personal communication

Prices for the powder vary depending on the continent of origin. China offers lower prices, while Europe and America have higher prices. The production process also differs, with China using coal and America using gas. The residual product is produced in all three continents and used in various markets, including pulp and paper. There is a quality difference within chemicals, with a significant difference between 98% and 99% purity. This difference affects not only the price but also the value and usage of the product, whereby China has the lower quality powder.

To see the price differences between sodium borohydride and current and alternative fuels, the fuel prices are normalized with the low caloric value. Different system efficiencies are not taken into account in the table. All fuels have different carbon taxes, which are included. For IFO380 and VLSFO, the fine for having a carbon intensity that is too high is included. For all fuels, the carbon allowances and energy tax are included. The carbon allowances are assumed to cost 90 euros per ton of carbon equivalent emission. The energy tax depends on the fuel type. This is discussed in TIS function legitimation. The highest possible tax rate is used in this overview. Table 4.6 gives an overview of normalised prices.

Fuel	Price Euro/ton		Normalized prices Including carbon taxes		Unit
IFO380	500		26.000		€/MJ
VLSFO	600		28.000		€/MJ
LNG	400	4000	16.000	89.000	€/MJ
Methanol	500		33.000		€/MJ
$NaBH_4$	15.000	50.000	590.000	2.000.000	€/MJ

Table 4.6: Bunker prices IFO380, VLSFO, LNG from [88], Methanol prices from [89], NaBH4 prices from personal communication

As the effects on prices are outside the scope of focal TIS, context TIS will be used to discuss alternative fuels that are currently being used. LNG and methanol are acceptable within EU regulations until 2040 [90]. LNG is currently an upcoming fuel, and it is expected that in 2030, 25 per cent of the vessels will have the option to sail on LNG [91]. Locking in fossil fuels for another decade postpones the problem [92]. LNG is used as a transition fuel, not only in the shipping market but also for nations' energy consumption [93]. In combination with production countries, LNG prices are volatile to conflicts. Like the Russian and Ukrainian war and the conflicts in the Middle East [94]. This can cause risk for shipowners, which will be mitigated by switching back to heavy fuel oil [95].

Methanol-powered ships are at the start [96]; however, although the technology is there. Shipowners are hesitating to convert vessels or build new builds on methanol [97]. As there is a limited supply of fuel, creating difficulty in securing enough fuel. The benefit of this fuel compared to LNG is the limited use of the fuel. The fuel is not used in large nations for daily power supply. Making it less volatile to conflicts.

Sodium Borohydride has similar problems to methanol. The fuel is limited in availability. However, with current prices, the fuel is not feasible. Prices should be lowered to become competitive. The break-even point will be determined in the shipowner's case.

Shipowner case H2fuel support system

The market for sodium borohydride as a fuel for ships is currently non-existent. However, a sodium borohydride market is large enough to start up the shipping market with small systems. Currently, the price of sodium borohydride is too high; even the lowest price from China is not competitive in the market.

There is value in the residual product. The residual product is more expensive than the original product. The weight of the residual product is 3.6 times the weight of the fuel. From the interview with the technology developer, it became clear that the residual product is not pure sodium metaborate tetrahydrate. But a mixture of different metaborates. As the products need cleaning, the value will drop. However, even a small value for the residual product can have a big impact on the product's viability. Unfortunately, the market size and, therefore the amount that can be sold is unknown.

For the shipowner, a case study has been made with the different powder prices. The case study will determine the break-even point if the residual product has no value and the current prices if there is no value in the residual product. A data collection with general data about the shipowners' vessels has been done. The data from table 4.7 combines the EU database for carbon emissions [98] and Clarkson [99], a ship database program. The data has been rounded to secure the anonymity of the shipowner.

Vessel	L (m)	B (m)	GT (ton)	FC (ton)	CE (ton)	Fuel cost	EUA	Fine CI	ETD
Vessel 1	200	30	40.000	3500	11.000	€2.000.000	€1.000.000	€175.000	€1.500.000
Vessel 2	225	20	35.000	4000	13.000	€2.500.000	€1.200.000	€200.000	€1.500.000
Vessel 3	200	20	30.000	2500	8000	€1.500.000	€700.000	€125.000	€1.000.000
Vessel 4	250	20	55.000	7500	24.000	€4.500.000	€2.200.000	€350.000	€3.000.000
Vessel 5	250	20	55.000	4000	13.000	€2.500.000	€1.200.000	€200.000	€1.500.000
Total				21.500	69.000	€13.000.000	€6.300.000	€1.050.000	€8.500.000

Table 4.7: GT: Gross Tonnage, FC: Fuel Consumption, CE: Carbon emission, EUA: EU Allowances, CI: Carbon Intensity, ETD: Energy taxation directive

The shipowner is expected to have a fuel cost of 13 million euros. When the new EU rules are active, these costs will increase by 15.8 million euros. Different taxes and fines for the use of HFO will increase the cost by 120 per cent. Giving the shipowner a great incentive to reduce carbon emissions in the fleet. The shipowner stated in the interview that an investment must have an acceptable return on investment. Otherwise, no investment will be made. As the compliance balance is fleet-based, reducing the carbon intensity by 2 per cent will save the shipowner 1 million in fines.

To save 2 per cent on all vessels, one 400 kW auxiliary system should be installed on one of the vessels, running 24 hours per day. According to the shipowner, some vessels always use at least 1000 kW per hour, whether sailing or in port. This means the system does not need a shutdown at any time. The owner also stated in the interview that a return on investment is important, so different cases have been proposed. Table 4.8 gives an overview of investment cost, fuel saved, system cost and cost saved. The saved cost is without the new fuel costs; this will be included later to determine the ROI.

	Low	Medium	High	
Efficiency	40	50	80	%
HFO saved	325	450	700	Tons
Percentage of fine compensated	74	100	160	%
Cost saved	1000000	1500000	2500000	€
System cost	1500000	2000000	5000000	€

Table 4.8: Overview Hydrogen systems investment

There are three different efficiency levels to consider when investing in a hydrogen fuel cell system. The first uses an internal combustion engine that runs solely on hydrogen with a low efficiency of 40% *(internal communication)*. The medium efficiency case uses a PEM fuel cell, which has an average efficiency of 50% [100], the same as current setups. Finally, the high-efficiency case uses a solid oxide fuel cell and a gas turbine in combination, which should achieve an efficiency of 80% [101].

