INTRANS - A method to analyze transitions in socio-technical systems in order to support strategic decision making at key stakeholders

A framework to gain insights and understanding of transitions and its key players, drivers, potential future states, transition barriers and possibilities to intervene

LNG case study - the transition from conventional fuels towards liquefied natural gas in the Dutch maritime sector

Jos J. Dekker
SPM5910: SEPAM Master’s Thesis Project

In fulfillment of the requirements for the Degree of
Master of Science

Jos J. Dekker
4011813

Delft University of Technology
Faculty of Technology, Policy and Management
MSc Systems Engineering, Policy Analysis and Management

Argos Energies
Inland Bunkering

Graduation committee:
Chair Prof.dr.ir. P.M. Herder Delft University of Technology
1st supervisor Dr.ir. R.M. Stikkelman Delft University of Technology
2nd supervisor Dr. P.W.G. Bots Delft University of Technology
External supervisor Mr. Piet van den Ouden Argos Energies
Preface

This Master thesis is submitted in candidacy for the Master of Science in Systems Engineering, Policy analysis and Management (SEPAM) at the Delft University of Technology, the Netherlands.

The report is aimed at everyone who is interested in (analyzing) transitions in socio-technical systems and people that are curious about the transition from conventional fuels towards liquefied natural gas LNG in the Dutch maritime sector.

SEPAM graduates are trained to work on large-scale and complex problems related to both the public and private sector. Transitions in socio-technical systems together with the LNG transition system case consisting of technology-, policy- and management aspects in an international multi-actor environment is therefore a perfect topic to graduate on.

I would like to take this opportunity to thank Piet van den Ouden, Rob Stikkelman, Pieter Bots and Paulien Herder for their great supervisory support during the graduation trajectory. Next to that I owe a big thank you to all representatives from key stakeholders that were willing to participate in this research.

Jos J. Dekker
Delft, March 2016
Management summary

Liquefied natural gas (LNG) seems to be a suiting solution to the worldwide maritime emission problem, but the adoption of LNG in the maritime sector goes very slow. Using LNG would significantly reduce emissions, natural gas is widely available in the world and LNG is in potential cheaper than current fuels. The LNG problem:

- Complex, technical multi-actor situation where actors have limited individual influence on change.
- LNG being a cryogenic liquid (-162 °C), asks for high-tech equipment on ships; from fuel tanks to gas turbines.
- Demand for an LNG infrastructure from gas source to end-user
- Public opinion, policy regulations on fuels, national-, European- and intercontinental emission limits, economic developments, permit granting systems, maritime classification- and safety standards and maritime funding structures.

The LNG situation shows strong similarities with situations referred to in the scientific literature as transitions in socio-technical systems. They are conceptualized as clusters of aligned elements, such as technical artefacts, knowledge, markets, regulations, cultural meaning, rules and infrastructures. Transitions in STS are known for not being caused by the change of a single factor, but being the result of combined changes in multiple processes over time between various structures of a socio-technical system.

Because of their limited individual influence, key players are faced with many uncertainties. With the aim of supporting key players, the main goal of this thesis is **developing a structured methodology that is generically applicable on transitions in socio-technical systems, providing understanding of the transition; its key players and drivers, potential future states, transition barriers and possibilities to intervene.**

The developed method INTRANS

INTRANS consists of a conceptual framework of assumptions, principles and rules together with a stepwise protocol of seven sub-analyses to apply the conceptual framework on a transition case study. It is based on aspects from several publications, completed with the concept of different transition entry moments for different stakeholder sub-sectors:

- **Without stakeholder entry moments there will be no socio-technical transition.**
- **Different stakeholder sub-sectors can have different transition entry moments.**
- **A sub-sector’s state is influenced by sub-sector characteristics, endogenous factors and exogenous factors.**
- **There is an interaction between system values and sub-sector entry moments**

The core of the concept is the determination and modeling of sub-sector states $S_{i,t}$. These are 0 if a sub-sector did not join the transition, and change into 1 when a function consisting of sub-sector characteristics, endogenous- and exogenous factors meets the entry moment conditions of that particular sub-sector. The stepwise protocol of sub-analyses to apply INTRANS on a case study includes seven steps:

1. **Starting point: defining the socio-technical system and the drivers for transition**
2. **Identify the necessary conditions for a socio-technical transition to happen and translate them into sub-conditions**
3. Identify crucial structures of assets and rules
4. Determine stakeholder sub-sectors and their characteristics
5. Determine system variables and relations
6. Identify transition barriers
7. Identify chains of events that could take away transition barriers

[1] To gain basic understanding of the STS and identify the drivers for transition the analyst applies the multi-level perspective framework by Geels (2002).

[2] To gain further understanding of the situation, the analyst defines the necessary conditions without a transition cannot happen. The process how to do this is retrieved from the TranScript framework by Patil (2014).

[3] The analyst applies the TranScript framework by Patil to focus on the crucial structures of assets and rules that are required in order to meet the necessary conditions of the transition. Also the key players who are able to influence the establishment of the crucial assets and rules are defined.

[4] The analyst identifies the relevant characteristics that cause a difference in feasibility to enter a transition between actors from the same stakeholder group. Per group three characteristics have to be described; design characteristics, operational characteristics and operational environment characteristics.

[5] The analyst combines the results of the previous steps in a model, describing the relations between sub-sector entry moments and sub-sector characteristics, endogenous factors and exogenous factors.

[6] The conceptual model, in combination with stakeholder participation is used by the analyst to determine the needs, what we have now and what should happen to go from what we have now to what we need. Qualitative operationalization of the conceptual model provides insight in the crucial assets or rules that are missing. When looking into the threshold values, quantification of the model is required. This step is inspired on the scheme of analysis from Bergek et al (2008).

[7] Based on the principles of scenario development, the analyst produces several potential scenarios. Participatory involvement of key stakeholders is crucial in this step. They can provide information about powerful players in the transition and likely future developments in the system.

Testing INTRANS on LNG case study
By applying INTRANS on the LNG case study it has become clear that a large scale LNG transition in the maritime sector will not happen under today’s conditions. Several barriers have to disappear, of which the most important are:

1) Unwillingness to pay more for green transport.
2) Missing emission penalties in shipping sector.
3) Missing ship-to-ship- and shore-to-ship bunkering facilities.
4) No funding structures for the sub-sectors inland container-, tanker- and dry bulk ships.
5) High price of LNG equipment.
6) Insufficient price difference between conventional fuels and LNG.
7) Uncertainties about future fuel price levels and developments in regulations.
8) Unclear and long licensing trajectories for LNG ship approval.
9) Lack of technical- and financial knowledge sharing
10) Regulation is running behind on technological development.

The stakeholders’ expectations about future developments in combination with their perspective on powerful stakeholders provided arguments for scenario developments. Six likely scenarios are described; (1) a fuel price scenario where the price of LNG decreases caused by the increase of LNG availability, (2) a strict emission penalties scenario where ships are heavily fined when not complying the SECA emission rules, (3) a scenario where the shipping market is willing to pay more for sustainable transport, (4) a scenario where LNG infrastructure can be shared with other markets like the Finnish off-grid wood & paper industry, (5) a scrapping bonus scenario decreasing the overcapacity in the inland shipping sector and (6) a resale value guarantee scenario where the funding problem is solved by decreasing the risk for financial institutions.

Changes can happen rather quickly. Take for example the oil price, which decreased 50% during the course of this research. Still, the overall image is that the LNG transition will start slow, followed by an exponential growth. Most interviewees predict this to happen in 10 to 20 years from today. It is however definitely too early to draw hard conclusions. Therefore the suggestion is to perform more research, make the INTRANS LNG model even more realistic and use a method like Exploratory Modeling and Analysis to provide more insights.
# Table of Contents

**Preface** ........................................................................................................................................... V

**Management summary** ...................................................................................................................... VII
   The developed method INTRANS ........................................................................................................ VII
   Testing INTRANS on LNG case study ............................................................................................... VIII

**Chapter 1: Introduction** ................................................................................................................... 1
   1.1 LNG is a solution to the maritime pollution problem ................................................................. 1
   1.2 Zooming in on the complexity of the LNG situation ................................................................. 2
   1.3 Search for a methodology to analyze the LNG situation in the maritime sector ............... 3
      1.3.1 LNG publications are fact-driven rather than conceptual ................................................ 3
      1.3.2 LNG situation as socio-technical transition ................................................................... 3
      1.3.3 Literature scan for methodologies to analyze transitions in socio-technical systems... 3
   1.4 Research questions ..................................................................................................................... 5
   1.5 Research framework .................................................................................................................. 5
   1.6 Relevance of master thesis ....................................................................................................... 6
   1.7 Further course of the report ..................................................................................................... 6

**Chapter 2: Literature study for INTRANS** .................................................................................. 7
   2.1 What are the requirements for INTRANS? ................................................................................ 7
   2.2 Multi Level Perspective framework ......................................................................................... 7
      2.2.1 Explanation of concept ....................................................................................................... 7
      2.2.2 MLP framework application example from literature ...................................................... 8
      2.2.3 MLP, what is useful for including in INTRANS and what not? ........................................ 9
   2.3 TranScript framework ............................................................................................................... 10
      2.3.1 Explanation of concept ..................................................................................................... 10
      2.3.2 TranScript application example from literature ................................................................. 11
      2.3.3 TranScript, what is useful for including in INTRANS and what not? ............................. 12
   2.4 Scheme of Analysis for analyzing the functional dynamics of a TIS .................................... 12
      2.4.1 Explanation of concept ..................................................................................................... 12
      2.4.2 Scheme of Analysis, what is useful for including in INTRANS and what not? ............ 13
   2.5 Scenario development .............................................................................................................. 14
   2.6 SNM & TM ............................................................................................................................... 14
1.1.2 Sub-sector fuel tank size................................................................. 75
1.1.3 Sub-sector suitability for LNG equipment ...................................... 75
1.2 Operational Characteristics................................................................ 76
  1.2.1 Sub-sector fuel consumption ........................................................ 76
  1.2.2 Sub-sector geographical bunker infrastructure requirements .......... 77
  1.2.3 Sub-sector subject to port dues? ................................................. 77
1.3 Operational Environment.................................................................... 79
  1.3.1 Emission requirements ............................................................... 79
  1.3.2 Sub-sector size of fleet ................................................................ 79

Appendix 2: Conventional vs. LNG – Prices – Energy density – Volume – Initial investment ....81
Appendix 3: TranScript application example ..................................................83
Appendix 4: Interview Summaries ..............................................................89
Chapter 1: Introduction

1.1 LNG is a solution to the maritime pollution problem

The world-wide maritime sector is anno 2015 still the ‘wild-west’ in terms of allowed fuels and emissions. The standard marine fuel for sea-going vessels is heavy fuel oil (HFO); basically the residue of oil refineries. HFO is very competitive in price, but has high environmental impacts; HFO combustion results in significant emissions of CO$_2$, NO$_X$, SO$_X$ and particulate matter PM. Where CO$_2$ is known as greenhouse gas (GHG), air pollution due to emission of SOx, NOx and PM has a big impact on human health and vegetation. Staggering statistics show that just 16 of the world’s largest ships produce as much lung-clogging sulphur pollution as all the world’s cars (Pearce, 2009). Since other transport modalities and industries worldwide are subject to heavy environmental regulations striving for a more sustainable world, the ‘unregulated’ maritime sector is no longer acceptable from a social point of view.

Therefore the IMO, as of January 2015, has lowered the allowed sulphur content (SO$_X$) in marine fuels from 1% to 0.1% in Emission Control Areas (ECA) (IMO, 2014). In 2016 also IMO’s ‘Tier III’ shall take effect aiming at stepwise reducing NO$_X$ emissions with 80% (IMO2, 2014). Maritime shipping companies are forced to shift from HFO towards a less polluting alternative. Three feasible alternatives for reducing emissions are (1) HFO in combination with end of pipe sulphur scrubbers, (2) start using marine diesel oil MDO and (3) shifting towards liquefied natural gas LNG (Burel, Taccani, & Zuliani, 2013). Because installing power plant scrubbers is a temporary, expensive solution and diesel is up to 40% (depending on the oil price) more expensive compared to LNG (AFDC, 2014), many studies agree that LNG is the most promising alternative for marine propulsion (Burel et al. (2013); Vandebroek & Berghmans (2012); Bernatik, Senovsky, & Pitt (2011)). Off all current options LNG is by far the cleanest fuel; significantly reducing CO$_2$, NO$_X$, SO$_X$ and soot/particles (figure 1.1).

Compared to oil:

<table>
<thead>
<tr>
<th></th>
<th>CO$_2$</th>
<th>NO$_X$</th>
<th>SO$_X$</th>
<th>Soot/particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>-25%</td>
<td>-90%</td>
<td>-100%</td>
<td>-100%</td>
</tr>
<tr>
<td>Health/vegetation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health/vegetation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1.1: Emission reductions LNG compared to oil, source: (SSN, LNG in Norway, 2012)

Compared to sea-going maritime vessels the European inland shipping sector is performing better in terms of emissions. This is thanks to heavy emission policies for ships on CO, HC, NOX and PM (CCRRI- and engine standards EU stage IV norms) and MDO as standard fuel. However, the potential price advantage of LNG in combination with announced increasing emission requirements makes it interesting also for the inland shipping sector to look into LNG. In addition, MDO as it is sold today cannot meet future requirements of a 0.001% sulphur limit, MDO with 0.005% sulphur content is the best that is available right now (SGS, 2012).

---

1 PM can cause cardiovascular and lung diseases, heart attacks, arrhythmias and cancer. It also affects plant growth and ecosystem processes and can cause damage and soiling of buildings. NOx and SOx can cause cardiovascular, asthma, reduction of long function and respiratory morbidity. They also acidify and eutrophicate soil and water, leading to changes in species diversity (European Environment Agency, 2014).

2 International Maritime Organization

3 ECA zones cover an area consisting of the North Sea, the English Channel and the Baltic Sea

4 LNG is natural gas cooled down to -162 degrees Celsius. It then becomes liquid and requires 600 times less volume compared to gas phase.
As a cleaner fuel LNG potentially can increase the level of sustainability in the maritime sector. Also natural gas is widely available in the world and LNG is in potential cheaper than MDO. Although the benefits of LNG as maritime fuel are strong and the pressure on maritime emission reduction increases, the adoption of LNG in the maritime sector goes very slow. Anno 2015 there is only a handful of ships in a few shipping sectors running on LNG. This leaves us with the question why this is the case, this is also the trigger to this research.

There is an increasing pressure on the maritime pollution problem. LNG seems to be a feasible solution but the adoption of LNG in the maritime sector goes very slow. Why is that?

1.2 Zooming in on the complexity of the LNG situation

The first step in figuring out why shipping companies are en masse sticking to conventional fuels is looking at the core elements of a transition to LNG. Let’s start with the technical core of the LNG solution.

Imagine LNG present in a ship and thus for a moment forget how the LNG should get there. Natural gas in a liquid state is not flammable so at a temperature of -162 °C LNG needs to be heated to convert it back to gas and combust it in a gas turbine. The electricity produced by this gas turbine then powers the engines of a ship. In the meantime LNG must be kept cold in special isolated- or membrane tanks to make sure the natural gas stays liquid and does not increase 600 times in volume. All technical equipment and pipelines therefore needs to be heavy isolated. Still always some LNG evaporates which is referred to as boil-off gas (BOG). BOG occurs when cold LNG evaporates due to heat entering the storage tank during loading, storage, unloading and transports (Dobrota, Lalic, & Komar, 2013). To prevent emitting methane, this natural gas should either be used for combustion or cooled down to liquid by BOG-units. Summarizing: conventional combustion engines and fuel tanks have to be replaced by gas turbines, LNG tanks, BOG units, safety equipment and heavy insulation before a ship can run on LNG. All of this is proven to be feasible since a handful of ships are already using LNG as a propulsion fuel.

Next to technical developments in the field of ship propulsion a transition requires infrastructural assets to transport natural gas in liquid state from source to end user. More specifically, a large scale adoption of LNG requires a multi-billion infrastructure, parallel to conventional HFO and MDO infrastructures, consisting of LNG liquefaction plants, receiving terminals, storage facilities, a transportation network and refueling facilities (Arteconi & Polonara (2013); Lin, Zhang, & Gu (2010)). Infrastructural developments are subject to classic chicken-egg games between users and suppliers. Currently there is little to no infrastructure in place for supplying LNG to the maritime sector. Also, the design of this infrastructure is still open for input. Multiple types of refuel facilities are under development, to be further analyzed in the course of this report. In the entire ARA area are for example four specific bunker locations (Amsterdam, Rotterdam, Antwerp and Mannheim) where refueling can take place on a truck-to-ship base.

Other elements that have a significant impact on the LNG situation are the public opinion on polluting emissions, policy regulations on allowed fuels, national-, European- and intercontinental emission limits, economic developments, permit granting systems (e.g. building permits, LNG permits), maritime classification- and safety standards and maritime funding structures.

Here we identify a complex, technical multi-actor situation which suggests that a transition would be the result of many changes, or transitions, in multiple areas in the network of interdependent stakeholders. We can argue that a transition will not take place as a result of changes in one or even several of the core elements. For example solving all technical issues related to the implementation

5 In the Netherlands in Q4 2014 there were three inland LNG fueled ships (Maritiem Nederland, 2014)
6 Amsterdam-Rotterdam-Antwerp area, the most commonly used inland shipping route of western Europe
of LNG on ships without a solid business case, or without a fuel infrastructure does not cause a large scale transition.

In a situation where actors are confronted with limited individual influence, investing in new, immature, technologies or markets asks for a solid investment strategy. More uncertainties obviously lead to a higher level of hesitance at stakeholders, especially when we are talking about significant amounts of money to be invested. Therefore we can argue that to facilitate a transition towards LNG, strategic (investment) decision making at key stakeholders has to be supported. This can be done by decreasing the amount- and level of uncertainties. To do this, we need to understand the transition; its key players and drivers, potential future states, transition barriers or show stoppers and possibilities to intervene. Is there a methodology which can be applied to provide us those insights?

1.3 Search for a methodology to analyze the LNG situation in the maritime sector

1.3.1 LNG publications are fact-driven rather than conceptual
Searching through scientific publications on the topic of “LNG as a maritime fuel” related to key words like transition, strategic insight, strategic decision making, analytical method, -methodology, -tool in databases ScienceDirect, Google Scholar and Scopus did not lead us to a methodology to analyze the LNG situation. We conclude, according to the publications we found, that research on this topic primarily focuses on technical feasibility (e.g. Acciaro, 2014; Burel et al., 2013; Vandebroek & Berghmans, 2012), safety aspects of LNG (e.g. Bernatik et al., 2011; Raj & Lemoff, 2009; Vandebroek & Berghmans, 2012), LNG infrastructure requirements (e.g. Jensen, 2004; Lin et al., 2010; Zellouf & Portannier, 2011) and on regulatory aspects (e.g. Dorigoni & Portatadino, 2008). This leaves us at looking for a methodology on a more conceptual level.

1.3.2 LNG situation as socio-technical transition
In scientific literature, complex, technical multi-actor situations where actors have limited individual influence are often referred to as socio-technical systems STS. Publications like (Kern, 2012; Kemp, Schot et al. 1998; Rotmans and Loorbach 2008) conceptualize socio-technical systems as clusters of aligned elements, such as technical artefacts, knowledge, markets, regulations, cultural meaning, rules and infrastructures. Transitions in STS are not caused by the change of a single factor because of the cluster alignment. They stress that transitions in STS therefore are the result of combined changes in multiple processes over time between various structures of a STS. In addition, (Chappin, 2011) uses the term distributed control to emphasize this interaction between various STS clusters: “No single actor can engineer the system – the system evolves as a result of the (inter)action of all actors involved and each actor can only partially influence the system”. The many similarities between the LNG situation in the maritime sector and the socio-technical transition concept as described here, justify shifting the search for a methodology towards the scientific scholar on transitions in socio-technical systems.

1.3.3 Literature scan for methodologies to analyze transitions in socio-technical systems
There are scientists that have published methods for analyzing socio-technical transitions. Key authors in the scientific scholarship on transitions are predominantly Dutch, of which the core authors on socio-technical transitions are Rotmans, Kemp and Geels (Chappin & Ligtvoet, 2014). In the 1980s research in the socio-technical field started to gain attention. However, it was not before the 1990s that the transition concept was introduced within the socio-technical research (Lachman,
2013). Most notable transition approaches developed since are: the Multi-Level Perspective (Geels, 2002), Strategic Niche Management (e.g. Schot, Hoogma, & Elzen, 1994), Transition Management (e.g. Rotmans, Kemp, & Asselt, 2001) and Innovation Systems (e.g. Freeman, 1995).

**Starting point: The TranScript framework**

Someone who performed research on this topic to develop a method for scripting socio-technical transitions is Anish Patil. In his publication TranScript (Patil, 2014), he discusses many of the authors and concepts just mentioned, before presenting his framework. The Transcript framework anticipates on the structural changes during transitions in STS at intermediate stages. TranScript aims at improving the understanding of transitions, by means of an actor-centered approach which helps with identifying policy levers by giving a clear idea to policy makers how to cater to the intrinsic drivers of different actors in order to nudge a transition towards a desired end-state. The framework can be explained as actors (with drivers) creating structures of assets and/or rules. At the same time actors’ actions are facilitated by structures of rules and actor’s drivers are influenced by external pressures. This clear and effective approach seems to be useful for identifying the structures of assets and rules which are required for a transition in a socio-technical system.

By constructing system configuration diagrams along with the relevant structures for a transition, TranScript provides great understanding about transitions. **However, the TranScript framework and its results are qualitative. To support key actors in a transition during strategic decision making we think it is necessary to provide a (semi-) quantitative method.** Since the other mentioned methods also seem to be rather conceptual, analytical and explaining, the development of a quantitative complement is our goal.

*In chapter 2; Literature study for INTRANS potential building blocks Multi-Level Perspective, Strategic Niche Management, Transition Management, Technical Innovation Systems and scenario development are analyzed next to the TranScript Framework. The result of chapter two is an overview of the best suiting part from multiple strands of research and understanding about what is still missing.*

The LNG situation shows strong similarities with situations which are referred to in the scientific literature as transitions in socio-technical systems. This field of knowledge contains several approaches to analyze such transitions. According to the knowledge of the author which is based on the literature scan, none of these approaches is concluding in providing all the in section 1.2 required insights. Because of the many useful components of these approaches it is argued that a new method should be developed, consisting of or inspired by a combination of the best suiting parts from multiple strands of research.
1.4 Research questions
The demand for the development of a new methodology can be translated into the main research question of this master thesis:

What structured methodology, that is generically applicable on transitions in socio-technical systems, will provide understanding of the transition; insight in its key players and drivers, potential future states, transition barriers and possibilities to intervene, in order to support strategic (investment) decision making at key stakeholders?

The development process starts with determining in more detail the type of structured methodology that is intended to be developed. The desired results after application are known, but what does that mean precisely in terms of methodology design? This leads to the first sub question:

[1] What are the requirements for a useful and effective methodology leading to the desired results as specified in the main research question?

The literature scan already showed several interesting approaches from the scholar on socio-technical systems. Before the methodology can be developed, sub question two must give insight in:

[2] What approaches, components, theories and/or lines of thought from the scholar on socio-technical systems or others are to be included in the new methodology?

The first two sub questions lead to the development of the new methodology. After this, it will be validated by applying it on the LNG case study. The applicability and effectiveness of the methodology can be determined by answering sub question 3:

[3] Does the proposed methodology provide understanding of the transition; insight in key players and drivers, potential future states, transition barriers and possibilities to intervene?

Eventually the goal is make a contribution to the literature on socio-technical transitions, where the LNG situation is treated as a case study. Therefore, after testing the modeling approach on the LNG case, it should be reflected on socio-technical transitions in general in order to answer the above main question:

[4] Is the proposed methodology generically applicable on transitions in socio-technical systems?

1.5 Research framework
The structure of the research is intended to be clarified in figure 1.2 showing the cohesion between the data input, research questions, activities and deliverables. The output as shown in this research framework thus is a new method to analyze transitions in STS meeting the requirements as defined in the main research question. For simplicity reasons during the further course of this report we give the method that we are looking for a name.

Because the method should provide INsight in multiple aspects related to socio-technical TRANSitions we call it <<Intrans>>.
1.6 Relevance of master thesis

From a scientific perspective the research presented in the master thesis report is relevant because multiple reputable approaches in the scientific scholar on socio-technical transitions are being combined to a new methodology. The contribution therefore is a new, generically applicable scientific methodology to analyze socio-technical transitions.

From a social perspective the research is relevant because socio-technical transitions predominantly are in favor of a society. The methodology is intended to facilitate key stakeholders in STS by supporting strategic decision making. Applying the proposed methodology on the LNG case study thus potentially contributes to the transition from conventional fuels towards LNG in the maritime sector. LNG has virtually no sulfur content and its combustion produces low NOX compared to heavy fuel oil and marine diesel oil. In this specific case also potential economic advantages play part as LNG potentially being cheaper than conventional fuels in the maritime sector.

1.7 Further course of the report

Chapter 2 zooms in on the actual requirements for INTRANS and takes the literature scan from section 1.3 to the next level. The existing approaches are analyzed in more detail and a discussion on what is useful to include in INTRANS takes place. In chapter three this knowledge is used in order to actual develop the new method. In 3.1 the conceptual framework will be explained and section 3.2 presents the stepwise protocol of sub-analyses to apply the conceptual framework on a case study. Chapter 4 is devoted for testing INTRANS on the LNG case study. Chapter 5 takes a step back from the LNG case study and evaluates the value of the new method. After the conclusions and recommendations in chapter 6, this thesis report will conclude with a personal reflection on the research trajectory and thesis writing process.
Chapter 2: Literature study for INTRANS

The methodologies shortly discussed in section 1.3.3 are analyzed in more detail here. Section 2.1 starts with a discussion on the type of the requested methodology. The sections after that all threat one of the approaches from the literature scan. The analyses consist of an explanation of the concept, an application example from the scientific literature and a discussion on what is useful to include in INTRANS and what not.

2.1 What are the requirements for INTRANS?

This section provides an answer to the first sub-question: what are the requirements for a useful and effective methodology leading to the desired results as specified in the main research question? In fact, the requirements for INTRANS can be directly translated from that question. INTRANS should be a (1) structured methodology that is (2) generically applicable on transitions in socio-technical systems. It should support strategic investment decision making at key stakeholders by (3) providing understanding and insight in the transition, its key players and drivers, potential future states, transition barriers and possibilities to intervene.

Where others complement the MLP framework (e.g. Foxon, 2011; Raven et al., 2012), we opt for including the best suitting parts from multiple strands of research in a new, optimal methodology. This because of the demanding nature of the methodology we are looking for, in combination with the broad range of interesting approaches published on this topic. Providing those insights asks for a representation of reality in a model; a more numerical approach in order to identify and describe future behaviors in the system. Therefore the approach will be to construct a conceptual framework; a theoretical structure of assumptions, principles and rules together with a stepwise protocol of sub-analyses. Applying the conceptual framework according to the stepwise protocol on a socio-technical transition case study then should lead to a quantifiable conceptual model. Operationalization of the conceptual model without empirical data will provide qualitative insights. Quantification with empirical data then leads to quantitative insights about e.g. threshold values or breaking points in transitions.

2.2 Multi Level Perspective framework

2.2.1 Explanation of concept

By far the most applied concept to analyze transitions in socio-technical systems is the multi-level perspective framework (Geels, 2002). Based on insights from evolutionary economics and technology studies it consists of three concepts: socio-technical regime, technological niches and landscape developments:

Socio-technical regime is the set of dominant practices, rules and technologies at the meso-level of a system that act as a selection and retention mechanism for innovations – influenced by the multi-actor network of engineers, end-users, policy bodies, lobby groups, suppliers, scientists and financial institutions.

Technological niches in MLP are seen as the micro-level where radical innovation and experimentation takes place. Niches are less subject to market- and regulation influences and therefore act as safe environments in which breakthrough developments can grow.

Landscape developments happen in the exogenous environment of the system. Landscape at the macro-level consist of a set of deep structural trends and contain a set of heterogeneous factors, such as oil prices, economic growth, wars, emigration, culture, environmental problems, political coalitions, etc. Changes take place slowly.
The relation between the three concepts is described as nested hierarchy; regimes are embedded within landscapes and niches within regimes. Normally a socio-technical regime is dynamically stable, leaving no room for innovations in technological niches. However, if landscape developments put pressure on a regime, this can create windows of opportunity for niche developments to escape the niche-level and break-through. After a while adjustments occur on regime level, causing the niche development to be incorporated in a new, dynamically stable regime. Therefore the MLP argues that socio-technical transitions occur as the outcome of linkages between developments at multiple levels. The main question to be answered with the MLP framework is how technological transitions come about; the main objective is understanding change over time. Figure 2.1 shows how socio-technical transitions come about in the multi-level perspective framework.

Figure 2.1: How transitions come about in the multi-level perspective (Geels, 2002)

2.2.2 MLP framework application example from literature
The main objective is understanding change over time. This is assumed to be the reason for the many historical case studies; for example “Exploring socio-technical transition in the electricity sector in the province of Ontario (1885-2013)” (Rosenbloom & Meadowcroft, 2014), “How biomass gasification technology has evolved in India, 1980s-2012” (Raven, Schot, & Berkhout, 2012) and the “Transition in the Dutch electricity system, 1960-2004” (G. Verbong & Geels, 2007).

Another example of a live changing transition is the transition from sailing ships to steamships (1780-1900). (Geels, 2002) applied the MLP framework on this historical case study to understand how this transition happened and to illustrate the applicability of his framework. The following is a summarized version of the original analysis that is published in the journal Research Policy issue 8-9 in 2002.

Describing the established regime is the first step of the analysis. The 18th century sailing ship regime was dominated by the British; countries had created monopolies and the British Navigation act restricted colonial trade to their own ships. Ships were made of wood and cargo-holding capacity was more important than speed. The latter was encouraged by guaranteed markets and by government
regulations; in particular the Tonnage Laws (1773), which based tax on ship breath and not the hold. Mail was in that time a crucial means for telecommunication and co-ordination.

Secondly the identification of landscape developments that started pressing on the regime. First there was the American War of Independence (1776-1783). American traders turned their attention to the Atlantic, Mediterranean islands and China, were they needed faster ships to evade patrols of the British East India Company. These market niches stimulated the emergence faster ships. Another development was the increasing freight prices and demand for ships stimulated by the French Wars (1789-1815). Professional ship-owners, shipbrokers and insurance companies emerged; the European fleet doubled, shipbrokers increased efficiency in shipping and insurance companies decreased risks.

Market niches for faster ships were urgent shipments, pressing mail and hurried passengers. Another market niche in general was the interconnected network of inland waterways that emerged in the context of the “canal-boom”. First experiments with steamships in the late 18th century happened there. The first market niche with steamships was created in 1807 on the Hudson River in America, for passenger services. Britain followed in 1812 when Henry Bell began offering commercial passenger services with steamships. Low coal efficiencies forced steamers to carry a lot of coal, so there was little capacity to transport freight. This restriction caused that steamers could only exists commercially focusing on passenger and mail traffic, together with low-volume high-value cargo.

In 1838, the British government introduced mail subsidies to stimulate the use of steamships for mail transportation. The subsidies created a protective niche environment for the use and development of oceanic steamships to improve communication and co-ordination in the freight shipping regime. This initiated an innovation wave in the 1840s.

Three major landscape developments then are identified. First, passenger transport on the North Atlantic boomed because of European emigration to Northern America, caused by the Irish potato famine, European political revolutions and the Californian gold-rush. Second, development of liberalization led to the abolishment of the British Navigation Acts (1849); between 1840 and 1887 there was a seven-fold increase in sea-born commerce. Third, the opening of the Suez Canal (1869) abled steamships to enter the long-distance freight shipping; competition increased and led to an innovation race on iron hulls, screw propulsion and better engines. These developments caused steamboats to break-out of the subsidized mail transport niche and to be included in the shipping regime (1850s+).

2.2.3 MLP, what is useful for including in INTRANS and what not?

The analysis of the socio-technical transition from sailing ships to steamships first of all emphasizes the explaining character of the MLP framework. The concept of landscape developments, socio-technical regimes and technological niches clearly provides understanding about change over time. The shipping regime through the years changed several times, initiated by landscape developments that on their turn provided opportunities to create market niches. Technological developments in protected niche markets, like the subsidized mail transport niche, than await a window of opportunity to break out, which is caused by changes in the landscape.

Geels showed that by deep-diving into a historical transition it is possible to identify the three concepts. By putting them into a series of adaptations and changes over time it is shown that there is no sudden shift from one regime to another, but that it is a stepwise process of reconfiguration where new regimes gradually grow out of the old ones.
Since we are focusing on ongoing-and future transition in this research, the MLP framework (Geels, 2002) cannot be used in its intended way. The identification of the socio-technical regime, landscape developments and technological niche developments however leads to great understanding of the system and the drivers for transition. Therefore the identification of these three concepts is proposed to be the starting point of the analysis to further build upon.

2.3 TranScript framework

2.3.1 Explanation of concept

TranScript framework (Patil, 2014) describes transitions as a process through which one or more new structures are established. It anticipates on the structural changes during transitions in socio-technical systems by means of an actor-centered approach. It basically states that structures (technical asset or institutional rule) are created by actors with a certain motivation. These structures, together with system conditions, are then facilitating actions at other actors. Figure 2.2 shows a schematic representation of the TranScript framework.

![Analytical Framework - TranScript (Patil, 2014)](image)

**Actors** have their own attitudes, agendas and perspectives; these form the intrinsic drivers for taking actions. **Structures** are technical or institutional, respectively assets and rules. Assets facilitate actors to do something (e.g. machinery, infrastructure, etc.); rules enable and constrain actor’s actions. **External Pressures** shape processes; system condition of the STS activates actors to take action and these actions are shaped by rules. The arrow **Actions/Processes** describes change; the result is a structure.

