UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

The Fuel-cell Trucks Ecosystem

Identifying change and strategizing in emerging ecosystem

Johannes Tröndle & Sendy Setiawan

Graduate School
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Supervisor: Johan Brink

Abstract

With the goal to reduce global greenhouse-gas emissions and transportation being a major reason for these emissions, new transportation solutions are needed. One solution is the use of fuel-cell trucks that are powered by hydrogen which are embedded in a young ecosystem. The purpose of this paper is to explore the perception of the fuel-cell truck ecosystem from the participants within it, and how they can identify changes and act strategically to be successful. The literature review covered the business ecosystems and their characteristics, identifying roles, mapping an ecosystem, and a framework on how to shape an ecosystem, including the consideration of risk and standards. The qualitative methodology of this research was combined with an abductive approach, while interviews were performed as the main source for data collection. The selected interviewees are experts in their fields and represent different industries in the ecosystem. With a case study research design being used, the interviews were analyzed using thematic analysis.

Our results show that the fuel-cell truck ecosystem is in between the birth and expansion stage, with not all value propositions being fully developed. All characteristics of an ecosystem are fulfilled, but the borders are blurry, roles unclear and the need for collaboration for value co-creation is high. Ecosystem participants perceive the close neighbors in their value chain as more important and seem to act without an ecosystem strategy. Generally, it can be summarized that participants wish for more collaboration, but not doing it enough by themselves. In an emerging ecosystem, our proposed strategic framework can help to enhance the ecosystem growth through collaboration with complementors, while identifying components that create competition benefits.

Keywords: *business ecosystem, innovation ecosystem, shaping strategy, ecosystem risks, industry standards, fuel-cell trucks, hydrogen, ecosystem framework, strategic framework*

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Sendy Setiawan

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Abbreviations List

LDV	Light-duty Vehicle
HDV	Heavy-duty Vehicle
FCEV	Fuel-cell Electric Vehicle
CGH2	Compressed Gas Hydrogen Storage
LH2	Liquid Gas Hydrogen Storage
CcH2	Cryo-compressed Gas Hydrogen Storage
HSS	Hydrogen Storage System (on-board)
HRS	Hydrogen Refueling Station
H2	Hydrogen
LPG	Liquid Propane Gas
PFAS	Per- and Polyfluoroalkyl Substances
PEM	Proton Electron Membrane
ICE	Internal Combustion Engine

1. Introduction

This first chapter explains what and why we explore and analyze the topic through the introduction and problem discussion. The research aims and research questions are based on the problem discussion. A technical background section brings a basic understanding of the relevant technologies around the fuel-cell truck ecosystem. To close this chapter, we present our delimitations and structural overview of the thesis.

1.1 Research Background

In 2015, the UN Paris Agreement was agreed upon as a landmark for all nations to undertake one common cause and was signed with a strong intention to reduce greenhouse-gas emissions (United Nations, 2015). The United Nations reported for the first time back in 1987 about the environmental trend of climate change, coming from the burning of fossil fuels that releases carbon dioxide (CO_2) into the atmosphere. Now, around 30 years later, the trend is still moving towards a concerning point where it could become highly difficult to limit earth warming below 2 ^{o}C which represents a tipping point that makes a reversal of climate change impossible (United Nations, 1987; McKinsey, 2022). Fossil fuels are used widely as the main energy source for transportation and contribute excessively to climate change and global warming, threatening our future (Dogan & Erol, 2019). In 2020, the transport sector accounted for 16.2% of total global greenhouse gas emissions, with 55% of total transport CO_2 emissions coming from commercial sectors, i.e. road freight, shipping, aviation, rail & pipelines (Ritchie, 2020; Roser & Ritchie, 2020). Of all the commercial transport sectors, road transport takes the biggest share and it becomes critical to be decarbonized first (Roser & Ritchie, 2020).

Battery electric powertrains are then used successfully for passenger cars and short-haul transportation since they already reached cost parity through improved battery energy density (McKinsey, 2022; Jokela et al., 2021). With medium and heavy-duty commercial vehicles having complex requirements, different solutions must be used, like powertrains with hydrogen as an energy source using fuel-cell technology in the form of fuel-cell trucks (McKinsey, 2022). The requirements for heavy-duty trucks (HDV) are then often to travel long distances, here battery-powered trucks can only reach a range of 400 km to 500 km by 2024 (Volvo, 2023; Daimler, 2023). Payload constraint is also another crucial issue, as the weight of the battery systems takes up the vehicle's capability to transport heavy goods (Jokela, 2021). With all of these limitations of battery-powered trucks, the materialization of fuel-cell trucks is now gaining momentum and becoming a major link for other commercial transport sectors, leading to an emergence of an ecosystem around fuel-cell trucks (McKinsey, 2022).

1.2 Problem Discussion

In the context of end-use application fuel-cell trucks, there is a well-known chicken-egg problem: Without parallel investments in hydrogen refueling infrastructure, there will be no investments in vehicles using hydrogen, and conversely, without complementary investments in hydrogen vehicles, there will be no investments in hydrogen refueling infrastructure (Zhao & Melaina, 2006; Meyer & Winebrake, 2009; Gim & Yoon, 2012; McKinsey, 2018). Additionally, the public authority is an important contributor in the adoption of this low-carbon energy source by regulating the safe transportation of hydrogen and by providing incentives to promote its use (Jouini & Duboc, 2017). Hence, the obstacles to the adoption of this technology include the need to scale up, industrialize various aspects of the value chain, and create demand (McKinsey, 2018, 2022).

Amado Screnci, director and board member of the hydrogen refueling station council argued that the first industries to accelerate have to be commercial vehicle and rail transport (The Hydrogen Europe Quarterly, 2022). The commercial vehicle industry itself possesses a main challenge to fulfilling the long distance and strict time requirements. The progress of hydrogen technologies in commercial vehicle transportation relies heavily on hydrogen storage as a crucial enabling technology, especially for applications in vehicles with fuel-cells that use proton exchange membrane (PEM) (Eberle, 2009; Mori & Hirose, 2009; Abe et al., 2019; US DOE, n.d.). Eberle (2009) believes that if the challenges related to on-board hydrogen storage in vehicles can be addressed, the remaining issues concerning the infrastructure for hydrogen are relatively surmountable. While this is an opportunity that every vehicle manufacturer should undertake, one of the main challenges is that there are several ways to store the hydrogen on-board and each technology requires a different commitment and investment. In the studies done by Kast et al. (2017) and Gangloff John et al.(2017), the technical feasibility and test simulation cycle for fuel-cell trucks was done only by using compressed gas hydrogen tanks. While the result was positive, the question is whether this architecture is the most suitable one for the industry. Furthermore, the trial of hydrogen in commercial vehicles has mostly been tested in smaller-scale demonstrations involving only a limited number of trucks (Willmer, 2022).

All of these intertwined factors make the industry hard to decarbonize because it involves an interconnected system and activities around the production, transportation, distribution, refueling infrastructure, and consumption of hydrogen. Participants involved need to come to an agreement on which technology to use for storing it, given that there are multiple options available (energy.gov, n.d.). While physical storage technology is currently more developed than storage in material form, no single system has been fully established yet, leading to uncertainty among actors as to where to invest their resources. To be prepared for the chosen technology when the market demands it, strategic management of the ecosystem is necessary. Each type of storage has different characteristics along its value chain, which adds complexity to the decision-making process. For instance, the tanks themselves vary in material and production systems across storage types, as do the handling, supporting infrastructure, and refueling systems. Agreeing on one standardized interface for distribution, in the context of which hydrogen type, is then important that different industries can work together. Investing in the most promising storage technology, which could be compressed, cryo-compressed, liquid hydrogen, or even a combination of some, is crucial for further success. With all the uncertainty around these developments of technology, hydrogen supply, and distribution, as also the demand for fuel-cell trucks, the alignment of complementors in the emerging ecosystem is a complex problem that needs to be faced by all participating companies. Managing the challenges of this emerging ecosystem requires a strategic approach from participants.

1.3 Research Aims and Questions

This research is conducted together with the company Volvo Trucks, which is facing challenges in the emerging fuel-cell truck ecosystem in the form of technology development, supply chain building, and utilizing their product. Our first aim in this research is to understand the ecosystem around fuel-cell trucks better. For that we first need to prove if it fulfills all aspects of a business ecosystem, using literature to define the term business ecosystem and identifying common characteristics. Providing a snapshot of the fuel-cell truck ecosystem with its elements and boundaries will show the connections and dependencies between the participants. The input from our interviewees' contrasting perspectives about key drivers, participating elements, and roles will be our basic comprehension of the ecosystem. Through this conceived ecosystem we want to identify the influence of the interviewees' perspective of and position in the ecosystem towards risks and challenges. Connected to our problem discussion, the first research question below will address the ecosystem structure throughout the empirical findings and literature review.

RQ1: *How is the fuel-cell truck ecosystem structured?*

The aim of the second research question is to propose a strategic framework to handle the uncertainties and evolving developments in the fuel-cell truck ecosystem, taking into account the insight obtained from RQ1. Facing this development with several possible outcomes, actors need to develop a strategy to handle the situation. The proposed framework has the goal to be a foundation to create an ecosystem strategy, which is an annexation of extant strategies of the ecosystem participant, that focuses on the alignment of participants to enhance the focal value proposition (Adner, 2017). This leads to our second research question:

RQ2: *What could be one strategic framework for participants within the fuel-cell truck ecosystem?*

1.4 Delimitations

Resources are limited and the topic of our research can become too broad, hence, a number of limitations must be applied. As our main topic is the fuel-cell truck ecosystem, only the hydrogen-related components that construct a vehicle are covered. Other components that build the vehicle, such as body and software systems are excluded from our research. Then our sub-focus will touch on the various methods to physically store hydrogen and not material-based storage, as physical storage options are more advanced in their development and are currently favored in the commercial vehicle industry. In relation to the assumed interconnected activities, the hydrogen value chain will only be focused on the perspective of the fuel-cell truck ecosystem. The method of hydrogen production technology will not be explored as we presume it has no impact on whichever hydrogen storage architecture is to be used.

1.5 Technical Background

With this section about the technology behind the fuel-cell truck and hydrogen production we want to give clarity for the reader to learn about the ecosystem and its participants. Discerning what components are needed for a functioning fuel-cell and the used hydrogen as a fuel are important to grasp borders and connections in the ecosystem. We also want to introduce the common jargon and terms used in this ecosystem and our thesis. This technological explanation is our basis of understanding throughout our research process about this topic.

1.5.1 Hydrogen Streams

The hydrogen value chain or business stream is classified into three streams: Upstream, Midstream-Downstream & Consumption (Kearney, 2020). Some argue that consumption cannot be separated as part of the downstream activities (McKinsey, 2022). Upstream operations consist of several business activities related to the production technologies of hydrogen (Kearney, 2020). Midstream-downstream operations are related to the conversion, storage, transport, and distribution of hydrogen, while consumption consists of end-use applications within several industries, including commercial vehicles (ibid.). The fuel-cell truck with on-board hydrogen storage is considered to be in the end-use of application and comprises light (LCV) and heavy-duty (HDV) commercial vehicles. Figure 1 provides an overview of the activities that are part of the hydrogen value chain. The hydrogen value chain is only one part of the ecosystem around fuel-cell trucks since they need hydrogen as fuel to be utilized by the end customer.

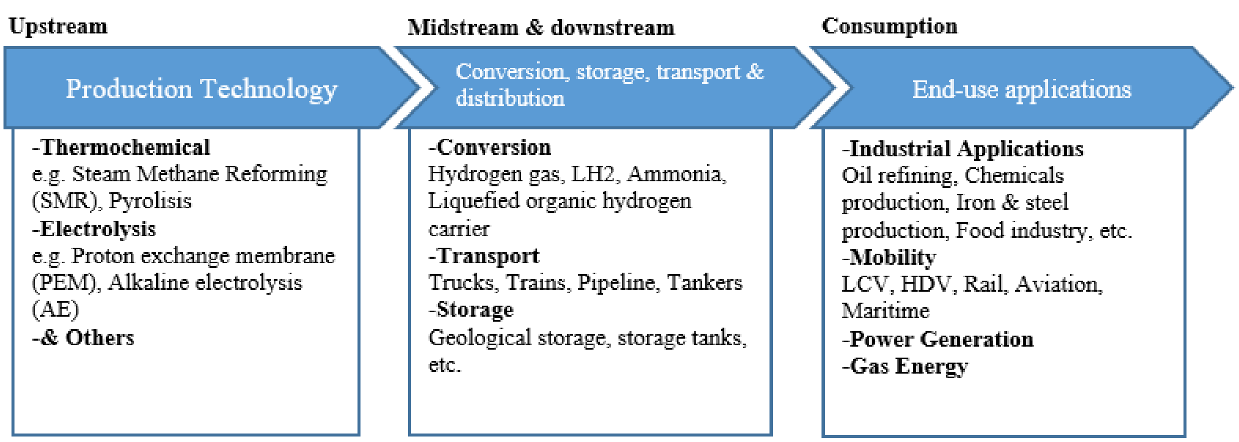

Figure 1. Hydrogen Value Chain (Kearney, 2020, p.3)

1.5.2 Hydrogen Refueling Infrastructure

The transportation and distribution of hydrogen are essential aspects of the hydrogen value chain. Presently, hydrogen is primarily transported via pipelines, cryogenic liquid tankers, trucks, or gaseous tube trailers (energy.gov, n.d.). Pipelines are commonly used when demand is stable and substantial, typically hundreds of tons per day, while smaller-scale or emerging demand regions use liquefaction plants, liquid tankers, and tube trailers (ibid.). The location of hydrogen production also adds complexity to the distribution of hydrogen (ibid.).

Hydrogen refueling stations (HRS) play a crucial role in the hydrogen infrastructure and can be classified based on the hydrogen type used - liquified, compressed, cryo-compressed - and the location of hydrogen production (Apostolou & Xydis, 2019). Off-site hydrogen production delivers the hydrogen from the central production hub to the station using road transport or specific pipelines, while on-site hydrogen production generates hydrogen locally in the station (ibid.). For a safe operation of a HRS, the following safety devices must be included; pressure relief valves, hydrogen sensors, and fire suppression systems that do not require water, and mechanical and electrical equipment, such as piping, valves, control panels, and dispensers that fill high-pressure hydrogen tanks with compressed hydrogen from the station's storage tanks (Qin et al., 2014; Alazemi & Andrews, 2015).

A purification component is necessary to ensure that the hydrogen meets the necessary standards for fuel-cell use, with a purity level of over 99.97%, and a hydrogen compressor is required to store the hydrogen at high pressure (Qin et al., 2014; Alazemi & Andrews, 2015; Ohi et al., 2016). A hydrogen gas booster regulates the hydrogen pressure during refueling, and a cooling unit lowers the temperature of the hydrogen gas to prevent the vehicle's hydrogen tank from exceeding 85°C during rapid refills (de Miguel et al., 2016). However, unique components for each type of hydrogen need to be taken into account.

1.5.4 Hydrogen Technology on Fuel-cell Trucks

A fuel-cell uses a “cold” burning process to produce energy out of hydrogen with the only byproduct being water steam (ENBW, 2022). The fuel-cell uses an anode and an electrode, to produce heat and electricity, which can be stored in a battery or directly used (ibid.). The distance a fuel-cell truck can travel is determined not only by its payload but also by the quantity of hydrogen it can store (Cunanan et.al., 2021). According to energy.gov (n.d), hydrogen can be stored physically and through material-based methods. Physical storage methods include (1) compressed gas in pressure tanks, (2) cryo-compressed gas in cooled tanks, and (3) liquid hydrogen in cooled tanks (Durbin & Malardier-Jugroot, 2013).

Compressed Gaseous Hydrogen

Compressed hydrogen (CGH2) is the most commonly used method of hydrogen storage at the moment, with tanks capable of holding hydrogen at high pressure (Durbin & Malardier-Jugroot, 2013; Zhang et al. 2016). This method has several benefits, including low energy consumption (Tarasov et al., 2007), affordability, and the ability to release hydrogen at ambient temperature (Zhang et al., 2016). Two types of compressed gas hydrogen tanks are widely tested and used (350 and 700 atm/bar), with the primary factor to consider being the composition of the high-pressure vessel. The vessel should be able to endure the embrittlement that may occur with hydrogen, while also being lightweight, inexpensive, and easy to manipulate (Durbin & Malardier-Jugroot, 2013). Initially, aluminum was used to construct the vessels, but carbon fiber reinforced plastic (CFRP) has been employed due to its durability and ability to meet safety standards (Mori & Hirose, 2009). The pressure vessel is divided into four types, with type III and IV materials currently suited for vehicular applications due to their advantages of durability, lightness, and less to no permeability (Mori & Hirose, 2009; Godula-Jopek et al., 2012; Li et al., 2019).

Liquid Hydrogen

Liquified hydrogen (LH2) is another option for on-board hydrogen storage, which has a higher density than gaseous hydrogen and can store a large amount of hydrogen on board (Mori & Hirose, 2009; Ahluwalia et al., 2022). However, boil-off is a major issue with LH2 since it must be stored at -253°C, which causes hydrogen loss and may lead to tank ruptures due to increased pressure (Hwang & Varma, 2014). Moreover, liquefying hydrogen requires a significant amount of energy (Ahluwalia, 2007). To reduce boil-off, thermal insulation is crucial for LH2 storage tanks, and stainless steel or aluminum alloy containers with sufficient insulation are used (Niaz et al., 2015; Usman, 2022). Multi-layer insulation and perlite powder are commonly used insulation materials because of their strong resistance to radiative heat transfer (Choi et al., 2022). The prismatic shape of the vessel is preferred over the spherical shape to increase volume efficiency (ibid.). Despite these challenges, the convenience of transporting and storing hydrogen in its liquid form makes LH2 an attractive option for extending the range of fuel-cell trucks, and additionally, it is beneficial for infrastructure development (Mori & Hirose, 2009).

Cryo-Compressed Gaseous Hydrogen

Cryo-compressed gas (CcH2) is a hybrid of compressed gas and liquid hydrogen, stored at extremely low temperatures around -230°C and a minimum pressure of 250-350 bar (Zhang et al., 2016). Cryogenic-capable pressure vessels in a CcH2 storage system have the ability to store high-density hydrogen without experiencing evaporative losses during routine use, similar to LH2 vessels (Aceves et al., 2010). The tanks consist of an inner vessel made of carbon-fiber-wrapped metal, a vacuum gap containing multiple layers of highly reflective plastic, and an outer metal vacuum shell (Moreno-Blanco et al., 2019).

In terms of technology maturity level, CGH2 is the most developed, followed by LH2 and CcH2 (PRHYDE, 2021). Figure 2 below shows how energy density and temperature differ between each method and technology. Higher density (g/L) with a temperature closer to room temperature (300K ~ 27^{o}C) is preferable. The dynamics of pressure, density, and temperature also add complexity for actors to decide which method or technology should be used. Using one technology brings the implication and challenges with it that all needed infrastructure must be built too, otherwise, it can’t be used.

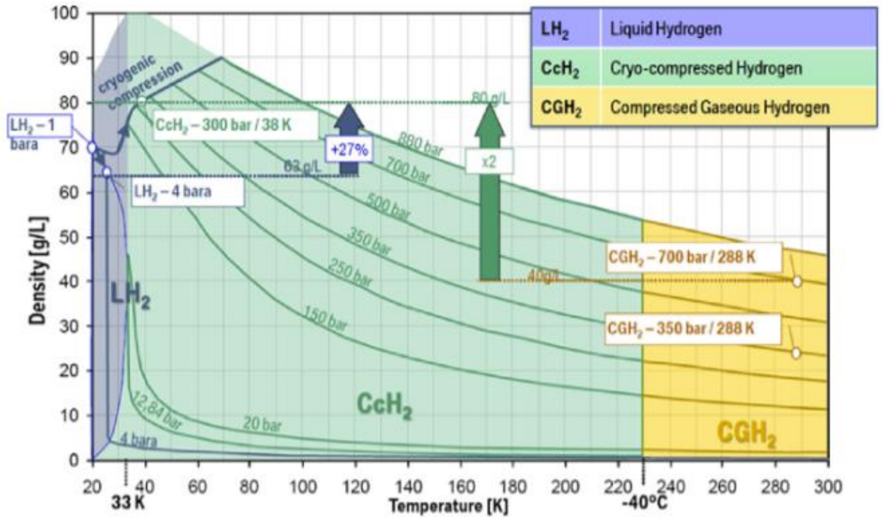

Figure 2. The energy density & temperature comparison of hydrogen (Kunze & Kircher, 2012, p.8)

1.6 Thesis structure

Following the proposal of Saunders (2012) and Bell (2018), this thesis is structured into six chapters as shown in Figure 3. First, we state in the introduction the problem discussion & research aim, outline the research area and deliver a technical background for a basic understanding of the technology. Second, the literature review displays what is already known about the topic of business ecosystems and introduces a theoretical framework. Followed by the third chapter, the chosen research design, strategy, method, and quality is explained. Fourth the empirical findings of the interviews are presented which is then continued by the fifth chapter where the findings are discussed. The sixth and last chapter concludes the analysis, answers the research questions, and suggests further research opportunities. Figure 3 summarizes this process and shows how the chapters are connected with each other.