According to internal communication, the hydrogen ICE is estimated to cost €0.5 million. The PEM fuel cell system has a fixed cost of €1 million while switching to a Solid Oxide Fuel Cell system is assumed to cost an additional €3 million [102]. The gas turbine is assumed to be cheap compared to the SOFC unit. It is important to note that these costs are rounded to the nearest half a million, as innovation calculations are still at a rough stage. Additionally, there is a fixed cost of €1 million for the extraction system, which is assumed by Hydroflexx.

In the lowest case, the HFO saved is not enough to prevent the full fine. In the medium case, the fine is completely saved, and in the high case, there is room left for additional shipowners to be incorporated. It is assumed that other shipowners will pay the full fine to pool with the shipowner from the interview, resulting in cost savings. Otherwise, shipowners who fail to comply will face a 10% annual increase in fines and other potential penalties from the EU.

The total amount of sodium borohydride used for the system is fixed at 700 tons to ensure a fair comparison of efficiency. The fuel cost will be between 10 and 40 million euros. For the investment to be profitable, the prices should be lower than €3.60 for high efficiency and €1.60 for low efficiency. Subsidies can be utilized to bridge the price gap, with a maximum of €1 per kg. This means that the break-even point is below €5 per kg. The suitability of sodium borohydride solution will depend on the value of the residual product. A recycling option must be developed before the market launch if the residual product lacks value.

Recycling case

Depending on the value of the residual product, a recycling case has a first priority or can be started after there is a certain market size. This section will cover two different recycling methods for sodium metaborate. The Brown-Schlesinger process which is currently used to produce sodium borohydride can be modified and an alternative technology called ball-milling will be discussed.

Brown-Schlesinger process

The current Brown-Schlesinger process has seven steps to produce sodium borohydride [103]:

1. Steam reforming of methane to make hydrogen
2. Electrolysis of sodium chloride to make sodium metal
3. Refining of borax to make boric acid
4. Converting boric acid to trimethyl-borate with methanol
5. Reaction of sodium metal and hydrogen to make sodium hydride
6. Recycling sodium methoxide by-product to methanol

Without details of each step, the main problem with this production method is hydrogen production through steam reforming of methane, creating carbon emissions. This step could be replaced by electrolysis of water to produce hydrogen. The other problem with this process is the electrolysis of sodium chloride to make sodium metal. This is an inefficient and energy-intensive process. Most of the costs are in these two steps. The production process can be modified to recycle the sodium borohydride; this is currently being researched.

2. Ball-milling
An alternative recycling process described in the papers is the use of ball-milling [104]–[106]. The exact scientific explanation is complex. However, a simplification is described by the writer of this research.

The example will use the following reaction [107]:

$$NaBO_2 \cdot 4H_2O + 4\ Mg_2Si > NaBH_4 + 4\ Si + 4\ MgO + 2\ H_2 \tag{4.2}$$

The input for the reaction will be placed in a mill filled with small balls of various sizes. The mill will rotate at a certain speed, causing the balls to smash into the reactants. Although the force of the balls is not high enough to cause any damage, the impact force is sufficient to break the bonds between the molecules. The hydrogen molecules will bond with NaB, while the oxygen molecules will bond with Mg. Under these conditions, silicon will not bond with any other molecule and will remain alone. As there are not enough NaB molecules, extra hydrogen will be released in this process. The benefit of this process compared to the Brown-Schlesinger process is that no hydrogen production is necessary. This will save the costs of the electrolyser, including the electricity cost for running the electrolysers.

To make the process circular, the residual products should be recycled as well. The first step is to react MgO with Cl_2, creating sodium chloride. The same step is (step 2) required as in the Brown-Schlesinger process to produce chloride and magnesium metal. This is an energy-intensive process. The magnesium metal can react with the silicon and the process is circular. The main benefit of this process is the removal of hydrogen production, and the extra hydrogen released when recycling can be used in a factory to produce the power needed for the processes.

Both processes face the same energy problem. Although the use of ball-milling could lower the prices, the inefficient electrolysis process of metal chlorides makes the fuel price too high. Without a solution to reduce the costs of electrolysis, the use of sodium borohydride will not be viable for the shipping market, as prices will not drop enough. Even if both processes are more efficient and have energy costs close to zero, prices will hardly drop below 5 euros per kg. A recycling method without the electrolysis of a metal chloride should be developed to make this product viable on a large scale.

To conclude, the market for sodium borohydride is still developing, with a rough estimate of the market size and prices. There is potential in using sodium borohydride as a fuel for ships, although the current price is not competitive in the market. However, there can be value in the residual product, which is more expensive than the original product. The recycling model can be a viable option for further market development. This conclusion is consistent with the statements made by Hydroflexx during the interview. Despite the fact that the market size is growing, there are still many uncertainties. Hydroflexx stated that the process of market formation is gradual and happens in phases, which is outlined in this function. This involves the shipping industry gradually accepting the idea of the product before slowly adopting the product itself.

4.4 Motor of innovation

The final aspect of the Technological Innovation System is defining the driving force behind the innovation, known as the "motor of innovation". This is a dynamic approach that combines the structure and functions of TIS. The question is which of the various functions of TIS and relationships between actors and institutions are the main drivers of innovation. Figure 4.5 gives an overview of the first part of the innovation whereby the arrow in the figure represents a timeline which exists of different stages of knowledge creation and diffusion and two different innovator groups which will have different roles depending on where the innovation is.