To apply TranScript for analyzing transition in an STS the following research the following six steps are developed (Patil, 2014):

1) Identify the necessary conditions without the transition cannot take place.

2) Translate necessary conditions into sub-conditions. The sub-conditions should cover all required relevant structures that would help in achieving the necessary condition.

3) Apply analytical framework to identify the actors that have the ability to influence these structures and the drivers required to motivate these actors. Each structure is produced by an actor.
4) Plot all the assets to get an overview of the total system in an AND/OR diagram.
5) Produce a system configuration diagram along with the relevant structures for transition.
6) Interpret the system configuration diagrams to outline the conditions under which this transition would take place.

2.3.2 TranScript application example from literature

Patil (2014) applied the TranScript framework on three transition case studies in STS in his publication to obtain the degree of doctor at the Delft University of Technology: Scripting Transitions; A framework to analyze structural changes in socio-technical systems. One of the three is the “Greening of Gas” case study. It studies the transition from the existing natural gas system towards a mixture of hydrogen and natural gas within the Netherlands. Mixing hydrogen with natural gas in the existing grid would be a head start towards a hydrogen economy, bringing economic- and environmental benefits. In appendix 3 a shortened version of the original application of the TranScript framework is presented. The following is a summary to only explain the application of the framework.

The first step prescribes the identification of the necessary conditions without the transition cannot take place. Greening of gas cannot happen without (1) excess hydrogen capacity in place and (2) being able to feed hydrogen into the existing network and having appliances that are compatible with the natural gas and hydrogen mixture. The second step is to translate these necessary conditions into sub-conditions. It is a process of finding all required relevant structures that would help in achieving the necessary conditions. This is done by asking the right (simple) questions. In the case of necessary condition 1 we need to ask: can we create excess hydrogen? The answer to this question is yes, excess hydrogen can be produced in three ways; green-black and carbon neutral hydrogen production. Each of these production methods lead to several subsequent questions. In the case of green hydrogen production (electrolysis of water using green power) questions are (1A) can we build new green power capacity? (1B) can we supply this green power to the grid? and (1C) can we convert this green power into hydrogen? After finding all relevant sub-conditions, step three is to identify the structures required to achieve them. Installing hydrogen capacity (structure) is done by actors in the Energy Sector, who are motivated by the rule Dutch Climate & Energy Policy together with system conditions “rising emissions” and “depletion of fossil fuel resources”. The Dutch climate policy on itself is developed by the actor Dutch government, motivated by the Kyoto Protocol (rule), rising emissions (system condition), security of supply (rule) and depletion of fossil fuels (system condition).

The fourth step provides the analyst an overview of all relevant assets that are required to achieve the necessary sub-conditions. The overview is created by constructing an AND/OR diagram with the relevant assets making transition paths visible. In the Greening of Gas case study the highest asset is hydrogen production, which will be established by the lower level assets Green Hydrogen, Nuclear Hydrogen, OR Black Hydrogen. Next, for example green hydrogen can be established only if the assets Green Power AND Green Power to H2 are present, etcetera.

The fifth step is a visualization of the required structures and how they relate to each other; where the final sixth step is about interpreting these system configuration diagrams. The discussion should address the question – how can this transition come about? The guiding principle is to look for incentives and identify actors that will benefit from them when taking action. In the case of installing green power for example, investments in additional auxiliary power inevitable. However, the Dutch merit order rule prescribes that auxiliary power has to be turned off-line when for example wind mills generate power. Therefore, more green power leads to fewer incentives to invest in auxiliary power. Without incentive to invest in auxiliary power, the network will be imbalanced. The leads to the insight that a transition will be only possible when auxiliary power owners will be stimulated, for example by a change in subsidy measures initiated by the Dutch Government.
2.3.3 TranScript, what is useful for including in INTRANS and what not?

Let’s go back to STS being clusters of aligned elements where a transition requires combined changes between various structures. This makes it unmistakably important to define these structures, the stakeholders influencing them and the drivers motivating these actors. The “Greening of gas” case study shows that TranScript is a useful approach to structure a transition in terms of these necessary structures. The actor-centered approach forces the analyst to identify and assign actors to each process that leads to a new structure. Knowing the intrinsic drivers of actors creating new structures therefore provides insight in how developments of crucial structures can be stimulated or de-stimulated.

TranScript is developed for modeling any system without direct knowledge of that system and still obtains relevant insights. For a helicopter perspective this is a suited approach to roughly identify different transition paths and to determine what actors have to be mobilized to realize these paths. This is stressed to be highly effective at the disposal of policy makers, but do these insights bring enough support for strategic (investment) decision making at the key stakeholders of a transition? At individual actors it is of high importance to know when a transition becomes economically feasible. Is that feasibility moment the same for every actor in a stakeholder group? And lastly, although there is a strong focus on crucial structures and the actors “responsible” for them, the TranScript analysis does not lead to a list of transition barriers. These barriers are the reasons at key stakeholders for some of the crucial structures not being present.

Because supporting strategic decision making at key stakeholders in a transition requires, next to a helicopter overview, a more detailed feasibility analysis including numerical insights, it can be argued that a more detailed, empirical model after applying the multi-level perspective and the first three steps of TranScript is necessary.

---

In addition to the MLP, TranScript (Patil, 2014) helps in understanding and structuring a transition through the identification of crucial assets and rules. Also, the actor-centered approach forces the assignment of actors to each process that leads to these structures. Because the new methodology INTRANS should support strategic decision making at key stakeholders, it is argued that next to understanding and structuring, more emphasis should be placed on the individual feasibility of a transition. Therefore it is suggested that a more detailed, empirical approach should be developed, building further on insights gained from MLP and the first three steps of TranScript.

2.4 Scheme of Analysis for analyzing the functional dynamics of a TIS

2.4.1 Explanation of concept

Technological innovation systems (TIS) are described as socio-technical systems focused on the development, diffusion and use of a particular technology (knowledge, product or both). For analyzing the functional dynamics of a TIS, Bergek et al. (2008) published a practical scheme of analysis for policy makers; an operationalization of the innovation system perspective. The description of a number of sub-analyses is developed to identify “system failures” or weaknesses, expressed in functional terms. Policy makers that seek to identify the key policy challenges for moving a specific TIS towards formulated process goals need to go through six steps:

1) Defining the technical innovation system TIS in focus.
2) Identifying the structural components of the TIS
3) Mapping the functional pattern of the TIS
4) Assessing the functionality of the TIS and setting process goals
5) Identify inducement and blocking mechanisms
6) Specify key policy issues.

When defining the TIS, three choices of the analyst are to be outlined: (1) the choice between knowledge field or product as a focusing device, (2) the choice between breadth and depth and (3) the choice of spatial domain. The researcher chooses a focus that reflects the nature of the question raised. In the second step the actors, networks and institutions such as culture, norms, laws, regulations and routines of the TIS have to be identified. Several methods are proposed: patent analysis, bibliometric analysis, expert interviews and looking into industry associations. The third step focuses on what is actually going on in the TIS in terms of the seven key processes, or key functions: (1) knowledge development and diffusion, (2) influence on the direction of search, (3) entrepreneurial experimentation, (4) market formation, (5) legitimation, (6) resource mobilization and (7) development of positive externalities. The fourth step is normative, where the analyst assesses how well the seven functions are fulfilled, where it is also possible to specify goals in terms of how developments should reach higher functionalities. In the fifth step, mechanisms are to be identified that either induce or block a development towards the desirable functionality as formulated in step 4. Step six than translates these inducement- and blocking mechanisms into policy issues.

2.4.2 Scheme of Analysis, what is useful for including in INTRANS and what not?
The first three steps for analyzing the functional dynamics of TIS are developed for the same reason as why MLP and TranScript are introduced in this chapter; understanding and structuring. The interesting line of thought as presented in the scheme of analysis is that in order to identify inducement- and blocking mechanisms, it is first necessary to describe what is actually going on. Next step is defining how well functions are fulfilled and set goals where developments should lead to. The identification of inducement- and blocking mechanisms is done by determining what is between the current- and desired level of fulfillment of the functions. This line of reasoning is easily translated to transitions in STS, where we want to identify the transition barriers for key stakeholders that are not entering a transition. However the scheme of analysis ends after translating the inducement- and blocking mechanisms into policy issues. In our case we are also looking for possibilities to intervene. The transition barriers therefore need to be translated into direct action plans, supporting strategic decision making at key stakeholders in a transition.

The scheme of analysis to analyze the functional dynamics of TIS (Bergek et al., 2008) is considered to be a good example of a straightforward and clear roadmap for a researcher. Next to that, the line of reasoning that is used to identify system failures and key policy issues can be translated into identifying transition barriers and intervention possibilities. Where the scheme of analysis stops after identifying key policy issues, we need to go further in order to support strategic decision making at key stakeholders; the barriers need to be translated into possibilities to intervene and leading to potential future states of the system.
2.5 Scenario development
Supporting key stakeholders during strategic (investment) decision making also requires insight in potential future states of the socio-technical transition. Therefore a search in the knowledge field of scenario development was conducted for best-practice inspiration. What returns in many publications (e.g. Hughes, 2013; McDowall, 2014), is the importance of participatory involvement of expert stakeholders to scope key issues, uncertainties and possible dynamics. The actual writing of storylines will then be based on the insights gained from the expert stakeholder involvement, in combination with insights from other parts of the analysis. Given the approaches discussed in this chapter these insights will contain the driving forces, landscape developments, stakeholders, critical assets and rules, transition barriers and possibilities to intervene.

2.6 SNM & TM
The search for methodologies in publications in the field of other “most notable” transition approaches strategic niche management SNM and transition management TM doesn’t lead to satisfactory. This because where literature on strategic niche management seems to be focusing on similar concepts as MLP for understanding the early adoption of new technologies (Schot & Geels, 2008), transition management has been criticized to be focusing more on management of niche-regime dynamics than management of the transition itself (Lachman, 2013).

2.7 Conclusion
This chapter provided answers to the first and second research sub-questions. In section 2.1 it became clear that INTRANS should be a (1) structured methodology that is (2) generically applicable on transitions in socio-technical systems. It should support strategic investment decision making at key stakeholders by (3) providing understanding and insight in the transition, its key players and drivers, potential future states, transition barriers and possibilities to intervene.

The remainder of the chapter anwered the second sub-question; what approaches, components, theories and/or lines of thought from the scholar on socio-technical systems or others are to be included in the new methodology? The results of the literature study can be summed up as follows:

- The three concepts socio-technical regime, landscape developments and technological niches and their interrelations from the multi-level perspective by Geels (2002) are to be included in INTRANS for general understanding of the system and the drivers for transition.
- The conceptual framework TranScript by Patil (2014) is to be included in INTRANS where actors, with certain motivations, produce crucial structures of assets and rules which on their turn influence the actions of other actors. Applying the first three steps of the TranScript framework will help in understanding and structuring a transition in terms of necessary conditions, crucial structures, actors and system conditions and drivers.
- The scheme of analysis to analyze the function dynamics of TIS by Bergek et al. (2008) is an inspiration because of the straightforward and clear roadmap to the identification of system failures and key policy issues. The line of reasoning that is to be included in INTRANS is that the identification of inducement- and blocking mechanisms is done by determining what is between the current- and desired level of fulfillment of the functions.
- When looking into potential future states of a socio-technical system and possibilities to intervene the principles of scenario development are to be included in INTRANS. Amongst others the importance of participatory involvement of expert stakeholders is underlined to scope key issues, uncertainties and possible dynamics.

These findings are the input for actual developing new methodology INTRANS in chapter three.
Chapter 3: Developing INTRANS

To construct a quantifiable conceptual model of an ongoing transition in a socio-technical system that supports key stakeholders in strategic investment decision making, this chapter proposes a conceptual framework and a stepwise protocol of sub-analyses.

**Conceptual framework**: theoretical structure of assumptions, principles and rules. The proposed conceptual framework in chapter 3.1 can be applied on a case study following the:

**Stepwise protocol**: sequence of sub-analyses that are proposed in chapter 3.2. Applying the protocol will result in a conceptual model. Operationalization of a conceptual model can be both qualitative and quantitative. Direct use of a conceptual model leads to qualitative outcomes and insights, where feeding the conceptual model with empirical data leads to quantitative outcomes and insights.

To illustrate some of the reasoning in this chapter we introduce a simplified case study on Electric Vehicles (EVs). *In the Dutch road transportation sector a socio-technical transition from conventional fueled vehicles towards the implementation of EV’s is ongoing. In the two year period between 31 December 2013 and 31 December 2015 the total number of EV's on the Dutch roads almost tripled from 30,211 to 90,275*. In the core the transition means that an EV is chosen over a conventional fueled vehicle. More characteristics of the EV transition will be discussed where needed. The case however should be seen as a light illustration rather than empirical evidence of the validity of the methodology.

The goal of chapter three is developing a conceptual framework, which is a theoretical structure of assumptions, principles and rules, together with a stepwise protocol of sub-analyses to apply the conceptual framework on a socio-technical transition case study. This should lead to a quantifiable conceptual model of the situation. Operationalization without empirical data then should provide qualitative insights, quantification with empirical data leads to quantitative insights about e.g. threshold values or breaking points in transitions.

3.1 Conceptual framework

First of all, the conceptual framework as presented here embraces the multi-level perspective (Geels, 2002), arguing that transitions in socio-technical systems are the result of landscape developments putting pressure on a, normally stable, socio-technical regime, creating windows of opportunity for innovative niche developments to break through. After a while adjustments then occur on regime level, causing the niche development to be incorporated in a new, dynamically stable regime.

Secondly, the framework acknowledges the analytical framework TranScript (Patil, 2014), stressing that actors are at the core of a transition, creating structures of assets and rules, which on their turn facilitate actions at other actors. Because of assuming that socio-technical systems being clusters of aligned elements where a transition requires combined changes between various structures, it is argued that transitions are not feasible when some of the crucial structures in the transition system are missing. But in the case of all critical structures being present on all levels, there are still stakeholders in the core of the transition who have to make an investment decision, embracing change or not. *Therefore it argued to complement the conceptual framework with several assumptions, principles and rules focusing on the individual feasibility of embracing this change.*

---

It can be argued that without sufficient individual feasibility to embrace a certain change in behavior, a transition will not happen. Appointing the moment when change is embraced as the moment an individual stakeholder enters the transition, this can be formulated as:

**Without stakeholder entry moments there will be no socio-technical transition.**

An entry moment in the EV example would be the result of an individual who changes from driving a conventional fueled- to an electric vehicle. Buying an EV is the transition entry moment.

Focusing on the individual feasibility of entering a transition suggests that there can be a difference in the level of feasibility between actors from the same stakeholder group. The characteristics responsible for the differences between actors make it possible to divide stakeholders into several sectors, if applicable. This leads to the formulation of the next framework assumption or rule:

**Different stakeholder sub-sectors can have different entry moments in a transition.**

In the EV example two end-user types are identified; business- and private users. They have different levels of feasibility to embrace change because they are subject to different tax policies. Business users have significant tax benefits for environmental friendly means of transport, causing the level of feasibility for business users to be higher. In short, because business users do not buy-, but lease a car, they annually have to pay an additional tax (adding 25% of the car catalog value to yearly income). When the car is fully electric, the business user receives a reduction of 21 percent points.

The following framework assumptions relate to the state of a sub-sector. The first assumption here is that a sub-sector, related to the transition, can have two states; it did or did not have its entry moment. An entry moment thus changes the state of a sub-sector. The second assumption is that factors influencing a sub-sector’s state can be divided into three groups: sub-sector attributes or characteristics $A_i$, endogenous system factors $E_{k,t}$ and exogenous factors $X_{j,t}$. Endogenous system factors can be influenced by stakeholders involved in the transition and are partially responsible for the necessary transition conditions. Endogenous system factors can influence sub-sector states, but sub-sector states can also influence endogenous system factors. Exogenous factors on the other hand cannot be influenced by the system. Exogenous factors influence sub-sector states, but also endogenous system factors.

A sub-sector’s state $S_{i,t}$ is influenced by I) sub-sector characteristics $A_i$, II) endogenous factors $E_{k,t}$ and III) exogenous factors $X_{j,t}$. The interaction between these factors is illustrated in figure 3.1.

Business- or private usage of an EV is an example of a sub-sector characteristic. The policy of tax benefits stimulating green transport can be seen as an endogenous factor. It is endogenous because the system itself has influence. For example if the system’s state reaches a certain level of EV adoption, the policy will change. An example of an exogenous factor is the oil price; differences in price between conventional fuels and electricity influence the attractiveness of entering the transition or not, but the EV system’s state cannot influence the oil price.

---

8 Full tax policy can be found on http://www.autoenfiscus.nl/elektrische-auto.html
The determination of sub-sector state $S_{i,t}$ in relation with sub-sector characteristics $A_i$, endogenous system factors $E_{k,t}$ and exogenous factors $X_{j,t}$ can be mathematically expressed as follows, where 1 means that sub-sector has had its entry moment and 0 means that sub-sector has not entered the transition:

$$S_{i,t} = \begin{cases} 
1 & \text{if } S_{i,t-1} = 1 \\
1 & \text{if } f(A_i, E_{k,t-1}, X_{j,t-1}) \geq M_i \\
0 & \text{other} 
\end{cases}$$

Equation 1

$$E_{k,t} = g(E_{k,t-1}, X_{j,t-1}, S_{i,t-1})$$

Equation 2

Where:
- $S_{i,t}$ = state of sub-sector $i$ on time $t$
- $E_{k,t}$ = value of endogenous factor $k$ on time $t$
- $A_i$ = Attributes (characteristics) of sub-sector $i$
- $X_{j,t}$ = value of exogenous factor $j$ on time $t$
- $M_i$ = entry moment conditions of sub-sector $i$

Sub-sectors join a socio-technical transition when a function consisting of sub-sector characteristics, endogenous- and exogenous factors meets the entry moment conditions of that particular sub-sector. Entry moment conditions $M_i$ of sub-sector $S_i$ depend on the values of the endogenous- and exogenous factors determined by sub-sector characteristics $A_i$. A model assumption here is that when a sub-sector has an entry moment on time $t$, the sub-sector’s state is also 1 on time $t + 1$. This is however only true when a sub-sector does not exit the transition in between. In the EV case this would mean that an EV owner sells the EV and chooses to drive a conventional fueled vehicle again.

A sub-sector is a group of individual stakeholders with “state” 0 or 1; where 0 means that no entry moment has taken place and 1 means that an entry moment did take place. It is to the analyst to decide, on a case by case scenario, at what percentage individual stakeholders an entire sub-sector has its entry moment; leading to a sub-sector state = 1. The function $f(A_i, E_{k,t-1}, X_{j,t-1})$ thus captures a group of individual stakeholders in a sub-sector.
The conceptual framework as presented here builds further upon the discussed assumptions from the MLP- and TranScript framework. It is extended by including the individual feasibility of entering a transition. Different stakeholder sub-sectors can have different entry moments; a sub-sector’s state is influenced by sub-sector characteristics, endogenous system factors and exogenous system factors. In addition to that, a change in a sub-sector’s state can lead to a change in endogenous system factors, potentially causing a chain of interactions; a chain of events.

On time \( t \) the state of sub-sector business EV users \( S_B \) is determined as follows. If \( S_{B,t-1} \) is 1 (already joined transition), the state of \( S_{B,t} \) remains 1. A characteristic of business car users is that an additional tax has to be paid when the car is used for private interests. The height of endogenous factor \( E_{\text{tax},t} \) has a significant impact on the attractiveness of EV’s. Forgetting all other factors, the entry moment condition \( M_B \) would be: when \( E_{\text{tax},t} \) becomes lower than \( X\% \), sub sector \( S_B \) would have its entry moment (state change from 0 to 1). The value of the endogenous factor \( E_{\text{tax},t} \), very simplified, is determined by the value of the tax on the previous time step; on exogenous factors like 20/20/20 EU emission regulations and on the system state on the previous time step; when a stimulation program has reached its goal (system state \( X \)), the benefits cease to exist.

The interaction between sub-sector states and endogenous system factors is illustrated in figure 3.1, but what would be the result of this interaction over time? Socio-technical systems are often characterized as chicken-egg dilemmas, where structure \( X \) will not be developed before structure \( Y \) emerges and vice versa. It can be assumed that taking away one or several barriers could lead to a whole series of other events. When event chains take away the barriers for a sub-sector to enter a transition, the sub-sector state would change from 0 to 1. The interaction between sub-sector states and endogenous system factors means that a change in sub-sector state potentially causes the set of endogenous system factors to take on different values on the next time step. This new set of values potentially causes an entry moment of another sub-sector and so on. Figure 3.2 captures the interaction between event chains, factor values and sub-sector entry moments in relation to different time steps.
3.2 Stepwise protocol

The stepwise protocol of sub-analyses focuses on how to apply the conceptual framework on a socio-technical transition case study; seven steps that the analyst needs to go through. Step 1 is based on the multi-level perspective framework, step 2 and 3 are retrieved from the TranScript framework, step 4 and 5 relate to the authors contribution to the conceptual framework, step 6 is inspired on the scheme of analysis from Bergek et al. and step 7 is based on the scholar on scenario development. The way of presenting the stepwise protocol is similar to the way Bergek et al. present their scheme of analysis: first introduce the different steps before discussing them. However, in the next chapter INTRANS will be tested on the LNG case study. This is more like Patil presents TranScript; a short discussion of the framework and the steps of the analysis before testing the framework by applying it on three different case studies. The seven steps of INTRANS:

1) Starting point: defining the socio-technical system and the drivers for transition
2) Identify the necessary conditions for a socio-technical transition to happen and translate them into sub-conditions
3) Identify crucial structures of assets and rules
4) Determine stakeholder sub-sectors and their characteristics
5) Determine system variables and relations Identify transition barriers
6) Identify chains of events that could take away transition barriers

Steps 1 – 5 lead to a conceptual model which needs to be operationalized to gain the insights required to support strategic investment decision making at key stakeholders. Operationalization of a conceptual model can be both qualitative and quantitative. Direct use of a conceptual model leads to qualitative outcomes and insights, where feeding the conceptual model with empirical data leads to quantitative outcomes and insights. Step 6 and 7 make sure that the required insights about potential future states, transition barriers and intervention possibilities can be gained.

Presenting the sub-analyses in a linear fashion doesn’t mean that there is no interaction between the steps. It is for the reason of simplicity that we will discuss the seven steps sequentially; again the EV case study will help illustrating.

Step 1: The starting point: Defining the socio-technical system and the drivers for transition

The socio-technical system is conceptualized as clusters of aligned elements, such as technical artifacts, knowledge, markets, regulation, cultural meaning, rules and infrastructure. The analyst has to consider what these elements are in the situation to be analyzed. General, practical knowledge of the situation that is required in step 1 is assumed to be available through basic research: common knowledge, search on the web, expert interviews etc.

The transition from conventional fueled cars towards EV’s can be described as a transition in the socio-technical system for land-based road transportation. The elements of this STS are shown in figure 3.3.

Next, the socio-technical regime, landscape developments and technological niche developments have to be identified by the analyst, as elaborated on in chapter 2.

Very simplified the regime of land-based road transportation is characterized by conventional fuels being mainstream and stakeholders having huge interests to keep it that way. Landscape developments like high oil prices and growing global awareness for emission reduction can put pressure on this regime. This external pressure creates a window of opportunity for technological developments in niches (like EV’s) to enter the regime level, possibly supported by a subsidy policy to stimulate environmental friendly transportation.
Step 2: Identify the necessary conditions for a socio-technical transition to happen and translate them into sub-conditions

Retrieved from TranScript (Patil, 2014), the analyst has to determine the necessary conditions that he assumes are needed to facilitate a transition. Next, all required relevant structures that help in achieving these conditions should be identified. A general rule of thumb is to identify all the assets first and then follow with all the Rules. Once the assets are identified, rules can be identified that shape the processes that develop them. In practice we saw in chapter 2.3.2 TranScript application example from literature that the necessary conditions can be further “studied” by answering numerous sub-questions. Therefore the deliverable flowing from this second step is a list of sub-questions that study the necessary conditions.

Step 3: Identify crucial structures of assets and rules

Also adopted from the TranScript research methodology is the assumption that all assets and rules required to satisfy the necessary sub-conditions are (to be) produced by actors. These actors have to be identified, together with the drivers that motivate them. The result of step three is an overview with the relevant actors per sub-question, the structures (to be) developed, the actions that lead to these structures and the system conditions and rules that motivate these actors. Examples of some methods to identify actors in a specific industry are (Bergek et al., 2008):

- **Industry associations** are a good source, as are exhibitions, company directories and catalogues.
- **A patent analysis** may reveal the volume and direction of technological activity in different organizations and among individuals and may thus be a useful tool to identify firms, research organizations or individuals with a specific technological profile.
- **Bibliometric analysis** (volume of publications, citation analysis, etc.) will provide a list of the most active organizations in terms of published papers etc. and these organizations will include not only universities but also institutes and firms.
- **Interviews and discussions with technology or industry experts** (gurus) as well as with firms, research organizations, financiers etc., is a good way to identify further actors. This may be called a “snowball” method to identify actors, where each actor may point to additional participants.

One of many required structures in the EV case is an (inter)national charging network. Without a dense network EV’s run out of power. Market parties should provide these assets to take away this barrier. External pressures and motivation for market parties are rules and system conditions like return on investment, EU subsidies, building permits, etc. And if for example in the EV case a local government’s permit granting system on charging points is not cooperative, potential EV users cannot charge and therefore will not buy an EV.
Step 4: Determine stakeholder sub-sectors and their characteristics

The analyst has to identify all relevant characteristics that are causing a difference in feasibility to enter a transition between actors from the same stakeholder group. The first step is determining which stakeholder group(s) is/are composed of actors with clear mutual differences. These stakeholder groups have to be further divided into sub-sectors. Next step is the identification of the characteristics that cause the differences between the stakeholder sub-sectors. A rule of thumb that we would like to introduce is that in general sub-sectors have three types of characteristics:

- Design characteristics
- Operational characteristics
- Operational environment characteristics

In the land-based road transportation sector we distinguish several applications of electric powered vehicles. Three of them are cars, trucks and buses. It could be argued that there is a difference in feasibility to go electric between these sub-sectors. Two design characteristics having an impact on the feasibility are size (is there enough space for a battery?) and lifespan (determines economic feasibility). Examples of operational characteristics are the average traveled distance (range of battery) and geographical route (charging points). Examples of operational environment characteristics are the compliance to different emission requirements and for example different financial possibilities.

Step 5: Determine system variables and relations

Our conceptual framework states that a sub-sector entry moment changes a sub-sector’s state. In this step the analyst describes the relations between the sub-sector characteristics, endogenous factors (mainly the assets and rules from step 3) and exogenous factors (mainly the landscape developments from step 1). The goal is to first construct a basic conceptual model with the most important relations. The basic model can be increased in complexity by taken into account more groups of endogenous- and exogenous factors, making it more realistic:

A (basic) INTRANS model of a socio-technical transition system can be increased in complexity and reality by adding endogenous- and exogenous factors that influence the moment of entry of sub-sectors.

The relations can be described according the basic formula that is introduced in the previous chapter:

\[
S_{i,t} = \begin{cases} 
1 & \text{if } S_{i,t-1} = 1 \\
1 & \text{if } f(A_i, E_{k,t-1}, X_{j,t-1}) \geq M_i \\
0 & \text{if other}
\end{cases}
\]

If a function of sub-sector characteristics, endogenous system factors and exogenous factor exceeds the entry moment conditions of that particular sub-sector, an entry moment will take place. The entry moment conditions are identified in step 2 as the necessary sub-conditions, leading to all crucial assets and rules in step 3.

Operationalization of the conceptual model can be both qualitative and quantitative; the analyst has to decide based on the questions he intends to answer. Direct use of a conceptual model leads to qualitative outcomes and insights, where feeding the conceptual model with empirical data leads to
quantitative outcomes and insights. Quantifying thus asks for assigning real data to the sub-sector characteristics, endogenous system factors and exogenous system factors. Quantification of the model can be done in Microsoft Excel. A quantified model allows us to analyze what happens to model parameters on different time steps when there is a change in

**Step 6: Identify transition barriers**
Transition barriers are defined as everything that blocks sub-sectors to enter the transition. There may be quite different things that block developments like the absence of certain crucial assets or rules, or threshold values of endogenous- and or exogenous factors that are not reached.

The basic thought here is; *what do we need, what do we have now and what should happen to go from what we have now to what we need.* Qualitative operationalization of the conceptual model gives us insight in what crucial assets or rules are missing for sub-sectors to embrace change. When looking into the threshold values, quantification of the model is required.

For the complete picture is it highly recommended to have participatory involvement of representative actors from stakeholder groups to get their perspective on transition barriers. On the one hand this results in high-quality input to the model. On the other hand misunderstandings and misconceptions about the exact transition barriers at stakeholders and stakeholders not finding each other might be a transition barrier itself.

**Step 7: Identify chains of events that could take away transition barriers**
In this step the analyst gains insight in the potential future state of the socio-technical transition he is researching. Given the interaction between endogenous system factors and sub-sector states, the analysis has to identify potential event chains that in a series of time steps take away enough barriers to facilitate sub-sector entry moments. The interaction also takes into account the effect on the system factors when a sub-sector enters the transition. This new set of values potentially causes an entry moment of another sub-sector and so on (chicken-egg).

The analyst has to acknowledge the importance of participatory involvement of expert stakeholders to scope key issues, uncertainties and possible dynamics. The actual writing of storylines (event chains) will then be based on the insights gained from the expert stakeholder involvement, in combination with insights from other parts of the analysis; the driving forces, landscape developments, stakeholders, critical assets and rules and transition barriers.

Stakeholders can use the identified event chains during strategic investment decision making by translating them into possibilities to intervene.
3.3 INTRANS research framework

In figure 3.3 the seven steps of INTRANS are visualized in a research framework. On a high level the input and output for the different sub-analyses are drawn. A deep-dive into the case study of interest is necessary for all of the steps. In the figure the sources of information that are used to analyze the LNG transition case study are already presented as an example. The green squares represent the theoretical input per sub-analysis. Step one to five result in a conceptual model that can be operationalized to perform steps six and seven. In most cases it is required to also quantify the conceptual model in order to also come up with numerical information. The next step is testing INTRANS on the LNG transition case study in chapter four.

Figure 3.3: Research framework INTRANS
Chapter 4: Testing INTRANS on LNG case

This chapter reports on testing INTRANS on the socio-technical transition from conventional fuels towards LNG in the maritime sector, the case study which is introduced at the beginning of this report. Analyzing the situation through the seven steps requires a substantial amount of data. Section 4.1 discusses the different sources that are exploited during the analysis. Because a significant part of the information originates from interviews with key stakeholders from the socio-technical system, also the set-up of these interviews is discussed there. Applying INTRANS on the LNG case study starts in section 4.2. After reporting on each of the seven steps this chapter concludes in section 4.5 with discussing the results; the value of the insights gained to support strategic investment decision making at key stakeholders.

4.1 Data gathering LNG situation

During the course of this research the author was contracted as an intern at Argos Energies Rotterdam. As a leading player in the European bunker market the core principle of Argos is supplying any required marine fuel at every possible specification at any desired moment. In that period (Q3 2014 – Q1 2015) Argos was in the starting phase of designing an LNG bunkering vessel for supplying inland-, short-sea and deep-sea ships with LNG on a ship-to-ship base; the Argos GL. Working together with the project manager / business developer provided direct access to the following information resources:

- Argos GL project meetings + technical meetings
- Argos GL project excursions to visit project members
- Dutch National LNG platform meetings – key speakers with updates from the LNG field
- LNG Bunkering Summit Amsterdam 2015, 26-28 January 2015

Two other major sources of information are:
- Published LNG research reports
- 26 interviews with key representatives from all stakeholder groups in the maritime fuel socio-technical system

The participatory involvement of key stakeholders plays a significant role in the analysis of the LNG transition situation. Interviewing key stakeholders is a well fit method for gaining qualitative information about people’s experiences, views and feelings. The interviews are designed following a semi-structured format. A list of topics to discuss has been the structure during all interviews. This guarantees the possibility to compare the results afterwards. The following interview structure is used in the conversations with key stakeholders from the maritime socio-technical system:

1. Introduction of stakeholder and personal job functions
2. Main drivers of stakeholders related to LNG
3. Perspective to powerful players in socio-technical system
4. Perspective on transition barriers
5. Stakeholder’s potential measures to block or accelerate transition
6. Future outlook & perception of the ideal situation

The results of the interviews is summarized and documented in appendix 4. When information from the interviews is used during the seven steps of sub-analyses in the following sections in this chapter it is mentioned and discussed.
4.2 Applying INTRANS on the LNG case study according the seven steps

4.2.1 Step 1: Starting point: defining the socio-technical system and the drivers for transition

Applying the socio-technical transitions concept on the LNG situation in the maritime sector leads to the first system boundary. The actual socio-technical system that we are analyzing is the *maritime fuel system*. STS are conceptualized as clusters of aligned elements, such as technical artefacts, knowledge, markets, regulation, cultural meaning, rules and infrastructure. These elements translated to the maritime fuel system give us the following socio-technical system (figure 4.1).

![Figure 4.1: Marine fuel socio-technical system](image)

Applying the multi-level perspective framework on the maritime fuel socio-technical system to determine the origin and the driving forces of the transition asks for a short recall of the project delineation as discussed in the introduction. LNG is just one of several thinkable solutions to achieve a more sustainable maritime sector. This means that, assuming small scale LNG\(^9\) technology is a market niche development, there are other niche developments in the maritime potentially leading to a more sustainable maritime sector. There are other fuels niches like hydrogen, ultra-low sulphur diesels and methanol, but also other emission reducing technologies like sulphur after treatment scrubbers. The reason why these niches started to develop is a change in the socio-technical regime in the maritime sector during the past decade(s): there is an increasing socially awareness of protecting the environment and improving people’s health.