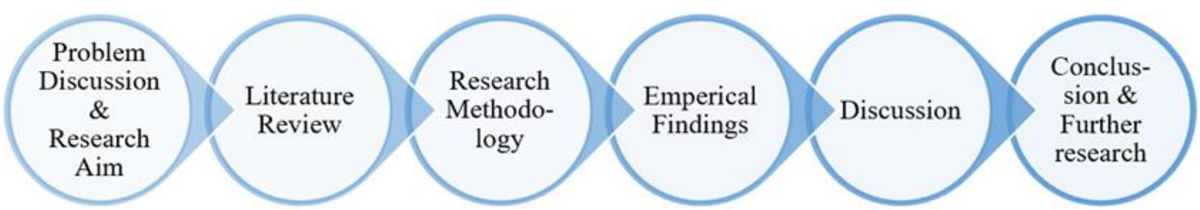

Figure 3. Structure of Thesis

2. Theoretical Frameworks

The second chapter is divided into five sections. In the first section, we define the business ecosystem and describe its characteristics. The second section explains approaches for mapping an ecosystem, identifying roles within it, and proposing an ecosystem strategy. In the third section risks connected to ecosystems are explored. While the fourth section describes the influence of standards in ecosystems. Lastly, we link those sections with each other in a short summary toward a strategic framework for ecosystems.

2.1 Innovative Business Ecosystems

The main theory that is used in this research is the business ecosystem with certain characteristics that are also reflected in the innovation ecosystem. We gained our understanding of the business and innovation ecosystem from the definitions and drew distinctions from other existing ecosystem types. To understand it deeper, the characteristics of the ecosystem are critically reviewed.

2.1.1 Definition Approach

The term business ecosystem was introduced in the field of management by Moore (1993) in the early 1990s in comparison to ecosystems known from biology. In recent years this term is studied more by researchers and the ecosystem concept is increasing in significance (Scaringella & Radziwon, 2017; Yoon et al., 2022; Dedehayir et al., 2016; Tsujimoto et al., 2018; Jacobides et al., 2018). With a growing number of literature, the term "ecosystem" itself seems to be used without a clear definition (Tsujimoto et al., 2018), leading to an ecology of meanings (Adner, 2017). The literature about ecosystems follows several streams (Jacobides et al., 2018; Scaringella & Radziwon, 2017), which can be distinguished into business ecosystems, innovation ecosystems (Jacobides et al., 2018; Scaringella & Radziwon, 2017; Tsujimoto et al., 2018; Dedehayir et al., 2016), platform ecosystems (Jacobides et al., 2018; Tsujimoto et al., 2018), entrepreneurial ecosystems, and knowledge ecosystems (Scaringella & Radziwon, 2017).

Following Iansiti & Levien (2004a) drawing boundaries of an ecosystem is impossible and borders between ecosystems are fluent (Rinkinen & Harmaakorpi, 2018), connected to several stages within the lifecycle of an ecosystem (Moore, 1993). With the development of an ecosystem around fuel-cell trucks just starting, the process should be considered dynamically rather than statically (Rong et al., 2015; Rinkinen & Harmaakorpi, 2018; Rong et al., 2018). This leads us to a more holistic definition of an ecosystem following Adner (2017) and Moore (1996):

> "*The alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize*." (Adner, 2017, p. 40)

"*An economic community supported by a foundation of interacting organizations and individuals […] produces goods and services of value to customers, who are themselves members of the ecosystem. The member organisms also include suppliers, lead producers, competitors, and other stakeholders. Over time, they coevolve their capabilities and roles, and tend to align themselves with the directions set by one or more central companies*." (Moore, 1996, p. 26)

Still some boundaries must be drawn for clarification within the holistic understanding of ecosystems, coming from the wide range of literature and research streams. Ecosystems tend to center around a platform (Adner, 2006; Iansiti & Levien, 2004a; Moore, 1996), which is picked up by literature around **platform ecosystems** and created several understandings of the term "platform" in the ecosystem context (Gawer & Cusumano, 2014). In the platform ecosystem, the platform is orchestrated and owned by one actor, who targets two types of groups - complementors and customers - to create innovation, network effects, and shared value (Gawer & Cusumano, 2014; Schreieck et al., 2016; Jacobides et al., 2018). This type of ecosystem is often found in high-tech businesses where modularity is easy to achieve, examples are Apple, Google, Microsoft, Alibaba, or Intel (Gawer & Cusumano, 2014; Schreieck et al., 2016; Jacobides et al., 2018). Pidun et al. (2022) argue that a platform ecosystem is transactional and aims to connect customers with producers who can meet their specific needs. It's all about finding the perfect match between what the customer wants and what the producer can offer (ibid.). The success of a transactional ecosystem depends on how many successful transactions occur, and how much both parties benefit from them, while both are increasing with a growing number of users (ibid.). Not always the platform is orchestrated by one company, platforms can be more:

"*[...] products, services, or technologies that act as a foundation upon which external innovators, organized as an innovative business ecosystem, can develop their own complementary products, technologies, or services."* (Gawer & Cusumano, 2014, p. 417).

We follow that definition of a platform in the further use of the thesis since the ecosystem around fuel-cell trucks has not developed one leading platform owner rather than products, services, and technologies.

While Moore (1993) mentions that business ecosystems have leaders, Iansiti & Levien (2004a) described the central players as keystones, but both pointed this kind of organization out as companies. We are following those descriptions of important organizations and want to distinct our definition from **knowledge ecosystems**, which often have a research-driven organization or network as their central organization (Clarysse et al., 2014), which is locally organized in a cluster (van der Borgh et al., 2012). Also, lies the main focus of activity on knowledge generation within a knowledge ecosystem (Clarysse et al., 2014; van der Borg et al., 2012; Scaringella & Radziwon, 2017), where we see the focus of an innovative business ecosystem on materializing a value proposition (Adner, 2017). **Entrepreneurial ecosystems,** on the other hand**,** put governments and entrepreneurial teams in the center of their ecosystem and activities with the goal to embrace entrepreneurship and economic growth (Isenberg, 2010; Scaringella & Radziwon, 2017; Alvedalen & Boschma, 2017). This ecosystem puts geographical proximity as an important metric to stimulate development in order to support the creation of new ventures (Brown & Mason, 2017). Again we want to distinguish our definition of central organizations within the innovative business ecosystem where the keystone role is taken by companies.

In similarity, all kinds of ecosystems are loosely affected by time and focus on evolutionary processes (Cobben et al., 2022). However, the emphasis of the ecosystem in our research is that it is not bounded geographically, thus, reflecting the characteristic of both **business and innovation ecosystem** (ibid.). Lastly, we want to draw a line to other research fields that offer theories which are related to ecosystem research, like open innovation, business models, supply chains, value networks, business parks and clusters, organizational ecology, coopetition, and multi-sided markets (Adner, 2017; Jacobides et al., 2017; Scaringella & Radziwon, 2017; Thomas et al., 2022). This great amount of intersections to other business and management research topics in combination with an unclear definition of business ecosystems (Tsujimoto et al., 2018), led us to use the definition approaches from Adner (2017) and Moore (1996) in combination with the clarification and distinction from other research streams and topics.

2.1.2 Characteristics of Innovative Business Ecosystems

An ecosystem has several characteristics which we describe in this section in more detail. The described characteristics are the most common ones and help to understand ecosystems better. To clarify the intention of the research, we introduce and explain the lifecycle, complementarities, network, and value co-creation that are part of the business and innovation ecosystem.

2.1.2.1 Lifecycle of an Ecosystem

As mentioned before, Moore (1993) introduced the business ecosystem in relation to biological ecosystems and with that also a **lifecycle** of birth, expansion, leadership, and self-renewable (or death if it fails). The lifecycle approach shows that an ecosystem is not static but rather in constant change and the outcome of a process (Jacobides et al., 2018), this makes it difficult to draw borders of an ecosystem (Iansiti & Levien, 2004a). In the **birth** stage, new value propositions around innovations are defined together with customers and suppliers, while the challenge is to protect your ideas from others and tie up lead customers, key suppliers, and important channels (Moore, 1993). This stage stretches from the technology discovery and development, initial testing, and the first successful demonstration of its operation, to the phase where technology is first used commercially (Dedehayir et al., 2018).

The second stage of the lifecycle is the **expansion** stage, here the goal is to cover the largest market possible by scaling-up with partners and suppliers through dominating your market segment and establishing a market standard (Moore, 1993). Adner & Kapoor (2016) stress here the importance of analyzing the technology readiness compared to the development of the new ecosystem, otherwise, the process of the substitution might be slowed down through gaps between those two factors. Encouraging suppliers and customers to work together by providing a vision is the third - the **leadership** - stage, where the challenge is to maintain a strong bargaining power in relation to other players within the same ecosystem (Moore, 1993). In the leadership stage, firms are becoming preoccupied with standards (ibid.), but this also binds companies together on common goals and lets them invest in a shared future (Iansiti & Levien, 2004a; Rinkinen & Harmaakorpi, 2018). Iansiti & Levien (2004a) give the keystones an important role within the ecosystem, they need to continuously improve the ecosystem to ensure their own survival and prosperity. This describes also the fourth stage mentioned by Moore (1993), where working together with innovators is the key while keeping the barriers high for other ecosystems to follow and allowing a **self-renewal** of the ecosystem, or when this fails initiate the death of the ecosystem.

While the ecosystem lifecycle sets boundaries to explain the constant change within the ecosystem, the term ecosystem emergence is brought by scholars as the process of how the ecosystem is shaped and developed (Stonig & Müller-Stewens, 2019; Daymond et al., 2022; Thomas et al., 2022). Stonig & Müller-Stewens (2019) follow this approach by describing creation and growth as the phase of the emergence of the ecosystem where successful companies shape their ecosystem and orchestrate the relations with partners and suppliers. Seidel & Greve (2017) explain the theory of emergence as the development where the process has to involve the novel creation, the growth to salient size, and the formation of a certain recognizable social structure.

2.1.2.2 Complementarities

An ecosystem consists of multiple participants, which experience together the stages of the lifecycle in a process of **coevolution** (Moore, 1993) with a shared fate (Iansiti & Levien, 2004a). In this process of coevolution, a group of interacting actors depends on each other's activities (Jacobides et al., 2018). A simplified example is brought up by Kapoor (2018) where the focal offer, e.g. electric cars, depends on upstream component offers, e.g. batteries, motors, and electronics, which are implemented in the focal offer, and downstream complement offers, e.g. charging stations and workshops, which are integrated by the user to the focal offer.

Within ecosystems, **complementors** play an important role toward value creation (Kapoor, 2018; Jacobides et al., 2018; Adner, 2017). A complementor should then not be mistaken for a supplier, where the relationship to a supplier is formal and follows a governance structure for effective coordination (Kapoor, 2018), the relationship to a complementor is more loose and shaped by an alignment structure (Adner, 2017) with the goal of joint-value creation and a conflict about value capture over time (Kapoor & Lee, 2013; Kapoor, 2018). This alignment leads to the coordination of activities, mutual agreements on standards, and respective business models about who does what (Kapoor, 2018, Jacobides et al., 2018). Kapoor (2018) then mentions that in many ecosystems complementors neither buy nor sell from each other, while the coordination can happen upstream and downstream, increasing the complexity of the ecosystem.

Jacobides et al. (2018) point out three different types of complementors: generic, unique, and supermodular complementarities. Generic complementarities are critical components for a value proposition or innovation but are easily available for companies, without the need for specific coordination between actors (Jacobides et al., 2018). An example of such a generic complementarity is electricity, which is needed for almost everything and can be bought without the need for an economic organization, therefore it is part of markets (Adner, 2017). Unique complementaries, on the other hand, can be seen as specific where “A doesn’t work without B” or more general where “A’s value is maximized by B (as opposed to B)”, with A and B being specific items, steps or activities (Jacobides et al., 2018). Apps for example can’t be run without an OS, while an OS can be operated without any apps. This leads also to the last type of complementary, the supermodular one, which can be summarized as “more of A makes B more valuable”, but can also be two-sided (Jacobides et al., 2018; Pidun et al., 2022). The example can here be again the app which in this case makes the OS more valuable through added functionality, while (possibly) more installations of the OS increases the value of the app (ibid.).

2.1.2.3 Loose Network, Value Co-creation & Value Capture

In human-made ecosystems, formal authority is not readily visible, but they are not completely self-organized either (Valkokari, 2015). They are actually structured designs that are constructed to make interdependencies more explicit and rely on the understanding and acceptance of shared purpose and operational procedures by their members, formally or informally (Moore, 1996; Iansiti & Levien, 2004a; Adner, 2006; Valkokari, 2015). As mentioned in our definition approach an ecosystem has an alignment structure that interacts between a multilateral set of partners (Adner, 2017), respectively a **loose network** of companies that directly or indirectly work together to a competitive advantage (Iansiti & Levien, 2004a; Jacobides et al., 2018). The importance here is that providers of complementaries are not part of the classical firm-supplier relationship, as described in the value system by Porter (1980), and these complementors are not integrated into hierarchies (Jacobides et al, 2018). The value chain is then not integrated vertically but horizontally within a network of relations (Moore, 1996; Clarysse et al., 2014). This loose network is often built on a **modular architecture** (Jacobides et al, 2018), which allows flexibility when the environment is changing. In such a network many micro-niches are continuously developing, allowing the ecosystem to grow, while they are organized through standard interfaces (Moore, 1993). The interfaces are thin crossing points with a limited need for interactions, creating significant autonomy for participating companies and making it possible to produce interdependent components by different producers (Jacobides et al., 2018; Jiang et al., 2019). Members of that ecosystem deliver then together specific components of an overarching solution to the customer, which they individually would not be able to do, resulting in **value co-creation** (Clarysse et al., 2014; Jiang et al., 2019; Adner, 2006; Rong et al., 2015; Scaringella & Radziwon, 2017).

2.1.3. Roles in Business Ecosystem

A role in the ecosystem is defined as characteristic behavior enacted by actors and it is recognized as those grouping and reflecting particular sets of activities (Dedehayir et al., 2018). Others frame it as operating strategies, which are recognized as consistent sets of operating decisions and can be implicit or explicit (Iansiti & Levien, 2004b). These activities are done with a deliberate understanding that there is an impact to a certain degree on the ecosystem, thus, influencing the ecosystem's health and evolution (ibid.).

The role of actors in the ecosystem is not static, however, researchers view it from different perspectives (Moore, 1993; Iansiti & Levien, 2004a; Dedehayir et al., 2018). Iansiti & Levien (2004a) argue that a company can have two different roles in two different ecosystems, regardless of what the stage of the ecosystem is. Moore (1993) described that during the birth stage of the ecosystems, firms already positioned themselves in relation to how they want to focus to deliver value to the customer. Dedehayir et al. (2018) suggest that because the ecosystem birth is vital, it is crucial for stakeholders during this period to acknowledge and identify their informal roles to ensure that essential activities are effectively carried out. Other than the dimension above which states that the role is related to the analysis of the actors and their activities, the role can also be perceived from the level of turbulence and the complexity of the actor's relationship with others in the ecosystem (Iansiti & Levien, 2004a). Overall there is a main distinction of roles into "Leader" and "Follower", also called "Shaper" and "Participant" (Hagel et al., 2008; Iansiti & Levien, 2004a; Adner, 2022).

The role that many researchers focus on is the central actor that positions a leadership role, and consider them to be indispensable for the ecosystem (Moore, 1993; Dedehayir et al., 2018; Jacobides et al., 2018). Ecosystems cannot emerge and even sustain without the existence of a 'leader', especially in complex industries, such as the automotive industry (Gawer & Cusumano, 2002; Adner, 2006; Donada, 2018). The labeling of this 'ecosystem leader' varies, but almost all of the researchers signify the role in shaping the emergence of the ecosystem. Teece (2018) put forward a bold explanation that the ecosystem manager or 'captain' establishes standards and determines which parts of the value chain should be internalized or supported externally. Moore, (1993), with a subtle difference, explained that an ecosystem leader guides the ecosystem's investment direction, and directs the technical standards while maintaining its bargaining power. The term keystone as a 'leader' is described in a more modest way to be effectively able to create value and share value (Iansiti & Levien, 2004a). Keystones create value but let the others within the ecosystem contribute and develop the value, and share the value with the ecosystem's participants while keeping a fair share of it (ibid.). With these activities, a keystone as a leader helps to drive momentum for the market it aims to be part of and to draw firms into the ecosystem (Iansiti & Levien, 2004a; Teece, 2018). Not only to ensure that the ecosystem value attracts firms, but the ecosystem leader also makes efforts and investments to control, influence, and limit other potential participants in the ecosystem, all with the goal of creating and sustaining a strong and resilient ecosystem (Foss et al., 2022).

However, there has also been the definition of a 'leader' which correlates to different styles of governance. The dominator role, with a bigger economic size than that of a keystone, usually aims to take over the ecosystem by exploiting its position through the vertical or horizontal integration strategy (Iansiti & Levien, 2004a; Dedehayir et al. 2018). This role may become more profound in the later stage of the ecosystem, as the stability of the ecosystem encourages actors to take over activities closest to their value chain, delivering the intention to expand (Moore, 1993).

Aside from the leading roles, other roles within the ecosystems can be categorized according to the position and actor's relationship within the ecosystem (Iansiti & Levien, 2004a; Yoon, 2019). Such roles as flagship and hub landlords are rarely touched by the researcher (Yoon, 2019). Kim et al. (2010), argue that essentially, every company can become flagship companies that directly contribute to the health of the keystone based on their strategy towards the environmental velocity and knowledge intensity aspects within an ecosystem, thereby indirectly influencing the stability of the ecosystem. A flagship company's strategy is not static within an ecosystem, meaning that external factors such as product life cycles and ecosystem dynamics affect it (ibid.). While considered similar to flagship because of the position in the linking nodes, hub landlords distinctively extract as much value as possible for themselves from the network and rely on the rest for value creation, putting their existence at risk (Iansiti & Levien, 2004c).

The last non-leading roles are the niche players, which many of the participants enact within the ecosystem (Iansiti & Levien, 2004a). Niche players are usually the target of the dominators, and operate by utilizing keystone resources (Iansiti & Levien, 2004b). It is important that they look into ecosystems where the keystone is strong and avoid the dominators, giving them a chance to thrive and contribute to value creation (Iansiti & Levien, 2004a). However, niche firms may also need to be aware that keystone firms will be 'forced' to swallow them if they are not able to advance and evolve their products (ibid.). Niche players have to consistently compete with everyone else, including other niche players; hence, niche players must concentrate their efforts on improving their specific area of expertise through differentiation and specialization by utilizing complementary resources from other niche players or within the ecosystem (ibid.)

Additionally, the role in the view of the concept of value creation has been brought by Dedehayir et al., (2018) to explain the actors function in the value chain, in a more conservative way. The roles that directly add value to the ecosystem emergence are categorized as 'supplier', 'assembler', 'complementor', and 'user', where the supporting value creation roles are categorized as 'expert', and 'champion' (ibid.). As an example, an expert is a university while the champion is the entrepreneur that opens up a new market (ibid.). In general, The roles are self-explanatory in the sense that each role involves a distinct set of activities that are performed by the actors themselves (ibid.). Lastly, Dedehayir et al., 2018 categorized the 'sponsor' and 'regulator', which have indirect effects on value creation, represented as investors and government institutions respectively.

2.2 Ecosystem Strategy

Following we explain a strategic approach based on Hagel et al.'s (2008) shaping strategy for business and innovation ecosystems further. It is important to remember that while an ecosystem has multiple members, every member needs to define its own strategy (Adner, 2017). Iansiti & Levien (2004a) think the following about an ecosystem strategy:

> *Stand-alone strategies don't work when your company's success depends on the collective health of the organizations that influence the creation and delivery of your product. Knowing what to do requires understanding the ecosystem and your organization's role in it.* - Iansiti and Levien, 2004a, p.1

This leads us to mention and combine different strategic aspects and approaches in the following section.

2.2.1 Ecosystem Mapping

According to Dedehayir & Seppänen (2015), the ecosystem starts when the invention or innovation is found, and the product and service requirement is addressed to all members of the ecosystem. Since the end product for fuel-cell trucks has yet to be commercialized, it can be argued that the ecosystem is still in the emergence or early stage (Dedehayir & Seppänen, 2015; Stonig & Müller-Stewens, 2019). Even so, as the ecosystem is emerging and developing, there is already a basic form that can be constructed. One of the approaches to understand the construction of an ecosystem is by determining the various roles in the ecosystem based on the location where activities are clustered and the inputs and outputs of firms are categorized (Adner & Kapoor, 2010). In our case, the ecosystem should be depicted as a structure through the "ecosystem-as-structure" approach, meaning that the links between actors are assumed from the alignment requirements (Adner, 2017). Elements that collectively characterize the configuration of the ecosystem comprise activities, actors, positions, and links (ibid.). Figure 4 describes the essential structure of an ecosystem according to Adner & Kapoor, 2010, where components and complements are categorized based on how they are grouped together with the focal product or value proposition in the flow of activities, rather than where they are made or sourced from.

