Tampere University

Joonas Timperi

GREEN HYDROGEN BUSINESS ECOSYSTEM ANALYSIS

A qualitative study

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ABSTRACT

Joonas Timperi: Green Hydrogen Business Ecosystem Analysis – A Qualitative Study
Master of Science Thesis
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The world is facing an energy transition away from fossil sources. Companies operating in energy sector are seeking new ways of creating profit and alternatives to fossil energy carriers and sources. This master's thesis was done at Wärtsilä as part of a research project X-Ahead. The aim of the project is to study various power-to-x technologies and markets that include green hydrogen, which is the subject in this study. The research objective is to identify key technology suppliers and potential off-takers for green hydrogen, and to find bottlenecks of industrial-scale feasibility of green hydrogen.

To meet the research objective, a qualitative study is conducted. Literature review in business ecosystem theory provided the basis to categorize key actors and their value chain profiles within the industry. The key actors in green hydrogen ecosystem were gathered using third-party sources, and off-takers and bottlenecks were studied in semi-structured interviews with nine experts.

Results of the data gathering of companies were summarized in an electrolyser value chain where the most prevalent actors were characterized by their chosen electrolyser technology and the business type. Interview results were synthesized into a swot-table for green hydrogen feasibility, where the most occurring sentiments were chosen from the respondents' interview notes. Results suggest that green hydrogen ecosystem is likely to form around those actors who can scale up their production fastest and secure the market gap of replacing grey hydrogen, which is seen as the most certain customer segment in all scenarios. Other long-term use-cases remain obscure and reliant on many factors in policy and regulation, as well as development of rival decarbonization technologies.

Keywords: green hydrogen, energy transition, business ecosystem, innovation ecosystem, ecosystem, sustained competitive advantage

The originality of this thesis has been checked using the Turnitin OriginalityCheck service.

TIIVISTELMÄ

Joonas Timperi: Vihreän vedyn liiketoimintaekosysteemianalyysi – kvalitatiivinen tutkimus
Diplomityö
Tampereen yliopisto
Sähkötekniikan DI-ohjelma
Huhtikuu 2022

Maailmalla on edessään energiatransitio pois fossiilisista lähteistä. Energia-alalla toimivat yritykset etsivät uusia tapoja tuottaa voittoa ja vaihtoehtoja fossiilisille energian välittäjille ja lähteille. Tämä diplomityö tehtiin Wärtsilässä osana tutkimusprojektia X-Ahead. Hankkeen tavoitteena on tutkia erilaisia power-to-x-teknologioita ja -markkinoita, joista yksi on tämän tutkimuksen kohteena oleva vihreä vety. Tutkimuksen tavoitteena on kartoittaa vihreän vedyn keskeisiä teknologiatoimittajia ja mahdollisia asiakkaita sekä löytää pullonkauloja vihreän vedyn teollisen mittakaavan toteutettavuudelle.

Tutkimustavoitteen saavuttamiseksi valittiin kvalitatiivinen tutkimus. Liiketoimintaekosysteemiteorian kirjallisuuskatsaukset antoivat perustan alan avaintoimijoiden ja niiden arvoketjuprofiilien luokittelulle. Vihreän vedyn ekosysteemin avaintoimijat koottiin ulkopuolisten lähteiden avulla, ja asiakkaita sekä pullonkauloja tutkittiin semi-strukturoiduissa haastatteluissa yhdeksän asiantuntijan kanssa.

Tiedonkeruun tulokset yrityksistä koottiin elektrolyysilaitteiston arvoketjuun, jossa vallitsevat toimijat luonnehdittiin valitsemansa elektrolyysiteknologian ja liiketoimintatyypin mukaan. Haastattelutulokset koottiin vihreän vedyn kannattavuuden swot-taulukkoon, mihin valittiin eniten esiintyneet ajatukset vastaajien haastattelumuistiinpanoista. Tulokset viittaavat siihen, että vihreän vedyn ekosysteemi muodostuu todennäköisesti niiden toimijoiden ympärille, jotka pystyvät nopeimmin kasvattamaan tuotantoaan ja turvaamaan markkinaraon harmaan vedyn korvaamisesta, mikä nähdään kaikissa skenaarioissa varmimpana asiakassegmenttinä. Muut pitkän aikavälin käyttötarkoitukset ovat edelleen epävarmoja ja riippuvaisia monista politiikan ja sääntelyn tekijöistä sekä kilpailevien hiilidioksidipäästöjen vähentämisteknologioiden kehityksestä.