Table 4.1 summarizes the key features of technological niches, socio-technical regimes and emerging trends in the socio-technical landscape of relevance to the (European) maritime fuel system related to sustainability goals.

---

\( ^9\) Because LNG is also imported to inject in the natural gas grid, LNG for transportation fuel application is often referred to as small scale LNG
Table 4.1: Key features of technological niches, socio-technical regimes and landscape developments in maritime fuel system

<table>
<thead>
<tr>
<th>Key Features</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Landscape developments</strong></td>
<td>Macro-economic &amp; socio-economic trends The global credit crunch, 2008: After a period of massive investments, overcapacity was the result in a declining shipping market. Anno 2015 the maritime shipping sector is still recovering. Oil prices were very high but made a huge drop in 2014 and 2015 leading to cheaper conventional fuels – low oil prices are temporary. Unemployment has been growing during the recession. EU has put a lot more emphasis on low carbon technologies to contribute to job and wealth creation. Macro-political trends Increasing political instability in regions like the Middle-East and Russia - Europe strives to become self-sufficient regarding energy. Major shift in public opinion on global warming - Increased importance of climate change on the political agenda in the EU and the Netherlands. (Kern, 2012), (Stern, 2006), (Eurobarometer, 2008)</td>
</tr>
</tbody>
</table>

\(^{10}\) Easy oil is easy to drill, high-quality light oil. Fields of easy oil in the world are dried up.
Concluding on MLP
One of the most important developments in the socio-technical landscape is the increasing awareness of the importance of improving sustainability to protect the environment; prevent climate change and global warming. Secondly, the global credit crunch in 2008 after a period of massive investment resulted in large overcapacities in the shipping sector. These main trends in combination with changing oil prices, the demand for level playing field between different modes of transport and the European desire to become less dependent on political unstable regions like the Middle East and Russia in terms of energy supply, put pressure on the maritime regime where oil feedstock products as HFO and MDO are the dominant fuel. National, European and IMO regulations on emissions limits are developed in the past years, or are under development. This makes room for technological niche developments to break out of the development phase and enter the market.

Next to LNG there are several other niche developments. Other alternative fuels for reducing emissions are LPG, Bio, \( \text{H}_2 \), ultra-low sulphur diesel and methanol. Other emission reduction technologies are diesel-electric propulsion, after treatment technologies, \( \text{H}_2 \) injection, \( \text{H}_2 \text{O} \) addition and engine modifications. Because of the large natural gas reserves in the world, the relatively low natural gas prices and the huge emission reduction potential of using natural gas instead of oil feedstock products, LNG gets a chance to break through the niche barriers to fight for a place in the new maritime fuel regime. Of course many challenges have to be overcome. What are the necessary conditions without the transition cannot happen?

4.2.2 Step 2: Identify the necessary conditions for the transition to happen and translate them into sub-conditions
Without the following conditions a large-scale transition from conventional fuels towards LNG in the maritime sector cannot take place:

- **Necessary condition 1: Total LNG infrastructural chain**
- **Necessary condition 2: Presence of LNG end-users**
- **Necessary condition 3: Availability of natural gas**

The *first necessary condition* is the availability of a total LNG infrastructure. Figure 4.2 shows the infrastructural supply chain necessary to supply ships with LNG. It starts at a gas well where natural gas is produced by on- and off-shore production platforms. The next step in the supply chain is a liquefaction plant. In this plant the produced natural gas is cooled down to minus (-) 162 degrees Celsius in order for natural gas to become liquid. Loosing 600 times of its volume LNG is then pumped into huge (200.000m\(^3\)+) LNG carriers to be transported overseas. The final destinations of LNG carriers are LNG import terminals like GATE in the Netherlands (capacity of 12 billion m\(^3\)/year). Because this part of the infrastructure is already installed to serve the large scale import of LNG, it is left outside of the further project scope. The next part, required to serve the small-scale LNG market still has to be designed. It consists of transport from the import terminal to smaller LNG storage facilities. From these facilities a network of refuel possibilities is required in order to refuel ships that are fueled by LNG.

The *second necessary condition* is the presence of LNG end-users. It may be clear that even if there is a dense LNG bunkering infrastructure available, without LNG users there will be no transition.

The *third necessary condition* is the availability of natural gas. Natural gas is widely available in the world and therefore in this research there is assumed that there also will be LNG available in the future. That is why this third necessary condition will be left outside of the research scope.
After analyzing the LNG situation following step one and two of INTRANS the results are the identification of the maritime socio-technical system, the understanding of the driving forces of the transition and the definition of the necessary conditions “total LNG infrastructural chain” and “presence of LNG end-users” without the LNG transition cannot happen. Necessary sub-conditions Q1 to Q7 as defined here are the starting point for step three of INTRANS. Per sub-conditions has to be determined what the crucial structures of assets and rules are that determine the “outcome” of the conditions. In addition, who are the actors that are responsible for these structures and what motivates them?

Each of the necessary conditions will be studied in more detail, by answering several sub-questions. LNG infrastructure and LNG end-users basically have the same sub-questions, off course with a different interpretation. Worth mentioning is that one of the sub-conditions for the second necessary condition is actually the first necessary condition; LNG end-users require the presence of LNG infrastructure. The origin of these sub-questions again can be found in the marine fuel socio-technical system. The entire STS in figure 4.1 has to support the implementation of LNG before end-users will shift towards using LNG and infrastructure suppliers will invest in LNG technology:

Q1. Is the business case profitable?
Q2. Is there investment capital available and accessible on the market?
Q3. Do we have access to proven and mature LNG technology?
Q4. Are the required laws, regulations and permits in place to support LNG?
Q5. Can we comply with international safety standards?
Q6. Do we have access to technological knowledge and user experience best practices?
Q7. Can we have LNG available for refueling ships?

Figure 4.2: Infrastructural chain for small-scale LNG from gas source to final customer
4.2.3 Step 3: Identify crucial structures of assets and rules

According to (Geels, 2002) the multi-actor network involved in STS consist of a producer network, user groups, societal groups, public authorities, suppliers, financial network and a research network. This network can be directly translated to the maritime fuel socio-technical system where the producer network is responsible for the fuel infrastructure, user groups are shipping companies, societal groups are lobby groups, suppliers are technical equipment suppliers, the financial network exists of financial organizations and the research network is split up into knowledge centers and classification & standards agencies.

Obviously ship owners as potential LNG end users are very important in an LNG transition. The classic chicken-and-egg game takes place between them and suppliers of the LNG infrastructure supply chain. Lobby Groups serve as a transition accelerator or brake. As an accelerator they make sure that stakeholder groups reach out to each other, share best practices and give them a united voice towards (inter)national Policy bodies. We can identify four political arenas in the maritime fuel system. In these arenas structures of rules, regulations and (de)stimulation initiatives are being developed related to the LNG transition system that influence actions and decision-making in other political arenas and at stakeholders. The levels are global arena World, Europe, Member State and regional Port.

From a technological point of view developments at cryogenic LNG equipment suppliers are crucial for a successful transition. A full-scale European LNG transition requires multi-billion investments causing Financial organizations to be an important spider in the web of interdependencies. In the maritime sector classification societies determine the specs and requirements of everything on board of a ship. Next to that, the intentions related to these LNG Class & Standards should make sure that interfaces throughout Europe are smooth. Lastly, Knowledge centers are responsible for taking away obstacles on all fronts.

Now we have identified the stakeholder groups in the maritime fuel socio-technical system, we can start with identifying the crucial assets and rules per necessary sub-condition. Each structure (asset or rule) is produced by an actor. Most of the information is obtained by the participatory involvement of key representatives of the stakeholder groups. Summaries of these interviews are presented in Appendix 3. Other sources of information are table 4.1 (MLP) and desk research.

**Q1. Is the LNG business case profitable for shipping companies and infrastructure operators?**

Without a (prospect of a) profitable business case infrastructure operators and shipping companies will not invest in LNG technology. Investments are bound by the primary rule of Cost Recovery. Not considering operational factors (we will come back to that in step 4), the factors that influence the profitability of the business case are:

1) Difference in price between LNG and conventional fuels
2) Price of LNG equipment
3) Amount of subsidies granted.

Table 4.2 shows the three factors and by what or who they are influenced.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Influenced by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference in price LNG and conventional fuels</td>
<td>Oil price, LNG price, price LNG infrastructure, competition on market</td>
</tr>
<tr>
<td>Price of LNG technologies and equipment</td>
<td>Economies of scale, R&amp;D improvements, competition on market</td>
</tr>
<tr>
<td>Amount of subsidies / incentives granted</td>
<td>Port of Rotterdam, province of South Holland, national government, EU</td>
</tr>
</tbody>
</table>
Structures that influence the oil- and LNG price are landscape developments which cannot be influenced by the state of the LNG transition system. The price of LNG technologies and equipment can be influenced by the state of the transition; economies of scale will result in lower prices when production volume for these technologies increase caused by a successful transition. Still, there is not a single actor that can create a structure that increases the economies of scale. From a Rotterdam perspective, the subsidies / incentives for investments in LNG projects in the maritime sector are structures of rules initiated by four policy bodies; EU, National Government, Province of South Holland and the Port of Rotterdam.

Interviews with representatives of the Port of Rotterdam, Province of South-Holland and the Ministry of Infrastructure and Environment are conducted and table 4.3 gives a summary of the actions, system conditions & rules and structures.

Table 1.3: TranScript Subsidies & Incentives for investments in LNG projects in the maritime sector

<table>
<thead>
<tr>
<th>Actor</th>
<th>Action</th>
<th>System conditions &amp; rules motivating actor</th>
<th>Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port of Rotterdam</td>
<td>Develop instruments to become most sustainable port city and to become the biggest (LNG)bunker hub of Europe</td>
<td>IMO SECA, Health of Rotterdam inhabitants, EU 2020 targets</td>
<td>Rotterdam Climate Initiative, World Ports Climate Initiative, Port due discounts for clean ships</td>
</tr>
<tr>
<td>Province of South Holland</td>
<td>Develop instruments to improve air quality in urban areas</td>
<td>Air pollution being prime environmental cause of death in Europe, European guidelines</td>
<td>Project Clean Inland Shipping</td>
</tr>
<tr>
<td>National government</td>
<td>Develop instruments to facilitate EU TEN-T funding trajectories (Ministry of I&amp;M) Fund sustainability projects (several ministries)</td>
<td>TEN-T, Lobbying of organization like LNG platform, TNO, EICB, Lloyd’s Register, DNV-GL, shipping associations, etc.</td>
<td>Framework to access EU TEN-T funding, Safety Deal LNG</td>
</tr>
<tr>
<td>EU</td>
<td>Develop instruments for funding projects that contribute to a more sustainable, better connected Europe</td>
<td>EU Transport Infrastructure Policy, IMO SECA, EU Energy Policy</td>
<td>Directive on the deployment of alternative fuels infrastructure (COM(2013)18) – TEN-T core network</td>
</tr>
</tbody>
</table>

A short description related to the subsidy- and incentive structures from table 4.3:

Rottterdam Climate Initiative: Under the umbrella of the Rotterdam Climate Initiative, the Port of Rotterdam Authority, Deltalings, DCMR Environmental Protection Agency Rijnmond (DCMR) and the City of Rotterdam work as partners to enhance the sustainability of the city, the port and the industrial complex. Goal is to invest in sustainability and adaptation to climate change in pursuit of a healthy and future-resilient city of Rotterdam for all those who live and work here. Objective is clean air, more green spaces, dry feet, cleaner energy at lower costs and job creation in the city as well as in the port and industrial complex.¹¹

**World Port Climate Initiative:** Fifty-five of the world’s key ports, acknowledging their unique capacity as key hubs in global supply chains, have come together in a commitment to reduce their greenhouse gas emissions while continuing their role as transportation and economic centers. The mission of WPCI is to 1) raise awareness in the port and maritime community of need for action, 2) initiate studies, strategies and actions to reduce GHG emissions and improve air quality, 3) provide a platform for the maritime port sector for the exchange of information and 4) make available information on the effects of climate change on the maritime port environment and measures for its mitigation.\(^{12}\)

**Port due discounts for clean ships:** Direct stimulation program in the form of granting discounts on port dues in the case of more sustainable ships, or even on LNG fueled ships. Also priority access for more sustainable ships can be granted at terminals.

**Project Clean Inland Shipping:** Main objective of the CLINSH project is demonstrating how improving the emission performance in the existing inland waterway fleet can improve air quality in urban areas. Focus is on state-of-the-art (emission reduction) technologies, fuel transition, on-shore power, high resolution modeling and awareness creation among skippers and policymakers.

**Safety Deal LNG:** Partnership between the Dutch National LNG platform, National Government, knowledge centers and the Dutch fire department. Financed by the ministry on Infrastructure and Environment (€350.000), the ministry of Economic Affairs (€350.000), the ministry of Safety and Justice (€90.000) and the industry (€350.000) the goal is to gain knowledge about safety aspects of LNG and develop suiting legislation.\(^{13}\)

**EU TEN-T:** As of January 2014, the European Union has a new transport infrastructure policy that connects the continent between East and West, North and South. The subsidy budget is €25.05 billion up to 2020.\(^{14}\)

**Q2. Is there investment capital available and accessible on the market?**

An interview is conducted with the director of Energy Transition and Public-Private Partnerships at ING Netherlands, a leading Dutch multinational banking and financial services corporation.

Without possibilities to loan money from banks, investments in LNG projects will be very limited. Since the credit crunch (2008) banks are heavily restricted by the ECB in their freedom in taking risks. Banks are obliged to reserve a certain percentage of a provided loan as private equity. This obliged percentage increases when the risk of a loan increases. The risk differs per asset class; assets in asset classes generate cash flow, have residual values, etc. The higher the risk, the more private equity a bank needs to reserve, the less money it can make per Euro loaned. Imagine a niche market where resale values don’t exist yet in combination with a conventional market taunted by overcapacity. Risks in the maritime sector thus are considered to be high. From a financial organization’s perspective it is therefore not attractive to grant funding to the maritime sector. Especially the inland shipping sector, mainly consisting of small organizations with often not more than one inland ship have a hard time in finding funding options for their projects. Maritime shipping organizations are rather big with many assets and high cash flows. Funding for sea-going vessels therefore is way less of an issue. Table 4.4 gives an overview of the action, system conditions and developed structure of financial organizations.

---


Table 4.4: TranScript framework of loaning by asset classes - investment capital rules

<table>
<thead>
<tr>
<th>Actor</th>
<th>Action</th>
<th>System conditions &amp; rules motivating actor</th>
<th>Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial institutions</td>
<td>Develop instruments to prevent 2008 from happening again</td>
<td>ECB regulations</td>
<td>Loaning by asset classes — higher risk means more private equity — less profit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Social responsibility</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Return on Investment</td>
<td></td>
</tr>
</tbody>
</table>

Q3. Do we have access to proven and mature LNG technology?
Technology is at the core of an LNG transition. Both infrastructural assets as LNG fueled ships require mature, proven safe LNG technology and equipment. The developments in LNG technology go fast but due to small production volumes and oligopolies of technology firms prices are high. Also many LNG projects are subject to start-up problems which suggest that still some more developments have to improve the quality of LNG technology. For example LNG storage tanks are specially designed case-by-case and ship engines are subject to methane slip due to technology immaturity. However, all types of combustion engines have 1-2% unburned fuel as emissions. In the case of LNG this means the emission of methane which is roughly 30 times more potent as a greenhouse gas than CO₂. From the stakeholder group of LNG technology and equipment suppliers four representative companies were involved in this research; General Electric (gas engines), Volvo Penta (diesel engines), Rommert Ship Design and de Kooiman Groep (Shipyard). Table 4.5 summarizes the structures of LNG technology and equipment suppliers. LNG technology thus is proven and safe, but not yet mature.

Table 4.5: TranScript LNG technology and equipment suppliers assets

<table>
<thead>
<tr>
<th>Actor</th>
<th>Action</th>
<th>System conditions &amp; rules motivating actor</th>
<th>Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG technology and equipment suppliers</td>
<td>Invest in and develop more cost-effective LNG technologies</td>
<td>TEN-T subsidies</td>
<td>Cost effective LNG tank storage systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IMO SECA</td>
<td>Spark ignited LNG engines</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Classification requirements</td>
<td>Diesel / dual fuel engines</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Technical knowledge</td>
<td>Boil-off-gas units</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Return on Investment</td>
<td>SOx scrubbers</td>
</tr>
</tbody>
</table>

Q4. Are the required laws, regulations and permits in place to support LNG?
LNG infrastructures as well as LNG end users are subject to many laws, regulations and permits in all four political arenas. Table 4.6 includes the most important structures we are dealing with and the system conditions and rules that are motivating the policy bodies. The world level applying to sea-going vessels is dominated by the International Maritime Organization (IMO); the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships. On European level the inland shipping sector is subject to regulations as provide by the ADN – the European agreement part of UNECE concerning the international carriage of dangerous goods by inland waterways. Next to the ADN, the inland shipping sector is subject to regulations provided by the Central Commission for Navigation of the Rhine – encouraging European prosperity by guaranteeing a high level of security for navigation of the Rhine and its environs. In our research participated representatives from the ADN safety committee, Ministry of Infrastructure and Environment and the Port of Rotterdam.
<table>
<thead>
<tr>
<th>Actor</th>
<th>Action</th>
<th>System conditions &amp; rules motivating actor</th>
<th>Structures</th>
</tr>
</thead>
</table>
| World - IMO           | Develop instruments for reducing SO$_x$ and NO$_x$ emissions for sea shipping | MARPOL treaty, Global warming, World's health | SECA & NECA Tier I, TIER II, Tier III, Baltic Sea SO$_x$, North Sea SO$_x$,
|                       |                                                                        |                                             | North American East and West coast NO$_x$ & SO$_x$, US Caribbean ECA: NO$_x$ & SO$_x$ |
| National Government   | Develop instruments to facilitate developments that are beneficial for Member State – rules and regulations for stimulating LNG | European legislation, IMO SECA, State treasury, Public health and welfare, TNO technical facts | Prospect of stable future policies, Framework that LNG bunkering permits should be granted by local authorities, Tax policy framework |
| Port of Rotterdam     | Granting permissions, facilitating progress.                          | IMO SECA, Rotterdam Climate Initiative, World Port Climate Initiative, TEN-T subsidies, Return on Investment | First port in EU to put all mandatory rules & regulation in place for the bunkering of LNG, Facilitate developments of LNG (break-bulk) terminal, LNG training center. |
**Q5. Can we comply with international safety standards?**
In the maritime sector classification societies establish and maintain technical standards for the construction and operation of ships. Classification societies set technical rules, confirm that designs meet these rules, they check ships during the process of constructing and also keep checking ships to make sure that they continue to meet the rules. Next to that, the classification societies are responsible for making sure that interfaces between different structures throughout Europe are smooth. The two biggest and most notorious classification & standard societies in the maritime sector Lloyd’s Register and DNV-GL are involved in this research. Table 4.7 shows the structures and motivation.

**Table 4.7: TranScript structures of classification & Standard societies**

<table>
<thead>
<tr>
<th>Actor</th>
<th>Action</th>
<th>System conditions &amp; rules motivating actor</th>
<th>Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classification &amp; Standard societies</td>
<td>Develop instruments for safeguarding and improving life, property and environment.</td>
<td>Extreme safety</td>
<td>Classification requirements (rules, guidelines and standards) that make sure that processes, equipment and people do what they are supposed to do and that interfaces support each other.</td>
</tr>
<tr>
<td></td>
<td>Return on Investment</td>
<td>Client wishes</td>
<td>Creation of support for LNG at policy bodies and end users.</td>
</tr>
<tr>
<td></td>
<td>Return on Investment</td>
<td>IMO SECA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Client wishes</td>
<td>ADN</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IMo SECA</td>
<td>CCNR</td>
<td></td>
</tr>
</tbody>
</table>

**Q6. Do we have access to technological knowledge and user experience best practices?**
The right knowledge has to be available to the right stakeholders. Research can take away barriers on all fronts and sharing knowledge therefore is a key requirement for efficient development of the right structures by individual stakeholders. Next to that, intermediate parties are necessary for connecting groups of companies and organizations with governmental organizations. Connecting those stakeholders will result in more efficient developments of structures, information trading and the formulation of a united voice with a strong lobby power. In the case of the LNG transition system knowledge centers like the EICB and TNO perform research to take away technological and societal barriers. TNO is founded by law to enable business and government to apply knowledge. Goal is to connect people and knowledge to create innovations that boost the sustainable competitive strength of industry and well-being of society. The EICB – Expertise- and Innovation Centre for Inland Shipping has as goal is to inform the inland shipping sector about programs, initiate projects for these programs and prepare innovative projects. It’s all about producing and sharing knowledge and connecting stakeholders. The Dutch LNG platform connects parties with mutual interests and gives them a united voice towards the National government. These three representatives are involved in this research; table 4.8 shows the structures and motivations.
Table 4.8: TranScript structures for knowledge production and knowledge sharing

<table>
<thead>
<tr>
<th>Actor</th>
<th>Action</th>
<th>System conditions &amp; rules motivating actor</th>
<th>Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>EICB</td>
<td>Develop structures to produce- and share knowledge and connect stakeholders in the inland shipping sector</td>
<td>Unsolved LNG challenges, Potential of inland shipping</td>
<td>International Inland Navigation knowledge network, Education program, Framework for subsidy application, Network of successful projects and studies</td>
</tr>
<tr>
<td>TNO</td>
<td>Produce and share knowledge to safeguard and improve LNG safety</td>
<td>Absence of the right laws and regulation, Absence of the right LNG education</td>
<td>Joint Industry Projects producing technological facts, Advising network to support governments with decision making</td>
</tr>
<tr>
<td>Dutch National LNG Platform</td>
<td>Develop structures for connecting companies and governmental organizations</td>
<td>IMO SECA, Green Deal Rijn &amp; Wadden, Energy policy Ministry of Economic Affairs, Environmental policy Ministry of Infrastructure and Environment, Platform Member’s wishes</td>
<td>Four core working groups with key market players tackling important challenges: safety – LNG chain – environment – bio LNG, Public Meeting framework with key speakers discussing progress to create support for LNG</td>
</tr>
</tbody>
</table>

Q7. Can we have LNG available for refueling ships?
The first part of LNG infrastructure is in development since the early 1960s; large scale import of LNG started to supply countries with natural gas. LNG is used to be injected as natural gas in gas grids, or is transported as LNG to supply off-grid areas with natural gas. Small scale LNG requires the same infrastructure as large scale LNG till the LNG is at an import terminal; Gas source – Liquefaction plant – LNG Carrier – Import Terminal. Because import terminals are way too big to provide small quantities of LNG, the second part of the infrastructural supply chain focuses on getting the LNG to the final customer. Small scale LNG infrastructure therefore demands for transport from terminal to a storage facility, the storage facilities and a distribution including transport to those refueling facilities. Representatives from the infrastructural chain stakeholder group that have participated in this research are Argos (bunker operator), GDF-SUEZ LNG Solutions (total infrastructure operator) and an LNG trader who rather stays anonymous.
Now the crucial assets and rules that are influencing the necessary sub-conditions are known, INTRANS prescribes to focus on the individual feasibility of the transition. Therefore step 4 defines stakeholder sub-sectors and determines their sub-sector characteristics. In step 5 the crucial assets and rules, the sub-sector characteristics and the landscape developments will be put in relations with the sub-sector entry moments related to the LNG transition in the maritime sector.
4.2.4 Step 4: Determine stakeholder sub-sectors and their characteristics

(Potential) LNG end-users are at the core of the transition. The feasibility however of LNG implementation is substantially different for different types of ships. The first division is the one between sea-going and inland waterway ships. Besides the differences between sea-going ships and inland ships, both sectors can be divided into another five sub-sectors. In the inland shipping sector we identify tanker-, container-, dry cargo-, passenger- and towage- & special transport ships. In the maritime sea-going shipping sector we can identify tanker-, container-, dry cargo-, passenger and offshore service vessels (wind, oil, gas). The sea-going shipping sub sector is further divided into short-sea shipping and deep-sea shipping. Short sea shipping encompasses the movement of cargo and passengers mainly by sea along a coast, without crossing an ocean. Deep-sea shipping refers to maritime traffic that crosses oceans. Figure 4.3 provides an overview of the LNG end-user sub-sectors in the sea-going- and inland shipping sector.

Inland shipping sub-sectors

Sea-going shipping sub-sectors

Figure 4.3: LNG end-user sub-sectors in the inland- and sea-going shipping sectors

Next step is the identification of the characteristics that cause the differences. This process is guided by the participatory involvement of representatives of several sub-sectors. From the inland shipping sector interviews are conducted with key representatives of industry association CBRB, inland barging company Vinotra, inland barging company Interstream Barging and towage operator KOTUG. From the seagoing maritime shipping sector interviews are conducted with key representatives of industry association KNVR and dry cargo specialist in ocean transport Spliethoff.

A rule of thumb that was introduced in chapter 3 is that in general sub-sectors have three types of characteristics:

- Design characteristics
- Operational characteristics
- Operational environment characteristics

Figure 4.4 presents the sub-sector characteristics.
As a **design characteristic** the **lifespan** of a ship influences the potential payback time of an LNG investment. The **fuel tank size** is one of factors to determine the required type of LNG bunker infrastructure. Due to the limited capacity of trucks (max 80 m³) only smaller-sized LNG-fuelled vessels can be supplied by trucks. Ships with larger fuel tanks demand other types of bunker facilities. Due to low flow rates and the time consuming event of changing LNG trucks, a fuel tank size of max 1 truck is preferable. In exceptional cases 2 trucks would be acceptable. The last design characteristic **suitability for LNG equipment** determines to what extent it is viable to retrofit a conventional ship taking into account the required larger LNG tanks, new gas turbines and other LNG equipment like a BOG unit (Boil-Off Gas\(^{15}\)).

As an **operational characteristic** the **fuel consumption** of a ship is crucial for determining the return on investment of implementing LNG. The difference in price between conventional fuels and LNG is considered to be a main driver for ship owners to look into LNG. **Shipping route** is crucial for the required type of bunker infrastructure. Fixed routes or fixed areas of operation for example require a less dense network of bunker facilities than others. Another characteristic is if a sector is **subject to port fees** or not; ports give discounts to less polluting initiatives. A last operational characteristic takes into account the huge difference in **port regulation in different ports**.

A first factor related to a ship’s **operational environment** is the type of **emission requirements** a ship is subject to. More stringent requirements require more drastic measures to reduce emissions. Sub-sector market conditions determine to a large extent the possibilities for ship owners to invest. The number of ships in a sector, developments in the demand for transport and transport prices are crucial for the investment potential of a sub-sector. Different levels of **permission trajectories** can cause different levels of difficulty in the design process between sub-sectors. A final characteristic influencing the feasibility of implementing LNG is related to **other modalities a sub-sector is competing with**. Some sectors are in threat of other modalities like road, train and plane.

---

\(^{15}\) Boil-off gas (BOG) occurs when cold LNG evaporates due to heat entering the storage tank during loading, storage, unloading and transports. It should either be used as fuel, or being cooled down to LNG again.
4.2.5 Step 5: Determine system variables and relations

We start with determining the variables that form the basic model of an LNG transition. These vary from the availability of crucial structures and variables influencing the development of these structures (step 3), to sector characteristics (step 4) and exogenous variables (step 1-2). All variables should be measurable and therefore the units are specified.

We are simulating sub-sector states, which change from 0 to 1 when a certain percentage of the individual ship owners in that sector have an entry moment. Ship owners are entrepreneurs and therefore assumed to only invest in LNG when this investment decision has a positive monetary effect. This is necessary sub-condition 1 (step 2): even if all other structures of assets and rules necessary for an LNG transition would be present, individual ship owners will not invest in LNG when the business case is negative.

The basic model therefore exists of those system variables that influence the profitability of the LNG business case for individual end-users.

Basic model: LNG business case for end-user sub-sectors

Table 4.10 provides an overview of the basic model system factors. Endogenous factors can and exogenous cannot be influenced by the state of the LNG transition system.

Table 4.10: LNG basic system factors influencing business case at end-users

<table>
<thead>
<tr>
<th>System factors</th>
<th>Unit[]</th>
<th>Exogenous / Endogenous</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 LNG price (incl. Infra)</td>
<td>P_LNG [€/ton]</td>
<td>Exogenous</td>
</tr>
<tr>
<td>2 MDO price (incl. Infra)</td>
<td>P_MDO [€/ton]</td>
<td>Exogenous</td>
</tr>
<tr>
<td>3 HFO price (incl. Infra)</td>
<td>P_HFO [€/ton]</td>
<td>Exogenous</td>
</tr>
<tr>
<td>4 Port due Discount</td>
<td>PDD [%]</td>
<td>Endogenous</td>
</tr>
<tr>
<td>5 Investment subsidies</td>
<td>Sub [%] (of LNG investment)</td>
<td>Endogenous</td>
</tr>
<tr>
<td>6 Green transport price multiplier</td>
<td>TM [%]</td>
<td>Endogenous</td>
</tr>
<tr>
<td>7 Inland emission penalties</td>
<td>I_Pen [€/yr.]</td>
<td>Endogenous</td>
</tr>
<tr>
<td>8 Maritime emission penalties</td>
<td>M_Pen [€/yr.]</td>
<td>Endogenous</td>
</tr>
<tr>
<td>9 LNG technology price reduction</td>
<td>P_Tech [%]</td>
<td>Endogenous</td>
</tr>
</tbody>
</table>

The price of LNG, MDO and HFO are exogenous factors in the basic model; the effect of a change in system state on these fuel prices is insignificant. Port due discount is a structure initiated by the Port of Rotterdam to stimulate the development of clean ships. As a stimulation measure is by definition temporary, it is an endogenous factor; if the system’s state meets the sustainability goals of the Port of Rotterdam, the PDD stimulation program will end. This goes the same for European Investment subsidies. The green transport price multiplier is added to the basic model because multiple interviewees indicated that shippers and consumers should be willing to pay more for more sustainable transport. Regulations on emission penalties are still in the making, for the inland- as well as maritime shipping sector. For the LNG system these are endogenous factors because the system’s state is the direct driver for those penalties. The final endogenous factor in the basic model is the LNG technology price reduction. It is assumed that when technologies further develop and production volume increases, the price of LNG technology will decrease.

The four sub-sector characteristics that play a role in the profitability of the LNG business case are

- Lifespan ship [year]
- Fuel consumption F_Cons [ton/year]
- Port Dues [€/year]
- Initial LNG investment [€]
An entry moment $M_i$ is defined as the moment where a ship owner / shipping company decides that a particular ship will be retrofitted into an LNG fueled ship, or that an LNG new-built is chosen over a conventional new-built. The moment of entry for an entire sub-sector is defined as the moment where at least 5 percent of the total amount of ships uses LNG as propulsion fuel or is LNG ready.

Next step is to describe the relations according to the basic formula which determines a sub-sector’s state [0 or 1]:

$$S_{i,t} = \begin{cases} 1 & \text{if } S_{i,t-1} = 1 \\ 1 & \text{if } f(A_i, E_{k,t-1}, X_{j,t-1}) \geq M_i \\ 0 & \text{if other} \end{cases}$$

Where:
- $S_{i,t}$ = state of sub-sector $i$ on time $t$
- $E_{k,t}$ = value of endogenous factor $k$ on time $t$
- $A_i$ = characteristics of sub-sector $i$
- $X_{j,t}$ = value of exogenous factor $j$ on time $t$
- $M_i$ = entry moment conditions of sub-sector $i$

A sub-sector state at time $t$ is 1 if its state at $t-1$ is 1. An entry moment happens if the yearly benefits of implementing LNG are bigger than the yearly costs, where the initial investment costs should be translated to yearly costs according to depreciation time of an LNG investment. Based on the business case of the Argos GL the monetary depreciation period of an LNG fueled ship should be approximately 50% of its lifespan. All of the above results in the following formula to calculate the state of a sub-sector on time $t$, where $f()$ equals:

$$F_{\text{cons}} \left( P_{\text{MDO}} - P_{\text{LNG}} \right) + (\text{Port Dues} \times PDD) + (P_{\text{trans}} \times TM) + E_{\text{penalties}} \geq \\
(1 - P_{\text{tech}}) \times \text{Investment}_{\text{LNG}} - (\text{Subs}_{\text{LNG}} \times \text{Investment}_{\text{LNG}} \times (1 - P_{\text{tech}})) \times 0.5 \times \text{lifespan}$$

**In words:** A sub-sector is assumed to have its entry moment when all benefits of implementing LNG added together (avoided emission penalties are also benefits) exceed the sum of the costs. The potential fuel price benefits can be determined by multiplying a sub-sector’s average fuel consumption with the price difference between marine diesel oil MDO and LNG. The potential port due discount can be determined by multiplying the average yearly amount paid as port dues with a discount percentage (depending on how clean the ship is). Adding to that the potential extra turnover generated if clients are willing to pay more for green transport and also the emission penalties that are fined when a ship’s emission exceeds the emission limit in that area, is the total sum of the benefits of implementing LNG.