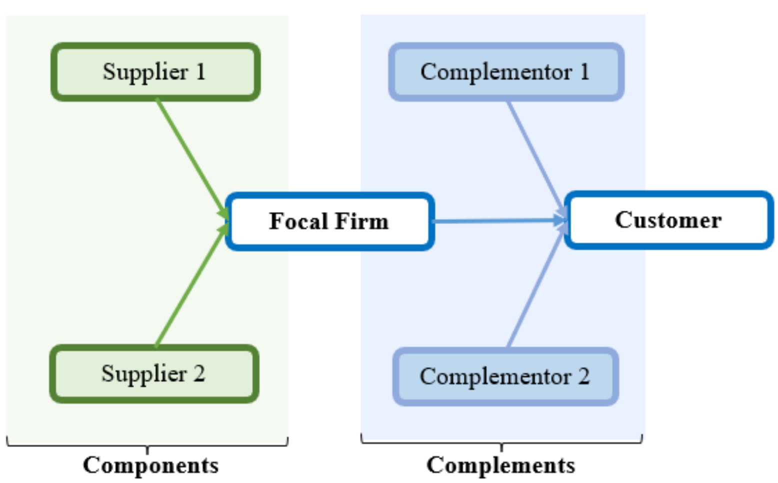

Figure 4. A generic model of an ecosystem (Adner & Kapoor, 2010, p.309)

When constructing an ecosystem model, the emphasis on value creation is considered from the perspective of structure and technological interdependence (Adner & Kapoor, 2010). The technological interdependence is based on the innovation challenges that each firm is facing, which means that the focal technology's value creation can be hindered by bottlenecks in technological complementarities within the ecosystem (Kapoor & Furr, 2013). Moore (1996) brought up the business ecosystem model from the bigger picture, explaining the functions of each actor without clarifying the input or output activities and separating them into micro, meso, and macro level. Figure 5 shows a typical business ecosystem as depicted by Moore (1996), where the business ecosystem extends from primary entities (micro) to the other stakeholders of these primary entities (meso), as well as other entities who may be relevant in certain situations (macro).

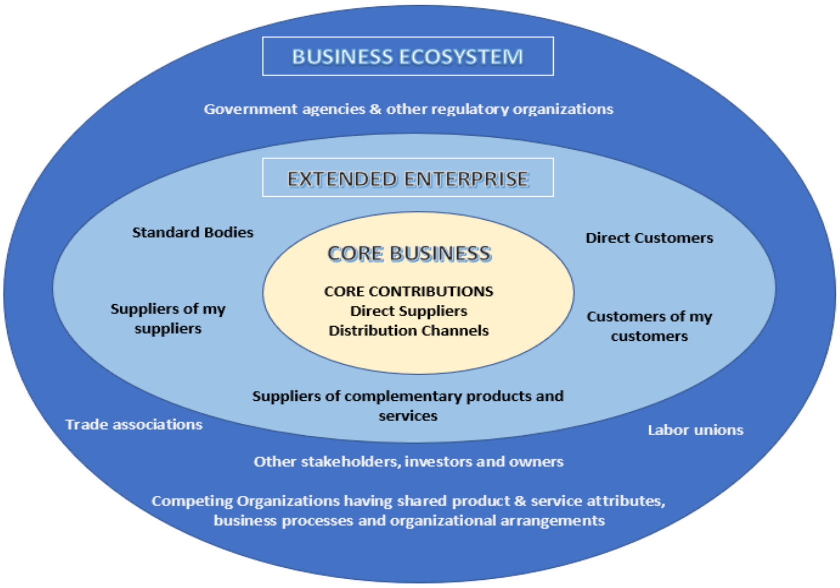

Figure 5. Business Ecosystem model (Moore, 1996, p.27)

2.2.2 Identifying and Choosing your Role

Identifying the role a player wants to take or already has within the ecosystem is critical to be successful (Iansiti & Levien, 2004a) and influences the ecosystem strategy (Adner, 2017). Choosing to be either a leader or a follower depends on the acceptance from actors that are needed for the value proposition (Adner, 2017) and on the aspiration of the company itself (Iansiti & Levien, 2004a; Adner, 2017). As mentioned before, the leader is the center of the ecosystem and captures the main value, and also sets directions and rules, where the follower agrees on these terms without striving for leadership itself. Every ecosystem can have a different constellation of roles, and it is important to keep in mind that the roles and constellations can change over time. There can be more than one leader in an ecosystem leading to shared leadership, where the competence of aligning the partners is shared (Adner, 2017). A leader also can be contested by other firms within the ecosystem, since there might be agreement on the structure but not necessarily on the roles (ibid.). In addition, a leaderless ecosystem is also possible, usually, this happens when the leadership comes with risks or burdens, or when it is unclear who candidates for the role (ibid.).

Followership, on the other hand, can be contested too, by companies inside and outside of the ecosystem, to secure their part of the value creation (ibid.). This variety of role constellations and competition within an ecosystem affects the choice of the role of a company (Iansiti & Levien, 2004a). It is summarized by Iansiti & Levien (2004a) as the level of turbulence and complexity of relationships within the business context of the ecosystem. Iansiti & Levien (2004a) propose then four different roles - the keystone, the niche, the physical dominator, and the commodity player - where the first two can be seen as leader and follower, while the third and fourth roles shouldn't be strived for in the long run since they are following a flawed strategy which can have negative impacts on the company.

Determining the position of other actors through mapping the ecosystem will show the constellation of roles within the ecosystem and identify the role you have. This is the first step that needs to be done, while the second step is to create clarity about the aspiration. The aspiration depends then on the goals and strategy of the company itself, but Adner & Kapoor (2010) mention then also the importance of the readiness of complementors for the aspiration of a company, especially in innovative ecosystems. When the innovation challenges for complementors are high it is less beneficial for a company to become a leader, in some cases, it might even be a slight disadvantage (ibid.). Detecting dependencies in the value proposition of the chosen product or service from complementors should be considered in the aspiration and the role the company wants to have.

Another factor that should influence the aspiration of a company is the health of the ecosystem, measured in productivity, robustness, and niche creation potential (Iansiti & Levien, 2004a). To measure the productivity of an ecosystem one can choose between a number of options, Iansiti & Levien (2004a) used the return on invested capital, because of its simplicity. Assessing productivity over time is then a good indicator of if and in which role a company should enter the ecosystem (Iansiti & Levien, 2004a). The capability to survive disruptive changes and new technologies is expressed in the robustness of the ecosystem, where high robustness provides predictability and buffers relationships between members against external shocks (ibid.). Robustness can be measured in the survival rate of actors within the ecosystem, either over time or in comparison to actors in an equal ecosystem (ibid.). The last indicator for a healthy ecosystem mentioned by Iansiti & Levien (2004a) is the potential to create niches, improving productivity and robustness through diversity. Measuring this indicator can be done by looking at the adoption of emerging technologies in the form of a variety of new businesses and products (Iansiti & Levien, 2004a). Important hereby is that created niches are meaningful, by adding valuable functions, which could lead to the distinction of old niches showing that they were adding not enough value to the ecosystem anymore (ibid.). With the identification of the roles in the ecosystem and defining the aspiration, a participant should then start to shape their strategy.

2.2.3 Shaping Strategy

Mapping the ecosystem and identifying the role you want to have in it are important to formulate the right strategy to shape the future of the business ecosystem and with that the future of the company (Iansiti & Levien, 2004a; Moore, 1993, 1996; Adner, 2006, 2017, 2022). Further, we concentrate on strategies within business ecosystems and not on approaches regarding industries, markets, competition, or company internals. Adner (2022) found that a unique alignment strategy is required for the roles and processes of the value proposition within the ecosystem. With the final goal of creating a win-win situation for every participant, or the previously described co-evolution in a winning ecosystem where everyone profits within its area (Moore, 1996; Adner, 2022; Jacobides et al., 2018), a strategy to shape the ecosystem towards this outcome is needed.

Hagel et al. (2008) presented the Shaping Strategy to reach the goal of shaping the ecosystem toward a preferred outcome, which is displayed in Figure 6. Shaping strategy is also one of the phenomena to focus on the research in this business ecosystem topic that is aimed at mobilizing actors (Möller et al., 2020). This strategic approach is created to not only react and adapt to changes that are happening in the ecosystem of the participant but more to actively shape the ecosystem (Hagel et al., 2008). While there can be differences in how to execute this strategic approach, depending if the participant is a "Shaper" or "Follower", the overall approach to building a strategy stays the same. The strategy has three key elements - "The View", "The Acts & Assets", and "The Platform" - which are used to influence potential participants directly or indirectly, to mobilize a critical mass for a winning strategy (ibid.).

The **shaping view** is the first element, it is needed to focus participants and show them opportunities they can perceive in the market (ibid.). It is about the mindset to influence perspectives, thus, cognitively motivating and convincing participants to accept the ecosystem's purpose through discursive processes (Thomas et al., 2021). The shaping view is not very detailed and presents a more long-term direction in which the ecosystem will develop. It is held more vaguely so that there is room for innovation and refinement, but clear enough to help participants in making difficult choices in the short term (Hagel et al., 2008). In the shaping view, orchestrators frame the vision to present a compelling motivation to act (Thomas et al., 2021). Framing the vision requires keeping up with the developments around them to ensure the enabling technologies are not disrupted and to cope with the emerging ecosystem dynamics (Dattée et al., 2018). The view will encourage the orchestrators to position themselves, creating a critical point to signaling the value to others and making them evaluate the ecosystem offering (Dattée et al, 2018; Thomas et al., 2021). Differences to a corporate vision are that a direction for the whole industry or ecosystem is enacted and the value creation is visible for all participating companies (Hagel et al., 2008.). In addition, business uncertainties must be accounted for on a high level and narrowed down for participants to recognize future value realization (Dattée et al., 2018). Through participation and resource commitments, the perceived risks will be lower because the trajectory is clarified into a shared vision and the positive outcomes become more inevitable (Hagel et al., 2008; Dattée et al., 2018).

The second element is a **shaping platform** where clearly defined standards and processes help to support and organize the activities of participants (Hagel et al., 2008). One goal of the platform is to support leverage so that participants can do more with less, while the second goal is to reduce risk by accelerating revenues (ibid.). While there are several types of platforms such as aggregation and social platforms, the mobilization platform is representative of the business ecosystem because it focuses on rallying individuals to work collaboratively toward achieving a goal that surpasses the abilities of any single participant (Hagel, 2015). A platform allows individuals to exercise their areas of expertise while delegating other tasks to fellow members they connect with (ibid.). Participation in a platform is a realization of the normative behavior of actors that can influence ecosystem performance (Thomas et al., 2021). Typically two different leverages are offered through a platform, the first is the development leverage which is often derived from shared technologies to reduce investments required to build and deliver products or services (Hagel et al., 2008). The second is interaction leverage, where the platform offers a reduced cost and effort for coordination of activities between a wide range of different participants (ibid.). From the perspective of the owner, the platform provides a concentrated knowledge flow as the participants engage with the shaper (ibid.). A platform can also foster relationships as a learning medium through sharing insights over time (Hagel, 2015).

The third and last element of the proposed shaping strategy from Hagel et al. (2008) is the **shaping acts and assets** of the shaper. This element is especially important to disperse concerns about the ability and convection of the shaping company to be successful (Hagel et al., 2008), while also showing the ecosystem value proposition enables value realization (Thomas et al., 2021). On the one hand, the company needs to create acceptance from smaller businesses through acts, like commitment towards one technology, while not pushing out those smaller companies from their niches in the ecosystem (Hagel et al., 2008). An example of an act could be the releasing of patents like Tesla did in 2014 to rapidly increase the development of the technology platform for electric cars (Musk, 2014). On the other hand, the shaping company should offer valuable assets as a signal of commitment (Dattée et al., 2018), where larger companies have an advantage over smaller ones through their higher credibility and ability to reach set goals in the shaping view and platform (Hagel et al., 2008). Strategic partnerships are a valuable asset for smaller companies in this area (ibid.), as an example pharmaceutical companies leverage the expertise of smaller companies with their experience and resources like Genentech does with Atlanta Therapeutics in the field of neuroscience (Roche, n.d.). To summarize this strategic approach, a company wants to achieve a critical mass quickly, mobilize multitudes of participants and continue shaping over time, to influence the ecosystem they are acting within (Hagel et al., 2008). Figure 6 on the next page summarizes the shaping strategy elements.

The shaping strategy should be used adopted depending on which role the company wants to have in the ecosystem, where there is a main distinction between “Leader” and “Follower” which can be interpreted as “Keystone” and “Niche” (Hagel et al., 2008; Iansiti & Levien, 2004a; Adner, 2022). While Hagel et al. (2008) state that every participant should try to adopt the shaping strategy because they can benefit from it, they also recognize that not every player has the capabilities to do so. In that case, an actor should use the opportunities offered by shaping strategies from other participants and take part in it as a follower, where one of the three main roles - influencer, disciple, hedger - can be the best fit (Hagel et al., 2008). An influencer commits early towards one shaping strategy and increases the efficiency of the assets, builds capabilities, and gets a strong market position by influencing the keystone, with the risk that the supported platform might not become standard (ibid.). The disciple commits to one platform with a clear strategic focus and direction, without investing in competing shaping strategies, if this platform fails a change to a different platform must be attempted (ibid.). Participating on more than one competing platform is what a hedger does, the developed product or services are then supporting more than one platform with the risk that high costs incur when different platform standards need to be developed (ibid.). Summarized participants that are not keystones, need to build their strategy on the same elements but have to choose a platform or platforms they want to join.

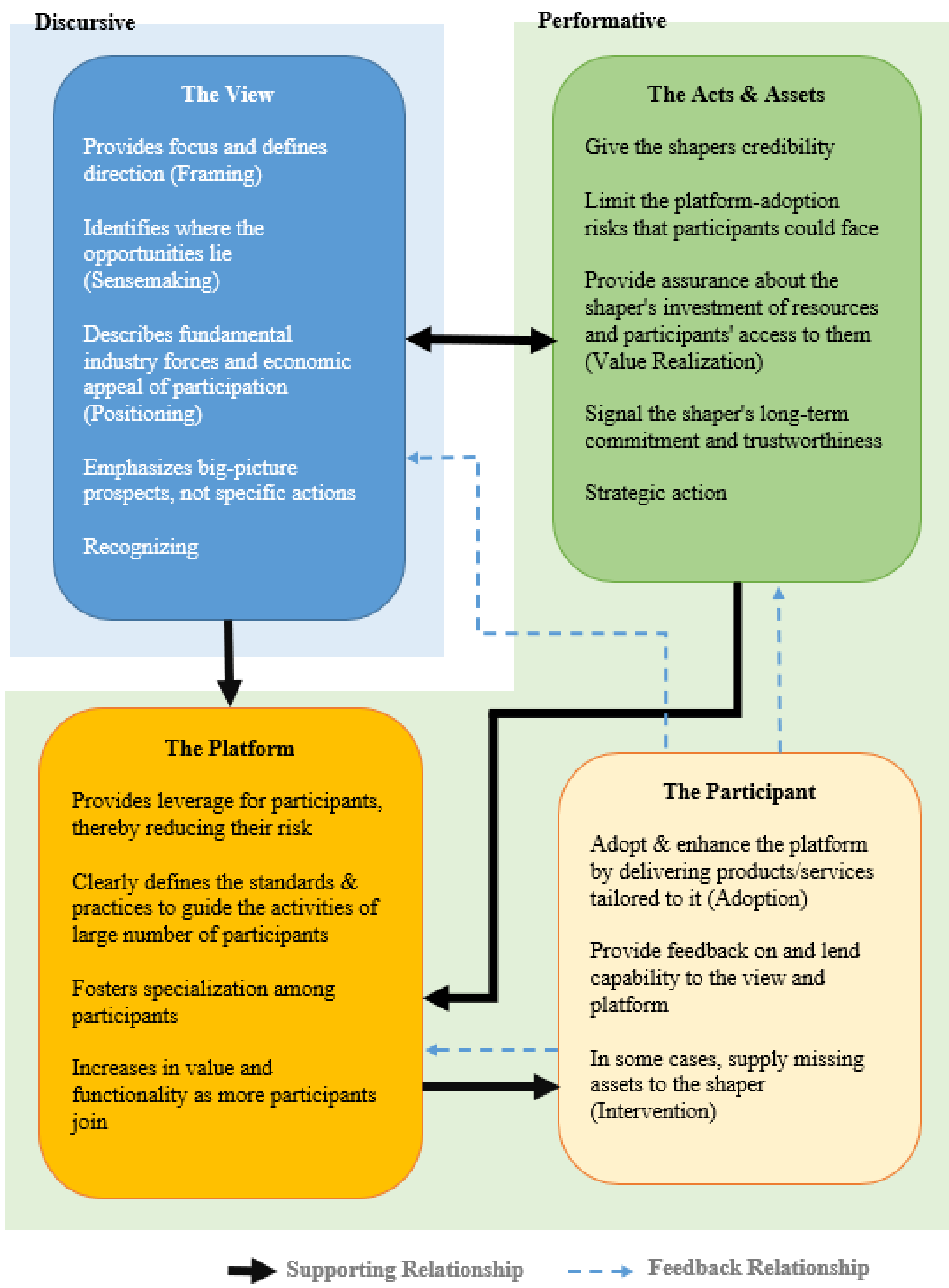

Figure 6. Shaping Strategy Formulation (Hagel, 2008, p.83)

Adner (2017, 2022) discusses, too, different approaches for leaders and followers in an ecosystem, in the context of aligning participants as described by Hagel et al. (2008) in the shaping strategy. A successful leader must evaluate their leadership claim before taking the lead in the ecosystem (Adner, 2022). To be accepted as a leader the other participants should consider your leadership as better as if they contend for leadership themselves, with key activities around identifying ecosystem boundaries, roles, and choice of partners (ibid.). Additionally, the leader is responsible for driving alignment, which is most effectively done by fostering followership in the ecosystem (ibid.). It is then about what others are willing to do with you and seeing the leadership as an opportunity to shape the vision of your followers (ibid.).

Adner (2022) points out with this strategic approach for leaders the importance of establishing all elements of the shaping strategy, as also performing a mapping and identifying the roles of participants in the ecosystem. Followers should use the shaping strategy differently than leaders, with having the power to determine the leaders in emerging ecosystems, which is not less strategic (Adner, 2022). A smart follower is picking the leader that is right for them, gaining influence, and creating momentum beyond the selected leader (ibid.). The followers should consider what they get in return and how the leaders seek to construct the value proposition and if this makes sense to other participants too (ibid.). The goal is to follow a leader that wins when a follower wins and at the same time the follower wins when the leader wins (ibid). Shaping the larger game can be also performed by followers through collaborating with other participants (ibid.). Together they can shape the rules of the ecosystem for all participants and gain more power in negotiating with the leaders (ibid.). Adner (2022) sees the need for followers to have their strategy as described in the shaping strategy by Hagel et al. (2008) but might have to adjust their elements toward the ecosystem leader to be part of a successful ecosystem.

Becoming a niche player in the ecosystem is what Iansiti & Levien (2004a) find as a valid approach for followers to develop specialized capabilities and capture value. For that, the follower must differentiate from other participants in the ecosystem and leverage the resources from keystones and complementors (Iansiti & Levien, 2004a). The keystone player on the other hand should follow the example of the shaping strategy. The biggest threat to the keystone and the ecosystem itself comes from domination approaches within the ecosystem strategy. A *physical dominator* wants to own a large portion of the ecosystem through vertical and horizontal integration of other participants (ibid.). This makes the dominator responsible for the total ecosystem and can generate high revenues, but also brings the risk of not being able to react to new upcoming ecosystems and missing to self-renewal of the ecosystem they act within (ibid.). The *value dominator* aims in contrast to suck out as much value as possible from the network of the ecosystem (ibid.). At the same time, they only add little or no value to the ecosystem, leaving not enough for the other participants to prosper and leading to the collapse of the ecosystem they are part of (ibid.). In a successful ecosystem strategy alignment and collaboration is important, with Adner (2022) stating:

> *"In a successful ecosystem, there are no losers — only partners that win in different ways. In contrast, in an unsuccessful ecosystem, there are only losers. Failing at leadership in an ecosystem is failing at value creation."* - Adner, 2022, p.86

2.3 Ecosystem risks

The need to interact to materialize a value proposition to the customers has always been the purpose of a firm when entering and participating in the ecosystem (Adner, 2006; Adner, 2017). However, there is a tendency for a firm to focus only on this goal, act rashly, and overlook the process of the ecosystem's emergence and evolution itself (Adner, 2006). Strategizing needs to come up with the ability to navigate and assess the risk to increase the success of your firm participation (Adner, 2006; Smith, 2013). There are not many scholars who specifically mention the risks within a business ecosystem, rather than many of them associated the risks with the strategy or the role a participant has taken within the ecosystem (Smith, 2013).

Adner (2006) determines three categories of risk within an ecosystem that can hamper the delay of innovation and value realization. Initiative risk is considered as a risk within the micro level where it needs to be resolved within the firm (ibid.). Interdependence risk calculates the joint likelihood of success from the commitments of every actor or complementors and in which order certain commitments must first be materialized (ibid.). This risk is correlated to the structure of interdependence where the location of the challenges impact firms' competitive advantage (Adner & Kapoor, 2010). It could be an upstream or component risk that can impact the firm's ability for producing the product, and a downstream or complement risk that can constrain the customers to experience the full benefit of the product (ibid.). Integration risk, on the other hand, is caused because the benefit does not exceed the cost at every adoption cycle, causing the participant that acts as complementor or intermediary not willing to provide an offering (Adner, 2006).

Risk can also be viewed as a potential threat that comes from other actors' deliberate activities, especially from the leading roles (Pierce, 2009; Smith, 2013). A core firm's actions, such as in the form of diversification or regulatory influence, can generate a disturbance to the ecosystem (Pierce, 2009). The motive or opportunity for acquiring greater share also can lead big firms into becoming a dominator, fostering the risks of driving ecosystem sustainability away from being healthy in the long run (Iansiti & Levien 2004a; Dedehayir et al., 2018).

2.4 Industry Standards in Ecosystems

Moore (1993) stated that standards are important to stabilize an ecosystem because it allows participants to target particular elements of value and compete about contributing to those values. Jacobides et al. (2018) find that one important factor to establish a connection between complementing participants is the use of standardized interfaces. This is represented in Hagel et al. (2008) shaping strategy through the platform element which has the goal to guide activities of participants through standardized interfaces and processes.