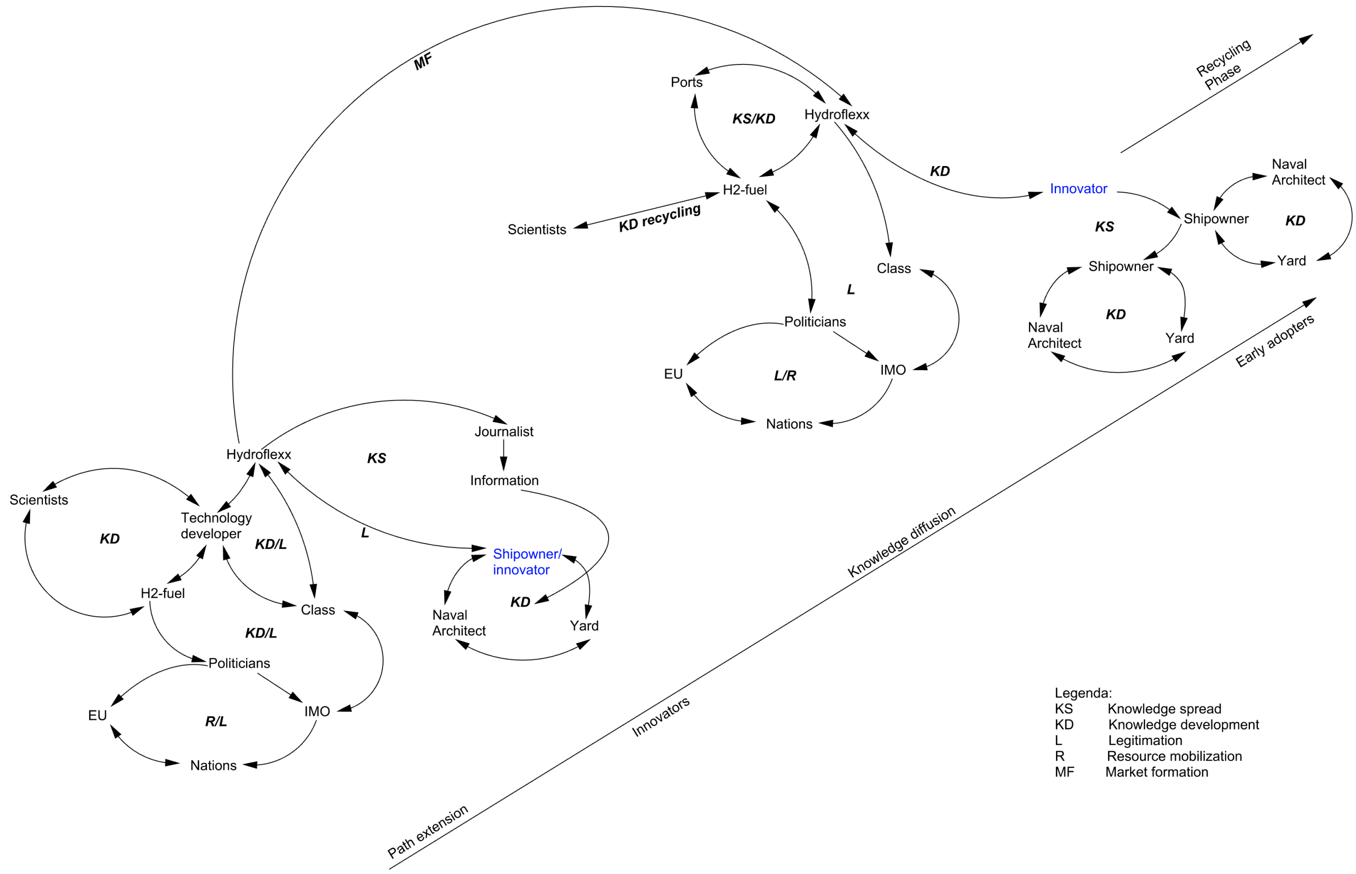


Figure 4.5: Motor of innovation

The product must be developed for use on large vessels, as these have enough auxiliary power to constantly run a small system. All parties involved, such as shipowners, shipyards, and ports, must be educated about the product. This happens in different stages of the technology and figure 4.5 represent this part in path extension, which is the creation of the technology. To convince the innovator group, shipowners, yards and naval architects must be informed and educated about the technology. Since this is a radical innovation, it is not just the product that must be understood, but also the fundamental technology behind it. Most shipowners, for example, are familiar with HFO and are comfortable with it, which makes incremental innovations easier. However, radical innovations take longer because all parties are generally lacking knowledge. Even if the shipowner has been informed and is ready to make a decision, other TIS functions, such as legitimation or resource mobilization, must also be in place. Guidelines, crew training, and handling protocols should be developed as everyone becomes familiar with the technology. In the innovator stage, the main part of this will be between Hydroflexx, the technology developer, Class and the IMO. Whereby Hydroflexx uses input from the shipowner as an extra source of information. Resources, such as subsidies and company capital, should be prepared by nations, the EU and the innovator. At last, fuel should be secured by Hydroflexx in advance so that a start-up is possible when the shipowner is ready. This is the start of the market formation.

During the start-up phase, it is essential to spread fundamental knowledge to promote innovation. Figure 4.5 represent this part above the innovator time line. It is important to combine the theory behind the novelty with product development. Once actors become familiar with solid hydrogen carriers, the product's spread should begin. At this stage, the innovation's motor will mainly run on three things to sell the first set of products: the spread of knowledge through media or marketing campaigns, the start-up of market formation, and entrepreneurial experimentation. The last function has not been discussed yet; however, it is crucial that the first few clients are willing to take risks and have enough technological knowledge and resources to support the innovation. An actor cannot develop everything independently and needs partners to support the development of ship-handling protocols and crew training programs.

The next phase in the motor of innovation, when a handful of vessels are active, will start then. Figure 4.5 represents this part between knowledge diffusion and the early adopters on the time line. Depending on the size of the startup phase from the market formation function, the next phase will include knowledge through the spread of mouth. Making knowledge development and influence on the direction of search the most important drivers of the innovation. Influence on the direction of search has not been discussed yet, as the function is difficult to describe and will depend on the phase of the innovation. In this phase, local and global peers will be important to convince the next group. In the literature review, this group is called the early adopters from Rogers' Diffusion of innovation framework. The early adopters are also in figure 4.5. In this stage of innovation, the technology is assumed to be developed, and the actor is no longer involved. The innovator or shipowner establishes a connection with Hydroflexx to learn about the product in practice, and H2-fuel works on the technology to recycle the product. The port needs to be informed about this new fuel, enabling them to acquire knowledge and prepare the harbour for fuel infrastructure. This phase primarily focuses on creating and spreading knowledge among early adopters and innovators, leading to the formation of new innovator groups. The port will be the first innovator group to construct the fuel infrastructure, while the parties working with H2-fuel will build a recycling facility, forming the second innovator group.

The last phase discussed will be the next phase of the market formation. Whereby the start-up case will not function anymore, as there is too much fuel needed. The recycling case has to start; this phase will be difficult as it is expensive, and enough incentive between shipowners should be there to have an ROI on the factory. The most difficult part of this phase is the switch in business model. From moving fuel from one producer to another to being a fuel owner. The fuel must be recycled and the business needs to lock in capital in fuel, which can take years to have a ROI on. As there is so much unclear, this phase is also not included in figure 4.5.

To conclude, the motor of innovation will run on different fuels. Constantly switching the type of fuel in the motor, to keep the engine running is necessary.

At last the sub-question of the case study can be answered: Which TIS functions are the main drivers of the motor of innovation?:

The main driving force behind the motor of innovation varies depending on the stage of the innovation. However, it can be concluded that the most crucial TIS function is knowledge development. Without the development and diffusion of knowledge, other TIS functions cannot occur. Therefore, knowledge development and diffusion are considered to be the primary drivers of the innovation motor.