The costs consist of the initial investment (which decreases ($P_{\text{tech}}$) if volume increases), reduced with the potential LNG subsidies that can be granted on the LNG investment. The costs of implementing LNG should be divided by 0.5 times the life span of the ship to estimate the yearly costs. If the yearly benefits exceed the yearly costs the sub-sector will have its entry moment.
Adding LNG Infrastructure to the basic model

Besides a positive return on investment we need a small-scale LNG infrastructure; enabling ships to bunker LNG where needed (necessary condition 2). Sub-sectors impose different requirements to this infrastructure. Sub-sector characteristics defining those requirements are:

- Fuel tank size [m³]
- Fuel consumption [ton/year]
- Geographical area of operation [area]
- Bunker profile [hour]
- Fleet size [ships]

We indicated three main refueling assets to be developed: truck-to-ship-, ship-to-ship- and shore-to-ship bunkering of LNG (necessary sub-condition 7; table 4.9). The availability of the three types of infrastructure is an endogenous factor in the LNG transition system. The development depends on the system’s state and other system factors. The availability of infrastructure can be described in the same way; a 0 on time \( t \) means that no infrastructure is developed and a 1 means that there is. The infrastructure characteristics on which the three types of infrastructure differ are:

- Minimal LNG volume to be traded by infrastructure operator [ton/year]
- Maximal capacity of ships (logistics) [LNG fleet]
- Required permits [permits]
- Geographical area of operation [area]
- Bunker profile [m³/hour]
- Capacity [m³]

Inland tanker- and container ships need a medium-high dense infrastructure because of a high variation of sailing routes. Inland dry-bulk ships often sail in schedules so only require one type of refuel facility in one place. Inland cruise ships ask for a very dense network and inland tugboats only operate in harbors so one type of infrastructure will do. Sea-going maritime ships can for logistic reasons and because of the huge volumes only be bunkered on a ship-to-ship base in harbors. Sea cruise ships also require a shore-to-ship infrastructure network because of they do not always enter a harbor. The required types of infrastructure per sub-sector are summarized in table 4.11 where truck-to-ship is TTS, ship-to-ship STS and shore-to-ship ShTS.

Table 4.11: Required type of LNG infrastructure per sub-sector

<table>
<thead>
<tr>
<th>Sub-sector</th>
<th>Inland Tanker</th>
<th>Inland Container</th>
<th>Inland Dry-Bulk</th>
<th>Inland Cruise</th>
<th>Inland Towage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Required infrastructure</strong></td>
<td>Two out of three</td>
<td>Two out of three</td>
<td>TTS or STS or ShTS</td>
<td>TTS and STS and ShTS</td>
<td>TTS or STS or ShTS</td>
</tr>
<tr>
<td><strong>Sub-sector</strong></td>
<td>Sea Tanker</td>
<td>Sea Container</td>
<td>Sea Dry-Bulk</td>
<td>Sea Cruise</td>
<td>Sea off-shore</td>
</tr>
<tr>
<td><strong>Required infrastructure</strong></td>
<td>STS</td>
<td>STS</td>
<td>STS</td>
<td>TTS and STS</td>
<td>STS</td>
</tr>
</tbody>
</table>

Concluding on the infrastructural aspect of the LNG transition the development of the different types of infrastructure depends on the availability of crucial rules (necessary sub-condition 4; table 4.6) and the traded LNG volume in the market (or expected trade). The investment decision at end-user sub-sectors is extended; not only based on the profitability of the LNG business case, but also on the availability of bunker infrastructure. The model would become even more realistic if also drivers behind the granting of permits are taken into account. System factors like the level of LNG safety requirements and public LNG support then should be added to the model. Table 4.12 gives an overview of the system factors related to the development of LNG infrastructure.
### Table 4.12: System factors related to LNG infrastructure development

<table>
<thead>
<tr>
<th>System factors</th>
<th>Unit[]</th>
<th>Exogenous / Endogenous</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Availability of Truck-to-Ship bunkering infrastructure</td>
<td>TTS [y/n]</td>
<td>Endogenous</td>
</tr>
<tr>
<td>11 Availability of Ship-to-Ship bunkering infrastructure</td>
<td>STS [y/n]</td>
<td>Endogenous</td>
</tr>
<tr>
<td>12 Availability of Shore-to-Ship bunkering infrastructure</td>
<td>ShTS [y/n]</td>
<td>Endogenous</td>
</tr>
<tr>
<td>13 Availability of European permits</td>
<td>EU permits [y/n]</td>
<td>Exogenous</td>
</tr>
<tr>
<td>14 Availability of local government permits</td>
<td>Local permits [y/n]</td>
<td>Exogenous</td>
</tr>
<tr>
<td>15 Public LNG support</td>
<td>Supp [low/med/high]</td>
<td>Endogenous</td>
</tr>
<tr>
<td>16 LNG safety requirements</td>
<td>Safety [risk of death per year]</td>
<td>Exogenous</td>
</tr>
</tbody>
</table>

This leads to the following mathematical expression to determine the infrastructure state:

\[
\text{Infra}_{zt} = \begin{cases} 
1 & \text{if } \text{Infra}_{z,t-1} = 1 \\
1 & \text{if } \\
\quad 1) \quad \text{Local and EU permits} = 1 \\
\quad 2) \quad \text{Total volume of LNG on } t \geq \text{Minimal LNG volume Infra}_x \\
0 & \text{if other}
\end{cases}
\]

**In words:** If the type of infrastructure is already present at \(t-1\), it is assumed to be also present at one time step later. The type of infrastructure will be developed if local government- and EU permits are present AND the total volume of (expected) LNG to be traded exceeds the minimal LNG volume that is necessary before that type of infrastructure becomes economically feasible. If one of these conditions is not met, there will be no infrastructure under development.

Mathematically the formulas for determining a sub-sector’s state are:

1) \[ f(\_\_) = \frac{F_{cons} \cdot (P_{MDO} - P_{LNG}) + (Port \text{ Dues } \cdot PDD) + (P_{trans} \cdot TM) + E_{penalties} \geq (1 - P_{tech}) \cdot Investment_{LNG} - (Subs_{LNG} \cdot Investment_{LNG} \cdot (1 - P_{tech}))}{0.5 \cdot lifespan} \]

2) \[ f(1,12,13) \geq \text{Infra requirements of } S_t \]
**Adding funding to the model**

A ship owner needs funding before an entry moment can take place (necessary sub-condition 2; table 4.4). A major observation from the stakeholder interviews is that especially for the Inland shipping sector it is extremely hard to loan money from banks. The inland shipping sector is dominated by small firms, often ship owners with one or several ships. The sea-going maritime sector on the other hand is dominated by large shipping companies with high value assets and cash flows, which reduces funding problems significantly. The inland shipping sector is taunted by overcapacity and poor earnings, making it a risky sector for banks to loan money to. In addition to that banks are, since the credit crunch (2008), restricted by the ECB in their freedom of taking risk. When a bank loans money to a more risky ‘asset class’, the ECB demands that the bank reserves a higher percentage private equity capital on that loan. In this way banks are still safe when times get hard, but from the bank’s perspective this means that less money can be earned per Euro loaned.

The first condition of a bank that considers a loan is of course that the LNG business case is **profitable**. Next, banks can accept a higher level of risk when an asset has a guaranteed **resale value**. Since there are only several LNG new-builds, a second-hand market does not exist yet. This is another indicator of the LNG chicken-egg dilemma; funding is required in order to eventually come to a second hand market of LNG ships, which would making it easier to get funding. Following on that, we can assume that the second hand market for LNG fueled ships increases in volume when more sub-sectors join the transition.

Getting funding for LNG projects also will become easier when market conditions improve. Current over capacity and poor earnings in the inland shipping sector are influenced by the demand for transport, **fleet size** and **transport prices**. The demand for transport is dominated by the growth of the European industrial- and energy sector. Both on their turn are dominated by the European economic growth.

Looking at the inland shipping sector, a quick ‘n dirty model calculation shows us that when 100% of the Dutch fleet invests in LNG with current technology prices (2015), would require a total funding of approximately €11 Billion. The sub-sectors Inland Cruise and Inland towage only account for 2% of this investment because of the small size of the Dutch fleet in these sectors. Therefore we can assume that funding for inland cruise ships and tugboats, next to the sub-sectors in the maritime shipping sector, is not an issue. More details about these calculations can be found in Appendix 2.

For the sub-sectors inland tanker, inland container and inland dry-bulk the funding aspect is a major transition barrier. The following sub-sector characteristics are relevant. The overcapacity on $t_0$ is approximately 15% for inland tankers and 10% for inland container and inland cruise.\(^\text{16}\)

- Fleet size
- Overcapacity
- Resale value
- Initial investment
- Profitability business case
- Earnings

The system factors that should be added to the model in order to extend the investment decision at LNG end-users with funding requirements as discussed above are summarized in table 4.13.

\(^{16}\) http://www.totaaltrans.nl/overcapaciteit-in-binnenvaart-lijkt-zich-te-stabiliseren/ (02/2015)
We now have a conceptual model that describes the relations between sub-sector characteristics, endogenous system factors and exogenous factors. The model is extended till we achieved the situation that describes these relations that a sub-sector will have its entry moment in the LNG transition when the business case is profitable AND the required LNG infrastructure is present AND the required funding structures are present. Underlying to these are the necessary conditions LNG technology, access to information, laws and regulations and safety standards. Now we can start working with this model. For obtaining quantitative insights in the situation we start with filling the conceptual model with quantitative data from 02/2015.

<table>
<thead>
<tr>
<th>System factors</th>
<th>Unit[]</th>
<th>Exogenous / Endogenous</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 ECB % private equity capital requirements</td>
<td>ECB [% on provided loans]</td>
<td>Endogenous</td>
</tr>
<tr>
<td>18 EU economic growth</td>
<td>EU [%/year]</td>
<td>Exogenous</td>
</tr>
<tr>
<td>19 Availability Inland Funding</td>
<td>Funding [y/n]</td>
<td>Endogenous</td>
</tr>
</tbody>
</table>

For simplicity reasons the mathematical expression to determine the state of funding possibilities consists of the following assumptions:

- ECB requirements are only influenced by the resale value guarantee. Low or high risk percentage therefore is determined by the amount of sub-sectors with state 1.
- The high- or low risk percentage determines the required decrease in overcapacity (or increase in EU economic growth)

$$\text{Funding}_{s,t} = 1 \text{ if :}$$

1) Business case sector $$s_i \geq 0$$
2) EU economic growth $\geq$ required growth at $$s_i$$ (ECB risk level)

$$\text{Funding}_{s,t} = 0 \text{ if other :}$$

The LNG investment decision now depends on the profitability of the business case AND the availability of LNG bunker infrastructure AND the availability of funding:

$$\text{State of funding possibilities}$$

1) \( F_{cons} \times (P_{MDO} - P_{LNG}) + (Port\ Dues \times PDD) + (P_{trans} \times TM) + E_{penalties} \geq \frac{(1 - P_{tech}) \times Investment_{LNG} - (\text{Subs}_{LNG} \times Investment_{LNG} \times (1 - P_{tech}))}{0.5 \times lifespan} \)

2) \( f(11,12,13) \geq Infra \ requirements \ of \ S_i \)

3) Available funding $\geq$ required funding of $$S_i$$

Table 4.13: System factors related to funding

For obtaining quantitative insights in the situation we start with filling the conceptual model with quantitative data from 02/2015.
4.4 Quantification of conceptual model

The quantification of the conceptual model starts with a deeper analysis on the sub-sector characteristics. Next the values of the system factors on time $t_0$ (2015) are defined. The quantified model will be constructed in Microsoft Excel to improve the visibility of the situation, to perform calculations and determine threshold values for certain transition paths.

4.4.1 Operationalization of the sub-sector characteristics

An extensive analysis on average sub-sector characteristics (appendix 1) is the foundation of the overview in table 4.14 and 4.15. The individual design characteristics, operational characteristics and operational environment of the inland shipping- as well as maritime shipping sub-sectors are presented.

Table 4.14: Inland shipping sub-sector characteristics

<table>
<thead>
<tr>
<th>Design Characteristics</th>
<th>Inland tanker</th>
<th>Inland container</th>
<th>Inland Dry bulk</th>
<th>Inland Cruise</th>
<th>Inland Towage etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifespan</td>
<td>30-34 yr.</td>
<td>30-39 yr.</td>
<td>30-39 yr.</td>
<td>40+ yr.</td>
<td>15-19 yr.</td>
</tr>
<tr>
<td>Fuel tank size</td>
<td>1 – 2 trucks (&lt;160m³)</td>
<td>1 – 2 trucks (&lt;160m³)</td>
<td>1 – 2 trucks (&lt;160m³)</td>
<td>1 – 2 trucks (&lt;160m³)</td>
<td>1 truck (&lt;80m³)</td>
</tr>
<tr>
<td>Suitable for retrofit (space)?</td>
<td>Yes</td>
<td>Yes – space loss of 1 or 2 containers</td>
<td>No – pushers have no space left</td>
<td>Yes – space loss of 1 or 2 cabinets</td>
<td>Yes – if smaller fuel tank is installed</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>500 m³ MDO / yr.</td>
<td>450 m³ MDO / yr.</td>
<td>750 m³ MDO / yr.</td>
<td>800 m³ MDO / yr.</td>
<td>500 m³ MDO / yr.</td>
</tr>
<tr>
<td>Req. bunker location density</td>
<td>Medium density</td>
<td>Medium density</td>
<td>Low density</td>
<td>High density</td>
<td>Low density</td>
</tr>
<tr>
<td>Port dues?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Emission requirements</td>
<td>CCRII</td>
<td>CCRII</td>
<td>CCRII</td>
<td>CCRII</td>
<td>CCRII</td>
</tr>
<tr>
<td>Permits</td>
<td>ADN, CCRN</td>
<td>ADN, CCRN</td>
<td>ADN, CCRN</td>
<td>ADN, CCRN</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4.15: Maritime shipping sub-sector characteristics

<table>
<thead>
<tr>
<th>Design Characteristics</th>
<th>Sea tanker</th>
<th>Sea container</th>
<th>Sea Dry bulk</th>
<th>Sea Cruise</th>
<th>Sea offshore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifespan</td>
<td>20-24 yr.</td>
<td>20-24 yr.</td>
<td>25-29 yr.</td>
<td>40+ yr.</td>
<td>25-29 yr.</td>
</tr>
<tr>
<td>Fuel tank size</td>
<td>&gt; 2 trucks – &gt; 160m³</td>
<td>&gt; 2 trucks – &gt; 160m³</td>
<td>&gt; 2 trucks – &gt; 160m³</td>
<td>&gt; 2 trucks – &gt; 160m³</td>
<td>&gt; 2 trucks – &gt; 160m³</td>
</tr>
<tr>
<td>Suitable for retrofit (space)?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>15,000 ton HFO/year</td>
<td>10,000 ton HFO/year</td>
<td>7,500ton HFO/year</td>
<td>12,500 ton HFO/year</td>
<td>10,000 ton HFO/year</td>
</tr>
<tr>
<td>Req. bunker location density</td>
<td>Medium density</td>
<td>Medium density</td>
<td>Medium density</td>
<td>High density</td>
<td>Low density</td>
</tr>
<tr>
<td>Port dues?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Emission req.</td>
<td>SECA, World</td>
<td>SECA, World</td>
<td>SECA, World</td>
<td>SECA, World</td>
<td>SECA, World</td>
</tr>
<tr>
<td>Fleet size</td>
<td>World: 14,000 NL: 200</td>
<td>World: 6,000 NL: 200</td>
<td>World: 10,000 NL: 400</td>
<td>World: 300 NL: 30</td>
<td>World: 850 NL: 125</td>
</tr>
<tr>
<td>Permits</td>
<td>IMO</td>
<td>IMO</td>
<td>IMO</td>
<td>IMO</td>
<td>IMO</td>
</tr>
</tbody>
</table>
4.4.2 Value of system factors on time \( t_0 (02-2015) \)

The value of system factors is presented in the same order as we presented the conceptual model. The model is constructed in Excel and will be discussed at the end of this section.

Table 4.16 shows the values of the system factors on \( t_0 (02-2015) \) for the basic model, based on the profitability of the LNG business case.

Table 4.16: System factor values related to the profitability of the business case at LNG end-user sub-sectors at \( t_0 \)

<table>
<thead>
<tr>
<th>System factors</th>
<th>Unit[]</th>
<th>Value on ( T_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG price (incl. Infra)</td>
<td>( P_\text{LNG} ) [€/ton]</td>
<td>473€/ton</td>
</tr>
<tr>
<td>MDO price (incl. Infra)</td>
<td>( P_\text{MDO} ) [€/ton]</td>
<td>487€/ton</td>
</tr>
<tr>
<td>HFO price (incl. Infra)</td>
<td>( P_\text{HFO} ) [€/ton]</td>
<td>322€/ton</td>
</tr>
<tr>
<td>Port due Discount</td>
<td>PDD [%]</td>
<td>+10% (&gt;CCRII) -15% (=CCRII + Green award) -30% (&gt;CCRII &gt;60%)</td>
</tr>
<tr>
<td>Investment subsidies</td>
<td>Sub [%] of LNG investment</td>
<td>30 %</td>
</tr>
<tr>
<td>Green transport price multiplier</td>
<td>TM [%]</td>
<td>0 %</td>
</tr>
<tr>
<td>Inland emission penalties</td>
<td>I_Pen [€/yr.]</td>
<td>€ 0</td>
</tr>
<tr>
<td>Maritime emission penalties</td>
<td>M_Pen [€/yr.]</td>
<td>€ 0</td>
</tr>
<tr>
<td>LNG technology price reduction</td>
<td>P_Tech [%]</td>
<td>0 %</td>
</tr>
</tbody>
</table>

The fuel price system at Argos Energies Rotterdam in February 2015 showed 473€/ton for LNG, 487€/ton for MDO and 322€/ton for HFO. Port dues in the Port of Rotterdam are increased with 10% if ships don’t comply with the CCR2 emission. A 15% discount is granted if the CCR2 emission limits are met and a 30 percent discount is granted if the CCR2 emission limits are outperformed with at least 60% (PoR, 2014). Appendix 1.2.3 shows that ships fueled by LNG can outperform the CCRII emission requirements with 60% leading to a significant discount of 30% on port dues. Regarding subsidies on LNG investments, the EICB (interview) assumes the subsidy to be on average 30% for at least the coming 5 years. No contradictory assumptions are found, so therefore it is also assumed here. The percentage of the green transport multiplier is 0% on \( t_0 \), which means that the transport price for normal and more sustainable transport is equal. In fact at Vinotra, since the introduction of the Argonon in 2011 (dual fuel 80% LNG 20% diesel), nobody specifically asked for it (interview). The inland- and maritime emission penalties are still under development; at this moment (Q1 2015) there are no possibilities to fine polluting ships. The last system factor is the LNG technology price reduction. Currently LNG technology and equipment is quite expensive. The production volume is very low and equipment often needs to be fabricated on demand. Therefore the price reduction is set on 0% on time step 0.

Table 4.17 provides an overview of the estimated average initial investment costs per sub-sector (appendix 2 provides the calculations).

Table 4.17: Estimated average initial investment costs of implementing LNG per sub-sector

<table>
<thead>
<tr>
<th></th>
<th>Inland Shipping</th>
<th>Maritime shipping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanker</td>
<td>€1 - 1.5 million</td>
<td>€7 - 9 million</td>
</tr>
<tr>
<td>Container</td>
<td>€1 - 1.5 million</td>
<td>€8 - 10 million</td>
</tr>
<tr>
<td>Dry-bulk</td>
<td>€2.5 - 3 million</td>
<td>€4 - 6 million</td>
</tr>
<tr>
<td>Cruise</td>
<td>€2.5 - 3 million</td>
<td>€10 - 12 million</td>
</tr>
<tr>
<td>Towage / Offshore</td>
<td>€1 - 1.5 million</td>
<td>€8 - 10 million</td>
</tr>
</tbody>
</table>
Entry moments of sub-sectors have a direct effect on the port due discount structure, LNG investment subsidies, (future) emission penalties and LNG technology price reduction.

Port due discount
The port due discount structure is developed by the Port of Rotterdam to stimulate the development of cleaner ships. Rotterdam wants to become the most sustainable port city (TranScript table 4.3). Ships performing worse than the CCRII norms pay 15% extra on their port dues, ships with a green award have a discount of 15% and ships performing +60% better than the CCRII norms (LNG ships) are eligible for a 30% discount. Stimulation structures are, by definition, temporary. When a certain percentage of the Dutch fleet uses LNG as propulsion fuel, the structure will change or disappear. The target percentage is unknown so is modeled as a variable, set at 10%. When the target is met, the discount is assumed to be reduced to 15%, still stimulating the development of clean ships. The port due discount formula therefore can be captured in an IF function (IF(logical test;[value if true];[value if false]):

$$IF\left( \frac{\text{LNG fleet}}{\text{Total fleet}} \times 100\% < \text{[target percentage]}; 30\%; \text{[new discount]} \right)$$

LNG investment subsidies
The European subsidies on LNG investments in the TEN-T core network program apply to all EU Member States. Since the Excel model currently only includes the Dutch fleet, the height of the EU LNG investment subsidies is not modeled as an interactive factor. The EICB assumes the subsidy to be 30% for at least the coming 5 years.

Emission penalties
Like discussed, the emission penalty policies are currently under development on a Member State and World level, they have to be added to the model in a later stadium.

LNG technology price reduction
In Argos’ business case is calculated that today’s LNG equipment is 1.5 -2 times more expensive than the same equipment for conventional fuels.

In the Excel model we assume that technology developments cause a yearly reduction of the LNG technology price of \([X]\)%, where X is set at 5%. In addition to that an extra price reduction takes place in the year after a sub-sector has its entry moment. The height of this reduction depends on the sub-sector’s fleet size and a multiplier. To compensate for the difference in the amount of equipment required for sea-going vessels the fleet sizes of maritime ships are multiplied by a factor [5]. Another assumption has to be made on what the maximum price reduction \([X]\)% is caused by economies of scale. In the Excel model there is assumed that each sub-sector accounts for its own percentage of the total fleet on that maximum price reduction. Therefore the formula for determining the LNG technology price reduction compared to time step 0 is:

$$P_{\text{red},t} = P_{\text{red},t-1} \times \left( 1 - \left( \text{[yearly price reduction]} - \frac{S_i \times \text{fleet}_i}{\text{total fleet}} \times [P_{\text{red,max}}] \right) \right)$$
Operationalization of part 2; adding infrastructure development to the basic model

Table 4.18 shows the values of the system factors related to small-scale LNG infrastructure developments on $t_0 (02-2015)$.

Table 4.18: System factor values related to the development of LNG infrastructure on $t_0$

<table>
<thead>
<tr>
<th>System factors</th>
<th>Unit[]</th>
<th>Value on $T_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Availability of Truck-to-Ship bunkering infrastructure</td>
<td>TTS [y/n]</td>
<td>1 [yes]</td>
</tr>
<tr>
<td>11 Availability of Ship-to-Ship bunkering infrastructure</td>
<td>STS [y/n]</td>
<td>0 [no]</td>
</tr>
<tr>
<td>12 Availability of Shore-to-Ship bunkering infrastructure</td>
<td>ShTS [y/n]</td>
<td>0 [no]</td>
</tr>
<tr>
<td>13 Availability of European permits</td>
<td>EU permits [y/n]</td>
<td>0 [no]</td>
</tr>
<tr>
<td>14 Availability of local government permits</td>
<td>Local permits [y/n]</td>
<td>1 [yes]</td>
</tr>
<tr>
<td>15 Public LNG support</td>
<td>Supp [low/med/high]</td>
<td>Low</td>
</tr>
<tr>
<td>16 LNG safety requirements</td>
<td>Safety [risk of death per year]</td>
<td>1 on $10^{-6}$</td>
</tr>
</tbody>
</table>

The interaction between the traded LNG volume in the market and the development of LNG bunkering infrastructure is already discussed:

\[ \text{Infra}_{x,t} = 1 \text{ if } \text{Infra}_{x,t-1} = 1 \]
\[ \text{Infra}_{x,t} = 1 \text{ if } \]
1) Local and EU permits = 1
2) Total volume of LNG on $t \geq$ Minimal LNG volume $\text{Infra}_x$
\[ \text{Infra}_{x,t} = 0 \text{ if other} \]

The total LNG volume is calculated with a SUMPRODUCT formula. It accumulates all products of the sub-sector states [0 or 1], sub-sector fleet size and yearly fuel consumption per individual ship, taking into account that sub-sector state 1 means that at least 5% of the fleet size is LNG ready.

The minimal traded LNG volume before infrastructure will be developed is assumed to be 1,000 ton/year for truck-to-truck bunkering, 15,000 ton/year for ship-to-ship bunkering and 25,000 ton/year for shore-to-ship bunkering. These assumptions are based on current business cases of Argos as well as GDF-SUEZ LNG Solutions. Maritime ships are assumed to at least bunker 50% of their LNG outside of the system. Furthermore, the LNG volume traded should be divided by the number of infrastructure types that are in place.

Operationalization of part 3; adding funding structures to the model

Table 4.19 shows the values of the system factors on $t_0 (02-2015)$ related to funding.

Table 4.19: System factors values related to the development of funding structures on $t_0$

<table>
<thead>
<tr>
<th>System factors</th>
<th>Unit[]</th>
<th>Value on $T_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 ECB % private equity capital requirements</td>
<td>ECB [% on provided loans]</td>
<td>Low risk: 8% $^{17}$ [High risk: 16%]</td>
</tr>
<tr>
<td>18 EU economic growth</td>
<td>EU [%/year]</td>
<td>1.006</td>
</tr>
<tr>
<td>19 Availability Inland Funding</td>
<td>Funding [y/n]</td>
<td>0</td>
</tr>
</tbody>
</table>

The assumption is made that ECB rules prescribe 16% when less than two sub-sectors contribute to the resale value guarantee. ECB 8% rule applies when two or more sub-sectors have joined the transition. The required European economic growth in case of the 8%-or 16% scenario is modeled as

$^{17}$ 16% is a model assumption for high risk loans. ING interview indicates 8% for low risk loans.
a variable. In the screenshot the values are 2% in the case of ECB requirements of 8% and 3% growth in the case of ECB requirements of 16%.

A final remark is that the EU growth rate is assumed to increase by up to 0.6% per year (EU, 2011). This is modeled by adding a random number between 0 and 0.6 to the growth rate in the previous time step \( t - 1 \).

**Proposed further expansion of the model**

The idea behind this systematic approach is that the model can always be expanded by adding more blocks of system factors. In this thesis research however the model including the LNG business case, LNG bunker infrastructure and funding possibilities is detailed enough to work with.

However, to give an indication on what types of model expansions there are possible we propose an expansion to model the structure of emission penalties in more detail. Exact penalty policies are to be developed in the very near future on the Member State- and World policy level. Till then, the values of the expected emission penalties in the model can be varied to explore the effects of different penalty heights. At least the following system factors should be added to the model when exact penalty policies are known (table 4.20); it is likely that penalties will be based on the amount of emissions exceeding emission regulations.

**Table 4.20: System factors to be added when modeling emission penalties**

<table>
<thead>
<tr>
<th>System factors</th>
<th>Unit[]</th>
<th>Exogenous / Endogenous</th>
<th>Value on ( T_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Emission requirements Inland</td>
<td>I_CO [g / kWh]</td>
<td>Endogenous: EU, CCRN</td>
<td>I_CO: 3.5 g/kWh</td>
</tr>
<tr>
<td></td>
<td>I_HC [g / kWh]</td>
<td></td>
<td>I_HC: 1.0g/kWh</td>
</tr>
<tr>
<td></td>
<td>I_NO(_X) [g / kWh]</td>
<td></td>
<td>I_NO(_X): 6.0 g/kWh</td>
</tr>
<tr>
<td></td>
<td>I_PM [g / kWh]</td>
<td></td>
<td>I_PM: 0.2 g/kWh</td>
</tr>
<tr>
<td>21 Emission requirements Maritime ECA</td>
<td>ECA(_{SO(_X)}) [%m/m]</td>
<td>Endogenous: IMO</td>
<td>ECA(_{SO(_X)}): 0.1%</td>
</tr>
<tr>
<td></td>
<td>ECA(_{NO(_X)}) [g / kWh]</td>
<td></td>
<td>ECA(_{NO(_X)}): 44*n(^{-0.23}) g/kWh (n[rpm])</td>
</tr>
<tr>
<td>22 Emission requirements Maritime World</td>
<td>World(_{SO(_X)}) [%m/m]</td>
<td>Endogenous: IMO</td>
<td>World(_{SO(_X)}): 3.5%</td>
</tr>
</tbody>
</table>

**The LNG system INTRANS Excel model**

Figure 4.5 shows the LNG INTRANS Excel model. Because of the time consuming developments in the maritime fuel system the time step is chosen to be 1 year. Therefore the time horizon should be between 10 and 20 years. The following discusses the different parts of the model.

**Purple:** the 10 shipping sub-sectors with their sector characteristics lifespan, fuel consumption, port dues, suitable for retrofit, LNG investment, required bunker infrastructure, fleet size and % overcapacity on \( T_0 \). These are assumed to be fixed in the time span of the model.

**Yellow:** variables that have a direct impact on the profitability of the business case; price of LNG, price of HFO, price of MDO, port due discount, green transport multiplier, LNG investment subsidy, inland emission penalties, maritime emission penalties and LNG technology price reduction.

**Blue:** variables related to infrastructural developments: local government infrastructural permits, European infrastructural permits, the presence of infra 1 (truck-to-ship), infra 2 (ship-to-ship) and infra 3 (shore-to-ship), the min. LNG volume before each three infrastructures will be developed, the maximum number of ships able to use the infrastructure, and the required permits per infrastructure.

**Green:** variables related to funding: ECB rules on % equity on loan, EU growth, funding structures present, ECB low percentage, ECB high percentage, and Required EU growth ECB rule.
White: model assumptions monetary depreciation time, yearly technology price reduction, transport price, % of sub-sector fleet per entry moment.

Grey: the state per sub-system of the different time steps. A state change therefore is visible if a 0 changes in a 1 on a certain time step.

The formulas that are used in the Excel model are discussed in this chapter. They are numbered and thus visible in figure 4.5.

1) Sub sector state:

\[ S_{i,t} = 1 \text{ if} \]
\[ F_{cons} \ast (P_{MDO} - P_{LNG}) + (Port \ Dues \ast \ PDD) + (P_{trans} \ast TM) + E_{penalties} \geq \]
\[ (1 - P_{tech}) \ast \text{Investment}_{LNG} - (\text{Subs}_{LNG} \ast \text{Investment}_{LNG} \ast (1 - P_{tech})) \]
\[ 0.5 \ast \text{lifespan} \]
\[ f(11,12,13) \geq \text{Infra requirements of } S_{i} \]
\[ S_{i,t} = 1 \text{ if} \]
\[ \text{Available funding} \geq \text{required funding of } S_{i} \]

2) Funding:

\[ Funding_{s,t} = 1 \text{ if} \]
\[ \text{Business case sector } s_{i} \geq 0 \]
\[ \text{EU economic growth} \geq \text{required growth at } s_{i}(\text{ECB risk level}) \]

\[ Funding_{s,t} = 0 \text{ if} \]

3) Infrastructure:

\[ Infra_{x,t} = 1 \text{ if} \]
\[ \text{Local and EU permits} = 1 \]
\[ \text{Total volume of LNG on } t \geq \text{Minimal LNG volume } Infra_{x} \]

\[ Infra_{x,t} = 0 \text{ if} \]

4) LNG price reduction

\[ P_{red,t} = P_{red,t-1} \ast (1 - \left( \left[ \text{yearly price reduction} \right] - \left[ \frac{S_{i} \ast \text{fleets}_{i}}{\text{total fleet}} \ast [P_{red, max}] \right] \right)) \]

5) Port due discount:

\[ IF\left( \frac{\text{LNG fleet}}{Total\ fleet} \ast 100\% \leq \left[ \text{target percentage} \right]; \left[30\% \right]; \left[\text{new discount}\right] \right) \]

To be able to show an actual turning point in the model, we assumed the availability of Funding on time t=1, and we increased the difference between fuel prices by decreasing the price of LNG on t=3 to 300. We can observe the following results: Inland dry-bulk ships in this situation would have an entry moment at t=4. As a result, shore to ship bunkering is developed on t=5, leading to the entry moments of inland tanker- and container ships on t=5 and a lower % equity capital requirement on loans. The entry moments in this situation caused the stimulation port due discount to have reached its goals and it changes on t=7 from 30% to 15%.
Figure 4.5: Quantified model LNG investment decision based on profitability business case AND the infrastructure development AND funding possibilities.
4.4.3 Step 6: Identify transition barriers

We arrived at a point where we can start reasoning about the aspects that are blocking the transition. Thanks to the quantification of the conceptual model we can perform calculations to determine threshold values for certain transition paths. The participatory stakeholder involvement gives insight in their perspective on transition barriers; which can be a transition barrier itself.

Qualitative identification of transition barriers
The first barriers are identified by indicating the missing system factors from table 4.10, 4.11 and 4.12. Interested in factors with high impact on the business case profitability, it is noticed that from table 4.10, system factors 6, 7 and 8 are missing or under development:

[Profitability transition barriers]
The absence of system factor 6 [the green transport price multiplier] indicates that although there is an increasing socially awareness of protecting the environment (landscape development step 1), this doesn’t lead to higher prices for greener transport\(^\text{18}\). The following explanations can be addressed:

- It is hard to address monetary value to externalities like cleaner air.
- Customers might be unaware of greener alternatives.
- Social awareness is not high enough.

Transition barrier 1: The increasing public awareness of “green” is not leading to higher transport prices for greener alternatives.

Level playing field is crucial for shipping companies because of the competitive market they are in. The absence of system factor 7 and 8 directly causes a competitive disadvantage for companies investing in greener technologies.

Transition barrier 2: Emission penalties for inland- and maritime shipping are still under development.

[Infrastructural transition barriers]
From the three types of infrastructures in table 4.11 only the truck-to-ship variant is (limited) available. Ship-to-ship- and shore-to-ship fuel bunkering facilities are still under development (system factors 10, 11 and 12). This means that at this moment (Q1 2015) only inland dry-bulk ships and tugboats can be served; having a fixed schedule and operating area. Others require a denser network, or larger quantities.

Transition barrier 3: Ship-to-ship- and shore-to-ship bunkering facilities are missing.