While standards can be distinguished by several types and functions (Tassey, 2000) we follow Grant's (2018) distinction between public and private standards. **Public standards** are open and available to all users, which include mandatory standards, e.g. safety or environmental standards, that are set by governments and are backed by law (Grant, 2018). Consensus standards are also part of public standards, these kinds of standards are usually set by standard bodies such as the International Organization for Standardization (ISO) or other professional organizations (ibid.). While public standards are open and most often free for everyone, they may use privately owned intellectual property such as patents, which results in licensing fees to the owner of the patent (ibid.). **Private standards** on the other hand are owned by companies or individuals (ibid.). The owned technology that becomes a standard can be implemented in a product or licensed to others that want to use this technology (Ibid). Establishing technology as a standard can take a longer time since they emerge through voluntary adoption, making them a so-called *de facto* standard (ibid.). *De facto* standards are products that emerge in the market before the standardization happens, while *de jure* standards are commercialized after the standardization occurred (Funk & Methe, 2001).

Funk & Methe (2001) describe that the establishment of standards has several goals and effects, with the first and most important one being reduced market uncertainty and product cost. This is described by Teece (2007) as the ‘rules of the game’, where constraints through standardization, e.g. by regulators or standard-setting bodies, shape the limitations of competition between ecosystem participants. As previously mentioned, platforms have the goal to guide the activities of participants (Hagel et al., 2008), an effect that was described by Funk & Merthe (2001) as a ‘bandwagon’. A ‘bandwagon’ is a reinforcing process where a growing number of companies adopt a standard, leading to a scaling of price performance mechanisms and increased returns based on the number of users. These mechanisms, Iansiti & Levien (2004a) increase the health of an ecosystem making it more robust through the development of niches. This is even the case if new standards lead to the death or closure of some niches since it is part of the life-cycle and provides opportunities for the development of new niches (Iansiti & Levien, 2004a). In an ecosystem, the alignment of participants leads to the coordination of activities, mutual agreements to standards, and respective business models about who does what (Kapoor, 2018, Jacobides et al., 2018). Where Funk & Methe (2001) concluded on the example of telecommunication standards, that the most successful process of standard establishment is done in cooperation between the market and regulators.

2.5 Link to a Theoretical Framework

The center of our literature review is the innovative business ecosystem as shown in Figure 7. With that as our main topic and our research questions in mind, we explored affiliated themes, as displayed in the outer circle of Figure 7. These themes are connected with the main topic of the innovative business ecosystem, but also we find connections between them, as described in the literature review. An example is here the connection between the platform of the ecosystem strategy and industrial standards in ecosystems. The connections between the themes, as also the gained information from them, is our basis for the development of the framework to be able to answer research question 2.

Figure 7. Link between literature themes

3. Methodology

This chapter outlines the methodology for our research. First, we introduce our assumptions and philosophy, as also our research strategy and design. In those sections, we explain why we have chosen a qualitative approach, specifically an abductive method, for this study. After that, we outline the research methods we employ, which include the literature review and interviews. The data collection is described and analyzed by a thematic coding approach. Finally, we discuss the research quality of the study, focusing on its trustworthiness.

3.1 Research Assumptions and Philosophy

Our understanding of what we do is influenced by the research philosophy, which guides us in the practice of our particular view of acceptable knowledge and the development of knowledge (Saunders et al., 2012). This affects the assumptions we make in every step of our work (ibid.), to ensure that these assumptions are consistent and effective. Bell et al. (2018) suggest thinking about the ontology and epistemology of the research. Starting with the ontological considerations, which can be distinct between objectivism and subjective constructionism (Bell et al., 2018; Saunders et al., 2012). With objectivism being concerned with social phenomena facing us externally beyond our influence (Bell et al., 2018), like the need of developing a fuel-cell truck ecosystem coming from the social pressure of a more sustainable future, we argue for a more subjective view on the topic. In subjective constructionism, reality is socially constructed by the consequent actions of social actors (Saunders et al., 2012). Here we see the development of the fuel-cell truck ecosystem and its technologies, as an active choice to drive the future in this direction by individuals and organizations since more than one solution is possible to increase sustainability in the transportation sector. In order to understand the reality behind it, it is necessary to study the details of this situation (ibid.). This leads to an imperative knowledge gaining in which we are interested in the 'how' and 'why' of social actions (Bell et al., 2018), where we see our values bound to the topic resulting in subjective research (Saunders et al., 2012).

3.2 Research Strategy

When developing a research project, the research strategy outlines the overall approach. According to Bell et al. (2018), researchers have three main options to choose from - quantitative, qualitative, or mixed methods. The choice of which strategy to use is dependent on the research methods selected by the researcher. Understanding the theory is crucial in determining the appropriate research method, as it enables the researcher to appreciate the assumptions that must be made about the reality being studied (Bell et al., 2018). In a quantitative approach, the researcher prioritizes the collection of numerical data, while in a qualitative approach, the emphasis is on collecting written or spoken words and images (ibid.). The mixed method, on the other hand, is a combination of both but emphasizes on how the research is approached, concurrently or subsequently, and needs to argue for how both methods are integrated (Saunders, 2012).

We have selected expert interviews and literature studies as our research methods, based on our theoretical understanding that the future of the fuel-cell truck depends on human agency (Bell et al., 2018). We take a constructivist view, which holds that the transition to fuel-cell trucks is an active decision rather than a product of social norms (ibid.). As we seek to study the development of the fuel-cell truck ecosystem, future predictions may not be objective or useful for a positivist approach. Instead, we adopt an interpretivist approach that focuses on the actions and perspectives of relevant experts and from them recommended documents (ibid.). In addition to theoretical considerations, practical factors played a role in our method selection. Collaborating with the Volvo Group granted us access to a larger network of experts, providing empirical insights to our study. In summary, our theoretical understanding and choice of research methods align with a qualitative research strategy that prioritizes expert interviews and documents mentioned by the interviewees for further reference or understanding, as the basis of our analysis.

Bell et al. (2018), distinctively explain that the approach to the relationship between theory and research can be deductive, inductive, or abductive. In our research, we argue that a deductive approach is not appropriate for our research because we don't test the theory and form hypotheses. While there are indications of inductive elements in our study since our goal is to develop theories based on empirical findings, an abductive approach is more appropriate for our research (Saunders et al. 2012). This is because we do not hold any particular personal views or preconceptions related to our research questions before data collection, and our findings take the form of recommendations that require us to identify and explain themes and patterns (ibid.). Another reason for our approach is that our research focuses on a possible participant strategy within the fuel-cell truck ecosystem and its different technological solutions, where one or a combination of them is planned for future use. This means that there is already a certain level of theory, but we are not testing that theory. Rather, the theory enables us to explore the phenomenon of technology and business development, and draw inferences to develop the existing theory (Thomas, 2010). To explain further the nature of our research design, we connect it to the way our research questions would be answered. We consider that the research answers would be descriptive according to the exploratory nature. Our goal is not to find causal relationships but rather to clarify our understanding of an ongoing complexity in the fuel-cell truck ecosystem. Through semi-structured interviews, we asked open questions to discover important contextual material (Saunders, 2012). We remained open to any possible findings during the interview process, and we planned to record all the best explanations that emerge from our data interpretation (Mantere & Ketokivi, 2013).

3.3 Research Design

Every empirical research study has to have a research design as it is a logical model of proof that allows the researchers to draw connections from a set of research questions to the research conclusions (Frankfort-Nachmias et al., 2015; Yin, 2018). We have considered several dimensions while designing our research methodology and concluded that it is suitable to approach our research as a single case study. A case can comprise organizations, social groups, events, phenomena, or individuals, in which the argument attempts to describe or explain (Gerring, 2016; Yin, 2018). Yin (2018) also recommends a case study to answer questions about a contemporary phenomenon over which we as researchers have less to no control. To be studied as research, a case should be bounded by time, space, and size (Gerring, 2016; Yin, 2018). In this research, we aimed to examine the phenomenon around the emergence of the fuel-cell truck ecosystem, additionally, we focus on the technologies, borders, and relationships, in order to gain an understanding of how participants can act strategically within the ecosystem. By defining the characteristics and roles within an ecosystem, we can clarify the borders of and participants in the ecosystem. Thus, we consider the emergence of the fuel-cell truck ecosystem as our unit of analysis, while the participants that are involved and being affected are considered as the unit of observation. Determining the unit of analysis and unit of observation is a necessity in answering the research problem and choosing the research design (Frankfort-Nachmias et al., 2015).

Collaborating with one of the truck manufacturers, Volvo Group, and having workshops prior to our research gave us a good understanding that innovation in the early phase involves inter-organizational activities between firms and institutions. This is important because we determine the emergence of the fuel-cell truck ecosystem as a unit of analysis and elaborate it from the research question. As shown by Dedehayir & Seppänen (2015), the rate of each life-cycle development ecosystem takes time and therefore, it is not possible to process this case study using a ‘diary’ type of observation, thus, the research can only be carried out as a snapshot at a particular time. The use of a case study can further be justified as our aspired proposition is to shed empirical light on the business ecosystem body of knowledge. While the case study has a concern of generalizability and external validity (Bell et al. 2018), we argue that with the propositions toward a conceptual level of strategy within the ecosystem, our research strives for generalization findings. As we analyze the data and findings, there are some levels of causality involved. However, our research question does not revolve around establishing causality, but rather describing why certain findings occurred.

3.4 Research Method

In our study, we utilize two qualitative research methods as part of the data collection process. Firstly, we conducted a literature review to become familiar with the topic of business ecosystems and related theories around ecosystem strategies. Secondly, we conducted semi-structured interviews to gather and enhance data.

3.4.1 Literature Review

To begin our study, we conducted a literature review to gain a deeper understanding of business ecosystems, their characteristics, and strategy approaches within them. Additionally, to gain a better understanding of the topic of hydrogen and fuel-cell trucks, we read documents related to these topics. According to Bearman & Scott (1991), there are two types of documents, personal and official documents, however, Bell et al. (2018) suggest that there are more types of documents that should be considered, such as personnel documents, public documents, organizational documents, media outputs, and visual documents. For literature to build the theoretical framework, we mainly utilized public databases from resources like GU library, Google Scholar, and EBSCO Research Databases, while organizational documents and media outputs will be used to enhance our understanding of the topic. The literature review to build our theoretical background is done systematically through relevant keywords and complemented with exclusion and inclusion criteria to ensure the scope is maintained reasonably. Our summary of keywords used for the theoretical frameworks are *business ecosystem*, i*nnovation ecosystem*, *ecosystem risks*, *shaping strategy*, and *industry standards.* As inclusion criteria, majority of the literature that we used is peer-reviewed, however, non-peer-reviewed articles are also taken in limitation to strengthen the understanding where the topic is not broadly explained by researchers. Also, we only considered English language literature. The documents selected for analysis were evaluated based on four quality criteria proposed by Bearman & Scott (1991), which are authenticity, credibility, representativeness, and meaning. It is important to ensure that the evidence is genuine and of unquestionable origin, free from errors and distortion, typical of its kind, and clear and comprehensible. The literature review will provide us with an understanding of the phenomenon and guide us to expect certain themes based on the findings (Bernard & Ryan, 2003).

For the literature review around the contextual knowledge i.e. related to hydrogen in fuel-cell truck applications, we differentiate the retrieval source according to the purpose and origin of the information. First, to gain a deeper understanding of the context, we used similar sources with keywords around onboard hydrogen storage or mobile hydrogen storage, combined using keywords such as gaseous hydrogen, liquid hydrogen, and cryo-compressed hydrogen. Secondly, we took other sources of information and literature based on the proposed arguments from the interviews. We analyzed public documents that have been mentioned or recommended by interviewees, such as government reports, business reports, and relevant news, which can provide valuable information about future developments and trends from political, organizational, and societal perspectives. We considered these documents that provide us with information contextually as secondary data and can be used for a triangulation to check given information by interviewees or support and deepen their arguments as proposed by them. This triangulation can be used to gain more confidence in the primary data, through these independent sources of information (Saunders, 2012). The upcoming section will provide a deeper analysis of the qualitative analysis of the documents.

3.4.2 Data Collection

The primary approach to gather data from organizations and companies involved in the development of the fuel-cell truck ecosystem is through interviews. The researchers have opted for interviews as a means to collect subjective and qualitative data, providing insights into the beliefs of industry stakeholders and their plans for the future. As per Bell et. al. (2018), qualitative interviews offer flexibility to respond to individual interviewees' answers and explore their perspectives on the research topics. There are three types of interviews, namely structured, semi-structured, and unstructured (ibid.). Since the goal of this research project is to examine current development and potential future scenarios by interviewing various individuals, a semi-structured interview format is used. An interview guide is prepared for semi-structured interviews to provide flexibility in covering all topics while allowing individuality for each interviewee; this approach is more efficient for exploration and ensures consistency between researchers, unlike unstructured interviews that can be more time-consuming and may yield different results depending on the researcher, while structured interviews lack the needed flexibility (ibid.). Prior to primary data collection, some activities were initiated as a pre-study to give us an understanding of the research topic and technical knowledge, two workshops and several internal meetings organized by the Volvo Group were attended for this purpose.

In qualitative research, the purpose of sampling is different from that of quantitative research, as it is focused on the research question rather than probability (ibid.). Purposive sampling, which involves selecting interviewees based on specific requirements that are relevant to the research question, is considered appropriate for this research. This approach involves using generic purposive sampling and snowball sampling, with a focus on selecting experts who can influence technological developments, such as company CEOs or managers, engineers, or other representatives for topics connected to hydrogen. To ensure a sufficient sample size, a minimum of 20 to 30 interviews is recommended (Warren, 2002; Mason, 2010), with theoretical saturation also considered important in determining the appropriate number of interviews resulting in a lower number being acceptable (Saunders, 2012). While there is a risk of low external validity associated with purposive sampling, collaborating with a company for our research provides access to a network of experts closely involved with the research topic (Bell et al., 2018). This is important to gain access to participants from all parts and industries within the fuel-cell truck ecosystem, to increase the validity and saturation of the study.

The researchers offered online interviews using Microsoft Teams platforms to all participants, as they are assumed to be more convenient and easy to schedule in a professional environment (Bell et al., 2018). Face-to-face interviews were offered if possible, but online tools are preferred due to cost savings and visual representation benefits (ibid.). The interviews were audio recorded and transcribed to capture not only what interviewees say but also how they said it, providing flexibility in asking questions without distractions (ibid.). An interview guide, which can be found in Appendix A, was created based on the literature review, analysis of relevant documents, and the attended workshops, serving as a support to ensure all topics are covered during the semi-structured interviews (ibid.).

For the primary data collection, around 40 requests for interviews were sent but only 19 accepted for the interview. These 19 participants are interviewed in 18 interviews which comprises 12 hours and 32 minutes in total time spent. The company type of the respondents is divided based on their activities within the hydrogen streams or value chain. Later in the empirical findings, when it is mentioned I1 or I2, we refer to the person interviewed and their perspective based on the company's position. Additional sessions for the primary data collection were held to give additional input or findings, such as the workshop visit to Processkontroll AB at Stora Höga, Sweden, and a presentation session by Air Liquide. A summary of all performed interviews can be found in the following Table 1. The position of the company in the ecosystem has been distinct in different type, with following meaning:

- Truck manufacturer : Manufacture and sells trucks
- HRS provider : Builds and/or runs the hydrogen refueling stations
- HSS provider : Manufactures mobile tank storage systems for trucks
- H2 Producer : Produces and distributes hydrogen to refueling stations
- System integrator : Is active as H2 producer and HRS & HSS provider, by covering a greater value chain
- Electricity provider : Produces electricity with an interest in producing hydrogen
- NGO : Non governmental organization with a focus on hydrogen
- Investor : Financial institution with a focus on hydrogen

Interviewee	Position	Company	Company Type	Country	Duration (min)	Date	Method
I1	PR & Communication Manager	IVECO	Truck Manufacturer	DK	24	3/14/2023	Teams
I2	CEO	Processkontroll	HRS & HSS Provider	SE	57	3/15/2023	Teams
I3	Senior Technology Advisor	Exxonmobil	H2 Producer	US	47	3/17/2023	Teams
I4	Advisor	NGO for Hydrogen Council	NGO	DE	37	3/18/2023	Teams
I5	CEO	Argo-Anleg	HRS & HSS Provider	DE	48	3/20/2023	Teams
I6	Senior LH2 Expert	Air Liquide	System Integrator	FR	32	3/24/2023	Teams
I7	CEO	REH2	HRS Provider	SE	36	3/30/2023	Teams
I8	Senior Principal Scientist Mobility	Shell	H2 & HRS Provider	DE	39	3/30/2023	Teams
I9	Fuel Systems Commercial Director	Chart Industries	System Integrator	US	36	3/30/2023	Teams
I10	Business Development	Total Energie	HRS Provider	FR	42	3/31/2023	Teams
I11	Development	Daimler	Truck Manufacturer	NL	49	4/3/2023	Teams
I12	Business Development Manager	Chart Industries	System Integrator	SE	32	4/4/2023	Teams
I13	Principal Engineer Hydrogen Infrastructure Technologies	Volvo	Truck Manufacturer	SE	44	4/5/2023	Face to Face
I14	Strategic Business Development	Vattenfall	Electricity Provider	SE	47	4/6/2023	Teams
I15	Investment Director	Hy24	Investor	FR	36	4/7/2023	Teams
I16	CEO & CTO (2 persons)	Verne	HSS Provider	US	43	4/7/2023	Teams
I17	Business Development Director	Plastic Omnium	HSS Provider	FR	63	4/11/2023	Teams
I18	Director of Public Affair	Worthington Industries	HSS Provider	AT	40	4/20/2023	Teams
				Total time (hours):	**12H 32M**		

Table 1. Interview Summary

3.4.3 Data Analysis

Thematic analysis is a commonly used qualitative research technique that will be employed in this study, as we primarily dealt with transcripted interviews (Bell et al., 2018). The university has provided us with Atlas.Ti software to aid in the coding process and analysis, which was used mainly to organize labels and word counts for importance. However, the interviews are manually coded, following the steps and principles outlined by Gioia et al. (2004) and Strauss & Corbin (1998). The coding process began immediately after transcribing the first interview to help sharpen our understanding and facilitate theoretical sampling (Bell et al., 2018). During the iterative process and first-order analysis, we identified and categorized insightful expressions into higher-order themes, similar to what Strauss & Corbin (1998) and Bernard & Ryan (2003) refer to as discovering a theme. We used various techniques such as repetition, similarities, and differences to scrutinize the rich narratives emerging from the interviews, which we believe should be done manually to gain a deep understanding of the data as authors.

In the latter stage of theme discovery, we engaged in activities such as cutting, sorting, and linking themes to theoretical material. Once all the categories and themes had been established, we connected them to the context both theoretically and methodologically. According to Gioia et al. (2004), this step is referred to as second-order analysis, which focuses on concepts that can help explain the observed phenomenon and may not have relevance to existing literature. Finally, we compiled the aggregate dimension and built the data structure in Appendix B, as we aimed to create a comprehensive picture that illustrates the connections between concepts, themes, and dimensions, particularly for the reader's understanding.

3.5 Research Quality

In line with the chosen research strategy of a qualitative approach, the research design is selected based on the desired research quality and characteristics. In qualitative research, trustworthiness is a significant criterion that comprises credibility, transferability, dependability, and confirmability (Guba & Lincoln, 1994). To ensure credibility, we made sure that the findings were derived from interviewees who are involved in the field of study and provided them with the findings as a return. Prior to the interview, we briefed and presented the research topic to the interviewees to ensure that the content is relevant. To ensure credibility, the interviews were recorded and transcribed, and both researchers were present for the interview.

Transferability, which refers to the extent to which the findings of a study can be applied to other contexts or situations, is an important criterion for evaluating the quality of qualitative research (Shenton, 2004). Considering the particular subject matter of our research, we anticipate that our study could have a low degree of transferability. This is because our research is focused on a particular point in time in a dynamic business context, which will be difficult to replicate. The actual conditions that unfold in the coming years will determine whether a certain technology outcome will flourish or not and whether our conceptual outcome still holds or not. Thus, any attempt to replicate our study in the future would not be comparable to the original research conducted by us (Bell et al., 2018).

To ensure dependability in our research, we aimed to make every phase of the research accessible and auditable to readers (Shenton, 2004). This involves recording each stage of the research process and structuring the report in accordance with the reference framework so that readers can validate our findings. In addition, we strived to minimize personal biases and maintain objectivity throughout the research. This involves transcribing interviews and ensuring the authors have a shared understanding of the findings. The coding process was also done collaboratively to ensure that all findings are reasonable and reliable. Through these efforts, we maintained a high level of confirmability in our research.

3.6 Research Ethics

Ethics in research refer to the set of guidelines and principles that direct the behavior of researchers regarding the rights of individuals who are involved or impacted by their work and that these ethical concerns may arise at various stages of the research process, such as when planning the research and collecting the data (Saunders, 2012). To ensure that the research was conducted ethically, researchers obtained informed consent from all participants prior to the primary data collection i.e. the interview. Consent was obtained regarding the recording of the interview and the privacy of their transcription. The explanation of requested access to transcription and the validity of the transcription was addressed at the beginning of the interview. With the acknowledgment from the interviewed participants, their names are not published in our report, but in order to maintain the reliability of the data, the company name and position are stated. Prior to publishing the empirical findings and interviewee details another consent was sent via email to every participant to ensure they are agree with the use of quoting statements.