Chapter 5

Conclusion and recommendations

The overall objective of this research is to understand what influences the decision of innovators to adopt or disregard a radical innovation. Without these innovators, the subsequent stages of adoption cannot proceed. The initial objective is to determine a general transition framework and subsequently focus on the innovator group and the maritime sector.

The objective and problem statement defined the main question of this research: Can the adoption of a given radical innovation in the maritime industry be influenced?

To answer the main question and meet the objective, three sub-questions have been answered:

1. Which transition frameworks are most suitable for describing the adoption process of radical innovations?
Different transition frameworks combined with path development and Rogers' DOI groups are defined. It is possible to combine innovators with TIS and (O)RIS along with path extension. Alternatively, a combination of SIS, TIS, (O)RIS, and path emergence can also prove to be effective. All combinations are suitable for describing radical innovations. Utilizing these frameworks supports the objective and describes the influence that developers have on innovators.

2. Which transition framework can be used to describe the adoption process of radical innovations in the shipping industry for the innovators?
The combination of the focal TIS framework and path extensions is a suitable approach for describing radical innovation within the shipping industry. The path extensions focus specifically on the innovator group. In case external effects occur that are important for the case study, context TIS can be used to map these effects. In a case study about sodium-borohydride, this framework will be applied to identify which TIS functions can influence the shipowners' decision.

3. Which TIS functions are the main drivers of the motor of innovation?:
The main driving force behind the motor of innovation varies depending on the stage of the innovation. However, it can be concluded that the most crucial TIS function is knowledge development. Without the development and diffusion of knowledge, other TIS functions cannot occur. Therefore, knowledge development and diffusion are considered to be the primary drivers of the innovation motor.

With the support of these sub-questions, the main question can be answered:
The adoption of radical innovations in the maritime industry can be influenced. Various TIS functions can have an influence on the decision of the shipowner. A technology seller, for instance, has a significant role in the development and dissemination of knowledge, which in time changes to the diffusion of knowledge. The technology seller can publish articles and communicate with shipowners, shipyards and naval architects about the radical innovation, thereby influencing their decision-making process. Once the knowledge is disseminated through these channels, other TIS functions, such as resource mobilization and legitimation, will take place automatically. Also, during the resource mobilization and legitimation process, the shipowner's search direction can be influenced. If there are new regulations implemented, such as subsidies for hydrogen carriers or regulations on extraction systems, the shipowner may shift their focus towards companies that produce such fuel and equipment.

Resource mobilization, on the other hand, can generally only be influenced on a subsidiary level. For companies, it is not possible to have control over someone's risk capital. They either have it or they do not. However, they can be influenced to use their risk capital on a particular innovation by providing them with the right knowledge.

To conclude, by disseminating knowledge, the diffusion of knowledge starts. This triggers other TIS functions, which can also influence the decision of a shipowner to adopt a given radical innovation.

Lastly, in order to further advance knowledge and understanding in this area, the writer of this research will provide some recommendations for additional research that can be conducted. The following recommendations are proposed:
- Conduct extra interviews with different shipowners.

This research only interviewed a single shipowner, the conclusion can change or be stronger if multiple shipowners are interviewed. Due to time restrictions on this research, this was not an option.
- Identify regulations and subsidies on a national level.

This was outside the scope of this research. However, some nations can have regulations and subsidiary programs in place, which can be helpful for innovation.
- Besides regulations from the EU, other unions, like the African Union, can have their own regulations and programs in place. Further research can identify differences and similarities between these and conclude if this information can be useful to influence shipowners to adopt a given innovation and if there are differences between these areas.

Bibliography

[1] European Council [EC]. "Fit for 55." (Apr. 2023), [Online]. Available: https://www.consilium.europa.eu/nl/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/.

[2] D. [DNV]. "Handbook for hydrogen-fuelled vessels - dnv." (Jan. 2, 2024), [Online]. Available: https://www.dnv.com/maritime/publications/handbook-for-hydrogen-fuelled-vessels-download.html (visited on 01/02/2024).

[3] European Union [EU]. "EUR-Lex - 52021PC0562 - EN - EUR-Lex." (2021), [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:562:FIN.

[4] Det Norske Veritas Germanische Loyds [DNV GL]. "EU ETS: Preliminary agreement to include shipping in the EU's Emission Trading System from 2024." (Jan. 23, 2023), [Online]. Available: https://www.dnv.com/news/eu-ets-preliminary-agreement-to-include-shipping-in-the-eu-s-emission-trading-system-from-2024-238068.

[5] International Maritime Organisation [IMO]. "Index of MEPC Resolutions and Guidelines related to MARPOL Annex VI." (), [Online]. Available: https://www.imo.org/en/OurWork/Environment/Pages/Index-of-MEPC-Resolutions-and-Guidelines-related-to-MARPOL-Annex-VI.aspx#1 (visited on 05/02/2023).

[6] M. Niermann, S. Timmerberg, S. Drünert, and M. Kaltschmitt, "Liquid organic hydrogen carriers and alternatives for international transport of renewable hydrogen," *Renewable and Sustainable Energy Reviews*, vol. 135, p. 110 171, 2021.

[7] M. Svanberg, J. Ellis, J. Lundgren, and I. Landälv, "Renewable methanol as a fuel for the shipping industry," *Renewable and Sustainable Energy Reviews*, vol. 94, pp. 1217–1228, 2018.

[8] H2-fuel. "H2 Fuel Technology." (), [Online]. Available: https://h2-fuel.nl/ (visited on 05/16/2023).

[9] Green Choiche [GC], "Opbrengst windmolen," *Opbrengst Windmolen*, Feb. 12, 2020. [Online]. Available: https://blog.greenchoice.nl/duurzame-energie/opbrengst-windmolen/.

[10] McKinsey Company. "Driving decarbonization: Accelerating zero-emission freight transport." (Jul. 28, 2022), [Online]. Available: https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/driving-decarbonization-accelerating-zero-emission-freight-transport.

[11] D. G. S. Schniederjans and C. M. S. Starkey, "Intention and willingness to pay for green freight transportation: An empirical examination," *ScienceDirect*, Aug. 2014. DOI: 10.1016/j.trd.2014.05.024.

[12] J. K. Kaminski. "Diffusion of innovation theory — canadian journal of nursing informatics." (Jun. 2011), [Online]. Available: https://cjni.net/journal/?p=1444.