[Funding transitional barriers]
Table 4.12 shows that funding for inland cruise ships, towage boats and sea-going maritime ships in general is not a problem. This is because those are mostly huge companies with many high-value assets. The problem of funding plays at individual ship-owners in sub-sectors afflicted with overcapacity.

Transition barrier 4: Funding structures for the sub-sectors inland container-, tanker- and dry bulk ships are missing.

\(^{18}\) This is recognized by shipping companies Vinotra and Spliethoff and also by the Port of Rotterdam
Quantitative identification by basic modeling

The quantified model provides the possibility to change factor values and determine threshold values for transition paths. The first observation is that under Feb-2015 system conditions no large scale LNG transition will happen. Even when local permits, EU permits, infrastructure and funding are assumed to be present the business case is not solid enough to rectify the LNG investments in any of the sub-sectors. With Feb-2015 values for fuel (€487/ton MDO, €473/ton LNG), port due discount (30%) and investment subsidy (30%), the LNG investment has to be approximately 35% of the current investment, before inland ships start profiting.

Transition barrier 5: High price of LNG equipment.

Between the start of this research in September 2014 and February 2015 the oil price decreased from approximately 100 dollar a barrel to 50 dollar a barrel\(^{19}\). During the same period the natural gas price decreased too, from approximately 4.5- to 3 USD/mmBTU\(^{20}\).

The quantified model show a turning point for inland container ships at a MDO price of approximately €575/ton with an unchanged LNG price. At a price difference of approximately €100/ton it starts to become financially attractive for the first sub-sector to invest in LNG. Without stimulation policies this is €150-200/ton. In that case, the inland cruise ship sector would be the first sub-sector of which LNG benefits will exceed the investment costs.

Transition barrier 6: Insufficient price difference between conventional fuels and LNG.

For the maritime shipping sector HFO is by far the cheapest residual fuel and because of the huge LNG investments we can assume that this business case will not work without external pressures. The picture changes when strict emission regulations are in place (SECA areas in 2015). Then LNG in this sector competes with other emission reduction alternatives like sulphur scrubbers or ultra-low sulphur fuels (€477/ton).

We can thus assume that ships that sail outside SECA will keep using HFO until further restrictions will be implemented. When ships enter SECA, they will have to switch to an alternative; scrubbers, low sulphur gas oil or LNG. For new-builds, a price difference between 50 and 100 €/ton will result in that LNG will be chosen over low sulphur oil feedstock fuels. This again appoints to the importance of transition barrier 2; the development of strict emission penalties.

Barrier identification by participatory stakeholder involvement

Participatory stakeholder involvement gives insight in the perception of key actors on the transition barriers in the maritime fuel system. 19 stakeholders are asked about their opinion on the biggest transition barriers. They were not limited to one answer. Table 4.21 shows the mentioned transition barriers on the left side, the stakeholder groups on the top, and shows how many stakeholder of each group mentioned a specific barrier. The table is ranked on popularity.

\(^{19}\) http://www.dollarkoers.nl/olieprijs/365/ (03/2015)
Table 4.21: Stakeholder participation: what are the biggest transition barriers for LNG in the maritime fuel system?

<table>
<thead>
<tr>
<th>Stakeholder group</th>
<th>LNG end-users</th>
<th>Knowledge centers</th>
<th>Classification societies</th>
<th>Financial services</th>
<th>LNG equipment suppliers</th>
<th>Policy bodies</th>
<th>LNG Infrastructure operators</th>
<th>Tot</th>
</tr>
</thead>
<tbody>
<tr>
<td># representatives</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>19</td>
</tr>
</tbody>
</table>

**Transition Barriers**

1. *Fuel price and future regulation uncertainties*: 3, 1, 2, 1, 2, 3, 12

2. *Lack of LNG infra*: 5, 2, 1, 2, 1, 11

3. *High LNG investments*: 4, 3, 1, 1, 9

4. *Funding problems inland ships*: 2, 2, 1, 2, 1, 8

5. *Unclear and long licensing trajectories (CCNR, ADN, Local Gov.)*: 2, 1, 1, 2, 5

6. *Lack of knowledge sharing (tech and financial)*: 3, 1, 1, 4

7. *Regulation runs behind tech developments*: 1, 2, 1, 4

8. *Knowledge and expertise at potential end-users is low*: 1, 1, 1, 3

9. *Safety aspects*: 1, 1, 2

10. *Lack of first movers*: 2, 2

11. *LNG systems are heavy and big*: 1, 1

There is a high level of consensus about the top four transition barriers. Where previous methods provided us with mostly rational or tangible transition barriers, the number one mentioned transition barrier by key stakeholders is about uncertainties of future developments. Even more important than today’s fuel prices or today’s regulations, is not knowing about the developments in the near future.

**Transition barrier 7: Uncertainties about future fuel price levels and developments in regulations.**

Both LNG end-users and policy bodies recognize the problems in the licensing trajectory for an LNG ship. However, the fact that the problems are recognized by both parties gives hope for a starting point to take away this barrier:

**Transition barrier 8: Unclear and long licensing trajectories for LNG ship approval.**

Mutual recognition of the problem isn’t the case for the barrier raised by LNG end-users and a financial organization. Both being parties facing huge investment decisions, they mention a lack of technical- and financial knowledge sharing. The fact that knowledge centers, classification societies and policy bodies did not mention this reveals a mismatch.

**Transition barrier 9: Lack of technical- and financial knowledge sharing.**
Analyzing the stakeholder participation leads to another mismatch. Four stakeholders argue that regulation is running behind on technological development. Both classification societies and policy bodies, responsible for developments in regulation, did not mention this. One example of this mismatch is given by a potential LNG end-user. KOTUG is looking into LNG-retrofitting one of its tugboats. From an operational point of view the calculated maximal pressure in the LNG tanks should be 16 bars. The allowed maximum by law is currently 10 bars, making the project from a technical point of view not feasible.

**Transition barrier 10: Regulation is running behind on technological development.**

Some other worries are about the level of knowledge and expertise at potential end-users, safety aspects, the lack of first movers and LNG systems being heavy and big making it hard to install.

We identified 10 significant transition barriers in this step:

11) The increasing public awareness of “green” is not leading to higher transport prices for greener alternatives.
12) Emission penalties for inland- and maritime shipping are still under development.
13) Ship-to-ship- and shore-to-ship bunkering facilities are missing.
14) Funding structures for the sub-sectors inland container-, tanker- and dry bulk ships are missing.
15) High price of LNG equipment.
16) Insufficient price difference between conventional fuels and LNG.
17) Uncertainties about future fuel price levels and developments in regulations.
18) Unclear and long licensing trajectories for LNG ship approval.
19) Lack of technical- and financial knowledge sharing
20) Regulation is running behind on technological development.

---

The identification of transition barriers in step 6 asks for the identification of event chains that can take them away (step 7). Event chains can be driven by external pressures, but also by pressures that are created by internal stakeholders. What should happen and who should make it happen?
4.4.4 Step 7: Identify chains of events that could take away transition barriers

Participatory stakeholder involvement on the topic of who has the “power” to make the LNG transition possible gives insight in their perception of the crucial and powerful players in the maritime fuel system. 16 stakeholders are asked what the most powerful players are from their perspective; who can make or break a transition. They were not limited to one answer. Table 4.22 shows a summary of the powerful players and how many stakeholders in each stakeholder group said this.

Table 4.22: Stakeholder participation: Who has the power to make the LNG transition in the maritime fuel system possible?

<table>
<thead>
<tr>
<th>Stakeholder group</th>
<th>LNG end-users</th>
<th>Knowledge centers</th>
<th>Classification societies</th>
<th>Financial services</th>
<th>Policy bodies</th>
<th>LNG infrastructure operators</th>
<th>Tot</th>
</tr>
</thead>
<tbody>
<tr>
<td># representatives</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>Who can make transition possible?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Government / EU</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>2 Gas source + infrastructure</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>3 End-users</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>4 Classification societies</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>5 Financial sector</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>6 shippers (who pay for transport)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Observations from participatory stakeholder involvement – Powerful players

[Observation 1]

14/16 stakeholders, including policy bodies, experience that the Government or the EU has the power to make or break the LNG transition. Also most scholars recognize that governments have a key role to play in bringing about transitions (Kern, 2012). Where market fails in addressing public needs it is up to governments to intervene.

[Observation 2]

9/16 stakeholders point out that companies related to the gas source and the LNG infrastructure are very powerful in the game of changing the maritime fuel system. This is mainly about the price of LNG having such a big impact on the business case, and the crucial infrastructural requirements in the transition system.

[Observation 3]

Five representatives emphasize that in the end it are the potential end-users that have the power to make or break the transition because of the direct decision of using LNG or not. Other, less often mentioned powerful players are classification societies because of the safety requirements, the financial sector because of the funding problem and the shippers, who should be willing to pay more for green transport.

[Observation 4]

The chicken-and-egg dilemma between end-users and infrastructure operators is underlined by the fact that 4/4 potential LNG end-users say that infrastructure operators are most powerful, while 2/3 infrastructure experience this the other way around.
**Observations from participatory stakeholder involvement – Future developments**

19 stakeholders are also asked about their expectations of any future development in the marine fuel system. They were not limited in their answering. Discussed developments can be categorized into six topics: (1) LNG end-users; who will use LNG in the future, (2) Transport market, (3) LNG infrastructure, (4) Timeline of developments, (5) Regulations and (6) Fuel price developments.

**Future type of LNG end-users**
Expectations on the future type of LNG end-users are mainly based on the higher economic feasibility for large fuel consumption. The underlying argument here is that investment costs have to be recovered by the difference in fuel price between LNG and conventional fuels. Other arguments for choosing were bunker profiles and space to install LNG equipment. From the six representatives that mentioned the type of LNG end-users, all six chose large fuel consumers: short-sea coastal vessels, sea-going ferries, inland cruising, tanker ships, dry-cargo ships and work boats. Also five representatives expect that inland ships will mostly install catalysts and scrubbers to comply with CCR-emission limits in the near future. They unanimously agree that this is a primitive and short term solution but that it is the easiest solution.

**Developments in the shipping transport market**
Seven statements are made about the expectations of developments in the shipping transport market. Four are about a decreasing inland shipping market in combination with too many inland ships. One of the reasons for less demand for transport is that the European shift towards natural gas causes less oil products to be transported. Which oil refineries will stay in Europe will determine the European tanker transport market. Two other statements are about shippers that will have to pay more when costs of transport are increasing because of increasing sustainability and higher fuel expenses.

**LNG infrastructure development**
Most representatives are rather positive; three statements are about that LNG infrastructure will be present in a few years from now. More interesting are two individual statements about infrastructure sharing. Apparently major off-grid industries in Central- and Northern Europe (Scandinavia) are currently looking into the possibilities of implementing LNG for their energy supply. Those countries do not have a high level gas infrastructure like for example the Netherlands have and are fore this reason depending on oil (products) to meet the energy demand of energy consuming industries. This development would lead to an LNG infrastructure which can also partly be used by the maritime shipping sector. Combined use of infrastructure means that investment costs can be shared.

**Timeline of developments**
Seven representatives dared to give an indication of when, how many years from now, a large scale LNG application in the maritime sector is possible. Four representatives expect that in 10 years from now (so around 2025) LNG becomes a feasible alternative on a large scale. Three other representatives are talking about 10-20 years from now that all policy barriers and infrastructural barriers are gone. It is striking that all seven representatives individually have similar expectations about this time line; not earlier than 10 years from now. They agree that it will be more exponential than linear.

**Laws and regulations**
Two representatives of policy bodies expect that processes related to laws and regulations (LNG permits) will become smoother in “the near future”. Two other representatives expect that new stimulation subsidies will be introduced to reduce overcapacity and make room for cleaner new-build ships.
Fuel price developments
Two representatives from the fuel sector expect that the current low oil price (2015) will be temporary. The common expectation is that the oil price will be high again at the end of 2016 / 2017. Four other representatives speculate about low LNG prices. This is due to gas production in North-America and the Far East in combination with Gazprom showing signals to construct an LNG plant with an annual capacity of 10 million tons near Primorsk. These developments are expected to result in lower LNG prices for Europe.

Scenario’s taking away transition barriers
The stakeholders’ expectations of future developments in the marine fuel system in combination with their perspective on which parties can make or break a transition can be translated into scenarios that potentially can take transition barriers away.

Fuel price scenario
It makes sense that a chain of events can be triggered when developments like the gas production in North America and the Far East and the construction of the Primorsk LNG plant set foot. Lower LNG prices in combination with higher oil prices after 2016 / 2017 positively affect the LNG business case. The quantified model in Excel showed that the MDO price should be around €150 more expensive than LNG before it becomes economically feasible for inland container- and inland cruise ships. With an LNG price of around €500/ton (Q1 2015) this would mean that the MDO price should be approximately €650/ton. Looking at the course of the MDO price in Rotterdam during the course of this research we see that the MDO price in September 2014 was approximately €650/ton (Shipandbunker.com, 2015). This makes it a realistic scenario that these developments in the fuel prices take away the barrier about the current level of fuel prices and potentially lead to the entry moment of ships in the inland container- and cruise sub-sectors.

Strict emission penalties sea-going ships in SECA scenario
Individual Member States currently are in charge of sanctioning ship-owners for non-compliance to the SECA emission rules. In practice this means that ships are only controlled at berth but not when sailing the SECA. Therefore ships can still run on HFO without being detected (NABU, 2015). The fact that Member States are in charge also means that there are major differences in the level of fines. Where ships in Rotterdam are “fined” with naming and shaming, ships in Hamburg have to pay approximately €150021 and in Norway fines are getting more serious; several ships are fined with approximately €10.00022. Looking across boarders we see even the latter penalty is low in comparison with California USA; where fines start at the level of $50.00023. The differences in regulation and low level of penalties for non-compliance doesn’t stimulate investments in cleaner technologies. Ships who do comply with the emission limits are losing money to ships that don’t invest and thus are cheaper. Therefore it is quite reasonable that co-operation between Member States regarding controls, enforcement and equalization of more serious penalties will be introduced. When strict emission penalties for the SECA areas are introduced this can have a huge impact on the situation. Especially short-sea ships are sailing in SECA; short sea shipping encompasses the movement of cargo and passengers mainly by sea along a coast, without crossing an ocean. There are about 5 000 vessels in the SECA at any time, on average. About 14 000 vessels visit the area in a year. 2 200 ships spend all of their time in the area and 2 700 more than 50 % of their time (European Shortsea Network, 2013). Especially for ships spending all of their time in

---

21 http://zaplog.nl/zaplog/article/marpol_annex_vi_zwavelreductie_en_stuurloze_schepen (06/2014)
SECA LNG is considered to be a serious alternative. Because of the huge fuel consumption (in relation to inland shipping) a relatively small difference in price can make up for the extra investment costs. Other sub-sectors can benefit from the infrastructure that will be developed for the short-sea ships. Other sub-sectors potentially also have an entry moment. This is also stressed by several representatives; “when short-sea ships are shifting towards LNG, the rest will follow”.

**Pay more for sustainable transport scenario**

Especially in a market afflicted with overcapacity, it would be stimulating when ship-owners can be distinctive by being green. If shippers demand for green transport, more ships would implement emission reduction technologies. It may take an event like a natural disaster, popular documentary about climate change, advertising campaign or equivalent to translate the increasing public awareness of “green” also into higher transport prices for greener alternatives.

**LNG infrastructure sharing scenario**

What would be a possible event chain when major off-grid industries in Central-and Northern Europe will implement LNG for their energy supply? An example of an off-grid industry in Scandinavia is the wood & paper industry in Finland. If this industry would implement LNG, short-sea ships on the wood & paper route can profit from that LNG infrastructure. A result could be that also in the Netherlands there will be invested in an extra bunker facility. This facility then could also be used by other sub-sectors taking away infrastructural barriers.

**Scrapping bonus scenario**

To take away transition barriers stimulation policies could be introduced by who is seen as the most powerful stakeholder: the Government. In the inland shipping sector the overcapacity has two negative effects; (1) transport prices are low, (2) there are no funding possibilities. This leads to the fact that there is no demand for new-builds in this sector. Especially those new-builds are assumed to be greener and the feasibility of LNG implementation should be higher than in the case of retrofitting (design, space, expensive). Therefore overcapacity has to be reduced in this sector to make it healthy again. To reduce the overcapacity in the inland shipping sector, the sector itself opts for introducing a scrapping bonus\(^\text{24}\). Older, more polluting ships will be scrapped making the sector more sustainable and also healthier in terms of earnings. In the past (1987-2000) there already was a scrapping bonus structure in the European inland shipping sector. Currently the scrapping bonus structure is at rest. This means that, when all 36 European Member States vote that there is a crisis, the scrapping structure can become active again. On the long term a healthier inland shipping sector means that new ships can be built, can be funded and can be equipped with LNG technology.

**Resale value guarantee scenario**

We saw that financial organizations a second hand value of assets in order to provide loans. To take away this chicken-and-egg funding dilemma some sort of resale value guarantee structure should be developed. It is reasonable to assume that somewhere soon a governmental organization or a public-private partnership will jump in. One of the possibilities is the Ministry of Infrastructure and Environment. It is also in their favor, because of the emission reduction agreement with Europe.

4.5 Conclusions of applying INTRANS on the LNG case study

Here the results of applying INTRANS on the LNG transition case study are to be discussed to answer sub-question three: [3] Does the proposed methodology provide understanding of the transition; insight in key players and drivers, potential future states, transition barriers and possibilities to intervene?

[Understanding LNG transition]

In step one the LNG situation is delineated to the marine fuel socio-technical system, consisting of ships (end-users), regulations and policies, markets and user practices, production system and industry structure, research network, fuel infrastructure, classification standards and a network of interests like financial institutions and lobby groups. Applying Geels’ MLP framework showed that the marine fuel STS is dealing with:

- An increasing global awareness of sustainability and environmental protection
- Overcapacity in the shipping sector as result of the global credit crunch in 2008 after a period of massive investment
- Changing fuel prices
- The demand for level playing field between different modes of transport
- The European desire to become less dependent on political unstable regions like the Middle East and Russia in terms of energy supply. This puts pressure on the maritime regime where oil feedstock products as HFO and MDO are the dominant fuel.

In step two it became clear that there are three necessary conditions without a transition towards LNG cannot happen;
1. The availability of a total LNG infrastructure
2. The presence of LNG end-users
3. The availability of natural gas

[Key players and drivers]

Following Patil’s TranScript framework, in step three the crucial assets and rules are identified required to meet the necessary conditions, together with the actors “responsible” for them. Extensive interviews with 19 representatives from maritime fuel system lead to the following insights:

- The LNG business case depends on stimulation structures initiated by policy bodies like the Port of Rotterdam, the Province of South Holland, the National Government and the European Union.
- The availability of investment capital depends on financial institutions that are bounded by ECB regulations and social responsibilities.
- A group of LNG equipment suppliers works on LNG technologies like LNG tank storage systems, spark ignited LNG engines, dual fuel engines and boil-off-gas units.
- Laws and regulation related to LNG and maritime polution are to be developed on four political levels; World (IMO), Europe (ADN & CCNR), National Government and the Port of Rotterdam.
- Classification & standard societies produce rules, guidelines and standards ensuring proper functioning of processes, equipment and people.
- The availability and accessibility of knowledge is guarded by actors like the EICB, TNO and the Dutch National LNG platform. They develop knowledge networks, education programs, public meetings and provide assistance in subsidy applications.
- LNG infrastructural asset development depends on LNG transport operators that need to invest in pipelines, trucks, ships and or trains; LNG bunkering operators that need to invest in ship-to-ship-terminal-to-ship-via-pipeline- and or truck-to-ship bunker solutions; and LNG storage operators that need to invest in storage tanks, floating barges, small scale LNG hubs and or intermediate bunker installations (IBIs).
In step four a distinction is made between different types of maritime fuel end-users with a different level of feasibility to implement LNG. There are seagoing- and inland ships and in both sectors five sub-sectors are identified; Tanker ships, container ships, dry-cargo ships, passenger ships and work ships. The feasibility is influenced by sub-sector characteristics:

<table>
<thead>
<tr>
<th>Design characteristics</th>
<th>Operational characteristics</th>
<th>Operational environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life span</td>
<td>Fuel consumption</td>
<td>Emission requirements</td>
</tr>
<tr>
<td>Fuel tank size</td>
<td>Required bunker location density</td>
<td>Market conditions</td>
</tr>
<tr>
<td>Suitability for LNG retrofit</td>
<td>Port fee liabilities</td>
<td>Permission trajectories</td>
</tr>
<tr>
<td></td>
<td>Port regulations</td>
<td>Market competition</td>
</tr>
</tbody>
</table>

[Modeling relations and entry moments]

The basic model only takes into account the business case factors. A sub-sector is assumed to have its entry moment when the benefits of implementing LNG exceed the sum of the costs. The basic model is extended with the requirements of having LNG infrastructure and funding available. What type of infrastructure is required depends on several sub-sector characteristics; fuel tank size, fuel consumption, bunker profile, fleet size and the geographical area of operation. The availability of the different types of infrastructure is depending on the availability of local and European permits and the total volume of LNG to be traded. The availability of funding depends on the initial LNG investment, the profitability of the business case, the fleet size, the level of overcapacity in the shipping sector, the resale value of the investment and the EU economic growth.

[Transition barriers]

Qualitative analyses, quantifying the conceptual model with Feb-2015 data, and stakeholder participation have led to the identification of 10 transition barriers. Some of the barriers are clearly under development (emission penalties, licensing trajectory and infrastructure), other barriers are assumed to change over time (fuel prices, LNG equipment prices, transport prices). There are also two barriers of which no consensus exists among the stakeholders (the lack of sharing technological- and financial information and regulation lacking behind on technological development). Before these barriers can be taken away, the involved parties have to get around the table.

[Potential scenarios]

The stakeholders’ expectations about future developments in combination with their perspective on powerful stakeholders provided arguments for scenario developments. Six likely scenarios are described; (1) a fuel price scenario where the price of LNG decreases caused by the increase of LNG availability, (2) a strict emission penalties scenario where ships are heavily fined when not complying the SECA emission rules, (3) a scenario where the shipping market is willing to pay more for sustainable transport, (4) a scenario where LNG infrastructure can be shared with other markets like the Finnish off-grid wood & paper industry, (5) a scrapping bonus scenario decreasing the overcapacity in the inland shipping sector and (6) a resale value guarantee scenario where the funding problem is solved by decreasing the risk for financial institutions.

Is the information that is gathered in this chapter valuable to support strategic investment decision making at key stakeholders?

The conclusion is that applying INTRANS first of all provides a clear understanding of the situation. For key stakeholders it is important to know the composition of the socio-technical system, what drives changes in the system and to know the other actors from the multi-actor network. Secondly it provides insight in the drives of other stakeholders for producing crucial structures necessary for a transition to
happen. Knowing the drivers of other key stakeholders is crucial in a later stadium. Stimulating other stakeholders to take away transition barriers finds its origin in these key drivers. Thirdly the list of transition barriers gives a clear overview of what should change in the marine fuel socio-technical system in order to facilitate the LNG transition. It seems evident that stakeholder interventions should have the effect of taking away transition barriers.

The quantified Excel model provides the ability to perform calculations on different scenarios. It can support strategic decision making because it can be used to determine threshold values for certain transition paths. Therefore it is a useful asset that provides arguments for strategic decisions. However, in this case study the use of the model is very limited due to time constraints. In the section recommendations this will be further discussed.

The answer to sub-question three is positive; applying INTRANS does provide understanding of the transition; insight in key players and drivers, potential future states, transition barriers and possibilities to intervene.
Chapter 5: Evaluation of INTRANS

Taking a step back from the LNG case study a discussion on the applicability of INTRANS has as goal to answer sub-question 4; Is the proposed methodology generically applicable on transitions in socio-technical systems? This includes a fair discussion on positive and less positive experiences gained during the research trajectory; call it an advice for potential successors. The second part focuses on the scientific contribution of this research. Several ideas, methods and frameworks are applied in a different context than the original.

5.1 General applicability of INTRANS

Applying INTRANS like it is done on the LNG case study requires a substantial amount of time and effort. The stepwise approach can be described as devious, but it leads to an enormous amount of high quality information. This is a result of the broad, but specific requirements; we want insight and understanding in many aspects of socio technical transitions and even want to be able to say something about potential future states of the system. This demands for an enormous amount of information and thus simply requires many sub-analyses which individually could be research topics as well.

[Importance of stakeholder participation]

INTRANS requires an analyst to deep-dive into a case study to achieve the right level of detail. Stakeholder participation has been found essential. The stakeholder interviews are valuable on many moments in the research trajectory. First of all to get familiarized in the STS of interest; approaching the right people in the field of interest ensures a jump start. Secondly stakeholder participation is valuable for testing and evaluating ideas during the research. Thirdly stakeholder participation can be essential for the identification of transition barriers and potential future scenarios in the socio-technical system.

[Reducing complexity]

INTRANS is applicable to complex case studies because of the clear structure of sub-analyses. Steps 1 to 4 are four different analyses that are combined in step five (relations & entry moments). It turns out to be and solid approach to start with a basic model, and step by step increase complexity by adding more variables to the model. The possibility to increase the basic model with layers of complexity in a structured manner guarantees that the analyst will not get overwhelmed.

[Model quantification]

The quantification process of INTRANS models again takes substantial time and effort, requiring a high level of detailed knowledge. The value of the Excel models regarding providing extra insights was limited in the LNG case study. Although it provided extra information on threshold values, they could also have been calculated without the Excel model. It however shows that INTRANS can lead to a quantifiable model. More research is suggested to explore further possibilities. In the LNG case study the value of constructing the quantified model in Excel was mainly the structuring the analyst’s thoughts and making visible the relationships and entry moments.

The goal of this research is developing a method that is generically applicable on transitions in socio-technical systems. In this research we applied our reasoning on two transition cases; LNG and Electric Vehicles. We can conclude that INTRANS is generically applicable on transitions in socio-technical systems when taken in consideration the substantial time and effort it takes and the requirement of having access to sufficient representatives from the STS of interest. However, the STS of interest should have a clearly definable moment of stakeholders entering the transition and it should be able to distinguish stakeholders that enter the transition according to differences in their characteristics.
5.2 A scientific mirror
After including several concepts in INTRANS and applying them on the LNG case study it is possible to draw some conclusions. Simply put: what are the positive- and negative aspects of partly including (1) the multi-level perspective by Geels (2002), (2) the TranScript framework by Patil (2014), (3) the scheme of analysis for analyzing the functional dynamics of TIS by Bergek et al. (2008) and (4) scenario development.

Multi-level perspective framework
The MLP framework is included in step one of the stepwise protocol in order to define the STS through the identification of the socio-technical regime, the landscape developments and technological niche developments. Analyzing a situation in this structured manner leads to a clear overview of the situation; one table is able to tell us the set of dominant practices, rules and technologies in a system, it shows new technological developments that are ready to enter the system and it shows the landscape developments that could lead to a certain level of pressure creating a window of opportunity for the niche developments. It is shown in the LNG case study example that the MLP framework application leads to an important basic understanding of the situation, being an essential start of the analysis.

TranScript framework
The TranScript framework is included in step two and three of the stepwise protocol in order to define the necessary conditions of a transition, the necessary sub-conditions and the actors responsible for creating the structures of assets and rules to meet those necessary conditions. Even so important is the identification of the drivers of those actors. What is found positive is that from a helicopter perspective it is possible to identify necessary structures and belonging actors, making it possible to focus and deep dive only on relevant aspects.
A comment has to be placed on the process of defining the necessary conditions and translating them into necessary sub-conditions. Necessary conditions can be defined in a rather objective manner; translating them into sub-conditions however seems sensitive to a certain level of subjectivity. It is a process of breaking down the necessary conditions into all relevant assets and rules that are required for a necessary condition to be true. Therefore it is strongly recommended to review this process with some expert(s) from the actual field.
It has also been found that to be able to find out what really motivates key stakeholders and what actions lay in their power, the interviews were inevitable in the LNG case study. Therefore applying TranScript was very time consuming. However it does lead to a clear overview of all relevant assets, rules, actors and drivers that are influencing the establishment of the necessary conditions.

Scheme of analysis for analyzing the functional dynamics of TIS
The scheme of analysis is not directly included in INTRANS but it has been a source of inspiration. First of all it was an inspiration because of the way of presenting the stepwise protocol covering a series of sub-analyses. It is well structured starting with defining and structuring the situation and ending with specifying key policy issues. Secondly because of the line of reasoning that the identification of inducement- and blocking mechanisms is done by determining what is between the current- and desired level of fulfillment of the functions. What is missing is the step that comes after defining these key policy issues. In INTRANS we also wanted to identify potential scenarios that will take a way these blocking mechanisms, scenarios that are triggered by stakeholder interventions. This missing in the scheme of analysis is solved by adding elements from the field of scenario development.
**Scenario development**

From the field of scenario development it became clear that to write actual storylines of event chains and stakeholder interventions it is crucial to involve expert stakeholders. The storylines are based on the key issues, uncertainties and possible dynamics together from the perspective of the export stakeholders, in combination with the insights gained related to driving forces, landscape developments, stakeholders and critical assets and rules. The main goal is to take away the main transition barriers in order to contribute to the establishment of the necessary conditions. The line of thought borrowed from the scientific field of scenario developments is pretty straightforward and worked out well.
Chapter 6: Conclusions & Recommendations

What structured methodology, that is generically applicable on transitions in socio-technical systems, will provide understanding of the transition; insight in its key players and drivers, potential future states, transition barriers and possibilities to intervene, in order to support strategic (investment) decision making at key stakeholders?

- Publications on transitions in STS are found to be mainly descriptive, qualitative and focused on analyzing transitions in the past.
- Aiming to support actors in ongoing transitions with qualitative and quantitative findings, INTRANS is developed as a conceptual framework together with a stepwise protocol of sub-analysis.
- The methodology has a well-founded, strong qualitative core being composed of several aspects from the multi-level perspective framework by Geels (2002), the TranScript framework by Patil (2014), the scheme of analysis for analyzing the functional dynamics of TIS by Bergek et al. (2008) and the scholarship on scenario development.
- The core contribution of this research is the introduced concept of different transition entry moments for different stakeholder sub-sectors. Describing the relationships between sub-sector characteristics, exogenous- and endogenous factors makes it possible to construct a quantifiable model in which entry moments and their effects on the system can be analyzed.
- INTRANS is successfully applied to the LNG as a maritime fuel case study. Although time consuming, it led to the understanding of the LNG transition, the identification of key players and drivers, the modeling of relations and entry moments, the identification of transition barriers and the identification of potential future states.
- INTRANS is generically applicable on transitions in socio-technical systems when taken in consideration the substantial time and effort it takes and the requirement of having access to sufficient representatives from the STS of interest. However, the STS of interest should have a clearly definable moment of stakeholders entering the transition and it should be able to distinguish stakeholders that enter the transition according to differences in their characteristics.
- Although the LNG INTRANS model has been successfully modeled in Excel, it is not used by its full potential. Due to time constraints the choice has been made to prove that INTRANS is quantifiable. Logical next step would be to explore the exact possibilities of the model; an exploratory modeling analysis.

Recommendations related to INTRANS

For analysts who are going to apply the INTRANS conceptual framework with the stepwise protocol of sub-analysis there are some recommendations that already are discussed during this thesis report.

1) Arranging interviews should be top priority. They are important but very time consuming. The process of arranging interviews can take weeks of preparation, not more than two interviews can be conducted per day due to geographical and time constricitions, summarizing the interviews takes a couple hours per interview and finally the interviewee has to approve the summary to be used in the research.

2) Stick to the modular building of INTRANS; because of the enormous amount of information there is a risk of getting lost. Also, when describing the relationships between sub-sector characteristics, endogenous factors and exogenous factors in a modular way, it is possible to construct the Excel model simultaneously. In this way the analyst’s thoughts are visualized.

3) Add a step 8 to the stepwise protocol to use the quantified model better. First thoughts go to exploratory modeling and analysis (EMA). This is an approach that uses computational
experiments to analyze complex and uncertain issues. It has been mainly developed for model-based decision support (Kwakkel, 2013).

**Recommendations related to the LNG case study**

It has become clear that before a large scale LNG transition in the maritime sector can happen, several barriers have to disappear. However, most barriers are related to financial aspects. These can change rather quickly. Take for example the oil price, which decreased 50% during the course of this research. The overall image of the LNG transition will start slow, followed by an exponential growth. Most interviewees predict this to happen in 10 to 20 years from today. It is however definitely too early to draw hard conclusions. Therefore the suggestion is to perform more research, make the INTRANS LNG model even more realistic and use a method like EMA to provide more insights.
Personal reflection on graduation process

In this final part of my Master Thesis I would like to take a step back from the actual content of the thesis and reflect the process of getting to this point. The journey started in May 2014 when I contacted Mr. Piet van den Ouden who at that time was working as a business development manager at Argos Energies in Rotterdam, developing an LNG bunker vessel. Exploratory conversations went well and in September 2014 I started my “internship” in a beautiful, brand new building in the Port of Rotterdam (with many very expensive cars).

I would like to describe the seven months (till March 2015) that I spend on a daily basis working at Argos as unique, intensive, fun and as a great learning experience. My great colleagues from the inland bunkering department took me in as one of them, which created an inspiring work environment. Next to that, my daily manager Piet van den Ouden allowed me to be present at any meeting or activity if it was related to the LNG bunker vessel project; e.g. technical meetings, business negotiation meetings, lobby activities and customer/project member visits. Besides being extremely relevant for the LNG case study in this thesis, these experiences also confirmed my fascination of working on the line where technology meets business.