4. Empirical Findings

In the fourth chapter, the empirical findings from the interviews and further sources mentioned by the interviewees are presented. The sections are constructed based on the structure of the thematic analysis with its aggregated themes and dimensions, which can be found in Appendix B. In the first section, we summarize the mentioned key drivers by the interviewees for further mapping. The second section concentrates on strategic approaches, which were mentioned by the interviewees and could be linked to the fuel-cell truck ecosystem. Section three displays the risks for the ecosystem that were brought up by the interviewed respondents. Findings connected to standards within the fuel-cell truck ecosystem and the development around them, are part of the last section.

4.1 Ecosystem Mapping

In this section we summarize and display the answer of the interviewees in connection to identified key drivers in the fuel-cell truck ecosystem. The boundaries of the ecosystem are seen differently by every interviewed participant and they are broken down into elements that we considered as key drivers. The structure of Table 2 on the next page is divided into participants of the interviews, located on the left side of the table, and the elements of the ecosystem which participants perceive as key drivers, located on the top of the table. Interview participants are distinguished and ordered with the same description of "company type" as brought up in the previous chapter 3.4.2. Based on their company's position in the ecosystem the answers were different for each interviewee. Depending on that, they find different elements like companies or industries as key drivers in the ecosystem. The interviewees mentioned the elements that have an impact on the ecosystem when they were asked about their opinion on the current situation and future expectancy. For example, I8 highlights the importance of electricity providers and electrolyzers for the provision of gaseous hydrogen, while I10 only highlights the hydrogen provider as a key driver to fulfill their requirement for hydrogen. Table 2 will then become the basis of the mapping of the ecosystem in the discussion chapter, where the position will be further discussed and elaborated in the context of the literature review.

		Key drivers mentioned																		
Company Type	**Interviewee #**	Renewable energy producers	Electricity producers	Hydrogen providers	Electrolyzers	H2 infrastructure providers	Hydrogen storage providers	HRS providers	Carbon fiber producers	Fuel-cell producers	Other HS components providers	HSS providers	Truck manufacturers	Logistic companies / Customers	Heavy industries	Other end-use industries	Research Institutes	NGOs for standardization	Governments	Investors
Energy Provider	I14	x	x	x	x	x	x								x					
H2 Producer	I3		x	x	x	x	x			x			x		x	x	x	x	x	
H2 & HRS Provider	I8	x	x	x	x	x	x	x				x	x	x					x	
HRS Provider	I7		x	x		x	x	x			x		x						x	
HRS Provider	I10	x		x							x		x	x		x		x	x	
HRS & HSS Provider	I2			x				x			x	x	x			x			x	
HRS & HSS Provider	I5					x	x	x	x		x		x	x						
HSS Provider	I16			x				x		x	x	x	x					x	x	
HSS Provider	I17							x	x		x	x	x	x				x	x	
HSS Provider	I18		x	x	x			x	x				x						x	
System Integrator	I6			x	x	x		x					x						x	
System Integrator	I9							x			x	x	x						x	x
System Integrator	I12			x									x						x	
Truck Manufacturer	I1							x		x			x						x	
Truck Manufacturer	I11			x	x	x		x					x			x		x	x	
Truck Manufacturer	I13			x				x			x	x	x	x		x				
NGO	I4	x	x	x	x								x	x	x			x	x	
Investor	I15	x		x		x			x		x		x	x	x			x	x	

Table 2. Summary of key drivers in the fuel-cell truck ecosystem

4.2 Strategic Approaches

The first aggregate dimension within the findings focuses on the strategy that actors undertake, both cognitively viewed and normatively performed. It is broken down into four themes, the first one being how they position themselves in the market, then how they perceive the development of the market, and the alignment of the actors, which is also described as ongoing collaboration on the strategic action.

4.2.1 Positioning in the Growing Market

Many of the interviewees addressed the same stance or intention to stay or become a leader, especially in their core capabilities area. The way the participant shares this intention is by understanding their own capabilities in order to undertake a certain position or action toward a certain development area. As some technology is still considered in the early stages of maturity, I9 expressed their confidence in their ability because they believe that the capability is built from the experiences in successfully delivering similar products in the past. I5 saw a similar case as they considered themselves experienced and have been producing the same products for different end-use applications within broader hydrogen streams.

Some of the interviewees are involved in the research and development phase and participate in the demonstration of trial projects in collaboration with other players because they want to build a competitive advantage and experience. The importance of research and development is addressed as an expression of how firms own certain capabilities:

> *"We are always at the forefront of innovation, development and technology. And so this is what we do all the time. We develop technologies, we improve them, we make them better, more reliable, to make them more affordable and more economically viable. This is why I think we should and we will succeed. We have the right approach and we understand the technology very well.*" - I6

With all this built experience and capability in this topic, a common view is shared between interviewees, about how the capability in a certain technology could lead to the ambition for strategic continuation toward that technology:

> *"With our experience that we have in building cryogenic hydrogen tanks for 50 years, we feel very confident of our ability to be a leader in this business going forward"* - I9

> *"By focusing on standardization on liquid hydrogen, we are clearly taking a lead and trying to also to support others."* - I11

In this emerging ecosystem most of the interviewees expressed that they are a leader in their industry, but not necessarily want to be the first mover in the ecosystem, waiting for the market to be more developed. Interestingly, having competencies and becoming a leader in a certain core specialty doesn't seem to change this view. I1, I11 & I13, all the truck manufacturers in our research, agree that positioning as an early mover is preferable rather than being the first mover or being the follower. As early movers, I1, I11 & I13 prefer to wait for a positive signal regarding the establishment of a certain technology, while someone else does perform the exploration of this technology. I7, as a system integrator in hydrogen infrastructure and tank systems, concurs that in this ecosystem and industry, becoming an early mover is important while being a follower will put any firm into a difficult position later on.

The relationship between positioning and strategy is evident since some of the interviewees have the ambition to be the leader in their industry. Although the reasoning behind the strategy is implicit, I2, I5, I9, I12, I17, and I18 all highlight that their company pursued vertical integration to a certain extent or at least partially. One example is I18, which specifically mentioned about being vertically integrated into their supply chain because they want to reduce complexity in the sourcing. A different approach is taken by I8 where they envision themselves to be fully vertically integrated, from the upstream where hydrogen is produced down to the distribution and infrastructure because they want to bring the hydrogen to the end customer. I14 highlighted that the decision for becoming vertically integrated depends on how one can manage the boundary toward their extension of capabilities.

Perception of one actor to another for leadership or certain positioning within the ecosystem also arose during the data collection. I2 highlights that the ecosystem is fuzzy because of actors throwing responsibility on one another. Some of the interviewees such as I14 & I5 catch the signal of positioning strategy from other players with a contrasting view, depending on how close their relative position is. I5 for example, states that a company is acquiring valve producers to dominate the market in this niche.

4.2.2 Development of Markets

Most interviewees believe that the markets connected to hydrogen will grow, with seeing it as a rather young market that needs to be formed first. I7 sees the potential for high market shares in the beginning because not many competitors are active, but also dependencies on other industries and fast-changing developments which he called investments into “white elephants”, a term used for short-living investments. More interviewees agree on the fast developments of the market, with I9 seeing especially the high business activities as a great chance for his company to grow in this fruitful market. With the change of the transportation sector towards the use of hydrogen as a fuel interviewees see here the best chance to be profitable, compared to other industries, like the steel or power industry, that need lower hydrogen prices to make profits in their business. Other industries were then mentioned by some interviewees as important to drive healthy growth of the hydrogen market and ecosystem. Industries that already need a lot of hydrogen can be easier scaled up, which will lower costs overall for hydrogen with I3 stating:

> *“The Industrial sector is what will probably be the fastest way to scale, whether it's steel, petrochemicals or refining, but that will then help these secondary markets*

[transportation], I mean that's at least one notion that I think you know makes a lot of sense for me." - I3

These industries that already use large quantities of hydrogen will create a baseline of consumption and secure investments into that market of green hydrogen. This point of view is especially common among interviewees that are not directly linked to the transportation industry and tend to concentrate on the overall production and use of hydrogen. Companies that are offering solutions in the distribution as also storage of hydrogen see here also the connection of more than one uptaker as important to grow the market. I5 as an example wants to build hydrogen refueling stations close to river harbors where ships and trucks that follow certain routes can consume the hydrogen, to guarantee a base revenue for the placed infrastructure. The use of local synergies is then something that I8 finds highly important to grow the market. I8 says instead of building a whole network from the beginning with low utilization, more local networks should be developed together with consumers to create the needed supply and demand to run a functioning system.

Concerns regarding the development of the market are then often related to the cost of the transformation. Most interviewees see the price of hydrogen as a fuel as a negative factor for the development, which will only get slowly better in the upcoming years. These concerns of high costs are then visible in all parts of the value chain around hydrogen. I9 and I10 mention higher costs for trucks with fuel cells compared to diesel trucks, I8 sees high costs for the development of the needed infrastructure and storage of hydrogen, as also the prices of electrolyzers to produce hydrogen. Most interviewees see then a solution for this in scaling up the production of all needed parts. This will lead to comparable production prices of fuel cells and combustion engine vehicles, believes I5, and I8 believe then the same for the production of electrolyzers. I7 thinks the import of hydrogen from other countries that could produce it with solar power will lower the prices, whereas I14 sees reduced prices decrease further due to large underground storage for hydrogen. The problems that the interviewees see in the up-scaling of the production to develop the market are the responsibilities to start this process. I13 describes that the truck manufacturers are developing fuel cell trucks, while HRS and hydrogen production are growing not fast enough. While I10 on the other hand sees it from a different perspective, that the HRS development is growing fast but the truck manufacturers are not producing enough. I14 thinks then that following market development will happen over all industry boundaries, especially towards sustainability:

"In the long run there will be a win-win cycle where the more resources that are produced sustainably by, for example, green steel, the less carbon-intensive the production ... gets. So the more we do, the better we get. It's a positive feedback loop, which is always nice to see." - I14

4.2.3 Aligning Complementors

The need to align with complementors to be successful was expressed by all interviewees. I1 says then as an example that it doesn't matter how good the truck is if you have no infrastructure to refuel, while I8 sees the need for trucks to justify the building of the new infrastructure for hydrogen distribution. But overall more than just the alignment between truck manufacturers and infrastructure providers is needed and demanded. I17 finds it important that there is an alignment about the used technology for the distribution network, if it will be compressed gaseous or liquefied hydrogen that will be available for the trucks since it might be difficult to build more than one network. In the same direction goes I6 with the need to select the best technology for the infrastructure and proceed with it, which he believes is liquid hydrogen, to secure the needed investments for the infrastructure. Here I11 sees not only the need for alignment between complementors from different industries but also the need for governments to align with the rest of the ecosystem as also with other governments. I11 sees a current problem that infrastructure built in one country might not work in another country through different regulations. A mix of several technologies sees I16 as an option if the alignment will not happen or might not be possible for every region. I13 thinks a reason for non-alignment could be the fear of sharing sensitive information, a fear that I17 does not share, as his company does more in this area than the average, to accelerate the growth of needed complementors.

Complementors are then needed to scale up the economy according to several interviewees, with I14 seeing the necessity to jump into a new future towards aligning on a wide scale, where I15 finds:

> *"Support from the manufacturers of vehicles and maybe being more open about their manufacturing plants and how much volume they are going to put on the market, at which date would definitely help to scale up the economy." - I15*

I7 agrees here with pointing out the right timing to build infrastructure but also the availability of trucks so that the utilization is secured. I9 finds then that at one point there is the need to act and build the needed infrastructure, like 10 refueling stations in Sweden, so that truck manufacturers can utilize their product. According to I13 and I6 openness to propose ideas and goals to other players is important so that they can plan and think about how to deliver their part and who they need to grow to do so, an example brought up was that hydrogen producers need to align together with electrolyzer producers. The carbon fiber producers on the other hand will not invest billions of Euros into new production plants if there are no clear commitments from other actors to use this capacity, states I5. An example from previous experiences with the building of hydrogen infrastructure for cars is brought up by I8, where the refueling stations were in place, but just not enough off-takers of the hydrogen, leading to the end of this project. More examples are mentioned but I2 summarizes the need for complementors to grow:

> *"You need to build the complete circle of life. You need to look at where the power is coming from? How do we regulate that? What about the production? What about the fuel and the vehicles?" - I2*

To achieve this alignment the companies of I1, I8, I10, I11, and I13 try to align by creating a platform called H2 Accelerate, where they want to use the opportunity to interact and learn from each other. I1 finds that no one can do this transformation by himself, and I13 is optimistic that under the right circumstances, they won't need to act alone in this field and many drivers will work on this topic. I15 thinks then it is important for the success to align with each other by putting the chicken and the egg in the same room and letting them talk to each other, a part where he wants to contribute.

4.2.4 Collaboration for Success

Perspectives on the purpose and mechanism of the collaboration are brought up by some of the interviewees. A multilateral collaboration between actors can happen through cross-complementarities, such as in the case of H2 Accelerate as mentioned by I10 and I13, where it comprises truck manufacturers and system integrators, and is aimed as a lobbying organization. The collaboration can also materialize bilaterally through a close partnership of the same players within the same industry, with an example of I1's company IVECO, a truck manufacturer, pursuing a partnership with another truck manufacturer, Nikola, to accelerate the commercialization of fuel-cell trucks till 2024. Another clear example is the case of Cellcentric between Volvo Truck & Daimler Truck for the joint venture of the fuel-cell powertrain, brought up by I13. From a complementary perspective, I8 also expresses that his company set up a new business model in collaboration with their complementor, i.e. truck manufacturers, to also accelerate the realization of hydrogen transportation by reducing the risk of their customers.

> *"It's publicly well known that we are working with a company in southern Germany to build trucks for us and we will even lease them out. So we will, together with this company, we will lease them out. If actually we buy them and we lease them out to our customers to make the access easier for our customers. And to take away some of the risks of our customers."* - I8

The company of I5 is also undertaking a collaboration with their adjacent partner in their value chain, with a truck manufacturer as well as a logistics company (customer) to get experience and to look for confirmation that a small road network, as long as it is defined and fixed, can be a starting point for operationalization of hydrogen for commercial vehicles. Another example is DB Schenker, which also collaborates with Hyzon Motors and Hylane - a leasing company, for a fixed route experience using hydrogen HDT (Hyzon, 2023).

> *"At the moment, I'm concentrating on so-called back-to-back logistic or truck applications where the truck is sleeping every day in the same space. That means truck logistics which have defined routes. They are not traveling from Kiel to Sicilia, but they travel from Duisburg to Rotterdam. And that's for me the starting points. What we're doing with Paul with the trucks, with the Mercedes 18 tonnes trucks, for last mile logistics"* - I5

I14 expresses that collaboration is essential and that companies should be willing to invest heavily in it. Regarding investment, many interviewees agree that the purpose of the collaboration is heavily related to the financial perspective. I11 highlights that collaboration is needed in order for actors to share responsibility and cost. I5 stated that collaboration is aimed to drive the hydrogen price down, especially on the network where demand is sufficient. I3 expressed that collaboration is needed to reduce the variety and quantity of technologies that would support the establishment of hydrogen infrastructure, which could drive the cost of investment. Besides that, collaboration in this ecosystem takes place in order to gain funding to support the testing phase of the hydrogen vehicle (Clean Hydrogen Partnership, 2023).

On the other hand, I6 sees collaboration as the medium or platform to transfer technology and they are confident in the know-how of hydrogen refueling and that it will help others to design their product. Lastly, I15 as an investor shares his view and expectation on how other players should collaborate in order for his company to be able to participate in the ecosystem.

> "*We put everybody around the same table. One produces hydrogen, one handles distribution, another one builds H2 stations, and a company brings hydrogen fuel-cell vehicles. We put all of this in the same entity or project, and we finance the chicken and the egg altogether. Our role is to bring together parties that cannot do it all by themselves individually and to coordinate and finance so that there is no gap in the deployment at the end"* - I15

4.3 Ecosystem Risks

The second aggregate dimension that is empirically presented in this section is the ecosystem risk, which is differentiated as interdependence risks and risks that hamper the growth. Interdependence risks impact the enablement of technology and are somewhat uncontrollable. Risks that hamper the growth are risks that might slow down the development but could be minimized by actions from the participants.

4.3.1 Interdependence Risks

Truck manufacturers seem to hesitate to announce future product volumes because some of the technologies they need are not mature enough yet, thinks I10. A risk for a technology gap is also identified by I3, who expresses the need to further improve those technologies around the storage of hydrogen. The same is noticed by I17 who sees the need for more mature components for hydrogen storage and brought up an example of hydrogen compressors, that were getting a matured product when bigger companies engaged in the development. I11 and I13, who are working for truck manufacturers, see then that not all technology and needed parts are mature yet and that the development is in an early phase. I11 is concerned that the development costs are high for a long time for truck manufacturers before they can bring a vehicle to the road, and if it does not work out the production is stopped. I13 finds that bad components could delay the whole ambitions of truck producers:

> *"[We need] good material products that have mature software, have mature Fuel cells that will not break down, etc. Because otherwise, I think if we fail, the whole*

ambition for hydrogen trucks could fail and so, or at least be delayed. Maybe not fail, but be delayed." - I13

Different technologies seem to bring different risks with them. I2, I3, I4, I5, I6, I8, I10, I13, I14, I15, I16, and I17, see challenges in the handling of either liquid, cryo-compressed or 700 bar compressed hydrogen. The boil-off of liquified hydrogen is a great challenge because of the loss that comes with it in the eyes of I3 and I4, while I8 finds it challenging to handle the low temperature and high pressure of cryo-compressed hydrogen, which leads to high costs for the storage. I4 mentions that liquified hydrogen could be useful for different situations, as an example for mass distribution and on trucks, while I5 finds that compressed gas should be used on the trucks. These different approaches could lead to operational and flexibility constraints, thinks I16, especially when not every hydrogen refueling station offers access to both types. The reduced transportation space and limitations in range when using compressed hydrogen are the uncertainties that must be solved for I16. For I13 it is unknown which is the best technology right now and one can only make assumptions about the development, which creates for him uncertainty about how to choose the best storage technology for the future. This possibility of multiple directions and solutions leads I15 to a risk to invest in something that might be obsolete in six months because the market decides to follow a different way.

The safe handling of hydrogen is then a risk that all interviewees are concerned about, directly or indirectly, depending on their previous experience and the chosen technology. I2 sees as an example the missing knowledge of truck drivers on how to handle a -250°C cold liquid as risky since he describes this as a process that is usually handled by experienced people working in an industrial area. I5 adds on this topic that special safety dresses would be needed for the refueling of liquified hydrogen. In an accident, the cold, highly flammable liquid would also spill everywhere in the opinion of I5, where I17 agrees with him that for compressed hydrogen the main danger is the high pressure. I13 states then that the safety issues between diesel and hydrogen are different and more must be done to ensure that everything is safe for the end user. Safety around the handling of hydrogen is also the highest priority for I3 and I15, where both stress the importance that inexperienced users on a bad day shouldn't be able to cause an explosion. This event could set back the whole industry. While bringing up the cases of the LPG incident in the past, I15 stresses then also the importance in the context of competition, where safety must be prioritized before making quick money, otherwise, the whole market is gone:

"First priority is to make it SAFE. There is a lot of money available, everybody is looking to get grants and get involved into hydrogen; but this is heavy industry, and energy. Like with any other energy vector, safety goes first. Any kind of energy vector or carrier will cause damage if the energy is not released properly, and this applies to hydrogen, electricity, diesel and kerosene." - I15

Another risk is the concern around high or not predictable costs for the end user. I8, I9, and I10, who all work for companies that might be interested in the distribution of hydrogen, see high prices for trucks as a risk that they can't influence but has an influence on their business when not enough are sold. I10 brings up an example of his previous experience, where prior to buying an electric car, people said it was because of the money savings, and after the purchase tends to say it's because of the environmental aspect. Most interviewees found the unpredictable price development as a risk for the customer to approve the use of the technology, when prices for hydrogen are too high they can't operate profitably. Uncertainties or missing knowledge about the possibilities to refuel the trucks are then a risk mentioned by I13, that a truck manufacturer can not control. I17 sees here the risks around the chicken-egg problem coming up, summarizing the dilemma for the customer:

> *"So nobody wants to buy the trucks because they don't have a network and people don't want to invest in the network, because they're not getting money because there are no, not enough vehicles too." - I17*

4.3.2 Hampering Growth

The second risk that becomes our findings is the risk that could slow or hinder the growth of the ecosystem. One way the respondents look at it is from the components perspective within the core business of the actors. From the mobile hydrogen storage perspective - especially on compressed gas hydrogen systems, there is a main concern about the availability of carbon fiber. I2 and I18 express that the problem is occurring now with the limited amount of production capacity, and it will be more visible once the whole business ecosystem starts to scale up. I5 & I17 also highlight the same concern, that the carbon fiber industry still has no intention to increase production capacity because of a lack of concrete commitments from other parties. Aside from the carbon fiber, I2, I5, and I17 also believe that other components that make the hydrogen storage system still need to be developed and ensured of its availability. I16 and I9 highlight a similar situation with the development of hydrogen refueling station components such as valves and gauges are not on a desired scale available today, and that is related to the technology maturity level.