[13] L. Lobao, "A sociology of the periphery versus a peripheral sociology: Rural sociology and the dimension of space 1," *Rural Sociology*, vol. 61, no. 1, pp. 77–102, 1996.

[14] N. V. Vercher, G. B. Bosworth, and J. E. Esparcia, "Developing a framework for radical and incremental social innovation in rural areas," *ScienceDirect*, Apr. 2023. DOI: 10.1016/j.jrurstud.2022.01.007.

[15] I. Stalmokaitė and B. Hassler, "Dynamic capabilities and strategic reorientation towards decarbonisation in Baltic Sea shipping," *Environmental innovation and societal transitions*, vol. 37, pp. 187–202, Dec. 2020. DOI: 10.1016/j.eist.2020.09.002.

[16] A. Bergek, Ø. Bjørgum, T. Hansen, J. Hanson, and M. Steen, "Sustainability transitions in coastal shipping: The role of regime segmentation," *Transportation research interdisciplinary perspectives*, vol. 12, p. 100 497, Dec. 1, 2021. DOI: 10.1016/j.trip.2021.100497. [Online]. Available: https://doi.org/10.1016/j.trip.2021.100497.

[17] E. M. Rogers, *Diffusion of innovation 3rd edition*. New York : Free Press ; London : Collier Macmillan, Jan. 1, 1983, vol. 248.

[18] J. I. Jenssen and T. Rand y, "The performance effect of innovation in shipping companies," *Maritime Policy & Management*, vol. 33, no. 4, pp. 327–343, 2006.

[19] I. S. Stalmokaitė and B. H. Hassler, "Dynamic capabilities and strategic reorientation towards decarbonisation in baltic sea shipping," *ScienceDirect*, Dec. 1, 2020. DOI: 10.1016/j.eist.2020.09.002.

[20] L. F. Frank, S. S. Sundqvist, K. P. Puumalainen, and S. S. Sintonen. "Do innovative attitudes and behavior lead to adoption? empirical evidence from wireless services in finland, germany, and greece." (Oct. 2008), [Online]. Available: https://www.tandfonline.com/doi/abs/10.1300/J037v15n03_02.

[21] M., "A.p. moller - maersk continues green transformation with six additional large container vessels," May 15, 2023. [Online]. Available: https://www.maersk.com/news/articles/2022/10/05/maersk-continues-green-transformation (visited on 06/07/2023).

[22] G. J. Tellis, J. C. Prabhu, and R. K. Chandy, "Radical innovation across nations: The preeminence of corporate culture," *Journal of marketing*, vol. 73, no. 1, pp. 3–23, 2009.

[23] F. W. Geels, "Multi-level perspective on system innovation: Relevance for industrial transformation," *Understanding industrial transformation: Views from different disciplines*, pp. 163–186, 2006.

[24] R. Heeks, M. Amalia, R. Kintu, and N. Shah, "Inclusive innovation: Definition, conceptualisation and future research priorities," *Social Science Research Network*, Jan. 1, 2013. DOI: 10.2139/ssrn.3438439. [Online]. Available: https://doi.org/10.2139/ssrn.3438439.

[25] E. Suroso and Y. Azis, "Defining mainstreams of innovation: A literature review," Jan. 1, 2015. DOI: 10.2991/iceb-15.2015.55. [Online]. Available: https://doi.org/10.2991/iceb-15.2015.55.

[26] R. Heeks, C. S. Foster, and Y. Nugroho, "New models of inclusive innovation for development," *Innovation and development*, vol. 4, no. 2, pp. 175–185, Jul. 3, 2014. DOI: 10.1080/2157930x.2014.928982. [Online]. Available: https://doi.org/10.1080/2157930x.2014.928982.

[27] M. Navarro, J. J. Gibaja, B. Bilbao-Osorio, and R. Aguado, "Patterns of innovation in eu-25 regions: A typology and policy recommendations," *Environment and Planning C: Government and Policy*, vol. 27, no. 5, pp. 815–840, 2009.

[28] K. Chapple, C. Kroll, T. W. Lester, and S. Montero, "Innovation in the green economy: An extension of the regional innovation system model?" *Economic Development Quarterly*, vol. 25, no. 1, pp. 5–25, 2011.

[29] M. Buerger and U. Cantner, "The regional dimension of sectoral innovativeness: An empirical investigation of two specialized suppliers and two science-based industries," *Papers in Regional Science*, vol. 90, no. 2, pp. 373–393, 2011.

[30] I. Porto Gomez, J. R. Otegi Olaso, and J. M. Zabala-Iturriagagoitia, "Rosa, rosae, rosis: Modelling a regional open sectoral innovation system," *Entrepreneurship & Regional Development*, vol. 28, no. 1-2, pp. 26–50, 2016.

[31] K. Hubner, J. Nill, and C. Rickert, "Greening of the innovation system? opportunities and obstacles for a path change towards sustainability-the case of germany," *International Journal of Sustainable Development*, vol. 4, no. 4, pp. 454–473, 2001.

[32] Y.-C. Chang and M.-H. Chen, "Comparing approaches to systems of innovation: The knowledge perspective," *Technology in Society*, vol. 26, no. 1, pp. 17–37, 2004.

[33] K. Kubeczko, E. Rametsteiner, and G. Weiss, "The role of sectoral and regional innovation systems in supporting innovations in forestry," *Forest policy and economics*, vol. 8, no. 7, pp. 704–715, 2006.

[34] A. Balaguer and D. Marinova, "Sectoral transformation in the photovoltaics industry in australia, germany and japan: Contrasting the co-evolution of actors, knowledge, institutions and markets," *Prometheus*, vol. 24, no. 3, pp. 323–339, 2006.

[35] E. Autio, "Evaluation of rtd in regional systems of innovation," *European planning studies*, vol. 6, no. 2, pp. 131–140, 1998.

[36] M. Trippl, "Cross-border regional innovation systems," 2006.

[37] Z. J. Acs and D. B. Audretsch, "Innovation, market structure, and firm size," *The review of Economics and Statistics*, pp. 567–574, 1987.

[38] T. Nilsen and R. Njøs, "Greening of regional industrial paths and the role of sectoral characteristics: A study of the maritime and petroleum sectors in an arctic region," *European Urban and Regional Studies*, vol. 29, no. 2, pp. 204–221, 2022.

[39] U. E. Hansen, C. Gregersen, R. Lema, D. Samoita, and F. Wandera, "Technological shape and size: A disaggregated perspective on sectoral innovation systems in renewable electrification pathways," *Energy Research & Social Science*, vol. 42, pp. 13–22, 2018.