Avainsanat: vihreä vety, energiatransitio, liiketoimintaekosysteemi, innovaatioekosysteemi, ekosysteemi, jatkuva kilpailullinen etu

PREFACE

The half a year working on this thesis has been challenging but rewarding, and I am grateful for the opportunity I had to work with many talented and enthusiastic people at Wärtsilä's X-Ahead team. Despite the difficulties with COVID, it has been a great time to work with everyone.

I would like to thank Wärtsilä for the interesting thesis subject, my siblings and my parents for showing much support during the thesis project, and especially for my sister and brother for help in proofreading and encouragement with the writing process.

Tampere, 12 April 2022

Joonas Timperi

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

AE	Alkaline electrolysis
AEM	Anion exchange membrane
BESS	Battery energy storage system
DAC	Direct air capture
EPC	Engineering, procurement and construction
EU	European Union
EV	Electric vehicle
FCEV	Fuel cell electric vehicle
GHG	Greenhouse gas
IEA	International Energy Agency
LRC	Lined rock cavern
P2X	Power-to-X
PEM	Proton exchange membrane
RBV	Resource-based view
RES	Renewable energy source
RQ	Research question
SMR	Steam methane reforming
SOE	Solid oxide electrolysis
SOEC	Solid oxide electrolysis cell
TRL	Technology readiness level
USA	United States of America
X2P	X-to-Power

1. INTRODUCTION

"I believe that water will one day be employed as fuel,
that hydrogen and oxygen which constitute it, used singly or together, will
furnish an inexhaustible source of heat and light, of an intensity of which
coal is not capable." – Jules Verne 1874

The climate change is forcing many political and national entities into increasingly rapid action to limit the greenhouse gas (GHG) emissions across the whole width of socio-economic landscape. In recent months and years, many countries and coalitions have emerged to promote this green transition.

Forced by the effects of the climate change, governments are taking action. With the advent of increasingly ambitious climate targets set out by policy, businesses and industries face high uncertainty in their operational environment to evolve their strategy to fit the new paradigm governed by megatrends such as decarbonization, sustainability, electrification, and digitalization. Hydrogen economy is one possible component planned to be present in various sectors of energy transition, which seeks to distance energy generation and consumption away from fossil sources towards renewable energy.

1.1 Energy transition

Hydrogen has been gaining increasing attention as a GHG-limiting energy carrier in recent years, culminating in many political entities such as EU, USA and many countries creating and fielding hydrogen roadmaps and strategies aimed to create a sustainable socio-economic landscape which is to be less reliant on fossil-based energy sources. Figure The primary driver for this change in policy is limiting the effects of the climate change and global warming to <2℃ or 1.5℃ compared to pre-industrial levels, as stated by the Paris Agreement which to date has been ratified by 192 parties of 197 in the convention. (UNFCCC, 2022b, 2022a)

These goals are targeted by promoting decarbonization, electrification and circular economy in energy-consuming sectors such as *energy* (primary energy), *heating and cooling*, *transportation* and *industry*, commonly understood under the umbrella term energy transition. Of special interest for hydrogen usage in these sectors are the ones requiring a high-density energy carrier or high-grade heat, so called hard-to-abate sectors. These include industries such as steelmaking, cement mills, heavy-duty transportation (trucks, aviation, shipping) and other sectors where direct electrification does not meet the various system requirements. Figure 1 shows the relative GHG emissions by these sectors, facilitating a case for hydrogen in their decarbonizing.