> *"But once, in my opinion, is to build up a production plant of carbon fibers. You're looking at 1 or 2 billion Euro. So that's extremely expensive. Until we have a clear vision from the truck manufacturer industry, because at the moment, what are Volvo announcing? What are MAN announcing? that they want hydrogen trucks but not that they will produce them. Can I buy it if I go to Volvo? Can I buy 20 - 40 tonnes trucks? No, you don't want to send it to me. Yeah, so why increase the production of carbon fibers now for an industry in which at the moment has only done verbal commitments?"* - I5

On the other hand, supply issues on the complementor level is also the concern where I9 expresses that the problem is more toward the lack of hydrogen production. I10 highlights that not only hydrogen supplies in general, but also the competitive clean hydrogen supply is currently lacking. I10 & I16 address that while the truck price is also a driving factor, the hydrogen price is more critical. I8 as a hydrogen and HRS provider highlights that low-price electricity is required to support the production of clean hydrogen. Meanwhile, I14 as an electricity producer gives a contrasting view that electricity from renewable assets has been quite competitive with the levelized cost of energy production gradually decreasing, and adding that the problem of reducing hydrogen prices is more on the electrolyzer side. I14 also highlights that electricity capacity may not be sufficient for now, but increasing the capacity of renewable electricity can be done easily and is a minor uncertainty.

Some interviewees also brought perspectives on the technologies that will hamper the growth, with I8 highlighting that if all hydrogen technologies need to be put in the refueling station it will slow the growth of the refueling network. I9 also states the importance of increasing liquefaction capacity. I5 gives a contrasting view that the technology on infrastructure is not an issue. On the other hand, I2 is concerned about the quality of the technology development because there are many government grants available that are given to new players entering the market with no sufficient experience.

> "*One bottleneck is also the availability of the refueling technology. So if we build a refueling station, you need to have storage. You need to have compressors. You need to have coolers, dispensers, and all that stuff needs to work*" - I8

Lack of demand is also mentioned several times by the interviewees. I8 & I15 state that in general, technology is not the main issue, but demand is the most important aspect to make good business cases. I10 expresses the concern on utilization of the refueling station which comes from the potential lack of vehicle availability. I10 adds that the timeline differentiation between vehicle commercialization and infrastructure deployment will bleed the HRS players in their financial operation. Thus, I11 gives the take that as a truck manufacturer it is worth taking the risk to not only give commitment but a promise with a guarantee on how many vehicles they can bring. The demand on all levels is being mentioned, with I10 highlighting that truck manufacturers need to drive demand on the customer side otherwise the development of the whole ecosystem will not continue. I14 also mentions the customer demand from not only the transportation side but also other industries as well.

4.4 Standards within the Ecosystem

The last empirical findings section is about the industrial standards that are being developed or are in place for the fuel-cell truck ecosystem. In the thematic analysis, we distinguish between the influence of policies, the role of standards, and the complexity of technological standards for this ecosystem.

4.4.1 Influences of Policies

The current policies influence the development of the fuel-cell truck ecosystem which is confirmed to be evident from the interviewees' perspective. I4 highlighted that one government policy may have an impact on a certain region's hydrogen development or the hydrogen-related business competitiveness, such as in the case of the Inflation Reduction Act (IRA) in the U.S. and per- and poly-fluoroalkyl substances (PFAS) ban in EU. I11 has concerns about the policies or regulations, especially on the infrastructure, which are only applicable locally and not necessarily functioning in another country. I3 agreed that this slows the industry down, for example, in the US it is prohibited to transport hydrogen in the tunnel. Another example is highlighted by I10, that in between EU countries, they have different regulations on the amount of 700 bar hydrogen tanks that can be carried, making it difficult to do cross-border transportation. Policy on the restriction on truck length in EU, is seen as not preferable by I16, while in the US the players have more degree of freedom which can lead to more options to be developed.

> *"Infrastructure is really submitted to local regulations and so the way or the rules you build, even in the European Union, an infrastructure in one country is not necessarily working in the next one*" - I11

I17 highlights that for the transportation sector, the policies on renewable and CO_2 savings targets are still unclear. I16 expresses that the lack of policies and regulations for new hydrogen technologies can become a major bottleneck.

Current published incentives are viewed in a positive way by some of the interviewees. For example, I3 states that the Inflation Reduction Act (IRA) in the US is beneficial for the production of low carbon intensity hydrogen, and I6 highlights that local or regional authorities should maximize this with follow-through policies. In contrast, I5 mentions that even though big players such as oil and gas companies are already involved and funded, there are still no refueling protocols for heavy-duty vehicles that work. Some of the interviewees also have an agreement with the lack of policies on certain funding or incentives. I2, I6, I7, I8, I9, and I10 highlight that hydrogen and its technology need to be subsidized, with I10 emphasizing that the subsidy on the truck now is insufficient and cannot justify the cost of the fuel-cell itself. I6, I8, and I10 also state the importance of giving penalties or additional taxation on the use of fossil fuels in order for hydrogen fuel to be competitive and attract customers, which will drive demand. I16 expresses their concern on measuring mechanism of incentives, by pointing out that some incentives may be heavily earmarked on the specific technology types which can hinder the development of other technologies, and suggests that incentives should instead be based on outcome metrics. Even if the incentives could not be fully utilized in the beginning, I11 highlights that they will be beneficial later on.

> *"But if there's no demand generated because of regulation, if there's some kind of incentive, or if there's a penalty for combustion engines in a particular region. If that's missing, then no customer will ask"* - I10

Some of the interviewees agreed that a certain action to influence policies is required. I8 states that companies influence the policy for product design purposes, with an example of truck length to accommodate more hydrogen tanks. I17 highlights the purpose of influencing the policymaker is to reduce the number of components being used in the system. I11 expresses that some companies are pushing their core technologies to become the standard. Lastly, I7 also addresses that regardless of what policies policymakers make, companies should always be open to providing information.

4.4.2 The Role of Standards

All interviewees think that the agreement and creation of standards will have a positive influence on the stability and development of the ecosystem in its entirety. A standardized regulation on how to handle and transport hydrogen in every EU country would create a mechanism for a growing market through less insecurity and easier access, was brought up by I10. Unified regulations and safety standards would then create the opportunity to test experimental vehicles on the roads states I16. I11 highlights the importance of standards to build a functioning market that can orient on agreed terms and that it would be easier to create a scaling infrastructure that everyone can use. In the same direction goes I15 that mentions if there would be ten different standards about the storage medium from ten different parties, no one would know what infrastructure would be needed and so no one would build any infrastructure. Standardized refueling procedures will also have a positive effect, believes I5, because they create trust in the process and reduce the uncertainty about the time needed to refuel. I10 shares his experience in the development of hydrogen cars, that creating standards for the tank system together with suppliers reduced the overall purchasing cost. For the whole ecosystem, it would then also be important to clarify and define standards of what is green hydrogen and what is low carbon (blue) hydrogen, states I14. I3 and I17 are looking at the whole lifecycle of their products. Pushing standards on the capture of CO_2 is then important for I3 to offer the most efficient and sustainable way for producing hydrogen, whereas I17 thinks about the use of carbon fiber hydrogen tanks after their use on trucks, since they are not easy to recycle, with the goal that everyone follows here standards to come closer to a zero-emission goal.

How these standards should be developed, is for most interviewees clearly through the implementation of the best practice, which is decided by the market. The role of governments is then more to reinforce and evolve the standards that the market has decided on.

> *"Government should be ready to adopt them. I don't think they should design them. They should be ready and open to make them evolve based upon recommendation from industry experts and professionals. The current Hydrogen standards were mostly designed for heavy industries like refineries, but hydrogen now has new applications going beyond that, which will require updated standards to allow for safe and convenient use cases." - I15*

I8 and I16 agree on that statement and see here a responsibility of bringing experts from different industries together so that they can discuss what the best practice is, instead of the government designing any standard. I1, I3, I6, and I7 think then that the market and companies know better and are more efficient than when governments make this decision. I13 sees more the need for a push from the regulatory side towards agreements from the individual players, whereas I11 and I16 think that working together with the ISO is a good practice to establish these standards. I11 brings up that the timing to set standards is still good for the moment since the ecosystem is still developing, with the confidence that issues around standards can be solved in time. I13 thinks that not all standards will be in place by 2025 since the process needs time.

The development of standards seems then not to stop the development of new technologies and best practices, since all interviews mention that their companies are looking for ways to improve themself further.

> *"We keep on at innovation levels, staying close to all technologies. So for sure if some day we find that some other technology would come, we will switch." - I17*

The focus lies either on developing certain technologies further, as I6, I8, I14, and I16 mentioned or on developing best practices around the topic of hydrogen as mentioned by I1, I2, I5, I6, I17. I12 summarizes that they are always trying to improve and develop further and wider with different initiatives in this transition.

4.4.3 Complexity of Technological Standards

The development of standards around the different technologies was mentioned as important, but also this process needs to be done carefully. I11 mentioned that there is a need to set gates in the process of standard setting to not create too many constraints, explaining that the technology can be used in different fields, for example, the aviation industry might then have other needs as the automotive industry. The need for openness to technologies is also highlighted by I4, I6, I8, I13, and I17, which indicate that maybe one technology becomes the main one, but the other two technologies satisfy customer needs in certain niches. I13 elaborates further that the different technologies develop their own ecosystem that comes less in touch on the product side. An early pick of one technology is seen as risky by I6 because the market is still emerging:

> *"I think it's too early to say that we are still in an emerging market with everything that is very nascent and trying to pick too early would be too risky." - I6*

I10 and I11 mention that even within one technology different standards could be established, as examples were brought up for compressed hydrogen with differences between 350 bar and 700 bar storing, or different standards depending on the amount stored on the vehicle like 100 kg or 200 kg of hydrogen.

The best technology is then dependent on the product a company offers. The interviewees I6, I9, and I12 are working for companies with a value proposition around liquified hydrogen and see that as the best technology. Where I16 works at a company with a value proposition around cryo-compressed hydrogen and sees that as the best solution for an ecosystem around hydrogen products. I2, I5, and I17 are then working for companies with a value proposition around compressed hydrogen and see the most benefits for wide application in this technology. Interviewee I4 works for the German Hydrogen Council and described that it is important that the members of the council find a compromise so that everyone can agree to the proposed idea or solution. Getting a better knowledge about each technology and its applications was highlighted by I2 since the topic is complicated. Choosing one technology to start with is then important for I17, with I13 guessing it will be 700 bar compressed hydrogen.

> *“Biggest hurdle that we had is that we had 3 - 4 - 5 ways of storing hydrogen and delivering it, and it was preventing everybody from getting started.”* - I17

I11 seems to be agreeing on that and finds that at one point a decision will be made, with some technologies being already more standardized than others, but a lot of work must be done on industry level to develop the technologies further. A growing and faster development at the side of the truck manufacturer is then seen by I16, with a market readiness for the first products. I5 wants that more quick infrastructure installations are done in the beginning, without the need for pipelines, to get started faster. Both activities could lead to the first implementations of standards in the market, through their early readiness.

5. Discussion

In the fifth chapter we discuss the empirical findings in contrast to our performed literature review and interpret those results. The first section in this chapter argues if an ecosystem is in place and captures it on a map. In section two we discuss the roles within the ecosystem. We discuss the strategic elements - the view, the platform, the assets & acts - in the third section based on the answers from the participants. The interpretation of ecosystem risks is performed in section four, while section five considers the role of industry standards for the ecosystem.

5.1 Ecosystem Mapping

Understanding the ecosystem a company is part of or wants to enter influences which role the company takes and with that the ecosystem strategy and company success (Iansiti & Levien, 2004a; Adner, 2017). A better understanding of the fuel-cell truck ecosystem can be achieved by looking at its characteristics that are described in detail by the interviewees and were identified in the literature review. The first characteristic is the life-cycle of the ecosystem, based on the answers in the interviews that the market is young with rather small business activities and that not every company has yet a clearly described value proposition, indicating that the ecosystem is in between the birth and expansion stage. Not all companies and industries are then in the same stage of the life-cycle within this ecosystem. In the birth stage companies still need to develop parts of their product and value proposition (Dedehayir & Seppänen, 2015), something that can be seen especially on the site of the truck manufacturers, which announced tests of their products in the upcoming years. Other companies are then further in the development of their product, like certain HRS providers, and enter the stage of expansion, where they try to scale up and cover the largest market possible. Some companies are then between those two stages, an example are here the 700 bar compressed hydrogen tank producers, which have a sufficient product but need to look at the development of other technologies, like liquified or cryo-compressed hydrogen, which make it difficult for them to scale up fast. Overall the fuel-cell truck ecosystem needs to look closely at the development of the technology compared to the market development, if discrepancies are too high the substitution rate from the old towards the new ecosystem can be slowed down (Adner & Kapoor, 2016).

This development shows then the need for a second characteristic, the complementors within an ecosystem. In the fuel-cell truck ecosystem, many complementary relationships can be found, but the description of these depends on the position of the actor within the ecosystem. Truck manufacturers see the most important complementor in the HRS providers (and the other way around). Other examples of complementors that have been mentioned were hydrogen producers, HSS producers, or electrolyzer producers. If these are complementors or outside the ecosystem, depends on the relationship with other companies since they also could be suppliers or customers for a company, based on their position. The need for co-evolution was often expressed in the wish to scale up the ecosystem, which could only happen in combination with complementors (Moore, 1993). HSS providers and truck manufacturers mentioned the need for higher volumes of carbon fiber if they should choose 700 bar compressed hydrogen as a solution for their product. HRS providers had the wish for more fuel-cell powered truck availability since there are not enough on the road today to make a profit with refueling stations. A point that is mentioned by truck manufacturers is the opposite, there are not enough refueling stations available, so customers won't buy fuel-cell powered trucks. These two actors are then in a supermodular complementary relationship (Jacobides et al., 2018) - more fuel cell trucks add more value to hydrogen refueling stations and the other way around. A problem here seems to be at which point this supermodular complement is effective. Since a truck moves around on different routes to different places, a minimum network needs to be available to refuel the truck. On the other hand, there is a need for a minimum amount of trucks that will refuel at a station every day to be able to make a profit with it. In the beginning stage of this ecosystem, there is not enough availability of both, something that also the interviewed participants see as a problem, and propose a local development. This would lead to a local supermodular complementary situation where certain regions are able to start with a lower minimum of trucks and HRSs than an international system would need.

To achieve this local development of the ecosystem another characteristic of ecosystems is important, the alignment of a loose network of companies. They need to work together on this local level and align their activities from hydrogen production, over hydrogen refueling stations, and fuel-cell truck availability, to customers who are active in this area. This leads them to value co-creation (Rong et al., 2015) because each actor by himself can't create value since they need the specific components from other players, a hydrogen producer doesn't build trucks, as also a truck manufacturer doesn't produce hydrogen. The modular architecture of this local ecosystem allows a certain flexibility through standardized interfaces. Each truck, independent from the manufacturer, will be able to refuel at the refueling station, as also every hydrogen producer can deliver his product to the refueling stations when the connection points are standardized. The existence of all these characteristics shows that the ecosystem around fuel-cell trucks is an active ecosystem in the ongoing development and takes the "ecosystem-as-structure" perspective (Adner, 2017). Because the "ecosystem-as-structure" approach ends with actors that need to be aligned, it can only be explained by depicting the actors' position within the ecosystem. The depiction of the business ecosystems as shown in Figure 8 on the next page is formulated based on the literature review and on the outcome of the empirical findings.

As Moore (1996) defines that the model of the ecosystem starts from the primary entities, our mapping in Figure 8 takes the perspective of truck manufacturers in the center, strengthened by the findings that they are expected by the others to drive the development and take the lead. The truck manufacturers, outlined in red, are the center of the first level, which is the core business of the ecosystem. According to Adner & Kapoor (2010), the components in the green boxes are grouped by their relation to the focal firm, here the truck manufacturer; thus, transactional inputs to the value proposition come from the hydrogen storage systems (HSS) providers, fuel-cell providers, and other components providers, which are then also located in the first level of the core business in the ecosystem. Priority is directed towards the HSS provider because it is related to the hydrogen type to use, and our findings show that no truck manufacturer wants to produce their own HSS. The technology type of on-board hydrogen storage is outlined in black, to show that it is not an entity but an important element because HSS providers specialize only in one type of technology. Solid arrows show the input or output from a certain entity towards another.

The extended enterprise in the blue area shows further involvement of ecosystem stakeholders in a slighter loose relationship with the truck manufacturers (Moore, 1996), and we defined these participants as the secondary entities (blue boxes). As emphasized from the findings, carbon fiber producer is the main input to the core business that complements the components path of the truck manufacturers. Based on the output from the primary entities, hydrogen refueling station (HRS) providers are the complementors that form the value proposition for the customers and its components value chain stretches from the hydrogen (H_2) providers to the HRS providers themselves. Hydrogen infrastructures and storage in mass application, impact the HRS based on the type of hydrogen they adopt and handle. Electrolyzers and other conversion techniques for hydrogen are also the key activities in this complementors path because they generate different opportunities for the HRS. The other complementors, end-use industries such as passenger cars, aviation, and shipping, are specified in the findings as they can become promising markets for fuel-cell, HRS, and HSS providers. Lastly, the organizations who are responsible for regulating the standards, are considered as the last influential entity in this sphere. In Figure 8 below, they are outlined with a dashed line because their output influences the whole core business and extended field, and they get input as well from these entities.

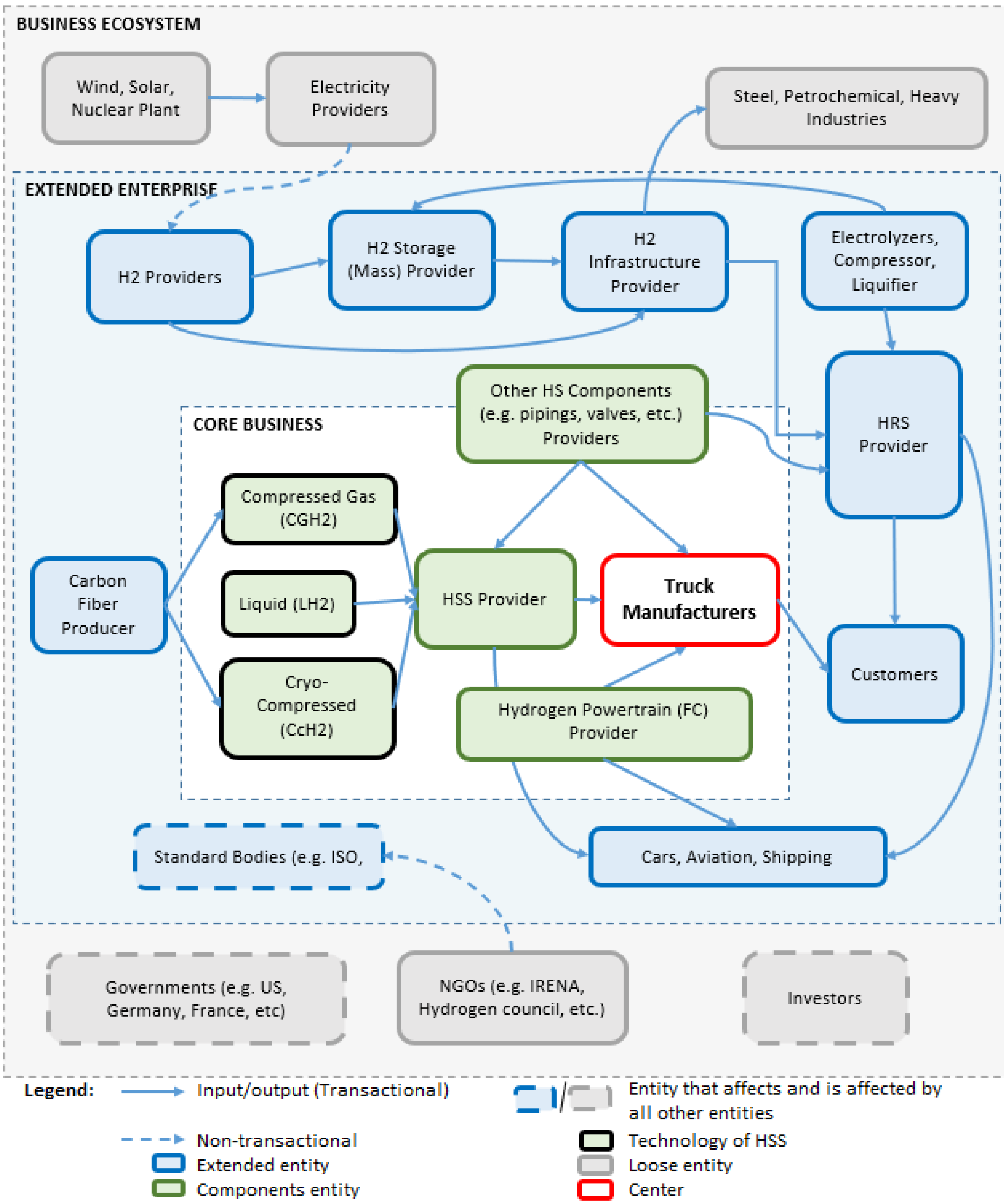

Figure 8. Map of the fuel-cell truck ecosystem

The outermost field in the gray area, that is the business ecosystem sphere, completes the context of our mapping with the loose network of entities that may be relevant in certain situations (Moore, 1996). Renewable electricity producer is specified from the findings in the context of modular complementarities, in this case, it's the cost structure for the hydrogen. Other upstream industries are concluded to have influence as outlets of the use of hydrogen, indirectly contributing to the cost and production of hydrogen. Governments are located at this level because of various regulations in certain countries or regions, which may or may not influence the development of the total ecosystem. Investors are also similar to the governments, as funding provision and involvement could contribute to the development of the ecosystem. Both governments and investors are drawn in a dashed outline because their scope of influence could affect all entities within the ecosystem.