[40] U. Dolata, "Technological innovations and sectoral change: Transformative capacity, adaptability, patterns of change: An analytical framework," *Research policy*, vol. 38, no. 6, pp. 1066–1076, 2009.

[41] T. Makkonen and T. Inkinen, "Systems of environmental innovation: Sectoral and technological perspectives on ballast water treatment systems," *WMU Journal of Maritime Affairs*, vol. 20, no. 1, pp. 81–98, 2021.

[42] N. Gaponenko, "In search of sectoral foresight methodology: Bridging foresight and sectoral system of innovation and production," *Futures*, vol. 135, p. 102 859, 2022.

[43] S. M. Azad, P. Khodabakhsh, F. Roshannafas, and S. H. Ghodsypour, "Modelling techno-sectoral innovation system: A new hybrid approach for innovation motors policymaking," *Kybernetes*, vol. 49, no. 2, pp. 332–361, 2020.

[44] F. Malerba, "Sectoral systems of innovation and production," *Research policy*, vol. 31, no. 2, pp. 247–264, 2002.

[45] G. Dosi and R. R. Nelson, "An introduction to evolutionary theories in economics," *Journal of evolutionary economics*, vol. 4, pp. 153–172, 1994.

[46] I. Miremadi, Y. Saboohi, and S. Jacobsson, "Assessing the performance of energy innovation systems: Towards an established set of indicators," *Energy Research & Social Science*, vol. 40, pp. 159–176, 2018.

[47] H. Bach, T. Mäkitie, T. Hansen, and M. Steen, "Blending new and old in sustainability transitions: Technological alignment between fossil fuels and biofuels in norwegian coastal shipping," *Energy Research & Social Science*, vol. 74, p. 101 957, 2021.

[48] J. Hanson, "Established industries as foundations for emerging technological innovation systems: The case of solar photovoltaics in norway," *Environmental innovation and societal transitions*, vol. 26, pp. 64–77, 2018.

[49] J. Ulmanen and A. Bergek, "Influences of technological and sectoral contexts on technological innovation systems," *Environmental Innovation and Societal Transitions*, vol. 40, pp. 20–39, 2021.

[50] A. Bergek, S. Jacobsson, B. Carlsson, S. Lindmark, and A. Rickne, "Analyzing the functional dynamics of technological innovation systems: A scheme of analysis," *Research policy*, vol. 37, no. 3, pp. 407–429, 2008.

[51] A. Bergek, M. Hekkert, S. Jacobsson, J. Markard, B. Sandén, and B. Truffer, "Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics," *Environmental innovation and societal transitions*, vol. 16, pp. 51–64, 2015.

[52] R. A. Suurs and M. P. Hekkert, "Cumulative causation in the formation of a technological innovation system: The case of biofuels in the netherlands," *Technological Forecasting and Social Change*, vol. 76, no. 8, pp. 1003–1020, 2009.

[53] F. W. Geels and J. Schot, "Typology of sociotechnical transition pathways," *Research policy*, vol. 36, no. 3, pp. 399–417, 2007.

[54] K. Onufrey and A. Bergek, "Self-reinforcing mechanisms in a multi-technology industry: Understanding sustained technological variety in a context of path dependency," *Industry and Innovation*, vol. 22, no. 6, pp. 523–551, 2015.

[55] A. Butzin and D. Rehfeld, "The balance of change and continuity in the german construction sector's development path," *Zeitschrift für Wirtschaftsgeographie*, vol. 57, no. 1-2, pp. 15–26, 2013.

[56] M. Grillitsch and T. Hansen, "Green industry development in different types of regions," *European Planning Studies*, vol. 27, no. 11, pp. 2163–2183, 2019.

[57] M. Trippl, M. Grillitsch, and A. Isaksen, "Exogenous sources of regional industrial change: Attraction and absorption of non-local knowledge for new path development," *Progress in human geography*, vol. 42, no. 5, pp. 687–705, 2018.

[58] C. Eason, "Why shipowners need to invest in technology development," *Fathom World - Shipping and Maritime Industry News*, Mar. 21, 2021. [Online]. Available: https://fathom.world/why-shipowners-need-to-invest-in-technology-development/.

[59] R. Hassink, A. Isaksen, and M. Trippl, "Towards a comprehensive understanding of new regional industrial path development," *Regional Studies*, vol. 53, no. 11, pp. 1636–1645, 2019.

[60] A. Isaksen and S.-E. Jakobsen, "New path development between innovation systems and individual actors," in *Path Dependence and Regional Economic Renewal*, Routledge, 2018, pp. 1–16.

[61] K. Eriksson, A. Majkgård, and D. D. Sharma, "Path dependence and knowledge development in the internationalization process," *MIR: Management International Review*, pp. 307–328, 2000.

[62] C. Williams. "Tanker explodes, sinks off virginia, killing 3." (Feb. 29, 2004), [Online]. Available: https://www.washingtonpost.com/archive/local/2004/02/29/tanker-explodes-sinks-off-virginia-killing-3/5e5d1824-a440-4c10-b433-f8d8d396c201/.

[63] J. B. Bonney. "Tote takes the lead in lng container ships — journal of commerce." (Dec. 13, 2012), [Online]. Available: https://www.joc.com/article/tote-takes-lead-lng-container-ships_20121213.html.

[64] LNG World News and LNG World News, "Japan: Transport ministry to introduce safety standards for lng-powered ships," Oct. 31, 2011. [Online]. Available: https://www.offshore-energy.biz/japan-transport-ministry-to-introduce-safety-standards-for-lng-powered-ships/.

[65] Maersk, "Maersk signs shipbuilding contract for world's first container vessel fueled by carbon neutral methanol," Aug. 2021. [Online]. Available: https://www.maersk.com/news/articles/2021/07/01/container-fueled-by-carbon-neutral-methanol.

[66] "New research shows safe and effective application of ammonia as marine fuel according to c-job naval architects - c-job naval architects." (Jul. 4, 2022), [Online]. Available: https://c-job.com/press/new-research-shows-safe-and-effective-application-of-ammonia-as-marine-fuel-according-to-c-job-naval-architects/.

[67] EU, "Piloting multi mw ammonia ship fuel cells," *CORDIS*, Jan. 1, 2020. DOI: 10.3030/875156. [Online]. Available: https://doi.org/10.3030/875156.

[68] UNESCO. "Around the globe in the world's first clean-energy ship." (Oct. 18, 2017), [Online]. Available: https://www.unesco.org/en/articles/around-globe-worlds-first-clean-energy-ship-0.