Very exciting were the interviews I conducted in the context of the LNG case study in this thesis report. Working at Argos provided access to contact information of many key players in the Dutch LNG environment. I traveled throughout the country meeting many inspiring people. Just an indication: CEO’s of big multinationals, senior engineers at prominent technological firms, ship owners, a shipyard, Port of Rotterdam, managers at energy-, consulting- and banking companies, the Province of South-Holland, the Dutch Ministry of Infrastructure and Environment and even an interview with ex-minister Mrs Tineke Netelenbos, who is now president of the Royal Association of Dutch Ship owners. The interviews form a unique source of information and they also made me improve my interpersonal skills. Let’s say that the interviews were a great try-out for the job-interviews that followed shortly after.

At the end of 2015 I started to orientate for job opportunities at technical companies on the line where technology meets business. At that time there were still three months of scheduled activities related to graduating ahead, but the thought was that you can never start to soon looking for a job. This process went extremely well. Skipping some steps, it resulted in me signing a contract for a dream start of my career at a manufacturing multinational, being part of an international graduate program called Build the Future. There was only one issue; a hard starting date of March 11th 2015. This resulted in a race against the clock which I “loosed”.

At the moment of writing this personal reflection we are almost one year and many spent saved annual leave days further. I found it extremely difficult to combine finishing my thesis besides this very demanding international job. Not being able to work on my thesis has provided me with a substantial amount of stress during the year. Although I would not recommend anyone doing it this way, I don’t regret my decision to take the job and postpone my graduation. The pro’s crush the con’s by far.

What affected this thesis in a positive way is the new fresh start in January 2016 with a fresh point of view. Fact was that the race against the clock hadn’t led to the quality I was content with. Postponing my graduation thus gave me the chance to improve the initial work. I am really happy with the end result and I would like to conclude with saying that altogether the graduation process was a great experience and with expressing my gratitude for the understanding and patience of my graduation supervisors.
Bibliography


Lin, W., Zhang, N., & Gu, A. (2010). LNG (liquefied natural gas): A necessary part in China’s future energy


Pearce, F. (2009). How 16 ships create as much pollution as all the cars in the world. *New Scientist Magazine*.


Prolog-Zwijndrecht. (2015, 02 03). Phone call. (J. J. Dekker, Interviewer)


Scheepssloperij-Nederland. (2015, 02 03). Phone call. (J. J. Dekker, Interviewer)


SGS. (2012). *SGS Emissiemetingen - when you need to be sure*. Rotterdam: SGS.


TNO. (2014). *Business cases and world-wide potential of small scale LNG*. Delft: TNO.
Appendices
Appendix 1: Sub-sector characteristics

The sub-sector characteristics in chapter 4.1 are divided into three categories; design characteristics, operational characteristics and operational environment. This appendix presents the background, calculations and sources used to come up with the data used in chapter 4.1.

1.1 Design Characteristics

1.1.1 Sub-sector life span

The life span of a ship can be measured as the age of a ship being demolished or recycled. This age is depending on several factors like efficiency, maintenance cost, the level of being technically outdated, market conditions and demolition prices. Although the exact moment of demolition is decided case-by-case, differences in the average life span may indicate a difference in feasibility of implementing LNG between sub-sectors.

As a first indication figure A1.1 shows the age split of all ships recycled in 2012. By far most of ships have a life span of 25-29 years (35%). However, 23.5% of the demolished ships were scrapped before the age of 25 and 41.5% after the age of 29. This is a significant difference when considering the feasibility of a business case for implementing LNG. Such an investment can be earned back by the difference in price between LNG and conventional fuels. A longer life span makes an investment profitable at a smaller difference in price. Therefore information from the interviews (Appendix 4), in combination with information from phone calls to several shipping- and demolition companies are used to determine the average life spans of the different sub-sectors from chapter 4. The results are shown in table A1.1.

![Age Split of Ships Recycled 2012](source: Lloyd’s List Intelligence)

Figure A1.1: Age split of ships recycled in 2012 source: (Register, 2013)

<table>
<thead>
<tr>
<th>Sub Sector</th>
<th>Average Lifespan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inland Tanker</td>
<td>30-34 yr. (source: Scheepssloperij-Nederland, 2015)</td>
</tr>
<tr>
<td>Inland Towage</td>
<td>15-19 yr. (source: interview KOTUG Towage, Appendix 4)</td>
</tr>
<tr>
<td>Sea Tanker</td>
<td>20-24 yr. (source: SIN, 2014)</td>
</tr>
<tr>
<td>Sea Dry Bulk</td>
<td>25-29 yr. (source: interview Spliethoff, Appendix 4)</td>
</tr>
<tr>
<td>Sea Cruise</td>
<td>40+ yr. (source: interview Spliethoff, Appendix 4)</td>
</tr>
<tr>
<td>Sea Offshore</td>
<td>25-29 yr. (source: interview Spliethoff, Appendix 4)</td>
</tr>
</tbody>
</table>

Table A1.1: Average lifespan ships in sub-sectors
From the average life span of the different sub-sectors can be concluded that sea-going vessels have a significant shorter life time than inland vessels. Main reason is the high cost of the special survey which ships are subject to every four years. Every four year a ship’s economic value will be determined and compared to the costs of a special survey. Ships with high economic value (for example cruise ships due to cabins) therefore have a significant higher average life span. Another remarkable observation is the significant lower life span of tugboats in comparison with other inland- or sea-going vessels. This can be explained by the extreme conditions related to the pulling activities in this sub-sector.

1.1.2 Sub-sector fuel tank size

Fuel tank size is one of factors to determine the required type of LNG bunker infrastructure. Due to the limited capacity of trucks (max 80 m³) only smaller-sized LNG-fuelled vessels can be supplied by trucks. Ships with larger fuel tanks ask for different types of bunker facilities. User feedback during interviews and field research by actually attending an LNG bunkering session on a truck-to-ship base, tells us that a truck change in the middle of a bunkering session is very time consuming. Bunkering with more than one truck therefore should not be strived for. A maximum of 2 trucks would be acceptable in exceptional cases.

Because of the time consuming change of trucks and the relatively low maximum LNG flow from trucks to ships, the sub-sector fuel tank size will be ranked on “feasible to bunker with 1 truck” (<+80 m³), “feasible to bunker with 2 trucks” (+- >80 < 160 m³) and “not feasible to bunker by truck” (>180 m³). User experience from Argos Bunkering is used to realize table A1.2.

Table A1.2: Estimation of fuel tank sizes of ships in the inland- and sea-going shipping sector

<table>
<thead>
<tr>
<th>Sub Sector</th>
<th>Fuel tank size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inland Tanker</td>
<td>1 – 2 trucks (&lt;160m³)</td>
</tr>
<tr>
<td>Inland Container</td>
<td>1 – 2 trucks (&lt;160m³)</td>
</tr>
<tr>
<td>Inland Dry Bulk</td>
<td>1 – 2 trucks (&lt;160m³)</td>
</tr>
<tr>
<td>Inland Cruise</td>
<td>1 – 2 trucks (&lt;160m³)</td>
</tr>
<tr>
<td>Inland Towage</td>
<td>1 truck (&lt;80m³)</td>
</tr>
<tr>
<td>Sea Tanker</td>
<td>&gt;2 trucks – &gt;160m³</td>
</tr>
<tr>
<td>Sea Container</td>
<td>&gt;2 trucks – &gt;160m³</td>
</tr>
<tr>
<td>Sea Dry Bulk</td>
<td>&gt;2 trucks – &gt;160m³ (splitthoff 1000-1500 m³)</td>
</tr>
<tr>
<td>Sea Cruise</td>
<td>&gt;2 trucks – &gt;160m³</td>
</tr>
<tr>
<td>Sea Offshore</td>
<td>&gt;2 trucks – &gt;160m³</td>
</tr>
</tbody>
</table>

1.1.3 Sub-sector suitability for LNG equipment

Now ships are compared to what extend it is viable to retrofit a conventional ship taking into account the required larger LNG tanks, new gas turbines and other LNG equipment like a BOG unit (Boil-Off Gas). From the interviews it became clear that most inland tanker ships have enough space for all LNG equipment. Inland container ships will have to give up space for one or two containers, cruise ships are losing one or two cabins and tugboats will have to accept smaller fuel tanks when retrofitting to LNG. However, push boats – pushing mostly dry-cargo barges, cannot be retrofitted because there is simply no space.

On sea-going vessels much more space is available, so there retrofitting will not be a problem – when only space for LNG equipment will be considered.
1.2 Operational Characteristics

1.2.1 Sub-sector fuel consumption

The fuel consumption of a ship is determined by several factors including engine efficiency, design, size, cargo, speed, destination and river flow (EVO, 2012). Although every ship has a different fuel consumption, per sector the average amount of consumed fuel is determined. Differences in fuel consumption are interesting because of price differences between conventional fuels and LNG are important in calculating the business case.

Inland Shipping

For the determination of the average fuel consumption per sub-sector in the inland shipping sector a concept report provided by EICB’s director serves as main source. The report analyzed the fuel consumption of inland ships in a research on LNG refueling facilities. It uses Dutch bunkering data from 2013 and makes a distinction between (translated to thesis terms) inland containers, inland tankers, dry cargo and passenger ships. Table A1.3 shows the amount of sub-sector vessels per fuel consumption class.

### Table A1.3: Number of ships per inland shipping sector in the Netherlands, source: (EICB, Onderzoek LNG-bunkerpunten [concept], 2015)

<table>
<thead>
<tr>
<th>Fuel consumption</th>
<th>Inland tanker</th>
<th>Inland container</th>
<th>Inland dry cargo</th>
<th>Inland passenger</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;250 m³</td>
<td>493</td>
<td>502</td>
<td>85</td>
<td>52</td>
</tr>
<tr>
<td>&gt;500 m³</td>
<td>146</td>
<td>124</td>
<td>37</td>
<td>17</td>
</tr>
<tr>
<td>&gt;750 m³</td>
<td>63</td>
<td>9</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>&gt;1000 m³</td>
<td>19</td>
<td>3</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>&gt;1500 m³</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>&gt;2000 m³</td>
<td>-</td>
<td>-</td>
<td>9</td>
<td>1</td>
</tr>
</tbody>
</table>

Now the average sub-sector fuel consumption can be calculated. Information on the average fuel consumption of tugboats is consulted from the interview with KOTUG (Appendix 4). Inland cruise ships consume on average 800-1000 m³/yr. (source Argos Inland bunkering). Results are presented in table A1.4.

### Table A1.4: Average fuel consumption in different inland shipping sectors

<table>
<thead>
<tr>
<th></th>
<th>Inland tanker</th>
<th>Inland container</th>
<th>Inland dry cargo</th>
<th>Inland passenger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average fuel consumption</td>
<td>500 m³/yr.</td>
<td>450 m³/yr.</td>
<td>750 m³/yr.</td>
<td>600 m³/yr. – Inland cruise app. 800-1000 m³/yr.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>500 m³/yr.</td>
</tr>
</tbody>
</table>

Maritime Shipping

For the determination of the average fuel consumption per sub-sector in the maritime shipping sector the CCNS report “International survey of fuel consumption of seagoing ships at berth” is the main source (CNSS, 2014). Part of the research performed in that report was plotting the hourly fuel usage of seagoing vessels and also mapping the size of these vessels in GT. For this thesis research we are interested
in the average fuel consumption of different sub-sectors, therefore the average fuel consumption of sub-sector vessels of 40,000 GT are presented in table A1.5

<table>
<thead>
<tr>
<th></th>
<th>Sea tanker (oil tanker)</th>
<th>Sea container</th>
<th>Sea dry cargo</th>
<th>Sea passenger (ferries)</th>
<th>Sea offshore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average fuel consumption</td>
<td>700 kg/hour.</td>
<td>300 kg/hour.</td>
<td>250 kg/hour.</td>
<td>400 kg/hour.</td>
<td>-</td>
</tr>
</tbody>
</table>

1.2.2 Sub-sector geographical bunker infrastructure requirements

The sailing route of a ship determines the geographical place where a ship needs to refuel. Therefore for example a scheduled ferry requires an entirely different bunkering infrastructure than an inland cruise ship which sails to every corner of Europe. Where a ferry only needs a refueling possibility at either one side of the line, an inland cruise ship requires a very dense network of bunker facilities.

Inland tanker- and container ships require a medium dense network of bunker facilities. Those ships sail between inland ports so if most ports have a LNG bunker facility it will do. Dry-bulk pushers are mostly scheduled for one customer and sail in line. For example Thyssenkrupp Veerhaven has eight pushers that transport ore for the Thyssenkrupp concern (ThyssenKrupp, 2015). This means that they sail in a cycle. Only one LNG bunker facility somewhere on that track will be enough to supply dry-bulk ships. A last inland sub-sector is inland towage. Tug boats operate in and around ports. They therefore only need a LNG bunker facility in the port they are operating in.

Maritime ships only sail between the bigger sea-ports in this world. Therefore they require a LNG bunker facility in every port they enter. Cruise ships need a denser network of refuel facilities because they not only enter ports, but many other places in the world. Sea offshore ships are, just like the other maritime ships mostly refueled on a ship-to-ship base.

1.2.3 Sub-sector subject to port dues?

The Port of Rotterdam is committed to reduce their greenhouse gas emission as a port while continuing their role as transportation and economic center. Stimulating ship owners to shift to less polluting alternative fuels is considered one of the solutions. Therefore the Port of Rotterdam stimulates the introduction of LNG as a cleaner fuel for shipping. As an example the ‘house rules’ of the port, the Rotterdam Port Management Bye-laws, can grant permits and exemptions related to LNG. Even more direct, discounts are granted on port dues in the case of more sustainable ships, or even on LNG fueled ships (interview Port of Rotterdam, Appendix 4).

When sea going- or inland ships use the port or other services of the Port of Rotterdam, they are subject to port dues. This accounts for a substantial amount of a ship’s operational costs. To illustrate this, an example calculation from the terms & conditions for port dues in the Port of Rotterdam is shown in figure A1.2.

In this example the port due of a 75,246 DWT sea-going container ship with a cargo of 39,000 ton containers is calculated. Every time such a ship arrives at a port it is subject to approximately €36K of port dues. A discount on port dues when using LNG would change the profitability of a LNG business case significantly.
Figure A1.3 shows the discount percentages for inland shipping port dues derived from the terms & conditions for port dues in the Port of Rotterdam. An inland ship fueled by LNG can outperform the CCR2 emission requirements with 60% leading to a significant discount of 30% on port dues. A practical example is ‘de Argonon’, the first inland ship using LNG as a fuel. The Argonon is subject to a 30 % discount on its port dues (Schuttevaer, 2011).

<table>
<thead>
<tr>
<th>Sub Sector</th>
<th>Subject to port dues in normal day-to-day activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inland Tanker</td>
<td>Yes</td>
</tr>
<tr>
<td>Inland Container</td>
<td>Yes</td>
</tr>
<tr>
<td>Inland Dry Bulk</td>
<td>Yes</td>
</tr>
<tr>
<td>Inland Cruise</td>
<td>No</td>
</tr>
<tr>
<td>Inland Towage</td>
<td>No</td>
</tr>
<tr>
<td>Sea Tanker</td>
<td>Yes</td>
</tr>
<tr>
<td>Sea Container</td>
<td>Yes</td>
</tr>
<tr>
<td>Sea Dry Bulk</td>
<td>Yes</td>
</tr>
<tr>
<td>Sea Cruise</td>
<td>No</td>
</tr>
<tr>
<td>Sea Offshore</td>
<td>No</td>
</tr>
</tbody>
</table>

Concluding on port dues; sub-sectors which are not subject to port dues in their normal day-to-day activities are inland passenger ships, inland tugboats, sea cruise ships and sea offshore ships. The simple reason is that they mostly don’t use port services when performing activities.
1.3 Operational Environment

1.3.1 Emission requirements
Like already elaborated on in the socio-technical regime in chapter 3.2 and the structures of rules in chapter 3.3 a very global overview of emission requirements per sub-sector is given in this section.

The inland shipping sector has to deal with European rules on emission limits. The current emission limits “Stage V emission limits for engine category IWP” set rules on CO, HC, NOx, PM, PN and A (EBU, 2014). All inland ships have to comply with these stage V emission rules. Note that tugboats call to maritime shipping regulation since they have to go and pick up large ships on sea.

The maritime shipping sector has to deal with IMO’s SOx Emission Control Area (SECA) which is implemented in January 2015 and NOx Emission Control Area (NECA) of which Tier III will take effect in 2016. In SECA as of 2015 a maximum of 0.10% sulphur is allowed in relation to the 3.50% allowed maximum in the rest of the world. In 2020 there will be a global maximum of 0.50%. So at this moment (2015) maritime ships have sulphur emission requirements on “world” level and on “SECA” level. Most of the maritime ships sail in- and outside SECA. Short-sea coasters however sail up to 100% of their time in SECA.

1.3.2 Sub-sector size of fleet
Many different sources are used to come up with the size of the sub-sector fleets. Also statistics from different years are used. The exact numbers are not interesting for this research; the goal of this analysis is to find global differences between sub-sectors. Therefore numbers in tables A1.7 and A1.8 are round up.

Inland Shipping
The scope of this research includes the implementation of LNG as maritime fuel in the Netherlands and the rest of Europe. Several sources are consulted to produce an overview of the amount of vessels per sub sector. The assumption is made that vessels navigating on European waters are owned by parties from European countries. For inland tankers, inland containers and inland dry-bulk the EICB statistics are used (EICB, 2012), which is already a composition of several other sources. For inland towage, or tug boats, best estimate of the European and Dutch fleet is composed by statistics from the European Tug owners Association (ETA, 2015) and Marcon International Inc. (Marcon, 2014). Inland Cruise statistics are provided by Argos Inland Bunkering.

Table A1.7: Fleet sizes of the inland shipping sub-sectors

<table>
<thead>
<tr>
<th>Sub Sector (inland)</th>
<th>Size of European fleet</th>
<th>Size of Dutch fleet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inland Tanker</td>
<td>2.000</td>
<td>1.250</td>
</tr>
<tr>
<td>Inland Container</td>
<td>7.000</td>
<td>4.000</td>
</tr>
<tr>
<td>Inland Dry Bulk</td>
<td>2.500</td>
<td>1.200</td>
</tr>
<tr>
<td>Inland Cruise</td>
<td>300</td>
<td>30</td>
</tr>
<tr>
<td>Inland Towage</td>
<td>1.000</td>
<td>125</td>
</tr>
</tbody>
</table>

Maritime Shipping
For sea-going vessels that sail in Dutch and European waters statistics are used from the Netherlands and the world. International trade via oceans is after all mostly intercontinental. Consulting the year report of the royal association of Netherlands ship owners (KVNR, 2014), the size of the Dutch fleet is 1047 and another 900 ships are owned by Dutch companies but sailing under another flag. Furthermore
the Dutch fleet is third with 126 ships of the 865 vessels worldwide for the offshore industry for oil, gas and windpower. For the other sub-sectors the size of the world fleet is derived from 2011 statistics (Equasis, 2012). There should be noted that there is a large group of 17,000 general cargo ships in the world. These ships are usually specifically designed for the task, making it very hard to compare this group with others. Therefore it is left outside the project scope. Dutch fleet is estimated with ratios dating from 2007, translated to 2015 (V&W, 2008).

Table A1.8: Fleet size of the sea-going maritime shipping sub-sectors

<table>
<thead>
<tr>
<th>Sub Sector (sea going)</th>
<th>Size of World fleet (amount)</th>
<th>Size of Dutch fleet (amount)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Tanker</td>
<td>14,000</td>
<td>200</td>
</tr>
<tr>
<td>Sea Container</td>
<td>6,000</td>
<td>200</td>
</tr>
<tr>
<td>Sea Dry Bulk</td>
<td>10,000</td>
<td>400</td>
</tr>
<tr>
<td>Sea Passenger</td>
<td>6,500 – 300 cruise-ships</td>
<td>30</td>
</tr>
<tr>
<td>Sea Offshore</td>
<td>850 offshore (oil, gas, wind)</td>
<td>125 offshore (oil, gas, wind)</td>
</tr>
<tr>
<td></td>
<td>10,000 (all kind of offshore)</td>
<td>100 (all kind of offshore)</td>
</tr>
</tbody>
</table>
Appendix 2: Conventional vs. LNG – Prices – Energy density – Volume – Initial investment

### Energy density / volume / prices

<table>
<thead>
<tr>
<th></th>
<th>MJ / liter</th>
<th>Kg / liter</th>
<th>MJ / kg</th>
<th>€/ton (Argos feb-15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG</td>
<td>22 MJ/liter</td>
<td>0.450 Kg/liter</td>
<td>49 MJ/kg</td>
<td>473 €/ton</td>
</tr>
<tr>
<td>MDO</td>
<td>36 MJ/liter</td>
<td>0.840 Kg/liter</td>
<td>42 MJ/kg</td>
<td>487 €/ton</td>
</tr>
<tr>
<td>HFO</td>
<td></td>
<td></td>
<td></td>
<td>322 €/ton</td>
</tr>
</tbody>
</table>

LNG engines need more liters LNG than diesel engines need liters MDO. However, LNG engines need less kg LNG than diesel engines need kg MDO. Ships are being built on their weight because of the simple reason that ships have to float. In that case we need to look at the energy density per kg. Taking into account that current gas engines are approximately 5% less efficient than conventional diesel engines, LNG and diesel engines thus approximately use the same amount of kilograms. Therefore prices can be compared in €/ton.

The volume however does play a role. Fuel tanks need to be 30-40 % bigger in the case when LNG will be used as fuel. Again, a bigger fuel tank does not mean a bigger ship, because the net weight stays the same.

**Initial Investments**

A new-built LNG fueled ship is substantially more expensive than the same ship with a diesel engine. LNG tanks are quite costly and gas / dual fuel engines are more expensive than conventional diesel engines. Besides that, all smaller parts needed on a ship like pumps, piping, safety valves, etc. are in general 1.5 – 2 times more expensive than current conventional solutions.

Initial LNG investments differ case by case. To identify differences between end user sub-sectors rough averages are taken from known projects in combination with user experiences discussed during the interviews (Appendix 4).

**Initial investments Inland shipping sector:**

The interview with Interstream Barging, who has 2 LNG-fueled inland tankers in its fleet, pointed out that a typical 2000 ton barge (inland tanker) is €1 to 1.5 million more expensive when fuelled on LNG. Lloyd’s, who is involved in several LNG projects for inland shipping, states that typical LNG-fuelled inland ship project require €1 to 1.5 million more compared to conventional technologies. Also the retrofit project of KOTUG, who plans to LNG-retrofit one of their tugboats is estimated to be an investment of €1 to 1.5 million. In the interview with shipyard Kooiman it became clear that in the case of pushers (for inland dry-bulk) a total new design is needed because of the required volume of LNG equipment. Therefore those new-builds turn out to become approximately €2.5 – 3 million more expensive when fuelled on LNG.

**Total investments Maritime shipping sector:**

Off course investments are higher in the maritime sector because these ships are way bigger than inland vessels. All interviewees, including Spliethoff and KVNR, agree on the fact that LNG retrofitting is not an
option (economically) in the maritime shipping sector. For new-builds however, LNG fueled ships are also in this sector 15-20% more expensive than conventional ships (Spliethoff interview).

Analysis of several Maritime shipping (proposed) new-build LNG projects (SSN, LNG in Norway, 2012) & (Wartsila, 2011) resulted in the following rough estimates for average total extra LNG investments.

Sea Tanker: €7 to 9 million  
Sea Container: €8 to 10 million  
Dry Bulk: €4 to 6 million  
Cruise: €10 to 12 million
Appendix 3: TranScript application example

The following is a shortened version of the application of the TranScript framework on the “Greening of Gas” case study by Anish Patil (2014). The full version is can be found in his publication for obtaining the degree of doctor at Delft University of Technology: Scripting Transitions; A framework to analyze structural changes in socio-technical systems.

A recap of the six steps for analyzing transitions in STS by applying TranScript:

1) Identify the necessary conditions without the transition cannot take place.
2) Translate necessary conditions into sub-conditions. The sub-conditions should cover all required relevant structures that would help in achieving the necessary condition.
3) Apply analytical framework to identify the actors that have the ability to influence these structures and the drivers required to motivate these actors. Each structure is produced by an actor.
4) Plot all the assets to get an overview of the total system in an AND/OR diagram.
5) Produce a system configuration diagram along with the relevant structures for transition.
6) Interpret the system configuration diagrams to outline the conditions under which this transition would take place.

The “Greening of Gas” case study studies the transition from the existing natural gas system towards a mixture of hydrogen and natural gas within the Netherlands. Mixing hydrogen with natural gas in the existing grid would be a head start towards a hydrogen economy, bringing economic- and environmental benefits. The following is a shortened version of applying the six steps on this case study.

[1] Identify the necessary conditions without the transition cannot take place.

Necessary condition 1: Need to have excess hydrogen capacity, as the current hydrogen capacity has been accounted for.

Necessary condition 2: Need to be able to feed hydrogen into the existing natural gas network and to have end-user appliances that are compatible with the hydrogen and natural gas mixture.

[2] Translate necessary conditions into sub-conditions. The sub-conditions should cover all required relevant structures that would help in achieving the necessary condition.

Translating Necessary condition 1 into sub-conditions can be done by asking the following question: Q1. Can we create excess hydrogen? The answer to this question is yes, excess hydrogen can be obtained in three different ways:

Green hydrogen: through the conversion of wind or solar power into hydrogen via electrolysis of water. This leads to the following questions:

Q1.A1) Can we build new green power capacity?
Q1.A2) Can we supply this green power to the grid?
Q1.A3) Can we convert this green power into hydrogen?
Black hydrogen: through the conversion of fossil fuels into hydrogen along with carbon capture and sequestration. This leads to the following questions:

Q1.B1) Can we produce hydrogen from fossil fuels?
Q1.B2) Can we obtain extra natural gas or coal to be converted into hydrogen?
Q1.B3) Can we utilize the CO2 emitted during the process?
Q1.B4) Can we sequester the CO2 emitted during the process?

Carbon neutral hydrogen: through the conversion of nuclear power into hydrogen via electrolysis. This leads to the following questions:

Q1.C1) Can we build new nuclear power capacity?
Q1.C2) Can we convert nuclear power into hydrogen?

Translation *Necessary condition 2* into sub-conditions can be done by asking the following two questions:

Q2. Can we feed hydrogen into the natural gas network – is it technologically feasible and is it institutionally allowed?
Q3. Can we have end-user appliances that are compatible with the hydrogen and natural gas mixture?

These conditions Q2 and Q3 are also further studied by Patil (2014). For the sake of this being an example of application we will take only Q1.A Green Hydrogen to the next step.

[3] *Apply analytical framework to identify actors that have the ability to influence these structures and the drivers required to motivate these actors. Each structure is produced by an actor.*

Q1. Can we create excess hydrogen capacity?

Since the current hydrogen production more or less meets demand, there is a need for additional hydrogen capacity. Figure 2.3 shows how actors active within the energy sector are motivated by the Rule of Dutch Climate & Energy Policy together with rising emissions along with the depletion of finite fossil fuel resources (system condition), to take action and install hydrogen capacity.

The Climate & Energy policy is developed by the Dutch Government. It is a framework to reduce emission and meet future energy demands with regards to the Kyoto Protocol. Figure 2.4 shows the Kyoto Protocol, rising emissions, security of supply and depletion of fossil fuel calling on the Dutch Government to develop the Dutch Climate & Energy policy.
Q1.A1 Can we build new green power capacity?

One of the main instruments flowing from the Dutch Climate & Energy policy is the SDE+ subsidy system that gives financial incentives for the production and supply of renewable electricity, gas and heat. The SDE+ feed-in tariff guarantees minimum payments, making investments in green power a safe bet. Figure 2.5 shows these dynamics leading to driving the energy sector to install green power assets.

Actors that invest in any assets are bound by the primary rule of Cost Recovery. Along similar lines actors would like the operating capacity of their assets as high as possible. In the Netherlands the effective operating capacity for each energy producing asset is managed by the Rule of Merit-Order; the ranked order based on the variable costs of electricity production. The variable costs are determined by the fuel price and the price of CO2. Green energy therefore will find a place in the market sooner than fossil fuel-based power. Two rules are developed here: EU ETS by the European Union (put a price on CO2 emissions) and the Merit-Order rule by the energy sector.
Q1.A2 Can we supply this green power to the grid?

Because of fluctuations in the availability of wind and solar power lead to imbalances on the grid, grid operators have to react with up- or down scaling of auxiliary power. In the case of wind energy this means that auxiliary power must be present for almost 100% of the installed wind capacity to ensure sufficient back-up (security of supply). Figure 2.6 shows these dynamics leading to the energy sector installing auxiliary power capacity.

Q1.A3 Can we convert this green power into hydrogen?

Converting green power into hydrogen allows the maximum production of green power because it then is no longer constrained by grid balancing. This allows investors to optimize their return on investment. There are already some pilot projects going on to test the applicability of this technology. The Dutch government is supporting new pilot projects through its energy and climate policies. These rules create drivers for actors to invest in pilot projects like power to gas. The dynamics of the energy sector investing in the Assets green power to hydrogen are shown in figure 2.7.

After applying the analytical framework also on Q2 and Q3, all relevant actors, assets, rules and system conditions are identified that could lead to the necessary conditions for a transition towards hydrogen via the natural gas network. Knowing that satisfying the necessary conditions is a pre-requisite for a transition but just meeting them does not guarantee a transition makes it possible to draw the first conclusions after step 3; if all structures are present it is possible; if some structures are missing the transition is not (yet) possible. Because the technology is still under development in pilot projects, it can be concluded that a transition is not yet possible.
[4] Plot all the assets to get an overview of the total system in an AND/OR diagram.
The highest level asset as defined in the previous step is the asset Hydrogen Production. There are three types of assets that will establish Hydrogen Production, being Black Hydrogen, Nuclear Hydrogen OR Green Hydrogen. The latter we analyzed in the previous step to require two assets, being Green Power AND Green Power to H2. Figure 2.8 gives an overview of the assets required for creating excess hydrogen capacity. It thus shows also the assets required for Nuclear- and Black Hydrogen.

![AND/OR diagram for the first necessary condition of excess hydrogen capacity](image)

Figure 2.8: TranScript - AND/OR diagram for the first necessary condition of excess hydrogen capacity (retrieved from Patil, 2014)

[5] Produce a system configuration diagram along with the relevant structures for transition.
The system configuration helps to identify the structures that are needed during transition and which actors would develop these structures. In figure 2.9 the required assets for green hydrogen are displayed in the middle, with rules on both sides, as how they are identified in step three. An arrow between structures means that one structure leads to another.
Interpret the system configuration diagrams to outline the conditions under which this transition would take place.

The information about the structures that need to be established, along with a potential sequence of structures, gives potential transition paths. The discussion should address the question – how can this transition come about? The guiding principle is to look for incentives and identify actors that will benefit from them when taking action. An example of a transition path can be discussed as follows:

The SDE+ rule has created incentives to install wind power capacity. Merit order rule says that auxiliary power have to be turned off-line when wind mills generate power. Therefore, more green power leads to fewer incentives to invest in auxiliary power. Without incentive to invest in auxiliary power, the network will be imbalanced. With this lobby, auxiliary power owners can go to the Dutch government to change the SDE+ rule to include auxiliary power. This dynamics is shown in figure 2.10.
Appendix 4: Interview Summaries

The participatory involvement of key stakeholders plays a significant role in the analysis of the LNG transition situation. Interviewing key stakeholders is a good method for gaining qualitative information about people’s experiences, views and feelings. The interviews are designed following a semi-structured format. A list of topics to discuss is set up and this has been the structure during all interviews. This guarantees the possibility to compare the results afterwards. The following interview structure is used in the conversations with key stakeholders from the maritime socio-technical system:

- Introduction of stakeholder and personal job functions
- Main drivers of stakeholders related to LNG
- Perspective to powerful players in socio-technical system
- Perspective on transition barriers
- Stakeholder’s potential measures to block or accelerate transition
- Future outlook & perception of the ideal situation

The results of each interview is summarized and documented in the next part. Figure A4.1 represents the high level of interdependencies between the stakeholders that are interviewed. It can be described as a web of interdependencies; it is one of the characteristics of a socio-technical system. Table A4.1 shows an overview of the interviewees sorted per stakeholder group.

![Figure A4.1: Web of stakeholders in the marine socio-technical system related to the LNG transition](image-url)
<table>
<thead>
<tr>
<th><strong>Table A4.1: List of interviewees sorted per stakeholder group</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Potential LNG end-users – Inland Shipping</strong></td>
</tr>
<tr>
<td><strong>CBRB</strong></td>
</tr>
<tr>
<td><strong>Vinotra</strong></td>
</tr>
<tr>
<td><strong>Interstream Barging</strong></td>
</tr>
<tr>
<td><strong>KOTUG</strong></td>
</tr>
<tr>
<td><strong>Potential LNG end-users – Maritime Shipping</strong></td>
</tr>
<tr>
<td><strong>KNVR</strong></td>
</tr>
<tr>
<td><strong>Spleithoff</strong></td>
</tr>
<tr>
<td><strong>Knowledge Centers</strong></td>
</tr>
<tr>
<td><strong>TNO</strong></td>
</tr>
<tr>
<td><strong>EICB</strong></td>
</tr>
<tr>
<td><strong>University of Groningen</strong></td>
</tr>
<tr>
<td><strong>LNG Class &amp; Standards + Consultancy</strong></td>
</tr>
<tr>
<td><strong>Lloyd’s Register</strong></td>
</tr>
<tr>
<td><strong>DNV-GL</strong></td>
</tr>
<tr>
<td><strong>REBEL Group</strong></td>
</tr>
<tr>
<td><strong>Financial Services</strong></td>
</tr>
<tr>
<td><strong>ING</strong></td>
</tr>
<tr>
<td><strong>LNG Equipment</strong></td>
</tr>
<tr>
<td><strong>General Electric</strong></td>
</tr>
<tr>
<td><strong>Rommert Ship Design</strong></td>
</tr>
<tr>
<td><strong>De Kooiman Groep</strong></td>
</tr>
<tr>
<td><strong>Volvo Penta</strong></td>
</tr>
</tbody>
</table>
### Policy Bodies

<table>
<thead>
<tr>
<th>Europe</th>
<th>Ministry of Infrastructure &amp; Environment</th>
<th>Province of Zuid-Holland</th>
<th>Port of Rotterdam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsidy Program</td>
<td>Legislation</td>
<td>Subsidy Program</td>
<td>Port Authority</td>
</tr>
<tr>
<td></td>
<td>Head of Dutch delegation in the ADN Safety Committee Genève</td>
<td>Project Manager</td>
<td>Project Developer</td>
</tr>
</tbody>
</table>

### Lobby Groups

<table>
<thead>
<tr>
<th>European Barge Union</th>
<th>Lobby</th>
<th>Chairman Dangerous Goods Committee</th>
</tr>
</thead>
<tbody>
<tr>
<td>National LNG Platform</td>
<td>Lobby</td>
<td>President</td>
</tr>
</tbody>
</table>

### LNG Infrastructure

<table>
<thead>
<tr>
<th>Anonymous</th>
<th>LNG Trader</th>
<th>Gas Structurer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argos</td>
<td>Bunkering</td>
<td>CEO</td>
</tr>
<tr>
<td>GDF-SUEZ LNG Solutions</td>
<td>Total Infrastructure</td>
<td>Manager Operations</td>
</tr>
</tbody>
</table>
CBRB – Representing interests of inland shipping companies – Keeping members informed about important activities and developments – Serve as helpdesk – Organize commissions and working groups.