In summary, Figure 8 presents only a snapshot and will change with the further expansion of the ecosystem. An example, therefore, is that important participants in a further developed ecosystem are not mentioned, like truck workshops, truck dealers, large-scale hydrogen transporters, or hydrogen trade unions, since they are considered not important in this early stage.

5.2 Roles Identification

As mentioned before, the role of a company is influenced by the level of complexity in the relationship and level of innovation between the complementors. Aligned with Adner (2022), many individuals in our research envision their companies as a leader in their own core business field, but not necessarily being a leader in the ecosystem as a whole. Related to the context of the fuel-cell truck ecosystem, it's evident that truck manufacturers called themselves a company that wants to drive change in the ecosystem, but do not necessarily want to be the leader. Other actors in the ecosystem trust and wish truck manufacturers to take the lead, aligned with the understanding that an actor should pick the right leader in the ecosystem (Iansiti & Levien, 2004a). It also means that other actors provide their acceptance to have truck manufacturers organize the activities within the ecosystem. As a perceived leader in the hydrogen ecosystem, one distinctive thing is expected from the truck manufacturers, i.e., related to vehicle availability. Truck manufacturers are expected to give commitment in a concrete way to give more confidence for other players to participate more in the development of the ecosystem. Additionally, truck manufacturers are expected to decide on the hydrogen storage system used. However, they are also being cautious in determining their positioning, assumingly because the development in the complementors and the technology itself is not in full clarity. This confirms what Adner & Kapoor (2010) expressed when complementaries are not fully developed yet, it is less preferable for a company to position itself as a leader.

It can be said that there is no clear leader in place in the ecosystem. In this phase, truck manufacturers didn’t take over the value domination, leaving room for niche creation. Whether it is intended or unintended, they don’t limit the participants and allow new niches, such as I7 & I16, to enter the ecosystem. As I2 stated that everyone is pointing the responsibility to each other, it is a sign that current authorization on the ecosystem governance is not fully held by a leader or keystone company, as confirmed by Adner (2017) that the ecosystem can be leaderless. Truck manufacturers also can be perceived to give the chance for certain product values to be developed to the complementors, as in the case of the HSS technologies, akin to what Iansiti & Levien (2004a) pointed out. That being said, truck manufacturers contribute to the productivity and robustness of the ecosystem, creating opportunities for others by increasing the number of participants and improving the survival rates of the ecosystem.

The motivation of other actors to participate in the ecosystem and to try to grab chunks of share is beneficial since this behavior contributes to the development of the emerging ecosystem. Looking from the perspective of the focal firm, i.e. truck manufacturers, other actors within the core business of the ecosystem identified themselves as niches (Ibid.). As evident from I2, I5, I9, I12, I16, I17, and I18, as HSS providers, they perceive the market for transport applications as an opportunity. I15 expressed that this ecosystem is a big market that has enough to offer everyone. Almost all of the HSS providers have the tendency to encourage their specialized technologies to be used on the truck while preparing themselves to be flexible with what the chosen technology would be. That being said, niches are also aware that truck manufacturers cannot fully determine the orientation for the development yet, and thus, they open for opportunities outside of their core businesses. It proves the need for niches to keep evolving (Iansiti & Levien, 2004a). Examples are I2 and I5, which provide hydrogen storage in other forms and applications and have started to build expertise also in hydrogen refueling infrastructure, and also I18 serves their products in other end-use applications such as buses. This means that niches, through their activity identification, keep their competitiveness with them, which leaves less room for keystones to acquire them and maintain the productivity of the ecosystem.

The other actors who are placed in the extended business field, i.e. the complementors, are slightly different in their role identification. With their current perception of the truck manufacturers and the chicken-egg problem, HRS providers see themselves as niches but also in some way consider themselves as being a first mover - to a certain extent. HRS providers such as I8 see that acquiring other companies in their value chain would be beneficial to them because they want to capture more value. However, this role may create potential issues for the ecosystem as it extracts the most value in the value chain and does not directly contribute to the robustness of the ecosystem (Iansiti & Levien, 2004a). They also have the same position as HSS providers, in that they see the other end-use of applications as other business opportunities, not relying only on the truck manufacturers for the transportation end-use.

5.3 Ecosystem Strategy

In this chapter we discuss the chosen strategic framework which we propose in the literature review, mainly based on Hagel et al. (2008) shaping strategy. The three sections consider each element - the view, the platform, the assets & acts - deeper in the context of the answers of the interviewees, the literature review, and our interpretation. Overall it is important to find agreements and contrasts to understand a possible strategic framework better since an ecosystem strategy should create a win-win situation for all participants (Moore, 1996; Adner, 2022; Jacobides et al., 2018).

5.3.1 The View

The view is the first of three elements for a successful ecosystem strategy mentioned by Hagel et. al. (2008). The view is then company specific the more detailed it gets but contains a clear ecosystem perspective in its general vision (Hagel et al., 2008). The only point that then all interviewees seem to share was the belief in a growing market around the hydrogen ecosystem in its total, which also could be seen as the basis to act or enter this ecosystem as a business. There was also an agreement about the need to grow and/or scale up the production of certain products, but there are great differences on who needs to scale up first and at which time, depending on the company and its position in the ecosystem. An example, therefore, is the previously mentioned chicken-egg problem, where the truck manufacturer sees the need for more hydrogen refueling stations, while HRS providers want a higher availability of fuel cell trucks. But not everyone sees the impulses for growth coming only from the inside of the fuel-cell truck ecosystem. Interviewee I3 thought, opening the view toward industries that already use hydrogen, heavy industries like steel or petrochemicals, could be a good driver for growth if the change from gray to green or blue hydrogen would start. Other participants that have a more general approach too, legitimize this view by agreeing to the potential of industries outside of the core fuel-cell truck ecosystem. I5 goes also in that direction but sees here a combination with other forms of transportation like shipping and aviation, or buses. Different off-takers and industries could generate a quicker baseline of hydrogen consumption, which secures investment in the infrastructure and make it sooner available. Otherwise, all players have to wait for truck manufacturers to produce and sell enough trucks to get their investment profitable. These views are supported by other HRS providers and also by truck manufacturers, showing that the view does not necessarily need to concentrate on only one customer, but that synergies can also create acceptance from different players within the ecosystem.

Another point that was mentioned as important by interviewees is alignment about the timeframe, as seen by Jacobides et al. (2018). This is important to make investments at the right time and create opportunities and security for other actors in the ecosystem. I15 stated then as an example the importance of a time frame issued by truck manufacturers when they want to bring out the trucks on the market and in which quantity, which is then also supported by I6, I7, I9, and I10. This connects to the previous statement that HRS providers but also everyone else in the ecosystem, need a certain baseline of utility to create profits out of their investment. For I10 as an example, it wouldn’t make sense then to build a larger amount of refueling stations in 2024, when there are no trucks in larger quantities available for logistics companies till 2027, connecting Adner & Kapoor’s (2010) findings that being a first mover is only good when the complementaries are ready too. These kinds of announcements about the availability of complementary products need to be published soon enough, since the lead time for components of refueling stations can be more than one year, excluding other parameters such as planning and construction time. Creating stability for the ecosystem through a clear view of what steps are next and when they are going to happen can be crucial for the growth of the ecosystem according to Thomas et al. (2021). The better the up-scaling of all participants is planned, the better the growth of the ecosystem can be pursued, allowing the customer to change from the old ecosystem towards the new one.

This leads then to the next important point mentioned by Hagel et al. (2008) in the strategic ecosystem view of a company, the communication towards collaboration and complementation, with presenting a bigger picture and recognizing other players. This was then expressed by interviewees as the need that certain industries must start to scale up first because they see a bottleneck in this industry, but also the need for leadership in important topics. The view of a leader should give a direction and orientation for the other actors, especially niche actors that are more dependent on a keystone player. More than one keystone that needs to take action in the ecosystem can be identified through the interviews. On the one hand truck manufacturers need to take over the aligning process and state what they need, on the other hand, HRS providers need to contribute with a clear view on their ambitions to build a network. One topic that is still in question and of high importance is the kind of technology that should be used. Three options are available right now for the leaders to choose from, 700 bar compressed hydrogen, liquified hydrogen, and cryo-compressed hydrogen. Each of these technologies has its pros and cons, but a decision for the nearer future should be expressed in the view to give other actors the possibility to align towards that view, or reject this position and offer alternatives in the form of new niches. Each technology has its supporters, which was made visible through the interviews, making it hard to align all players behind one view of a company and maybe generate the need for compromises and alignment between several leading key players.

A continuous update on the view seems to be important, based on either new knowledge or other developments that are happening in the ecosystem, which can be referred to the described life-cycle by Moore (1993). Since the goal of the view is to focus participants and show them opportunities (Hagel et al., 2008), a constant exchange between participants is needed. Especially safety topics should then be addressed and expressed in the view since there is a fear that one fatal accident could bring the ecosystem down, or at least slow its growth. Another uncertainty mentioned is the costs of the transformation, with higher costs for all products compared to products in other ecosystems that are actually in use like ICE trucks and diesel as a fuel. Every participant had different expectations about what is a good price and at which price the new ecosystem can contest the old one. A clear view and timeline about the price development and expectations could gather more participants in the ecosystem with the collective goal to achieve these prices and be able to expand and establish the ecosystem.

While expressing the previously mentioned points in the view of every participant should have a positive effect on the ecosystem, according to the shaping strategy by Hagel et al. (2008), the reality looks different. Most companies don’t present a clear view of the ecosystem based on the response of the interviewees which brought up several points as missing when observing other participants. It is additionally important to inform about the views of the different actors in the ecosystem, something that some companies might also not do (not necessarily the interviewees). Also not every interviewee, or respective the company he works for, would agree on how this element needs to be designed. While I13 mentioned that there is a fear of giving away too much sensitive information to competitors, I17 found that doing more on this topic will have a positive influence. This is a decision that the actors need to decide by themselves through defining which information is helpful for complementors and which information could be negative for the upcoming competition. An aspect that should be considered for this process is that according to Adner & Kapoor (2010), the sufficient development of needed complementors is incremental to develop a lead over competitors through superior components of the own value proposition. Summarized, all information that helps to let the number of participants in the ecosystem and complementors grow should be shared, while information about the components for a superior value proposition should be kept secret.

5.3.2 The Platform

The second element of a successful ecosystem strategy is the platform, which helps through clearly defined standards and processes to organize and support activities from participants (Hagel et al., 2008). Different platform activities are mentioned by interviewees, which could indicate that the organization of such platforms is a natural process between actors in the ecosystem. Still, all participants expressed in a way the wish or need for more such activities, as example collaboration. One form of collaboration that was mentioned between different actors is the creation of a joint venture - Cellcentric. In this joint-venture two truck manufacturers put resources together to produce fuel-cells for trucks. Even though they are competing in the market of ICE trucks, the leverage factor of this platform to reduce risk and do more with less investment is seen as a possible success factor for both companies in this new ecosystem. Another platform that was mentioned is H2-Accelerate, which includes the participation of companies from I1, I8, I10, I11, and I13. The goal is here to offer a better organization and tuning between different complementors, which is shown in the mixed group of participants in this platform. On a platform with multiple participants, the risks can then be minimized, since in this concrete example, providers of refueling stations and trucks work together to bring these important complements in the right market together. In such an early stage of ecosystem development, platforms offer great opportunities to standardize interfaces. In H2-Accelerate several truck manufacturers and HRS providers work together, leading to the need for a refueling concept that every truck can be refueled at every station. I8 also tries to offer a platform for its customers by bringing two components together. In this business model, the company buys fuel-cell trucks from a manufacturer and leases them to logistic companies. They will use these trucks on previously agreed routes, where the company of I8 offers the possibility to refuel the truck with hydrogen, reducing the cost and risk of buying trucks while ensuring utilization for the HRS. With a platform like this, a company can get direct feedback and build experience in a real-world case, while sharing the gathered knowledge with other participants. Interviewee I5 even tries to build a platform with customers outside of the ecosystem, by combining the needs of shipping companies for hydrogen refueling stations with the availability of these stations for trucks too, an approach that is mentioned by other interviewees like I3 or I15 in the combination of heavy industries.

These examples of platforms that were mentioned by the interviewees have several important effects on the ecosystem. One of the most important effects seems to be the solving of a problem that most participants saw as critical, the question after the chicken and the egg - respectively the question of who comes first, hydrogen refueling stations or fuel-cell trucks. Platforms with several different participants offer here a great chance to align the two important keystones and work together on solutions for the end customers. This is what I15 wished for, to put the chicken and the egg in one room and let them talk to each other. Another example of this kind was mentioned by interviewee I11, who expressed the need to set the board first, before playing the game. This could be interpreted as the need of building first a market for all players before competition around this market should start, following the description of Adner & Kapoor (2010) by building complements first. In a sense both those analogies, the chicken-egg problem and setting the board, can be represented by a platform in the real world, which companies started to do in different ways. Something that could be criticized about these initiatives for platforms is that mainly large companies are participating. Bringing more participants into those platforms, especially niche players could strengthen the health of the ecosystem. Leveraging their opportunities would increase the survival rate and with that robustness (Iansiti & Levien, 2004a), this results in a more attractive ecosystem to be a leader in and a higher resistance towards change and disruption from other ecosystems.

While the previously mentioned examples of platforms are then more between different companies, interviews pointed out the importance of governments and standard-setting organizations too. With this ecosystem being in an early stage between birth and expansion, the technological development is not finished. The three forms of deployment of hydrogen, 700 bar compressed, liquified, and cryo-compressed, can still have a great influence on the further development of the ecosystem. Most participants saw here the need to develop a standard that will be used as best practice by all actors. To do so governments are seen as the best solution to push and adopt those standards for everyone in the whole ecosystem and in all countries, respectively markets. For the process of interface standardization, a platform is already established, i.e. the ISO. Several interviewees said that their company is participating in this organization to create widely accepted standards that are essential, like the nozzle for the refueling process of fuel-cell trucks. Technical questions about the standardization of interfaces might then be answered through that organization, but which technology to use will not be answered. Actors that want to influence the development of these technologies need to build platforms (and views) to gather participants and a certain mass around that technology. These platforms have the potential to reduce the risk and cost for every participant by putting forces together for the challenges of each technology while sharing the risk of development and uncertainty. Based on the answers from the interviews, there is only a limited willingness to build platforms around the technologies that already exist. As discussed before most participants saw the need for one best practice technology, but yet it is not defined which technology this could be. The development of more than one technology towards the needed maturity is legitimate in the view of, as an example I4, which sees a place for use for every technology and hydrogen type. This could indicate that some platforms that might start in this ecosystem move out of it, depending on further development. An example could be the use of liquified hydrogen, which is seen by I5 as better suitable for aviation applications than on trucks, creating new niches and pushing out certain parts of the ecosystem as described by Iansiti & Levien (2004a). Still, the start of the development of a platform around the technology and use of liquid hydrogen could be in the ecosystem around trucks. Moving on is then a decision that must be made by its participants.

Achieving effective and efficient platforms, which allow the sharing of costs and risk, is something that was communicated by all interviewees, the most concrete examples brought up, were around building these on a local level. Developing infrastructure in this early stage of the ecosystem seems for many participants too risky, either because the utilization of the HRS would be too low, or because trucks could not be used in a proper way since there is no HRS nearby. Creating platforms on a local level is a proposal that different players could agree on, to ensure that taken investments are fruitful, by delivering all needed parts of the ecosystem that the end customer needs in one region. The downside here is that the technology of hydrogen is mainly considered for long-range heavy-duty trucks, which usually do not drive shorter ranges, and directly several regions need to be connected in the beginning. Bringing in as many parties as possible, keystones and niche players, to solve these problems by aligning them is essential for the success of the platform, but also the ecosystem (Adner, 2017; Jacobides et al., 2018). The regional built systems, that contain all needed parts can be connected with each other over time, an approach that the EU already follows, with initiatives and incentives to build refueling stations for fuel-cell trucks along all big motorways and transportation routes. Participants that are taking part on such platforms can then generate a benefit by gathering experience with the new technologies and learning from challenges that come up during this process.

5.3.3 The Assets and Acts

Resolving concerns of participants inside, as also possible participants outside of the ecosystem, and proving the ability for success through assets and acts of a company, is the third and last element of a successful shaping strategy (Hagel et al., 2008). The goals that are set in the first element, the view, need to be transformed towards reality in this element. This is something that does not always happen and can create mistrust between different actors for example, about the seriosity or willingness of reaching a set goal. Interviewee I5 brought up the example of announcements done by certain truck manufacturers with the willingness of producing fuel-cell trucks, but the lack of availability of exactly these trucks. In combination with no announcement from these manufacturers to build up a manufacturing plant for these trucks, the willingness and ability to actually reach the goal of providing the needed amount of fuel-cell trucks is questionable. I5 sees this lack of an act towards the up-scaling of production facilities as a signal for other actors within and outside of the ecosystem to hold back investments in their production capabilities. The example from I5 was that carbon fiber producers are not interested in building a new plant for more than €1 billion if others do not make the same act and demand growth for carbon fiber is predictable. A view that was further developed into an act is the example of H2-Accelerate, where several different players come together to provide a platform. The founding of this platform needs now to be followed by activities that show the ability and willingness of these players to build local ecosystems. Sending out a positive signal to all other actors, especially niche players, that this ecosystem has the potential to reach the next stage in the life-cycle.

An important role is taken by governments, they need to provide incentives to stimulate such developments and make it attractive for large companies to invest in this early stage. This was pointed out by all interviewees. Showing that players that might not be in the center of the ecosystem, are still playing an important role, with acts they undertake to support the views of players inside the ecosystem. The need for such an act comes from the high cost of the low quantities that are available in the birth and expansion stage of the ecosystem. Most interviewees agree that overcoming this early stage and reaching a phase where prices can reach a level that is comparable with the old ICE ecosystem is crucial for the survival of the fuel-cell truck ecosystem. But governments can and do more than only provide financial stimulation according to our findings. Actual policies and upcoming policies have a high influence on the possibilities for customers and producers to fully utilize their products. One example that was mentioned here by several interviewees is that trucks with hydrogen on board are not allowed to drive through tunnels in many countries. If regulations like this are not updated by the governments the demand will not grow, since a truck that can't drive through a tunnel is less attractive for a logistics company to purchase. A different industry that could be affected by an upcoming EU policy, is the manufacturers of electrolyzers. The ban on PFAS chemicals would influence the production and availability of PEM-electrolyzers, since they use these chemicals, but can't be sold or produced anymore in the EU (Hydrogen Europe, 2023). Acts of governments have a high-level influence on activities in the ecosystem, showing their importance for all players that are part of the ecosystem.

Other important acts that are demanded by interviewees are the construction of an infrastructure for the transportation of hydrogen, an increase in the production of green hydrogen, and a growing demand from logistic companies. These demands can then be seen as wishes, which can be interpreted as the wish that someone else should do the first step, leading us back to the previously mentioned chicken-egg problem. Doing such an act would create acceptance from other participants and motivate them to follow this example. In such cases, larger companies have a benefit. They can use assets, like an existing brand or production capacity, that smaller companies don't have, generating a higher credibility for the ability to reach such a goal. Signing long-term contracts for example the supply of a component with a smaller company, would be a strong act from a leading company because they have the assets to fulfill such a contract. On the other side, the smaller company can strengthen their capabilities, through the security of having a minimum off take for a longer period.

Assets are an important factor for a company to be a leader and a shaper of the ecosystem. The need for leadership from a keystone player was mentioned by different interviewees, showing a lack of leadership from players with enough assets to manifest that leadership. Large truck manufacturers could be an example of possible leaders since they have the assets that are needed for that role. Different interviewees from companies that are active as HRS or HSS providers, wait for a decision regarding the type of hydrogen on the truck manufacturers. They are seen as the keystone player in such a decision since their trucks must be able to use the products offered by these ecosystem players. With that comes the responsibility for truck manufacturers to leverage their assets for smaller niche companies. Otherwise, a domination of the ecosystem could happen, which in the long term could hamper the growth and development of the dominated ecosystem

(Iansiti & Levien, 2004a). Assets and acts are powerful tools, with other participants observing those carefully before they decide to follow.

5.4 Ecosystem Risks

Defining a strategic framework should also consider risks because risks within the ecosystem can hamper or slow down the value materialization (Adner, 2006). As the ecosystem is argued in between the birth and expansion stages, the enabling factor becomes important for the ecosystem to close the stage and move on to the next one. The risk that comes from technological development is perceived by the interviewees as the main enabler for challenges, and it differs depending on the firm's relative position in the ecosystem. Truck manufacturers become the most vocal in sounding their concern about lagging technological development for the HSS because there is not a single technology ready on the market. In terms of maturity level, compressed gaseous hydrogen is the most mature technology compared to the rest, which still requires more development and standardization effort. This is confirmed by I9, I10, and also by the research done by PHRYDE (2021). This different specialization of technology owned by different actors also determines their action to influence the standardization and policies, which creates risk for other companies if such regulation leans toward one technology (Pierce, 2008). Technology development can influence the niche players in the ecosystem heavily since they tend to develop and specialize in one of the three technologies. This forces them to adapt to the progressing development or find and create new niches in other ecosystems.