[69] C. [CC]. "Conference in dubai 2023 about climate change (cop 28)." (Dec. 28, 2023), [Online]. Available: https://www.climate-chance.org/en/event-calendar/cop28-dubai-2023/ (visited on 12/28/2023).

[70] "Neo orbis: Sailing on hydrogen." (Nov. 28, 2022), [Online]. Available: https://www.portofamsterdam.com/en/neo-orbis-sailing-hydrogen (visited on 12/28/2023).

[71] *Duurzame zeevaart: ondersteuningsmogelijkheden*. [Online]. Available: https://www.rvo.nl/onderwerpen/duurzame-mobiliteit/zeevaart.

[72] A. [ABN]. "Transition loan rewards sustainable businesses with lower interest rates." (Apr. 26, 2022), [Online]. Available: https://www.abnamro.com/en/news/transition-loan-rewards-sustainable-businesses-with-lower-interest-rates (visited on 12/28/2023).

[73] EU. "Clean energy transition." (), [Online]. Available: https://cinea.ec.europa.eu/programmes/life/clean-energy-transition_en (visited on 12/28/2023).

[74] EU. "Connecting europe facility (cef) transport." (), [Online]. Available: https://www.rvo.nl/subsidies-financiering/cef-transport (visited on 12/28/2023).

[75] EU. “Horizon europe.” (Dec. 20, 2023), [Online]. Available: https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en (visited on 12/28/2023).

[76] “Eu clarifies subsidy stacking rules for upcoming hydrogen pilot auction.” (Oct. 6, 2023), [Online]. Available: https://www.hydrogeninsight.com/policy/eu-clarifies-subsidy-stacking-rules-for-upcoming-hydrogen-pilot-auction/2-1-1530403.

[77] I. [IMO]. “Imo meeting summaries.” (Jan. 2, 2024), [Online]. Available: https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/CCC-9th-session.aspx (visited on 01/02/2024).

[78] Statista. “Shipyards worldwide.” (Jan. 2, 2024), [Online]. Available: https://www-statista-com.tudelft.idm.oclc.org/statistics/1102673/active-shipyards-worldwide/ (visited on 01/02/2024).

[79] L. [LR]. “Lack of yard capacity and capability could compromise the maritime industry’s retrofit ambitions — lr.” (Oct. 10, 2023), [Online]. Available: https://www.lr.org/en/about-us/press-listing/press-release/lack-of-yard-capacity-and-capability-could-compromise-the-maritime-industrys-retrofit-ambitions/ (visited on 01/02/2024).

[80] J. O. Mandra and J. O. Mandra, “Repair yard shortage puts maritime energy transition at risk,” Oct. 11, 2023. [Online]. Available: https://www.offshore-energy.biz/repair-yard-shortage-puts-maritime-energy-transition-at-risk/ (visited on 01/02/2024).

[81] S. Chambers and S. Chambers. “Repair yard capacity for engine retrofits questioned.” (Oct. 11, 2023), [Online]. Available: https://splash247.com/repair-yard-capacity-for-engine-retrofits-questioned/ (visited on 01/02/2024).

[82] The International Institute of Marine Surveying (IIMS). “Engine retrofit report 2023 finds lack of yard capacity could compromise retrofit ambitions.” (Oct. 11, 2023), [Online]. Available: https://www.iims.org.uk/engine-retrofit-report-2023-finds-lack-of-yard-capacity-could-compromise-retrofit-ambitions/.

[83] S. and S. “Ship concept 2030: Are the world’s shipbuilders doing enough to foster innovation?” (Sep. 28, 2023), [Online]. Available: https://splash247.com/ship-concept-2030-are-the-worlds-shipbuilders-doing-enough-to-foster-innovation/ (visited on 01/02/2024).

[84] B. [BV]. “Energy taxation directive (etd).” (Jan. 2, 2024), [Online]. Available: https://marine-offshore.bureauveritas.com/sustainability/fit-for-55/energy-taxation-directive (visited on 01/02/2024).

[85] KPMG, “Energy taxation directive,” Aug. 31, 2021. [Online]. Available: https://kpmg.com/xx/en/home/insights/2021/08/energy-taxation-directive.html (visited on 01/02/2024).

[86] Reports and Data, *Sodium borohydride market, by type (Powder, pellets, solutions, and granules), by application (Pulp paper, pharmaceuticals, metal reduction, fuel cells, reducing agents, and others), and by region Forecast to 2032*, Dec. 2023. [Online]. Available: https://www.reportsanddata.com/report-detail/sodium-borohydride-market.

[87] Absolute reports. “Absolute reports® - global sodium borohydride industry.” (Dec. 30, 2023), [Online]. Available: https://www.absolutereports.com/global-sodium-borohydride-industry-25823040 (visited on 12/30/2023).

[88] S. [SB]. “World bunker prices.” (Dec. 31, 2023), [Online]. Available: https://shipandbunker.com/prices (visited on 12/31/2023).

[89] Methanol Institute. “Methanol price—methanol institute—www.methanol.org.” (Dec. 15, 2023), [Online]. Available: https://www.methanol.org/methanol-price-supply-demand/ (visited on 12/31/2023).

[90] O. “Shippers eye methanol fuel as means to decarbonize global fleet.” (Sep. 20, 2023), [Online]. Available: https://www.opisnet.com/blog/shippers-eye-methanol-fuel-as-means-to-decarbonize-global-fleet/.

[91] M. Buitendijk and M. Buitendijk. “Te: ‘quarter of eu shipping will run on lng by 2030 locking in fossil fuels for decades’ — swz—maritime.” (Feb. 17, 2022), [Online]. Available: https://swzmaritime.nl/news/2022/02/18/te-quarter-of-eu-shipping-will-run-on-lng-by-2030-locking-in-fossil-fuels-for-decades/.

[92] M. Buitendijk and M. Buitendijk. “Is there a future for lng as a shipping fuel? — swz—maritime.” (Oct. 20, 2022), [Online]. Available: https://swzmaritime.nl/news/2022/10/21/is-there-still-a-future-for-lng-as-a-shipping-fuel/#:~:text=With%5C%20multiple%5C%20market%5C%20forces%5C%20fuelling,billion%5C%2C%5C%20according%5C%20to%5C%20UCL%5C%20researchers..

[93] IEA. “The role of gas in today’s energy transitions – analysis - iea.” (Jul. 2019), [Online]. Available: https://www.iea.org/reports/the-role-of-gas-in-todays-energy-transitions (visited on 12/31/2023).