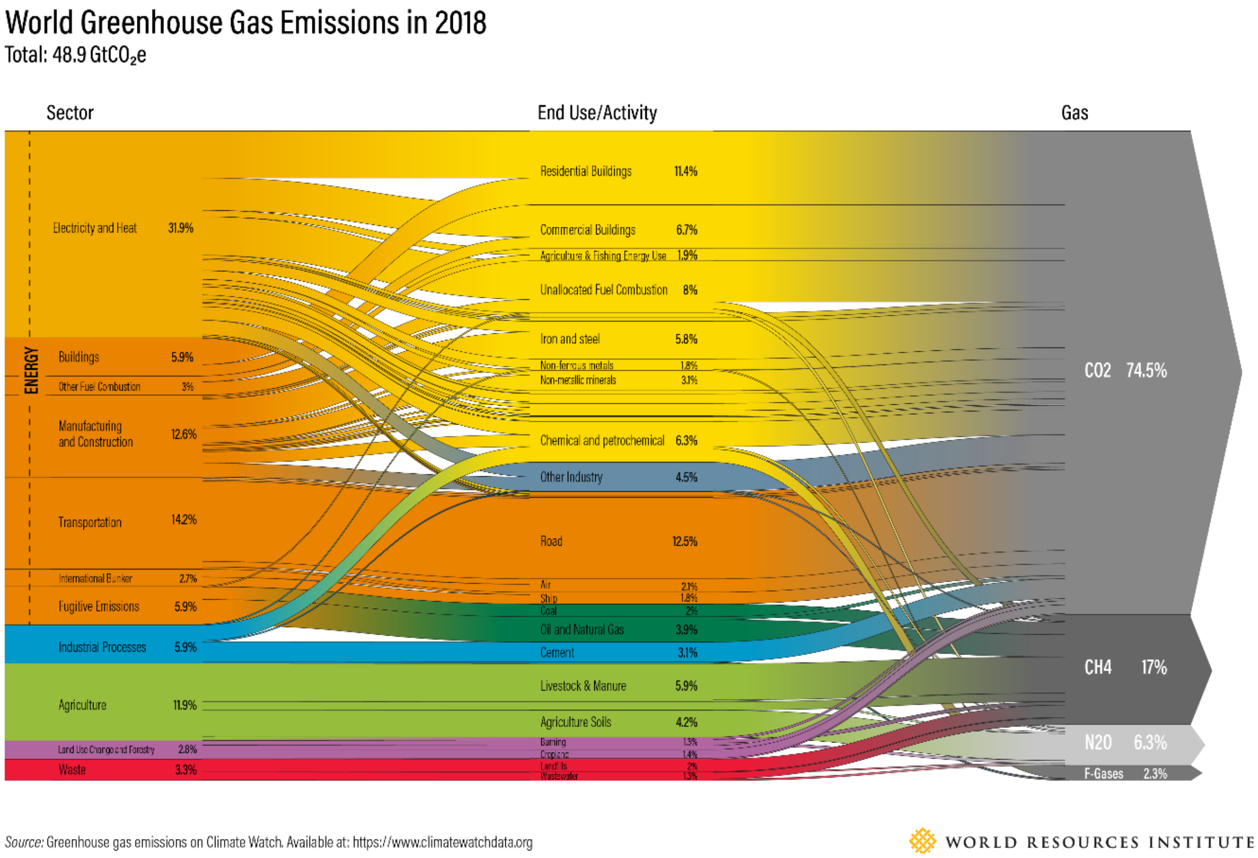

***Figure 1** GHG emissions by Sector, End Use and Gases 2018* (World Resources Institute, 2018)

In the below figure, world's map is highlighted based on status of hydrogen strategies. Europe is collectively relatively advanced in released strategy and policy, along with countries such as Canada, Chile, Australia which are planning long-term export-based hydrogen economies due abundant renewable energy access, while some like Japan and South Korea are strategizing to become importers of hydrogen.