Not only the HSS is affected, but the different maturity level also impacts the technological development of the HRS - which is also determined as a complement risk. The interfaces and other components, such as the development of nozzles in the fuel dispenser and valves on the tank, both contribute to the complement risk, as mentioned by I16 who specializes in the cryo-compressed. Interestingly, I5, I17, and I18 see that technology maturity on the compressed hydrogen for the HSS and HRS is no longer a risk. This is also strengthened by the input from the system integrator and HRS providers such as I3 and I5 who see the opportunity of compressed hydrogen to be used in the distribution as the most viable option. The remaining challenges and risks around 700bar hydrogen are only related to the integration on the truck, leaving truck manufacturers to manage those initiative risks (Adner, 2006). Additionally, the different characteristics that each type of hydrogen possesses also provide technological development risks and make it difficult for actors to decide which technology to be invested in, not only in the HRS but also in the HSS. Compressed hydrogen has limitations on space restriction on the truck and has a low energy density, liquid hydrogen has boil-off properties that needed to take care of, and cryo-compressed low temperature and high pressure are difficult to handle. Bringing all technologies into every HRS creates greater complexity and investments, which will end up slowing down the scaling-up process. On the contrary, having all technologies in one HRS will result in greater flexibility for different applications.

It can be argued that the risk of safety and the missing knowledge to develop and implement certain technologies are part of technological development risks. In general, hydrogen is a dangerous substance to handle; thus, concern about hydrogen leakage becomes a key issue. Different types of hydrogen have different degrees of safety risk. This creates concerns on the side of the customer regarding the safe use of these technologies. Interestingly, HSS providers sound their confidence related to their own specialized HSS, stating that safety is not a critical issue. As I13 also confirmed that a lot of testing needs to be done, it means that HSS, when being assembled into the trucks, creates more safety risk than when it is a stand-alone system. Safety correlates to other technical risks, i.e., missing knowledge, which takes place in two areas. First, at the research level, it is important to have more experts at the table to scale up the technology development. Second, for the end users or customers, it is important for actors to educate the operators because safety risks related to the handling of hydrogen are high and difficult to control on the operational level, regardless of what type the hydrogen storage is used for. Therefore, safety risks need to be resolved in the early stages. This could determine if the ecosystem's expansion stage will be reached and stabilize the development. Otherwise, the declination of the ecosystem can start because one critical incident that impacts the customers could spread to all ecosystem participants. Reflection on the historical case of the LPG passenger car explosion incident was brought up by one of the interviewees as an example to prove that a new business can be cut-off instantly when it is no longer considered safe for the customers. That being the case, the technology development risk is one of the interdependence risks to the enabler of the value materialization (Adner, 2006), which takes time to develop and there is a possibility that it cannot be fully managed. This means some sort of mechanisms such as platforms and standards are needed to increase customer security and for ecosystem development.

The second dimension of risks is related to supply and demand. Lack of supplies can be perceived from the components and complement perspective. As mentioned in the assets and acts section, carbon fiber availability is the main driver to scaling up the business, especially for compressed gas hydrogen systems. This means a lack of carbon fiber is a main risk for the system and is independently controlled only by a handful of carbon fiber producers. On the complementor side, hydrogen production price is the main concern and it is driven by the electricity price and electrolyzer cost. However, the risk on the electricity price seems to be more manageable because renewable sources are out there and the production cost of hydrogen is gradually decreasing. The electricity producers, which usually have big assets, can increase their production capacity through on-time investment according to the market necessity. Electrolyzer costs, on the other hand, are directly related to the demand from hydrogen users, for which a chained risk is formed. During our research the utilization of HRS is still low, coming from the low availability of fuel-cell trucks and with that a low amount of end-users. This results in a low demand for hydrogen, meaning only a few electrolyzers are needed which can not benefit from economy of scales, sustaining high prices for these electrolyzers. The lower adoption rate of HRS because of the low utilization rate explains the integration risks and can delay the development of the ecosystem (Adner, 2006). As these risks hamper growth, the unpredictable cost for the customers becomes another interdependence risk. Customer preference and approval are impacted by the cost and are considered difficult to manage because the root of the cause is spreading along the value chain.

5.5 Ecosystem Standards

Standards have been previously mentioned in the discussion, showing their importance for the strategy regarding view, platform, assets & acts, and risks. Summarized standards show positive effects on the stability of the ecosystem (Grant, 2018), which affects the strategic elements too, based on the answers from the interviews. All participants saw a development towards more standards as positive, regardless if they are “de jure” or “de facto” standards. What must be considered is that the participants believed that their concept of a best practice will become the standard. This is not necessarily true, since in the process of standardization many compromises must be made and different views and opinions need to be considered, leading to a standard that is accepted by a wide range of players. The different types of hydrogen are a good example of this kind of perception. I6, I9, and I12 work for companies with strong experience in liquified gasses and hydrogen, believing that the technology around it is the best for the ecosystem. I16 has the same beliefs around the concept of cryo-compressed hydrogen, while I5, I17, and I18 share these beliefs but see 700 bar compressed hydrogen as the best solution for the ecosystem. All of the interviewees are right based on their perspective on the ecosystem, but which technology is used for what area and standard must be considered by a wider range of participants. Achieving agreements in the standardization process is important and needs time, so that everyone can voice his concerns, especially in the early phases of the ecosystem these decisions need to be made well-founded. Otherwise, the chosen standards might not be accepted by the market, leading to a new phase of uncertainty.

Again an important role plays governments through their strong assets and credibility in the standardization process. This can have a positive influence on the strategy of companies and the whole ecosystem, but also a negative one. Interviewees described that governments should ratify standards fast in the form of policies, as soon as the market has decided on them, without them interacting too much in that process. Since most of our interviewed participants are working for a company, they see the decision-making sovereignty by the market, with governments just approving them. The power of the governments and organizations like the EU is to unify these standards in the individual market of each country, easing access for companies and creating a ‘bandwagon’ effect, as described by Funk & Methe (2001). Additionally, they can speed up the process of standard adoption and market growth through incentives, as the U.S. government does with IRA to reduce the price for hydrogen with fewer CO_2 emissions. Not only incentives are a viable way to push standards and make a change more attractive, but increasing costs for CO_2 emissions were also mentioned by the interviewees as a viable tool. Negative influences towards the development of standards can have existing or upcoming policies. We mentioned these examples already more than once, in some countries, it is questionable if hydrogen can become the new standard as truck fuel as long as there are laws that forbid the transportation of hydrogen on the road. The other example is a proposed law against PFAS chemicals, which are used in PEM-electrolyzers, a standardized electrolyzer to produce hydrogen (Hydrogen Europe, 2023).

Ecosystem leaders can influence the development of standards too, for the same reason as governments, they have valuable assets to strengthen their claims. Many of our interviewees found the opinion of truck manufacturers important when it comes to the decision of which technology should be chosen. But they also need to be cautious about such decisions, since choosing the wrong technology could influence their ability to compete against other keystones if their competitor chooses a different technology with a higher adoption rate. The goals of setting standards and creating platforms can be similar, with both wanting to get as many followers as possible (Teece, 2007). This creates stability since a high number of adopters reinforce the view and assets & acts done by the company. An ecosystem strategy with many participants is attractive for investors to join, allowing reinforcement of the previous elements and increasing credibility for further actions undertaken. Attention must then be paid to the further development of internal capabilities, with I4, I6, I8, I13, and I17 seeing a place for all technologies, which could later on influence the dominance of one technology and change the market. Staying open to all possibilities while developing standardized interfaces can be the best strategy for a keystone player to ensure long-term leadership in the ecosystem and create a win-win situation for all participants in a healthy ecosystem.

6. Conclusion

In the sixth chapter we conclude the outcome of the previous chapter and our performed research. First, we answer both research questions, by a summarized structure of the ecosystem and the presentation of a framework. Secondly, the theoretical and practical implications of our research are discussed. Lastly, we identify the limitations of our research and provide thoughts for further research on this topic.

6.1 Answer Research Question #1

The construction of business ecosystems through mapping and identifying the roles provides a foundation to understand how every actor is involved in the fuel-cell truck ecosystem. The aim of the first research question - ***“How is the fuel-cell truck ecosystem structured?”*** - is to understand the fuel-cell truck ecosystem better, which we concluded in the following answer:

Through our research, we could identify an ecosystem with a core value proposition of fuel-cell powered trucks. This moves truck manufacturers to the center together with their closest value chain. A complementary value chain could be found in the extended ecosystem around the production and distribution of hydrogen. In the outermost layer governments and investors interfere with all participants, while related industries around hydrogen, like the steel and power industry, can positively influence the development of the fuel-cell truck ecosystem. The roles in the system are not clearly defined and distributed, with different actors needing to find their place in the ecosystem. Collaboration and connections between the elements of the ecosystem are weak and need to be strengthened for further development.

The ecosystem is in between the birth and the expansion stage, coming from the different market readiness of the offered products, with all characteristics described in the literature review being existent. Through the early stage of the ecosystem, coevolution is highly important to deliver the value proposition of a utilizable fuel-cell truck to the end customer. The complementors are organized in a loose network, where the most important complements, availability of HRS and fuel-cell trucks, are performed by different participants. This allows a modular architecture with keystone and niche players, to react to changes inside and outside of the ecosystem, while complementaries offer value co-creation for participants, as an example through new technologies or lower prices coming from scaling up production capacities.

However, every participant perceives other actors as key drivers from the lens of their position within the ecosystem. The position of the interviewees in the ecosystem is determined through the combination of the literature review and performed interviews, which leads us to the map displayed in Figure 8. It was found that participants regard other actors that operate close to their value chain as key drivers in the development. Understanding the key drivers also leads actors to discern risks that could inhibit their value materialization and hamper the growth of the ecosystem. Most actors believe that they have control over the risks that directly adhere to their capabilities, but spill-over risks to other participants are dicey, suggesting that alignment and standardization are crucial. From an inward perspective, the actors perceived that their own capabilities influence their positioning decision. They also identify that their capability or technology is better than others, which becomes the justification when they legitimize their actions to strive for leadership in their niche. In the context of competition, every actor envisioned themselves as a leader, striving to command and aspiring to drive the development within their core technology capabilities. However, every actor sees no one is currently taking the leadership in this ecosystem. Except for the electricity producer, participating actors, both complementors or components, yearn that truck manufacturers should take leadership. Yet, truck manufacturers are still uncertain about their role and position themselves as early movers instead of first movers and leaders. They neglect their role as ecosystem leaders and leave the initial development to complementors to ensure that their product can be utilized better, with the risk that this hampers or stops the ecosystem's growth. This causes niche players to leave the door open for other opportunities in the adjacent ecosystem, e.g. cars, aviation, or steel industry, to limit their reliance on the truck manufacturers. With no keystone players, this could potentially risk the niche players' existence in the ecosystem and leads to a blow-up of the borders, leaving them undefined. While agreeing to the ecosystem’s value proposition, the actor's position proves that several ecosystems are intertwined with one another. Thus, mapping the total ecosystem depends on the perception of the actors and their own value proposition.

6.2 Answer Research Question #2

In our second research question we asked: ***What could be one strategic framework for participants within the fuel-cell truck ecosystem?*** The goal was to find if there are any strategic approaches a player in the ecosystem can follow, to be successful within this environment. Through a literature review we found different approaches around the business ecosystem that were containing strategic elements, we summarized them in one framework with eight steps (see Figure 9, next page), to answer this research question:

1. Mapping of the ecosystem
2. Identifying the role your company wants to take and the roles of other participants in the ecosystem
3. Creating the element “The View”, with a clear perspective for the ecosystem and a general vision
4. Building the element “The Platform”, which helps with clearly defined standards and processes to organize and support activities from participants
5. Using the element “The Assets & Acts” to prove the ability for success and resolve concerns from participants inside and outside of the ecosystem
6. Enabling and strengthening these elements through standards that are accepted by all participants
7. Observing and managing risks that could weaken or threaten the previous elements
8. Repeat steps 1 to 8 periodically or after changes appeared that influence the ecosystem

Our empirical findings support all of these steps, as they have been directly or indirectly mentioned by the interviewed participants. Some companies are already performing parts of the recommended actions like providing a platform or using assets and acts to leverage, but none seem to actively follow a comparable strategy with all of its elements. The interviewees left the impression that the actual state of the ecosystem comes with a certain messiness, and miss or no communication from different participants. If more participants follow a strategy, these factors can be reduced and an ecosystem based on collaboration with the goal of a win-win situation can be created and brought to the third stage. The provided strategy must then be updated continuously, as the ecosystem is constantly changing, with inputs from the inside and outside. A high priority should be the alignment of complementors to master the expansion phase of the ecosystem.

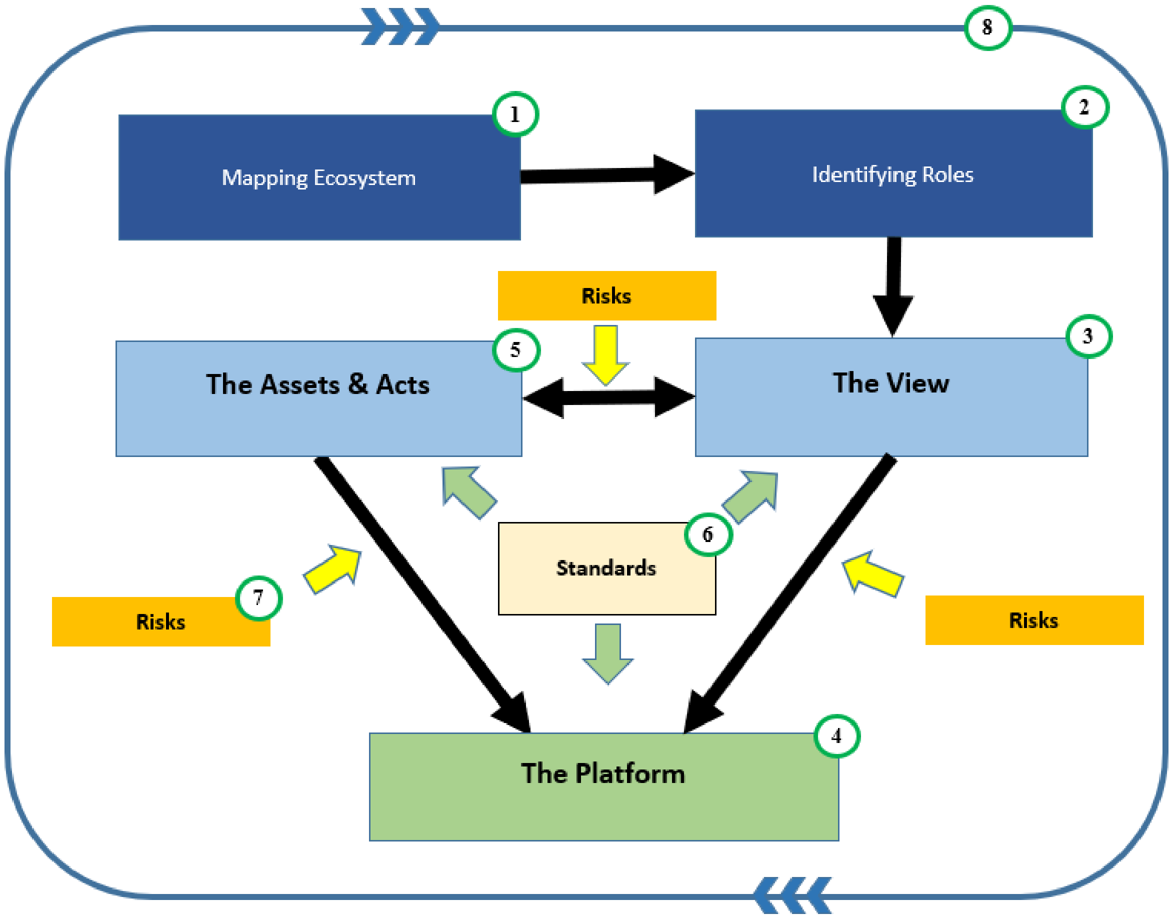

Figure 9. Conceptual framework on ecosystem strategy

6.3 Implications

In this study, we associated the business ecosystem framework with shaping strategy and believe that it could contribute to the theoretical concept of the business ecosystem, by investigating and explaining the business ecosystem in a manufacturing context for a contemporary topic, i.e. fuel-cell truck ecosystem. Business ecosystems have been researched by many scholars and examples of case studies used in previous works of literature mostly explain a mature or finished ecosystem, that is being in the leadership, renewal, or death stage. Therefore, our research brings new insights by providing context into the birth or expansion stage and how the relationship and connection between actors happen at this stage. Much literature that discusses the business ecosystem focuses on the platform ecosystem because ICT, digitization, and the digital business industry are growing. Having used a manufacturing context in our research brings validation and refresher to the business ecosystem theory as the modularity concept in this field is considered vague. Also, previous literature often focuses on the perspective of the leader and core of the ecosystem, and seldom around the networks and the spheres around it, adding a point to our research information. Lastly, by adding the shaping strategy, and standards into context, this research also provides a summarization concept of several theories that could holistically explain the phenomena.

In our research we find that the participants have been able to express their needs and expectations in the context of the ecosystem, showing that the chosen framework follows a natural pattern of behavior and can be applied to other ecosystems too. Using such a framework as a basic strategic approach could enhance the chance of success in an ecosystem, the more companies following it the easier the collaboration will be. The importance in these early stages of the ecosystems is the alignment of participants to build a functioning market and reduce risks for every participant through clearly defined commitment. We found that the greatest problem seems to be the communication and readiness for collaboration in this ecosystem, this could also be true for other ecosystems. Following Adner & Kapoor (2010) our research agrees that at least in the early stage of an ecosystem the focus for value creation comes from collaboration with complementing participants and developing unique components. Resulting that there is no need to compete against complementary industries, rather there is a need to create a win-win situation, which is true for most ecosystems in the early stages. Finally, we can summarize that we need more collaboration to build new sustainable ecosystems that can challenge existing ecosystems to be successful in our efforts towards neutral CO_2 emissions and climate crises.

6.4 Limitations & Further Research

We are fully aware that our research is not free from limitations and still can be improved. As our aspiration is to get empirical validation to maximize the holistic approach to the theory and the phenomenon, it is preferable that the company category and its representatives should cover all the entities mentioned. In our case, we were not able to get the empirics from the governments and customers, hence, we cannot completely eliminate perspective biases. Second, the methodology used for this research is a case study with a snapshot of the current situation, where the technology and market development rate are uncertain, and the ecosystem may drift, thus, within the same research area, the result may change in the near future. Therefore, it is best for the research to be complemented with longitudinal research to cover the development rate period as widely as possible.

Through our research, we could identify topics for further research that we couldn't cover or only touched on. The first topic which should be further researched is the replacement of stable and established ecosystems by new ecosystems, where the replacement is driven through a social context. Our research provides here an example where the stable ecosystem around ICE trucks should be replaced by fuel-cell trucks, where the main driver, in the beginning, is the social pressure towards a CO_2-neutral future and less a better value proposition. This is an important topic since more business ecosystems must be replaced by more sustainable ones to fulfill the goals of the UN-Paris Agreement. The second topic could be around the network relations in ecosystems with a focus on influencing positions, on the leader as also follower side. We found here in our research that there is the need for leadership but not all participants agree on who it should be, and which participant has the greatest influence. Our third recommendation for further research goes into the topic of costs regarding no collaboration between participants, in the context of the "invisible hand". We could find that participants express the wish for more collaboration, but are not actively collaborating for fear of losing potential market shares or giving away competitive relevant information. This non-collaborative behavior comes with the cost of a slower growth rate or faster decline rate of the market. These costs could be higher as non-realized earnings through a lower market share. Our fourth and last recommendation is to revisit the business ecosystem with fuel-cell trucks as a center. Since it is unknown how the development will continue, our research could contribute to further research when the ecosystem is fully developed or dead and provide reasoning for the success or failure of the development.

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Appendices

A. Interviews Guide

Status & Role -> Where are they within the ecosystem?
Responsibilities, Tasks, Actions

1. Could you please explain briefly about your company and your company's role within the hydrogen ecosystem?
   Follow-ups:
   - What are your products and services?
   - What are you developing?
   - What's your value proposition?

Complementors -> Finding more out about the relations within the ecosystem.
Components, Dependencies, Awareness about technology

2. To what kind of companies or users do you deliver your products or services?
3. Explain complementors to the interviewee then ask:
   On which complementors are you depending on? Can you mention any key drivers?
4. Explain components to the interviewee then ask:
   On which components are you depending on? Can you mention any key drivers?
5. Are there key technologies that you think need to develop further?

Challenges -> Goal of getting a reflected answer about the future of Hydrogen
Technology, Infrastructure, Overall development, Bottlenecks, Cost

6. Where do you see challenges in technology development within the next 5 years?
7. Where do you see challenges in the development of infrastructures?
   - It can be Technical or safety or anything.
8. Where do you see challenges for your product development?
9. What do you think are the bottlenecks within this ecosystem?
10. Where do you see the problem in the cost structure, in order to reach cost parity with the transportation application today?

Opportunities -> Reflected answer to the future regarding standards / big movement
Technology Development, Standards, Platforms, Government Decisions, Positive Infrastructure development, Interested Consumers

11. What is your perception of the compressed gas / liquid / cryo-compressed gas hydrogen?
    Follow ups:
    - What do you think are the drivers to go with a certain technology?

- How do you frame the vision or motivation to go with certain technology (as a leader)? Or what affects you to go with certain technology (as a participant)?
- How confident are you with certain technology to be developed in 5 - 10 years? What are the barriers and how would you deal with them?
- How do you see the development in the US and Europe for certain technologies?
- What are the strategic actions you will undertake?

12. Do you see the development towards a standard from a market / government perspective?
13. Where do you see opportunities about your product/services within this development?
14. Where do you see an opportunity for your company/institution to drive the development?
15. How do you see the opportunity for the demand to develop?
16. What are your expectations towards the truck manufacturer in the process? (and/or other players depending on your relative position)

B. Data Structure