Robert Kasteel is the director of the CBRB. One of the main tasks for the CBRB is lobbying for the interest of the inland shipping sector, mostly at governmental organizations. Often this means fighting for level playing field between the inland shipping sector and other modalities like road transport and coastal transport. This includes submitting proposals at the ADN safety committee in Geneve and the CCNR commission in Strasbourg.

The following is a summary per discussed subject.

**LNG – Why – Where – What role in organization?**

First of all:
- European Union should ban heavy pollution by maritime ships from European harbors by law. It is alarming and unfair that it is still common practice that those ships are welcome in our harbors.
- Level playing field between inland- and coastal ships on the topic of degasification of tanker ships should be fixed. Coastal vessels are authorized to degas at the bouys and pollute as soon as they are sailing on sea.
- Financial institutions are partly responsible for the current overcapacity in the inland shipping sector. In the years prior to 2008 lending was way to easy and based on wrong terms and conditions.

The CBRB promotes developments leading towards a more sustainable and cleaner inland shipping sector. Therefore LNG developments are monitored, for example through the EICB, which is affiliated to the CBRB. In terms of CO₂ the inland shipping sector already complies to future Euro-6 norms. SOₓ and NOₓ- and particulate matter emissions however cannot be reduced enough with currently available diesel engines. Technology developments in ship engines are related to developments in truck engines. The lifespan of a truck engine however is 5 years against 20 years for a ship engine. This in combination with the inland shipping sector being a relatively small market for engine producers causes technology developments in this sector to be delayed.

Three main solutions:
1) Shift to a different fuel – LNG in combination with after-treatment.
2) Expensive technology – Too expensive and technically impossible to install on smaller inland ships.
3) European Union should come up with a different norm – US EPA 4 norm instead of Euro-6 norm. DG move of the European Commission makes the decisions on this topic.
**LNG Transition bottlenecks / barriers**

1) LNG investments are high – Fuel consumption has to be very high in order to earn back investments (f.i. Rotterdam-Basel).

2) Bad inland shipping market conditions – Low margins and profits lead to problems with funding.

3) Monopolies in gas supply and LNG equipment drive prices up – LNG players need more competition.

4) LNG Infrastructure is lacking – Especially in the case of unpredictable shipping schedules this is a problem.

**CBRB’s measures to influence LNG transition**

1) Support shipping companies during LNG trajectory.

2) Lobby about legislation trajectory – Brussels, the Hague, Genève, Strasbourg. Other Member States are hesitant regarding the implementation of LNG. This is caused by a lack of technological knowledge and is mainly based on emotions. The interests for Member States like France and Switzerland are limited.

3) Lobby for LNG subsidies – European-, national- and local governments (Port of Rotterdam).

**Future (what-if) scenarios**

- Difficult and time-consuming processes to gain European permits discourages market parties to look into LNG.

- Natural gas can fulfill a helpful role in obtaining a cleaner inland shipping sector, but LNG is definitely not the only solution.

**Ideal situation**

- Inland shipping sector should maintain- and further expand its leading position regarding to emissions.

- Inland shipping sector has room for expansion – there is more space left on inland waterways than on European roads.

- Brussels should use the many years of knowledge and experience which are present at the CCNR in Strasbourg. Leave power to decide there instead of involving more Member States in inland waterway issues.

- Brussels should drop the Euro-6 norm for the inland shipping sector and implement a copy of the US EPA 4 norm. Otherwise requirements are demanded which cannot be met.
Vinotra – Rotterdam based independent carrier with a versatile and modern fleet of approximately 20 tankers in the transportation and bunkering of various mineral oils. Flagships are the Vinotra10 (with 12000MT the biggest of her kind in Europe), the Amulet (also ‘Ecotanker’; fully diesel-electric barge) and the Argonon (dual fuel 80% LNG 20% diesel).

Erik Kooren is shareholder and safety manager at Vinotra. Vinotra is like as a broker for cargo; most barges in the fleet are owned by others but operating under long-term charter contracts by Vinotra.

The following is a summary per discussed subject.

**LNG – Why – Where – What role in organization?**

Vinotra is transporting and bunkering various mineral oils, therefore it is in Vinotra’s interest that oil and HFO constructions will be preserved. The oil transportation market is declining, caused by a shift towards a more efficient, less oil consuming world economy. The present overcapacity in the inland tanker industry therefore will increase and future profitability will further decline.

Sustainable shipping is unattractive from a commercial point of view; since the introduction of the Argonon in 2011(dual fuel 80% LNG 20% diesel), nobody specifically asked for it. There can be concluded that there is no market demand for sustainable shipping because in general sustainability negatively affects profitability. However, when fuel cost reductions are possible, ship owners definitely consider taking action. Main driver will always be profitability, not sustainability.

Providing the market with LNG as a bunker fuel is not on Vinotra’s agenda, simply because currently there is no market demand for it. Also in current market conditions another dual fuel ship like the Argonon should not be expected.

**Transition bottlenecks / barriers**

In the case of tanker transport:

1) Supply of LNG – The exact shipping routes between for example Rotterdam and Basel often change on a last minute base. With the currently very limited amount of LNG bunker locations risks of running dry are too high. Another disadvantage of the current state of the LNG infrastructure is that you have to order a spot to bunker LNG at least two days in advance.

2) Costs of shipping are too high – Only profitable to shift towards LNG if ship operates on long trajectories. In order to earn back the initial LNG investment, fuel consumption has to be high.

3) Lack of information – Front runners and suppliers of LNG equipment and gas engines should share their experiences with the rest of the market. No information automatically is translated to a negative experience with LNG. Reputation of LNG should be improved.
4) Technology still in development – resulting in high prices and startup problems. Also methane slip due to technology immaturity is killing the environmental benefits of LNG.

**Powerful players – who can make or break transition?**

1) Gas sources like Shell – Powerful in oil & gas and transport of oil & gas. Shell is able to create an LNG demand (for example the Greenstream).

2) Government – LNG will not be blocked by governments, however on an European level progress is very time consuming. Lot of member states – Romania for example has other thoughts about LNG than the Netherlands.

**Future (what-if) scenarios**

- Market will only invest in LNG fuelled vessels if clients guarantee a charter contract for X years. With a guarantee the funding problem at banks will also disappear – low risk.

- New-builds in the tanker sector will only be special projects – there is no demand for new-builds due to over capacity.

- Many inland ships will install catalysts to comply with CCR-emission limits – stimulated by governmental subsidies. Also MDO in combination with hydrogen injections and catalysts will be sufficient for complying with CCR-regulations in the future.

- In the inland shipping sector the expectations are that the demand for LNG on the short term will not be high. Cruise ships and dry cargo ships (coal, ore) have the best perspective for implementing LNG.

- Ocean-going sea vessels are the last authorized ‘heating oil-fired plants’ in the world. In 2007 the world wide shipping sector used 360 million tons of HFO (http://vorige.nrc.nl/economie/article1874079.ece/Ze_varen_allemaal_op_stookolie_vuile_reut). What should we do with this huge amount of refinery residue?
Interstream Barging – Inland barging company specialized in liquid products such as petroleum, chemicals and vegoil. With a fleet of 144 barges Interstream Barging is market leader in terms of tonnage in Western Europe.

René Overveld is Manager safety Management & Operations at Interstream Barging as well as Chairman Dangerous Goods Committee at the European Barge Union (EBU). Interstream Barging has two LNG powered barges in its fleet; Greenstream and Green Rhine. René Overveld is directly involved in these projects.

The following is a summary per discussed subject.

LNG – Why – Where – What role in organization?

The Greenstream is in operation since April 2013, the Green Rhine since September 2013. Interstream Barging had a leading role in the preparation processes: guiding the legislation process at the ADN in Genève, lobbying for exemptions and bunker locations, securing the supply of gas, developing a training together with STC and guiding the construction of the barges.

The current state of affairs:
- 75 LNG bunker events.
- 4 LNG trainings (41 persons).
- 4 Bunker locations (Amsterdam, Rotterdam, Antwerp, Mannheim).
- Permission to build ship three and four.
- Green award.

Drivers for Interstream Barging are based on staying ahead in a high competitive market. In the end it is all about money. Being sustainable saves fuel cost and results in port due discounts.

Is the Greenstream a success?
- In terms of technology – Yes, many new (also non-LNG) technologies are successfully implemented.
- A typical 2000 ton barge is 1 to 1.5 million more expensive when fuelled on LNG. Since the LNG price the Greenstream pays is unknown, it is hard to draw conclusions on the return on investment. Greenstream is chartered by Shell, which also delivers the required LNG.
- After fixing some immaturity issues, the ship operates great.
- Also in terms of legislation procedures the project is a success – road to build ship three and four is free.
**Transition bottlenecks / barriers**

1) Infrastructure – Current bunker possibilities are very limited (4) and only by truck. Time consuming + not on route + hard to plan upfront.

2) Licensing trajectory is way too long + difficult to get bunker location permits at local authorities.

**Powerful players – who can make or break transition?**

1) Gas source – Major oil & gas companies should take the lead.

2) EU / national government – Should stimulate and facilitate the infrastructural aspect.

**Interstream’s measures to influence LNG transition**

1) When the LNG business case improves – Combining the knowledge present at Interstream Barging with the LNG business at Argos – together boost the LNG market.

2) Actively contribute to LNG groups like LNG4All – For example with the goal of reducing investment costs by producing LNG equipment standards like for LNG tanks.

3) Lobby for fixing infrastructural problems – Bunkering inland ships with trucks is no ideal match.

**Future (what-if) scenarios**

Ideal situation: Being able to bunker LNG everywhere – between Rotterdam and Mannheim at least another two or three bunker locations / bunker vessels.

Now there is proof of concept – especially after the successful Greenstream project, it is possible to accelerate. Still not happening though.

- Future will be dominated by overcapacity in the inland tanker sector. In 2005 there were 1350 single-hulled inland tankers in the Netherlands. By then it was calculated that there would be room for 850 double-hulled by 2018. In 2014 there are already 850 double-hulled inland tankers, but also 250 single-hulled. This huge overcapacity is bad for transport prices.

- Next to that, there will be less demand for transport. A European shift towards natural gas causes less oil products to be transported.

- The European tanker transport market will be determined by which oil refineries will stay. This will determine the possibilities to invest – also in LNG fueled barges.

Koos Smoor is manager fleet performance & innovation at KOTUG. Anticipating on future demands KOTUG is at the final preparation phase for LNG- retrofitting one of their tugboats. Although most of the time tugboats operate in harbors they have to comply with legislation for sea-going ships.

The following is a summary per discussed subject.

**LNG — Why — Where — What role in organization?**

Looking at some roughly estimated facts, we can conclude that the business case for an LNG retrofitted tugboat isn’t easy:

<table>
<thead>
<tr>
<th>Fuel Consumption</th>
<th>40 m³ diesel / month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime tugboat</td>
<td>15 – 20 years</td>
</tr>
<tr>
<td>Costs LNG retrofit</td>
<td>€ 1 – 1.5 million (comparable with retrofitting inland containership)</td>
</tr>
<tr>
<td>Benefits LNG retrofit</td>
<td>€ 40.000 / year (fuel costs)</td>
</tr>
</tbody>
</table>

The relatively low fuel consumption in combination with the absence of other benefits (tugboat isn’t subject to port dues, discounts there won’t affect business case), result in an unattractive payback time of 25+ years. Of course this is a market snapshot; fuel prices are dynamic and future investment costs can change.

Harder to express in terms of money are the indirect, more strategically effects of investing in an LNG retrofit. KOTUG believes that LNG will be the main future fuel in the maritime- and inland shipping sector. Since tugboats also operate on LNG terminals, the expectation is that in the near future the demand for LNG fuelled tugboats will rise. Therefore it is interesting to build up an LNG track record, creating goodwill and a trustworthy image.

Securing future markets in combination with positive first-mover publicity makes the project worth considering. However, it is hard to convince the board of directors when direct financial impacts are bad.

**LNG Transition bottlenecks / barriers**

1) Business case – Fuel consumption has to be high in order to obtain a reasonable investment payback period. Even with subsidies and sponsoring by project participants money still is a problem.

2) Lack of distribution of crucial information to the market regarding exact costs, fuel prices and benefits.
3) Current bunkering possibilities – large distance between operating area and the Seinehaven in the east of the Europoort Rotterdam.

4) Technology developments vs. regulatory regime – legislation runs behind the technological developments. Just one of many examples: from an operational point of view the maximal pressure in the LNG tanks should be 16 bars, the allowed maximum by law is currently 10 bars.

**KOTUG’s measures to influence LNG transition**

As an independent market party KOTUG influences the transition when it decides to LNG-retrofit one of their tugboats. Along this trajectory many other companies and institutions will be introduced to the LNG business case.

**Future (what-if) scenarios**

- Short-sea shipping has the highest potential to shift to LNG.
- When short-sea shipping shifts to LNG, rest of the shipping sector will also shift.
- Manufacturers of shipping engines have the responsibility to supply good 100% gas engines. The efficiency of current dual-fuel engines is too low.
- In 10 years from now, LNG infrastructure will be present – especially for short-sea shipping.
Royal Association of Netherlands Ship owners – Dealing with all issues that deal with shipping in the Netherlands. Representing collective interests – Individual counseling – Network organization.

Mrs. Tineke Netelenbos is the President of KVNR – representing more than 95% of Dutch salt water ships. Next to fighting for collective interests of shipping companies KVNR has a broad mission; including improving the quality of the Dutch fleet, improving the environmental impact of the Dutch fleet and trying to prevent a modal shift away from (especially) short sea shipping.

The following is a summary per discussed subject.

**LNG – Why – Where – What role in organization?**

The KVNR is strongly involved in the IMO negotiations about stricter sulfur emission limits. In the first place the KVNR is involved in the environmental affairs committee – the short-sea shipping sector is vulnerable for a modal back shift towards road transport. Secondly the KVNR is involved in the technical committee to secure seaworthiness and reliability of alternatives.

- Low-sulfur fuels are 70-100% more expensive than HFO.
- LNG retrofitting is not an option (economically) according to an internal workgroup.
- Retrofitting with scrubbers is possible in the case of big ships. In the case of small ships there are no scrubbers available yet.
- For new builds LNG is an option.

**Transition bottlenecks / barriers LNG**

1) Chicken- and egg game – Bunkering facilities and LNG infrastructure are required before ship owners will invest in LNG fueled ships.
2) Level playing field
   - Uncertainty about LNG price in relation to diesel – example of shore power: after shipping companies had already invested in shore power, government decided to introduce excise duty causing business case to become negative.
   - Distribution of LNG bunkering permits by local authorities – small municipalities will not have the same knowledge as municipalities like Rotterdam.
3) Funding of retrofitting is a problem – Even with a funding guarantee ‘Garantie Ondernemingsfinanciering’ of 50% the financial sector refuses to finance retrofitting.
4) Extra training of personnel is required.

**Powerful players – who can make or break transition?**

1) End-users – Shipping companies will make the final LNG investment decisions.
2) Suppliers of Gas + bunkering infrastructure – Security of supply for shipping companies.
3) Government – Regulations can force to shift towards cleaner fuels and ports can reduce port dues for cleaner ships (there is no way that LNG-fueled ships will get a total exemption of port dues).

‘When there will be an increase in demand of LNG the rest will follow.’

**KVNRR’s measures to influence LNG transition**

1) Lobby at governmental organizations – IMO, I&M, EU.
2) Education – Educate shipping companies about technological developments and provide mediation along the process towards certification (ILT).
3) Conferences – Rewarding first movers like Anthony Veder on conferences to raise attention.

Again – there will be no lobby if there is no demand for LNG.

**Future scenario / Ideal situation**

In the near future the maritime shipping sector will definitely use a cleaner fuel. What kind of fuel this will be depends on the type of ship, the area where it operates and the availability of tank storage and bunkering facilities.

There is a need for a more holistic approach. In the case of scrubbers – scrubbers reduce SO\textsubscript{x} emissions, but increase CO\textsubscript{2} emissions. Regulations also have to be global to secure level playing field. Next to that, regulations should not hamper innovation – rules should be adjusted to the current fleet.

The maritime shipping sector will become more sustainable. This means that shipping becomes more expensive because of higher fuel expenses. More focus should be on the shippers. They simply choose for the least expensive shipping company, while costs of transport are increasing.
Spliethoff Group – Worldwide Ocean Transport. One of the largest ship management companies in the Netherlands (>100 vessels). Broad portfolio in all types of dry cargo: Dry cargo, break-bulk & project cargo (SpliethoffTM) – Project & heavy lifts (BigLift ShippingTM) – Container & Ro-Ro cargo and door-to-door services (TransfennicaTM) – Short sea (Wijnne BarendsTM) – Yacht transport (Sevenstar Yacht Transport®).

Sjaak Klap is Vice President Business Development at Spliethoff focusing on new shipping services, collaborations, new markets and fleet renewal. Although Spliethoff Group endeavors to minimize its vessels’ environmental impact by limiting their emissions of SO\textsubscript{X}, NO\textsubscript{X}, fine particles and CO\textsubscript{2}, drivers behind strategic (investment) decisions are financial 99,99% of the time. Image doesn’t play a large role because of clients not being consumers in combination with a market unwilling to pay more for ‘green’. However, super-efficient ships are required in order to compete with low market prices of “virtually bankrupt” shipping companies.

The following is a summary per discussed subject.

**LNG – Why – Where – What role in organization?**

Ships in the current fleet which are active in Emission Control Area’s (SO\textsubscript{X}) need a solution to comply with stricter sulfur emission limits. Retrofitting current fleet towards LNG is no option due to huge investments and the required space for LNG tanks and equipment, leading to a reduction of cargo capacity. Scrubbers however are the perfect solution for current vessels; Transfennica vessels will have scrubbers before the end of 2014. Distillate fuels (MGO) will be used by Spliethoff on vessels sailing in SECA’s part-time and for vessels where installing a scrubber is not feasible due to e.g. vessel size and age.

However, Spliethoff’s fleet also requires renewal and for new builds LNG is a feasible alternative. An important aspect is the availability of LNG and its price. Conventional fuels are seen as a commodity; never worry about availability and price is almost the same all over the world. This differs from LNG – infrastructure is lacking and the gas price shows huge differences. Low gas prices in North-America causes the business case attractive for ships active in that area. This will not change the fact that LNG fueled ships are 15- to 20% more expensive than conventional ships. Implementing scrubbers in new builds is cheaper.

Spliethoff’s future fleet will exist of ships fuelled on HFO with scrubbers and/or LNG fueled ships. LNG will only make it if the price of LNG is lower than the price of HFO. With the current extreme low oil price (November 2014) this will be tough. This is a serious threat for LNG developments.

**Transition bottlenecks / barriers LNG**

1) Financial aspect – LNG vs. HFO. Large impact of uncertainties; we need a long term vision – if you look at LNG with current market conditions, LNG isn’t a feasible option. Spliethoff needs long term fuel contracts (+5 years), otherwise no LNG-fuelled ship will be built.

2) Investment cost for LNG are high in comparison with HFO.
3) International policies – uncertainties in policies like IMO – MARPOL / European rules that shifted from 2020 to 2025.

- Technology is not a barrier.
- Supervision and control of regulations is lacking, but that will be solved.
- Funding projects is not a problem for Spliethoff.

**Powerful players – who can make or break transition?**

1) Upstream oil & gas companies. Increasing importance of gas → increasing importance of LNG → recognition of importance of small scale LNG.
2) Companies in supply chain like Argos, Gate and transport infrastructure.
3) Government – will need to contribute to make projects profitable.

**Spliethoff’s measures to influence LNG transition**

1) Lobby towards government – partly individually and partly via KVNR (limited because competition is also involved in KVNR). Lobby is about subsidy possibilities from Brussels.
2) Bringing LNG under attention in the market by being a front runner / first mover.

**Future LNG scenario / Ideal situation**

The ideal situation is LNG as future fuel. Also in the top of Spliethoff LNG is supported. Current fuel HFO is no longer an ethical option. It is literally the residue of an oil refinery. Also the implementation of scrubbers is a temporary solution. The installation of an open-looped scrubber takes SO\textsubscript{x} from exhaust gases and dumps it in the sea – this can’t be the intention of stricter emission limits.

If a major industry shifts towards LNG (independently of shipping sector) we find our self a basis to build on. Investments in LNG infrastructure in that case won’t need to be recovered fully by the shipping sector, resulting in cheap and simple logistic services. The exact country and industry cannot be mentioned in this report, but it concerns industries in countries without a high level gas infrastructure like the Netherlands have. In such countries the introduction of LNG can be a great alternative for energy consuming industries.
TNO – Innovation for life. Headquartered in Delft TNO is the biggest research institute of the Netherlands.

TNO is founded by law to enable business and government to apply knowledge. Goal is to connect people and knowledge to create innovations that boost the sustainable competitive strength of industry and well-being of society.

Alex Vredeveldt is Sr. Scientist and Naval Architect at TNO. Projects often focus on safeguarding and improving safety. TNO contributes to the introduction of LNG by informing suppliers and customers about this fuel and advising on legislation and permits.

The following is a summary per discussed subject.

LNG – Why – Where – What role in organization?

TNO is always involved in new and innovative technological projects. Joint Industry Projects are created to come up with scientific facts to support safety discussions. Often TNO is consulted to formulate second opinions on government policy decisions. From a safety perspective LNG as a marine fuel is subject to several discussions.

Cryogenics in the maritime sector have a very good track record in terms of incidents because of the highly educated people working with it. Scaling up to many ships dealing with LNG requires knowledge and expertise at a large group of people. Currently this knowledge is not present which substantially increases the possibility of wrong responds in case of future incidents. Another point of discussion is the fear for an unnoticed LNG leak accumulating LNG between the tank and the hull of the ship. Ship structures simply are not designed to deal with extreme low temperatures increasing the risk of failure.

The absence of the right laws and regulations in combination with the lack of an appropriate LNG education is feeding the LNG safety discussion. TNO is contributing to the safety discussion by producing technological facts. These facts can be used as arguments during political discussions. These technological facts are mainly flowing from joint industry projects initiated by TNO.

Transition bottlenecks / barriers LNG

1) Safety (education) – The lack of expertise at shipping companies asks for a ‘drivers license’ for working with LNG. Hardware developments will not be the problem – human made errors can be prevented with proper education.

2) LNG price uncertainty – Not transparent how LNG price is established.

3) High price of LNG equipment – Oligopoly on LNG technology results in high prices – there is a need for more competition.


**Powerful players – Who can make or break transition?**

1) Oil and gas majors – Can to take away price uncertainties which is required for the market to invest.

2) Government – Can stimulate infrastructure developments and make business case more attractive by granting subsidies

**TNOs measures to influence LNG transition**

TNO contributes to the safety discussion in two ways:

- Producing scientific facts by performing research like the research on the vulnerability of LNG tanks in case of a ship collision or dropped objects.
- Research on the acceptable values of identified variables.

Research includes desk research as well as real experiments. Results are presented to the political discussion, which is responsible for final conclusions.
EICB – Expertise- and Innovation Centre for Inland Shipping. Goal is to inform the inland shipping sector about programs, initiate projects for these programs and prepare innovative projects. It’s all about producing and sharing knowledge and connecting stakeholders.

Khalid Tachi is EICB’s director and well known in the LNG society. Current main client is the Port of Rotterdam. Focusing on the inland shipping sector the EICB translates niche experiences of projects and first movers to the rest of the market. This is necessary because skippers on average don’t identify themselves with the first movers. Also in the case of LNG first-movers, projects are known to be more image- than economically driven. These projects are resulting in proof of concepts and technology and findings should be shared with and translated to the rest of the market. In this way the EICB tries to create market support for innovative developments.

The following is a summary per discussed subject.

**Transition bottlenecks / barriers LNG**

“Still a lot of money is ‘wasted’ on finding LNG barriers, everybody knows them already”:

1) Immaturity of LNG environment:
   - There are only 5 first-mover ships.
   - Rest of the market doesn’t identify themselves with those companies/vessels.
   - Shipyards and suppliers of LNG equipment have limited routine resulting in high prices.
   - Laws & regulations are lacking behind.
   - Classification societies are still working on the exact level of safety standards (very high).

2) Knowledge and expertise at potential individual end-users is low – It requires a lot of commitment and information before an LNG investment decision can be made. Therefore it is very hard for small shipping companies to look into LNG.

3) Funding problem – Bad market conditions in combination with relatively long payback periods in some cases (very much depending on type of ship, shipping schedule and fuel demand).

**Powerful players – Who can make or break transition?**

1) Government vs. Classification societies – Responsible for the currently extreme high LNG safety standards. This can make or break the transition. Lower safety requirements would result in more feasible projects with better business cases. The government is also able to stimulate the transition in terms of subsidies.

2) Financial sector – Feasibility of transition will be increased if a solution is found on the funding problem.

3) Reputable companies like Shell, Argos, GDF-SUEZ – If LNG is supported by market majors, others will be stimulated to look into LNG as well.
4) Industry associations have limited power – They can create awareness. In many cases lobby has focus on conservation of status quo instead of lobbying for changes.

**EICB’s measures to influence LNG transition**

EICB has market potential as a starting point. By analyzing market potentials in terms of room for improvements the EICB tries to trigger market players. Providing crucial information to the market therefore is the main measure to influence the LNG transition.

**Future LNG scenario / Ideal situation**

Ideal situation:
- More realistic safety requirements.
- Shorter licensing procedures.
- More accessible funding structures.
- More focus on helping skipper to make the right investment decisions.

Prediction:
- Bunkering infrastructure will emerge – This is a much smaller barrier than everybody thinks.
- Acceptation and support will grow – In 2009 it was unthinkable to use LNG as an inland waterway fuel – now it is seen as the future main fuel.
- The LNG adoption curve will develop in an exponentially way more than in a linear way. Depending on future market conditions, shipping margins and level of investments, a time-span of 10 years seems reasonable for LNG to become a feasible alternative on large scale.

It’s all about when the critical mass decides to shift. Some important developments:
- EU Stage 5 engines for the inland waterway sector in 2021 (proposal); very strict emission requirements.
- Developments in the LNG price. Market needs a robust LNG price. Current low oil prices are bad for gas developments – some say that one of the reasons of the low oil prices is boycotting the USA with its shale gas exportation plans. When in the future oil prices rise again, LNG becomes more attractive.
- Developments in worldwide economy. Currently the shipping sector (one of many) is dealing with the ‘triple dip’. When economy strengthens → more transport → better margins → investments become feasible → funding problem diminishes.
Lloyd’s Register – Improving safety, quality and performance to protect Life and Property. Areas of business are Energy, Marine, LRQA, Rail, Consulting and Research & Innovation. Lloyd’s Register Marine is a leading provider of marine classification services around the world, helping ensure that internationally recognized safety and environmental standards are maintained at every stage of a ship’s life.

Bas Joormann is as Inland Waterway Product Manager at Lloyd’s responsible for worldwide inland waterway operations. In practice inland waterway activities mainly concern Western Europe. In the Netherlands approximately 80 percent of the inland new-builds have Lloyd’s classification. The worldwide inland waterway section at Lloyd’s accounts approximately for 1 percent of total turnover.

The following is a summary per discussed subject.

**LNG – Why – Where – What role in organization?**

Lloyd’s is facing high level of competition on the inland waterway market. New projects are assessed on 1) Clients – bad reputation clients are refused, 2) Is the project challenging from a technical point of view and 3) Commercial attractive?

Lloyd’s responsibilities include approving technical drawings, supervising during construction, granting class certification and granting certificates on behalf of a nation.

To remain market leader in the upcoming LNG market it is strategically justified to make no profit or even small losses on first-mover LNG projects.

**Transition bottlenecks / barriers LNG**

1) Uncertainty of LNG price – Signal from inland waterway clients (also uncertainty about future policies regarding excise duties).
2) Big ship investments – Both retrofits as new-builds are expensive. In a market dominated by bad financial results it is hard to invest in more expensive technologies. Typical LNG-fuelled inland ship projects require €1 – 1.5 million more compared to conventional technologies.
3) Availability of LNG – Infrastructure is lacking
4) Legislation – Procedures are time consuming at the CCNR, ADN and local governments.

**Powerful players – Who can make or break transition?**

1) Government shapes arena – National- as well as European level. Regional governments are very limited in power. In general governments are positive about LNG.
2) End users in maritime sector – If there is no demand, no transition will happen.
3) Classification societies – Knowledge is power. In every committee representatives of classification bureaus are present to provide knowledge, no voting power.
**Lloyd’s measures to influence LNG transition**

- Make sure that market will benefit from future governmental proposals and legislation.
- Stimulate market by promoting feasibility of LNG fuelled inland vessels.
- Perform LNG studies to provide knowledge to market & for internal use at Lloyd’s.

**Future LNG scenario / Ideal situation**

- Future maritime fuel mix will be decreasingly conventional. A higher share of HFO means a high uptake of emissions abatement technology. The space left by the declining share of HFO will be filled by low sulfur alternatives (MDO/MGO or LSHFO) and by LNG. The most optimistic scenario for LNG will be a market share of 11% by 2030.
- Scrubber technology is not a long-term solution. It is primitive but it will be the most chosen medium term alternative to comply with emission requirements.
- Expectation is that there will be more freedom in European legislation to comply with emission requirements. Control measurements should take place at the exhaust of a ship, less focus on how this reduction should be reached.
- Expectation is that also future gas prices will be lower than prices of oil products.
- Main goal in the shipping sector will be to lower operational costs.
- The process of granting LNG bunkering permits by local governments will be smoother.
- European legislation (CCNR & ADN) will be adapted in the near future taking away political barriers for a transition from conventional fuels towards LNG.
DNV-GL – The world’s leading ship and offshore classification society, the leading technical advisor to the global oil and gas industry and a leading expert for the energy value chain including renewables and energy efficiency.

Matthé Bakker is head of solutions Oil & Gas Netherlands at DNV-GL with a background at the faculty of TPM, Delft University of Technology. “DNV GL is all about managing risk; making sure that processes, equipment and people do what they are supposed to do”. Although the company operates on a commercial basis projects have to fit in DNV-GL’s corporate mission of: safeguarding life, property and environment.

The following is a summary per discussed subject.

LNG – Why – Where – What role in organization?

DNV GL has been involved in LNG since the early 1960s – pioneering in the development of design standards and technology for LNG carriers. Since then it has been on the forefront of LNG related governance. As such it was an easy step for DNV-GL to also focus on LNG as marine fuel when the IMO started with SO\textsubscript{X} and NO\textsubscript{X} emission regulations. DNV-GL is present in the maritime shipping sector more than the inland shipping sector and experiences strong incentives to look into LNG as fuel.

Transition bottlenecks / barriers

Ranked in order of importance:

1) Uncertainty of LNG price – gas price is extremely dynamic. Cheap shale gas in North America, medium prices in Europe and high prices in Asia. Market is currently dominated by long-term contracts which are not preferable for the upcoming small scale LNG initiatives. Although a spot market is more dynamic which brings along extra price uncertainties, this will be preferred by initiatives entering this new market.

2) Uncertainty of Policies – first movers are punished by changing policies.

- In ECA zones SO\textsubscript{X} emission limits – what will happen with NO\textsubscript{X} emission limits in Europe?
- Announced rule: in 2020 every port in Europe must facilitate LNG bunkering. Last week EC changed date to 2025 and only big ports in Europe are required to facilitate LNG bunkering.
- Fines for not complying to ECA rules are low – who is going to perform checks? \rightarrow change at shipping companies will only happen when required.

3) Availability of LNG

- Infrastructure is a European challenge.
- Ideally LNG as Fuel needs a public available network but at the moment infrastructure is being developed for specific customers to minimize the investment risk.
**Powerful players – who can make or break transition?**

1) **Gas source** → GATE – Fluxys → Shell – Exxon – GDF-Suez

- Shifting from business – business to business – consumer.
- Gas as fuel is interesting in terms of potential volume – however if a small scale party causes an accident the total LNG market will have a bad reputation (high stakes). For this reason the gas source has a strong lobby for high safety requirements in small scale LNG market. → This can lead to too high requirements and therefore too high costs for small scale LNG market.