[94] E. Roda. “European gas prices likely to fluctuate in late 2023 as markets evaluate middle east conflict, among other factors.” (Oct. 19, 2023), [Online]. Available: https://renantis.com/media-centre/european-gas-prices-likely-to-fluctuate-in-late-2023-as-markets-evaluate-middle-east-conflict-among-other-factors/.

[95] M. Buitendijk and M. Buitendijk. “‘unlike the dutch, the germans don’t write off lng as a marine fuel’ — swz—maritime.” (Apr. 20, 2021), [Online]. Available: https://swzmaritime.nl/news/2021/04/20/unlike-the-dutch-the-germans-dont-write-off-lng-as-a-marine-fuel/.

[96] DNV GL. “Methanol as fuel heads for the mainstream in shipping - dnv.” (Apr. 20, 2023), [Online]. Available: https://www.dnv.com/expert-story/maritime-impact/Methanol-as-fuel-heads-for-the-mainstream-in-shipping.html (visited on 12/31/2023).

[97] S. [SW]. “Shipowner hesitant towards green methanol despite its widespread adoption among carriers.” (May 25, 2023), [Online]. Available: https://shippingwatch.com/regulation/article15898233.ece.

[98] E. [EU]. “Data.europa.eu.” (Feb. 20, 2024), [Online]. Available: https://data.europa.eu/data/datasets/co2-emissions-data?locale=en (visited on 02/20/2024).

[99] Clarksons. “Clarksons research.” (Feb. 20, 2024), [Online]. Available: https://www.clarksons.net/n/#/portal (visited on 02/20/2024).

[100] S. Saathoff and S. Saathoff. “Fuel cell efficiency 101: The key metrics.” (Feb. 17, 2023), [Online]. Available: https://www.plugpower.com/fuel-cell-efficiency-101-the-key-metrics/#:~:text=PEM%20fuel%20cells%2C%20Plug’s%20technology,for%20extracting%20power%20from%20fuels.%E2%80%9D.

[101] L. van Biert, T. Woudstra, M. Godjevac, K. Visser, and P. Aravind, “A thermodynamic comparison of solid oxide fuel cell-combined cycles,” *Journal of Power Sources*, vol. 397, pp. 382–396, 2018.

[102] IEA. “Stationary fuel cell application.” (Jan. 1, 2021), [Online]. Available: https://www.ieafuelcell.com/fileadmin/publications/2021/2021_AFCTCP_Stationary_Application_Performance.pdf (visited on 01/29/2024).

[103] Y. Wu, M. T. Kelly, and J. V. Ortega, “Review of chemical processes for the synthesis of sodium borohydride,” *Millennium Cell Inc*, 2004.

[104] C.-L. Hsueh *et al.*, “Regeneration of spent-nabh4 back to nabh4 by using high-energy ball milling,” *International journal of hydrogen energy*, vol. 34, no. 4, pp. 1717–1725, 2009.

[105] L. Ouyang *et al.*, “Low-cost method for sodium borohydride regeneration and the energy efficiency of its hydrolysis and regeneration process,” *Journal of Power Sources*, vol. 269, pp. 768–772, 2014.

[106] W. Chen *et al.*, “Hydrolysis and regeneration of sodium borohydride (nabh4)–a combination of hydrogen production and storage,” *Journal of Power Sources*, vol. 359, pp. 400–407, 2017.

[107] M. Huang *et al.*, “Efficient regeneration of sodium borohydride via ball milling dihydrate sodium metaborate with magnesium and magnesium silicide,” *Journal of Alloys and Compounds*, vol. 729, pp. 1079–1085, 2017.

Chapter 6

Appendix 1 - Interviews

6.1 Interview - Shipowner

Knowledge development

- What is your current knowledge about alternative fuels?
- How did you get knowledgeable?
- How is knowledge spread within your company?
- In which state of technological development are you interested in the technology?

Market formation

- What can be your role in the market formation?
- Are you willing to pay other shipowners to enter their pool and prevent a fine?
- If yes, how much?
- If no, why not?

Legitimation process

- Do you have experience with risk-based design?
- If yes, would you do it again?
- If no, would you consider a risk-based design?
- What can be your role in crew training and protocol development?

Resource mobilization

- Do you have an increase in resources for R&D to reach the goals of institutions like IMO or EU?
- Do you have a budget to implement solutions?
- Would you implement a solution to reach the goals of the institutions, even if there is no return on investment?

Influence on the direction of search

- What/where is your network of peers?
- Do you have a global network?
- Do you have a local network?

Entrepreneurial experimentation

- Did you implement one of the following technologies:

  • Scrubber
  • LNG-powered vessel
  • Wind-assisted propulsion
  • Air lubrication

- If yes, in which year?
- How did you get knowledge about this technology?
- Did you get help from one of your peers? If yes, in which network?
- What is your view on fuel cells compared to an internal combustion engine on hydrogen, even if the efficiency of the ICE is lower? Would you still prefer an ICE?

The transcript is confidential and not available in this report.

6.2 Interview Technology company

Technology

- What is H2 fuel?
- How safe is H2 fuel?
- In which state is technological development?
- When will the technology be commercially available?
- What is the carbon profile of H2 fuel?
- How competitive is the fuel compared to current fossil fuels?

Knowledge development

- How will clients learn about your product?

Market formation

- How do you see the market formation of H2 fuel within the shipping market?
- What are the plans for a recycling facility? And which prices can be reached with a recycling facility?

The transcript is confidential and not available in this report.

6.3 Interview Hydroflexx

Knowledge development

- What do you know about alternative fuels for vessels?
- How did you get this knowledge?
- Do you spread this knowledge?
- How will clients learn about solid hydrogen carriers?
- How will clients learn about your product?
- How will shipyards and naval architects learn about this new technology?

Market formation

- How do you see the market formation?
- What can be your role in the market formation?

Legitimation process

- Do you have experience with risk-based design?
- If yes, would you do it again?
- If no, would you consider it?
- What can be your role in creating guidelines and regulations for the design of solid hydrogen systems?
- What can be your role in developing protocols for handling of the system on ships?
- What can be your role in developing crew training?

Resource mobilization

- What do you know about subsidizes?
- Do you think these play an important role in market formation?
- The shipowner stated in his interview that he only invests if there is an ROI. In case there is no ROI, are you willing to fill this gap to force the market?

Influence on the direction of search

- What/where is your network of peers?
- Do you have a global network?
- Do you have a local network?

The transcript is confidential and not available in this report.