2) **Government** – Environmental issues

- Stimulators of LNG (e.g. Rotterdam Climate Initiative, TEN-T)
- Question: Is Dutch Ministry of Infrastructure & Environment more powerful than EU?
  Answer: Can agree with that, but it’s more nuanced. In the maritime shipping sector the IMO and the EU are most powerful. For the inland shipping sector Europe develops directives, resolutions and stimulation programs (TEN-T). Individual states have substantial power – directives and resolutions are shaped through lobby processes. Dutch I&M has a strong lobby power because of the size of the Dutch fleet.

**What can be done to facilitate / speeding up the transition?**

1) DNV-GL provides the market with rules and standards to take away technical barriers.

2) DNV-GL is active in the industry. ISO standard “Guidelines for systems and installations for supply of LNG as a fuel to ships” is initiated and chaired by DNV GL (safety zones) – DNV-GL can put issues on the agenda at the IGF, IGC, CCNR and ADN.

3) DNV-GL deals with government on different levels.
   - Advice about safety and technology.
   - On a European level initiating LNG communication policy.

4) DNV-GL performs many studies and assessments (e.g. LNG Masterplan, Port of Rotterdam).

**Future what-if scenario’s**

The transition space is very much related to uncertainties. Taking away uncertainties or not causes the formation of new paths, or the elimination of existing paths towards a more sustainable maritime sector.

- No infrastructure → No LNG fuelled ships.
- European subsidies → More infrastructural investments.
- Lower port costs / gas price / infrastructure price → better business case.
- Public available infrastructure not present → customized infrastructural solutions.
- Change in policy → direct change in business case.
Mrs. Elisabeth van Opstall is leading a financial project (building a Total Cost of Ownership (TCO) model) working together with the Province of Zuid-Holland, the Port of Rotterdam authorities and EICB regarding the introduction of LNG as maritime fuel. Goal is a model that provides insight in the economic and social costs & benefits of LNG retrofit compared to conventional fuel. The economic and social insights will facilitate investment decisions in the inland shipping market.

The following is a summary per discussed subject.

**LNG – Why – Where – What role in organization?**

- From a transition perspective the highest goal is shifting towards a more sustainable maritime sector.
- LNG is currently the cleanest fuel for the Maritime sector and therefore one of the solutions for the maritime emission problem.
- In terms of transition phases – LNG as maritime fuel is somewhere between phase 1 (pre-development) and phase 2 (take-off / acceleration). Technologies are proven but still expensive (further development and standardization of the technique is needed), rules and safety regulations are in process of being adapted, infrastructure is on the agenda and following on the developments in the LNG market. Next step is moving away from a pilot phase towards volume. Volume (inland shipping but also sea vessels) is needed to work towards an independent market.
- Rebel is developing a Total Cost of Ownership model to provide more insight in the feasibility of LNG as a sustainable solution for (part of) the inland shipping fleet. The TCO model combines public and private perspectives. Insight in the individual business case for LNG retrofit are combined with social costs and benefits effects and projected on the inland fleet.

**Transition bottlenecks / barriers – in general and LNG**

**General:**
- Stakeholders not finding each other – in many cases interests may seem contradictory, but when we bring parties together, it turns out they often have common interests. Connecting parties and translating their needs to a common goal is a necessary intervention.
- Financial risks – transitions are about fundamental changes, which are uncertain and bring along financial risks.
- Classical chicken-egg problem – we all need each other to move first.
- Technical innovations are required – LNG equipment is still improving (expensive)
- Stakeholders look at challenges from their current perspective and from the system in which they operate (which lacks innovation). Example: conventional cars need gas stations – in the case of electric cars we don’t necessarily need charging points at gas stations.
LNG:

- A transition needs first movers like Deen and Danser to kick-start new technologies. We should not underestimate the importance of these parties that take the effort to innovate.
- Finance is very important – in order to move to a market for LNG we need temporary stimulations in order for stakeholders to make a move. Public stimulations can vary from emission norms (obligatory) to providing funds/loans, subsidy or discount on port dues (voluntary). Eventually LNG (systems) should develop towards a marketable product/technic that does not need further financial support.
- The inland shipping market is an important bottleneck. It currently deals with overcapacity, margins are low and ships are overleveraged—banks are not willing to invest in this overleveraged market.
- The inland ship owners tend to focus on short term business — retrofitting of ships is a big challenge since it requires an initial investment in a more expensive system (then the ‘conventional’ system) with a longer ROI period.
- Current safety regulations are based on conventional fuel systems, regulations that fit the construction of LNG powered vessels and LNG infrastructure are lacking. It will still take some time (a couple of years) until safety regulations for the use of LNG (systems, infrastructure) are standardized.

**Powerful players – who can make or break transition?**

On the highest level the EU sets standards → it’s a problem with social effect on a European level and funding is available. However, even if the EU would decide not to fund, the Dutch government may still decide to facilitate the LNG transition - the Dutch fleet is the biggest in Europe which provides the Ministry of Infrastructure and Environment a strong lobby/ responsibility in Brussels. Other players on the Dutch governmental level are for example the Ministry of I&M, Provinces and Port authorities.

Other powerful players are of course shipping companies – they decide what kind of fuel they use. However, without funds from financial organizations options are very limited.

Technical developments and research are needed to innovate.

Cooperation between all stakeholders is needed to succeed: Financial triangle between Banks – Shipping companies – Public authorities.

**What can be done to facilitate / speeding up the transition?**

Most important is creating a self-contained market. Shipping companies are in need of temporary facilitation. Infrastructure and regulations are essential and will follow market pressure. Shipping companies need a push, this can be done in various ways: – fast hard way: this is the norm, comply or you are out of business – slower soft way: discuss barriers and take them away.

In the end the most suitable solution can’t be stopped. However, lobby of public authorities and established companies can slow down or speed up the transition.
ING – Leading Dutch multinational banking and financial services corporation.

Dirk Jan van Swaay is director Energy Transition and Public-Private Partnerships at ING in the Netherlands. LNG as a maritime fuel is a current energy transition issue at ING, next to topics like hydrogen buses, energy storage and heat-cold models.

The lack of funding for LNG projects by banks is a main transition barrier according to many interviewees, causing the interview at ING to be very interesting.

The following is a summary per discussed subject.

LNG – Why – Where – What role in organization?

In the recent past ING developed several Multi-Agent Information System (MAIS) models to generate key figures required to support investment decisions. MAIS models are already used for the public transport sector (hydrogen), heat-cold implementations and a sustainable health care sector. Models are used as a simulation test-bed to experiment with different strategies to predict real-life impacts.

Market parties are screaming for key figures to support (financial) decisions. For example the Dutch Ministry of Infrastructure & Environment – who needs quantitative information to present at the Central Commission for the Navigation of the Rhine (CCNR), or General Electric – who is developing gas turbines for inland ships and wants to know what market impact will be. ING can be a supporting role in building such a model together with other market parties.

Eventually the LNG issue for ING is off course about funding – on what grounds will funding requests be denied or honored? The maritime sector is currently dealing with huge overcapacities in combination with poor earnings. A bank loan is generally assessed on its asset class and on its cash flow generations. A simple example is a transport container – it is transparent what its resale values are in relation to age, size and specs, what amount of cash flows can be generated, etc.. In the case of a clear, low risk asset class, European rules prescribe banks to hold 8% equity capital on loans. LNG investments are substantially more risky than investments in containers, caused by the absence of resale values and clear cash flow generation indications. European rules then prescribe a higher percentage of bank equity capital on those loans.

This higher percentage of equity capital in combination with a market dominated by overcapacities and poor earnings lead to the unattractiveness of funding LNG projects.

Transition bottlenecks / barriers LNG

1) Lack of (financial) LNG insight.
2) Lack of actions to take away overcapacity (maybe in the form of scrapping bonuses?)
3) Lack of impact reporting – impact of transition is measurable → report to market.
**Powerful players – who can make or break transition?**

The Dutch Ministry of Finance has the biggest interests in energy issues. Energy taxes account for approximately 18 Billion Euro every year, roughly 10 percent of the total annual tax income. Therefore it is very important to involve the Ministry of Finance in everything that has to do with energy transitions. If an energy transition leads to a reduction of tax income, there is no doubt a new form of tax will be introduced in order to fill that tax gap. Not taking this into account will lead to business cases shifting from positive to negative.

**ING’s dependencies**

ING is dependent on European legislation on the percentage equity capital required on loans. Unknown resale value of ships with LNG propulsion causes this percentage to be high → unattractive investment for banks.

**ING’s measures to influence LNG transition**

“Let’s build a MAIS model together to provide the market key figures”

**Future LNG scenario / Ideal situation**

Transport by water has to be and will be cleaner in the near future. Some sort of scrapping bonus is required to reduce overcapacity in the shipping sector and simultaneously make room for cleaner new-builds.

For banks it is important that there will be some sort of resale value guarantee for LNG investments. Maybe this guarantee can be provided by the Ministry of Economic Affairs or the Ministry of Infrastructure & Environment. It is especially in favor of the latter, who has an emission reduction agreement with Europe.

If fossil fuel prices will rise and transporting will become more expensive, profit margins for other fuels become higher. In this way shippers will pay for the transition towards, for example, LNG.

Peter Vrolijk is project manager and naval architect at Kooiman. With current market conditions the ratio between new builds and repairs at Kooiman is 20%-80%. Over the long run this ratio is 50-50%. Ship are designed in the Netherlands, mostly the ship’s hull is constructed abroad (often Eastern Europe) and the final assembly phase takes place in the Netherlands again. Kooiman Group designed an LNG fueled pusher for ThyssenKrupp Veerhaven, however, the project was cancelled.

The following is a summary per discussed subject.

**LNG fueled pusher project**

A consortium of ThyssenKrupp, TU Delft, DST Duisburg and Kooiman Group performed research on how the pusher of the future should look like. Results of this study included LNG to be the future fuel, a fuel tank with capacity for at least one week, engines should be cleaner and more efficient, the pusher should be able to push six barges and the pusher of the future should be able to deal with expected longer periods of shallow water on the Rhine.

ThyssenKrupp ordered four pushers at Kooiman Group in a time span of five years. In a reaction to the research results Kooiman Group suggested to design pusher #5 LNG fueled. Extra motivation for Kooiman Group was to be frontrunner in LNG technology. After completing the design, including subsidies for LNG and recommendations of CCNR and ADN, ThyssenKrupp cancelled the project. Uncertain economic situation caused an investment stop at ThyssenKrupp so no pusher #5 will be constructed at all.

Pushers are big fuel consumers making them attractive for LNG investments. Large fuel quantities reduce the payback period of LNG investments, which can be €2.5 to 5 million. The following barriers where addressed during the design project.

**LNG barriers during design**

**LNG systems are heavy and big:** Existing pushers cannot be made LNG ready due to limited space. LNG-fueled pushers have a total different design, increasing investment costs.

**Bunkering options are limited:** ThyssenKrupp pushers sail in a cycle with 8 ships, causing bunkering to may last a maximum of 2 to 3 hours in order to not disturb the cycle. Limited LNG bunkering locations and techniques causing bunker durations to exceed this maximum.

**High safety requirements:** Classification requirements are extreme high; for example 100 % of the LNG and NG pipelines on board of the ship should be x-ray inspected. Safety requirements result in a costly and time-consuming design- and construction process.

**Uncertain LNG price:** Leads to uncertain business case.
Limited knowledge end-users: Although handling LNG can be dangerous, the obliged LNG training is very limited in knowledge.

Environmental damage blow-off: It seems that the restriction of filling ratios of LNG tanks is not that strict defined (now in rules and regulations the filling ratios are defined for cargo tanks, in case these tanks will be used for fuel storage the interpretations of rules seems to be more flexible). This might result in a shorter holding time than required by the rules and regulations and might cause earlier blow off (blowing natural gas into the environment).

Unknown what to do in case of a sinking LNG vessel: What will happen? How to react? Design requirements?

Future (expected) LNG developments

- LNG is feasible for large fuel consumers like pushers, work boats and passenger ships. Bunkering is most easy for pushers due to fixed routes and bunkering locations. Work boats have short trips and are known for fast bunkering, which is currently an LNG barrier.
- LNG price will determine the adaptation of LNG.
- LNG will be the future (transition) fuel because worldwide gas reserves are bigger than oil reserves.
Ministry of Infrastructure and the Environment – Livability and accessibility, with a smooth flow of goods and people in a well-structured, clean and safe environment.

ADN Committee - Part of United Nations, determines rules and conditions for the international carriage of dangerous goods by inland waterways. Liquefied Natural Gas is on the list of dangerous goods allowed for carriage.

Jean-Paul de Maat is head of the Dutch delegation in the ADN Committee. Until January 1st 2015 it was (is) forbidden to carry LNG on inland waterways without a special clearance signed by the ADN committee. As of January 2015 it will be (is) generally allowed to transport LNG under ADN regulations. The following is a summary per discussed subject.

**LNG – Why – Where – What role in organization?**

The ADN Treaty has three main goals, to be considered of equal weight. The first is about unified regulations on safety – securing and improving safety. Secondly the ADN is contributing effectively to the protection of the environment by preventing any pollution resulting from accidents. Thirdly the ADN is facilitating transport operations and promoting international trade.

Since half the European fleet is Dutch, it is very important for the Netherlands to be a part of the ADN Treaty and to be an active party in the ADN Committee in order to promote the Dutch fleet.

Topics like LNG make it to the agenda when there is a change in market behavior and market parties start to apply for special authorization to carry dangerous goods. In the case of carrying LNG the Dutch shipping company Chemgas was Europe’s first applying for special authorization. The path towards special authorization can be time consuming and can be a major obstacle for market parties. To take away this obstacle the ADN regulations has to change.

**Transition bottlenecks / barriers for the carriage of LNG**

1) Uncertain demand for LNG due to an uncertain fiscal regime – especially uncertainties about excise duties cause market players to be hesitant regarding the LNG business case demand for example as fuel for inland vessels. The actual price of LNG is very important for the business case to become positive or negative.

2) Chicken- and egg game between the many stakeholders involved in the LNG environment. Due to large interdependencies it is hard to be a first mover when you can only be successful when others move as well.
3) Granting of LNG bunkering permits by local authorities - a smaller barrier is that LNG bunkering may only take place on special locations authorized by local authorities, which are in many cases small municipalities with limited knowledge. When the right knowledge isn’t present, a request for an LNG permit is difficult to be judged by local authorities.

**Powerful players – who can make or break transition?**

The government has to possibilities to facilitate a transition towards LNG on the one hand by developing rules & regulations and on the other hand by making subsidies available. The Dutch Ministry of Infrastructure & Environment can supply technical regulations and can put topics on the political agenda.

The relation between the Dutch government and the transport industry is important; those two worlds don’t know each other always quite well. Not every business has the knowledge or the possibilities to obtain the right permits and special authorizations – that’s where Head of Delegation like Jean-Paul de Maat jumps in.

For business it’s important that future policies are stable. If it’s clear what for example taxes will be on the long term (despite the height of tax), companies can deal with it. However, changing policies bring along major risks – think of business cases which are calculated on wrong policies. Therefore changing policies can make or break a transition towards LNG

**Future LNG scenarios**

In the end LNG could be the main fuel for inland vessels. This probably will not happen in a few years, we are talking about the medium term. In the coming years market parties have to deal with uncertainties. It’s all about working together – CBRB, VNCI, VNPI, BLN, Classification societies and Government.
Province of Zuid-Holland – Most densely populated province in the Netherlands. With an annual budget of € 1 billion the province strives for a balanced habitat in terms of housing, work, travel and recreation.

Mrs. Ingrid van Leeuwen is Program Manager of Clean INLand SHipping (CLINSH) at Mobility & Environment. Main objective of the CLINSH project is demonstrating how improving the emission performance in the existing inland waterway fleet can improve air quality in urban areas. Air pollution is the prime environmental cause of death in Europe, whilst also continuing to affect ecosystems and obstructing economic development. Focus of the project is on state-of-the-art (emission reduction) technologies, fuel transition, on-shore power, high resolution modeling and awareness creation among skippers and policymakers.

The following is a summary per discussed subject.

**LNG – Why – Where – What role in organization?**

Drivers for provincial projects are mainly about the improvement of habitat, air quality, transport and/or economy, often based on European guidelines. In the recent past the province was involved in LNG-retrofit projects at Danser Containerlines and Dolderman. The first is a high-tech state-of-the-art retrofit while the latter is a retrofit intended to be completed with minimal resources. The province provides subsidies and in return those companies share experiences and data in a ‘Knowledge and Expertise Center’ situated at the EICB. The idea is to create a Total Cost of Ownership model. The Centre will facilitate ship owners and more specially regional policymakers. Goal is to make information about the LNG permit trajectory available to speed up those processes.

LNG is one of the alternative fuels discussed in the CLINSH, next to for example GTL. Data gathered from the funded projects will be used as input for models like an air quality impact model and a total cost of ownership model.

**Transition bottlenecks / barriers LNG**

1) Incoherent legislation and policy – Investment stay out when developments in legislation and policies are vague and slow.
2) Subsidies are wrongly spent on LNG new builds – The sector is already facing overcapacity, focus should be on retrofits.
3) Funding of LNG projects – Banks are unwilling to fund.

**Powerful players – Who can make or break transition?**

1) European policy and legislation – On the European level we are also dealing with countries without LNG interests, which also have a vote in commissions like CCRN.
2) Financial sector – If banks will not fund LNG projects in the maritime sector, investments will stay out.
Province’s dependencies

The provincial executives (College van Gedeputeerde Staten) decide about what topics will be on the provincial agenda. In theory they have the power to for example decide that the shipping sector is no longer a provincial matter. This is however not in the line with expectations.

Province’s measures to influence LNG transition

Measures to influence the LNG transition are limited because of the regional focus.
- Show market that it is possible to successfully implement LNG. The direct link to the citizen and entrepreneurs causes the Province to be more effective than for example the Ministry of Infrastructure & Environment.
- The CLINSH project – Perfect example of that it is not impossible to put topics on the European agenda as a Dutch Province. It is however very rare.
- The province is involved in the discussion about the ‘Brandstofvisie’ published by the Ministry of Infrastructure & Environment.

Future LNG scenario / Ideal situation

The ideal future situation will consist of:
- Freedom for skippers to choose for solutions which are most attractive from an economic perspective.
- More general understanding in Europe, leading to faster European procedures and permit acquisition.
- More room for innovations and funding constructions.
- More cooperation and sharing of information between market parties.

Prediction is that policy barriers will be gone in 10 to 20 years from now. After that developments in LNG assets and users will accelerate.
Port of Rotterdam – Port Authority is responsible for the development, construction, management and operation of the port and industrial area in Rotterdam and promotes the effective, safe and efficient handling of shipping and industry in the port of Rotterdam and the offshore approaches to the port.

Jelle Paulusma is project developer at the Port of Rotterdam focusing on LNG. Next to his activities at the Port of Rotterdam he is also a member of the executive committee of the Dutch National LNG Platform. Rotterdam is the first port in Europe to put all mandatory rules & regulations in place for the bunkering of LNG (truck-ship & ship-ship).

The following is a summary per discussed subject.

LNG – Why – Where – What role in organization?

The Port of Rotterdam has traditionally been a bunker port with cheap heavy fuels. Having several oil refineries within the port made the availability of cheap HFO a fact. This caused growth in other industrial segments and made Rotterdam the bunker port of Europe with aligned shipping line movements. Times are changing and in the port vision 2030 Rotterdam is leading in efficiency and sustainability. Initiating the Rotterdam Climate Initiative the Port of Rotterdam aims at improving the climate for the benefit of the people, the environment and the economy; to become the most sustainable world port city. On the global level the Port of Rotterdam is involved in the World Ports Climate Initiative where fifty-five of the world’s key ports have come together in a commitment to reduce their greenhouse gas emissions while continuing their role as transportation and economic centers.

Ship movements within the port affect the environment as well. Therefore the Port of Rotterdam stimulates the introduction of LNG as a cleaner fuel for shipping to reduce the emissions of sulphur, nitrogen and particular matter (PM) especially in the built environment of the city Rotterdam. However, to maintain a competitive position amongst other European ports it is key that measures will not negatively affect the level playing field. For example as a result of IMO’s Sulphur Emission Control Areas some shipping companies already have decided to divert to southern European ports, which falls just outside this SECA, to unload cargo and to make the last steps by other commodities such as road- and rail transport. Declining popularity should not be the result of national and regional measures contributing to a more sustainable port.

Transition bottlenecks / barriers LNG

Inland shipping: Bad market conditions due to overcapacity is causing funding to be the biggest barrier for the inland shipping sector. Infrastructure issues are easily solved because of the relatively small quantities of bunker fuel per ship in this sector. This can be supplied by truck. More permits have to be granted for bunkering locations. The process of granting permits by local authorizations will be simplified during the lifespan of the LNG Masterplan.
Short sea shipping: Funding is not really a barrier in this, more healthier, sector. Due to larger quantities of bunkering fuel, it isn’t feasible to supply coastal vessels by truck. This would result in many trucks lining up to bunker one coastal vessel. Therefore this sector requires infrastructure like bunkering stations or bunkering vessels. These are currently not present.

Powerful players – Who can make or break transition?

1) Shippers – When shipper would be willing to pay more for sustainable shipping, more LNG investments are realized.
2) Europe – Can set up (de)stimulation programs. For example stimulate cargo loaders to prefer sustainable shipping companies, or grant subsidies to set up an LNG infrastructure. Measures should be implemented on European level to maintain level playing field between European ports.

Port of Rotterdam’s measures to influence LNG transition

- In addition to national regulations, the city of Rotterdam Port Management Bye-laws – the ‘house rules’ of the port – are also in force. Permits and exemptions may be granted related to LNG.
- Direct stimulation programs in the form of granting discounts on port dues in the case of more sustainable ships, or even on LNG fueled ships. Also priority for more sustainable ships can be granted at terminals.
- Lobbying for level playing field in Brussels. Also harmonizing regulations directly with other ports via the Tower Group (5 biggest bunker ports). For example LNG port dues can be harmonized so discounts are the same in every European port.
- Lobbying for- and stimulating the development of a public LNG infrastructure in the Port of Rotterdam

Future (expected) LNG developments

- LNG will be implemented at off-grid industries in Central- and Northern Europe (Scandinavia) in the short term. LNG infrastructure required for the shipping sector should be combined with the infrastructure required for these industries. This leads to the fact that other industries will determine the LNG adoption curve for the European maritime sector.
- Gazprom shows signals to construct an LNG plant with an annual capacity of 10 million tons near Primorsk. This will result in lower LNG prices for Europe for the fuel side.
- Dry-cargo inland ships have a short depreciation time. LNG therefore is not attractive because LNG investments have a relatively long pay-back period.
- Tanker-ships are more suitable for LNG because most tanker ships have space to install LNG equipment.
- Short Sea shipping has the highest potential to shift towards LNG. This sector is known for its large fuel consumption in combination with standard sailing routes, which is preferably for bunkering.
Because of confidentiality reasons the summary of the interview with an Energy Trade and Wholesaler is made anonymous.

** – Player in the energy transition, match maker between supply and demand in the renewable energy transition. ** strives to reach 100% renewable and clean fossil energy sourcing. ** has renewable assets, a specialized carbon group, trade biomass globally and has established a position at an LNG terminal.

Mrs. ** is as an LNG structurer dealing with purchase- and sales contracts of LNG.

The following is a summary per discussed subject.

** LNG – Why – Where – What role in organization?**

** started with LNG to maintain security of supply of gas – gas-fired plants are an important asset for balancing demand fluctuations. Sustainability was not a driver of LNG until small-scale LNG started to take off in 2011. Currently LNG is purchased on large scale; the client takes care of the transport.

LNG intended for the gas grid has to compete with the TTF price (natural gas) requiring the LNG price to be equal to, or lower than the TTF price minus the cost of importing and storing LNG. The 2011 Fukushima nuclear disaster caused Japan to import LNG on large scale, resulting in higher prices and an availability reduction worldwide. Importing LNG to Europe for a reasonable price became more and more difficult. That’s where small scale LNG becomes interesting, since LNG as a fuel for trucks, ships and off-grid industries has to compete with other fossil fuels instead of natural gas. Now also the sustainability aspect plays a part since natural gas is clean in comparison with other fossil fuels.

Till so far (November 2014) ** supplied approximately 130 trucks and several ships with LNG. The biggest challenge for is importing LNG at reasonable prices. The safety aspect doesn’t play a large role because of ** being wholesaler and not the owner of the actual LNG assets.

** Transition bottlenecks / barriers LNG**

1) Funding – many shipping companies have to / want to invest in LNG, but the banks are reticent in financing the shipping sector.

2) Chicken- and egg game between the LNG infrastructure and its users.

3) Pricing of LNG – important to make the business case work for shipping companies.

Subsidies wouldn’t be needed if market mechanisms work well. To kick-start a change however subsidies are helpful. The business case however shouldn’t fully rely on it.

** Powerful players – who can make or break transition?**

1) Companies in supply chain like Argos, Deen and Shell – big companies in the chain. If major players choose to invest in LNG, risks are reduced for others. The market needs front runners to break first barriers.
2) Due to the high level of interdependencies, many stakeholders are important. Therefore there are more parties that can break the transition than there are parties to make the transition.

**dependencies**

In the first place ** is depending on its clients – offering security of supply to the clients. Because purchasing LNG is required before selling, the suppliers of LNG are the next parties ** is depending on. Companies like Shell for example are present in many parts of the supply chain. The Dutch government seems to appreciate the interests of Dutch capacity holders in LNG terminals, but is not backing Dutch companies like the German government is backing Eon in such situations.

**measures to influence LNG transition**

1) Investing in LNG infrastructure would be an option – however currently not involved in such investments. Possibilities to invest in order to create own LNG market.

2) Offering LNG at attractive conditions.

**Future LNG scenario / Ideal situation**

Ideal situation for small scale LNG:

- High prices for LPG and other oil products would make LNG more attractive. If business cases are more profitable, less subsidies are required, which will speed up investments.
- Market parties who want to shift towards LNG are more decisively than parties who have to shift towards LNG because of IMO rules.
- Public infrastructure available for everyone.

The shift towards LNG is developing very slowly – the expectation is that we need to think about a term of 10+ years (optimistic estimate).

Giuliano Franzi is CEO of Argos Energies. The departments of Argos have different business strategies. The bunkering department strives to be a long-term player. The demand for energy in this sector is growing faster than in other market segments. In a high competitive market therefore you have to believe in the long-term future. The future demand will be served by traditional fuels in combination with approximately 10 percent LNG in 2030.

The following is a summary per discussed subject.

**LNG – Why – Where – What role in organization?**

Argos Bunkering is supplier of any type of marine fuel. This means that in terms of volume it doesn’t matter what the future demand for marine fuels will look like. Argos should be able to provide it all. However, some fuels are more lucrative to supply than others. HFO is currently a break-even, or even a loss-making bunker market to be active in. This is caused by the extreme high level of competition due to low entry barriers. There are many small suppliers in a market sensitive for fraud and criminality. Leading players like Argos stay active in the HFO bunker market because of the huge amount of infrastructural assets in combination with the strategy of being a long-term player on the European bunker market. Some players must and will leave the market.

Since scrubbers are clearly an intermediate solution to the environmental emission problem, general estimations of a 10 percent LNG market share in 2030 seem likely. For Argos it is interesting to enter this market because it will be (is) a much healthier market. Due to huge infrastructural investments entry barriers are high, limiting the amount of LNG suppliers and especially limiting the amount criminal parties. Better profit margins cause it to be interesting to be a first-mover in the LNG bunker market. By this Argos will build a reliable LNG image and also stimulate shipping companies to shift towards LNG by providing the necessary infrastructure.

For Argos it is next to LNG bunkering not interesting to focus on LNG trading. For trading you need access to the source, which means a position at GATE terminal. Companies like Shell have billion dollar structures in upstream and trading of gas thus very hard to compete with. However, in the current MDO market Argos is the biggest buyer in the ARA-area. This leads to the privilege of choosing between the best contracts each year. Achieving this with LNG will be hard, but strategy is to gradually become a party buying LNG regularly and thus become interesting to traders.

**Transition bottlenecks / barriers**

1) Access of cheap LNG – GATE has an oligopoly which automatically gives them power to influence prices and conditions.
2) European legislation is slow and procedures are long, but this is not a real hurdle.

3) Hard business case – Be ready to lose money in the first three years.

4) Current low oil price – OPEC adopted new strategy: for years production went down to keep oil prices high. This year (2014) OPEC decided to not let market share further decline, leading to over production and low world oil prices.

**Powerful players – who can make or break transition?**

1) Gas source – The problem is to find good agreements with players like GATE to get reasonable LNG prices.

2) EU – Should try to avoid super dominant players on the LNG market (Shell – GATE) to make room for smaller players like Argos to kick-start small scale LNG

3) Shipping companies – Investments in LNG will totally depend on hard financial facts.

**Argos’ measures to influence LNG transition**

The only thing Argos can do is trying to influence the market through lobbying. Especially via direct customer relations, but also on conferences the business case should be made clear. LNG is good in terms of cost & environment – Argos is very strong in inland bunkering.

The most important aspect is the economics of shifting to LNG to work. When this is the case it will also interesting to create own LNG market demand – for example via Argos’ share in Interstream Barging.

**Future (what-if) scenarios**

- LNG will be cheap, especially in the beginning – Gas production in North-America and the Far East will increase leading to lower gas prices.

- Low oil price will be temporary – Expectation is that oil price will be high again at the end of 2016.

- LNG will kick in when vessels are renewed – Coastal vessels, inland cruising and seagoing ferries have highest LNG potential.

- As soon as demand for LNG will rise, Argos will accelerate by expanding assets. Hopefully after one year the decision can be made to order (or find partnerships for) two or three extra LNG bunker vessels. In that case not only the ARA-area, but for all of Europe can be supplied.

- Investment decisions are very much depending on the difference between the price of LNG and the price of conventional fuels like MDO and HFO

- HFO – Another purpose has to be found. Bitumen production only will not be enough to replace the amount currently used as marine fuel.
Leon Sluiman
GDF-SUEZ LNG Solutions
Operations Manager
Jan 7th 201

GDF SUEZ – With 147.400 employees worldwide, activities in close to 70 countries and 81.3€ billion revenues in 2013, GDF SUEZ is the No. 1 independent power producer in the world. GDF SUEZ LNG Solutions is a combination of the power and knowledge of Cofely as technical service provider and GDF SUEZ Energie Nederland on the field of LNG and the gas market.

Leon Sluiman is Manager Operations at GDF SUEZ LNG Solutions. He is partly responsible for the company’s strategy to serve as a catalyst for the Dutch LNG market in several phases.

The following is a summary per discussed subject.

**LNG – Why – Where – What role in organization?**

LNG activities account for approximately 30-40% of GDF SUEZ’s revenue. The company serves the entire LNG chain; own gas wells, LNG production plants, LNG carriers, long-term LNG storage capacity and is now realizing a bunker infrastructure. Infrastructure developments are needed for GDF SUEZ to be able to serve as a catalyst in the Dutch small-scale LNG market. In several steps a complete infrastructure will be realized for the maritime sector: permanent bunker facilities for ships, intermediate storage and transshipment. In potential this small-scale market could grow to 10-15% of the total turnover of GDF SUEZ in 2025-2030. The Dutch market is one of the first-mover markets in Europe and therefore the Netherlands is perfect pilot country.

**Obstacles**

1) **Different Bunker Habits** – The different potential LNG user groups have different bunker habits. For example in inland shipping it is common that ships sail to a bunker location. Small fuel quantities and short bunker duration ask for a dense network of small LNG bunker facilities in this sector. Sea-going vessels with large fuel quantities are refueled during loading / unloading. Sea going ships therefore ask for other facilities like for example a bunker vessel.

2) **Different Risk Profiles** – Working with LNG requires knowledge and expertise to avoid accidents, which is not present at every end user group. Therefore implementation of LNG in the truck- and inland shipping sector is more risky than implementation in the coastal- and deep-sea sector. In the coastal- and deep-sea sector the level of education is higher than in the truck- and inland shipping sector.

3) **Comparison with LPG** – Back in the days the Dutch government positioned LNG next to LPG, because of both being liquid gases. LPG is however way more risky than LNG because LPG is heavier than air, leading to huge explosion risks in case of a leak. This negative image of LPG automatically influences the acceptance of LNG as a fuel.

4) **Fuel costs** – Potential LNG users are only interested in a transition towards LNG if fuel costs will drop. The difference between MDO and LNG needs to become larger.
5) **Depreciation time** – Coasters used to have a depreciation time of approximately 7 years. With current state of technology this is enhanced up to 15 years. LNG new-built coasters should have a depreciation time of approximately 20 years to become profitable.

*What projects (could) serve as a catalyst for the Dutch LNG market?*

The activities related to LNG infrastructure in the Netherlands by GDF SUEZ LNG Solutions can be divided into four phases. The phases are bounded by the annual volume of the LNG market. The biggest market risk is creating volume after passing the threshold value of the next phase.

1) **Phase 1:** Truck-to-Ship – small LNG volume supplied by trucks to ferries, inland ships and fishery ships.

2) **Phase 2:** IBI – Intermediate Bunker Installation. Bigger volume of LNG storage makes it also possible to supply coastal ships.

3) **Phase 3:** Floating barge – floating storage of LNG for the bunkering of ships.

4) **Phase 4:** LNG hub – small scale LNG hub with retail function for LNG distribution and LNG bunkering of ships.

Phase 4 can be reached in approximately 10–15 years from now. A typical LNG refueling station for road transport (trucks) needs to supply at least 6500 ton LNG / year in order to become profitable. A typical sea-coaster consumes about 8500 ton LNG / year. A couple of clients like that can boost developments in infrastructure.

GDF SUEZ LNG Solutions is already building an LNG bunker vessel. It will be a 5100 m³ sea-going vessel with Zeebrugge as home port. This vessel can be used to refuel sea-going vessels, but has also a feeding function for future LNG hubs.