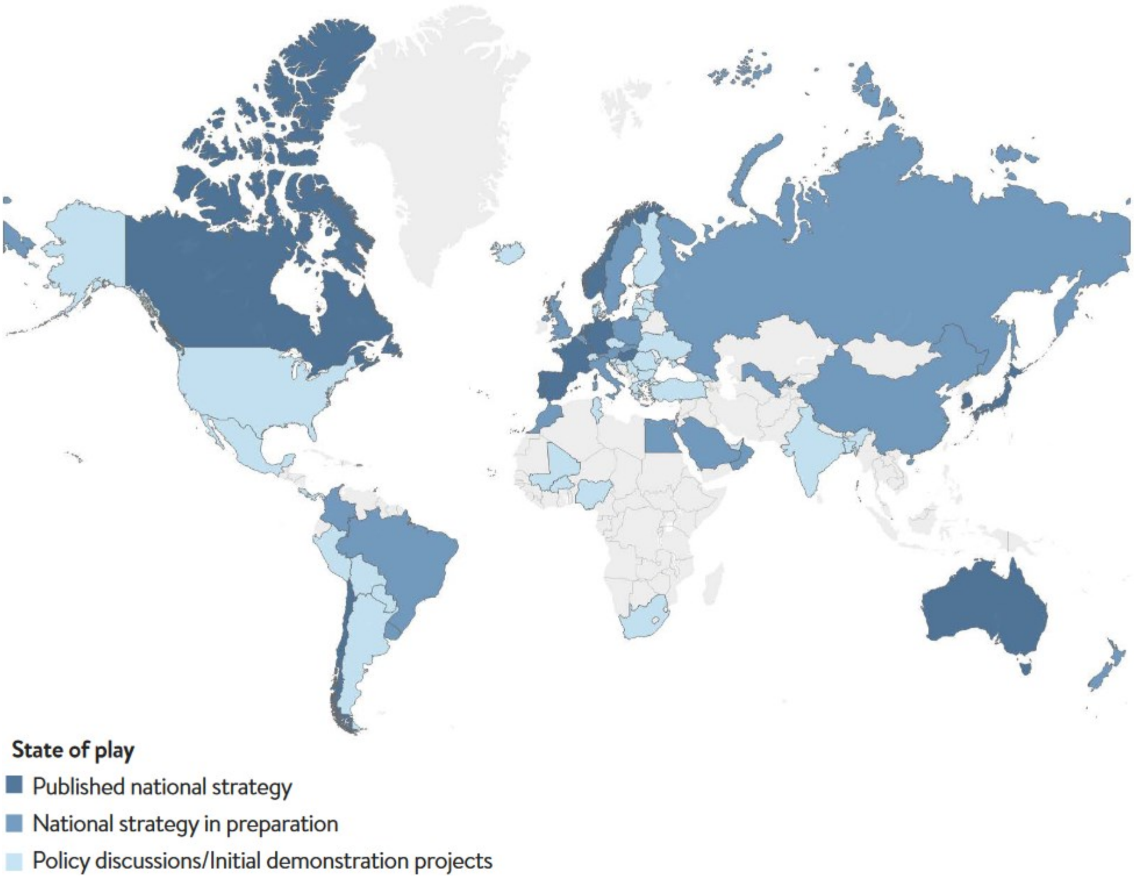

Figure 2 *Overview map of countries hydrogen strategies as of June 2021.* (World Energy Council, 2021)

Table provided in appendix B showcases specific sectoral targets which are targeted by green or clean hydrogen. These include various hydrogen economy use cases, also listed in appendix A's Figure 13:

- heating (replacing natural gas and oil-based fuels),
- several industrial uses like chemical feedstock and steel making,
- power generation in X-to-Power (X2P) via fuel cells or gas engines utilizing hydrogen, and
- transport fuels with fuel cells for passenger cars (fuel cell electric cars FCEVs), heavy duty vehicles, buses, as well as possible maritime fuels or even aviation fuels with synthetic kerosine.

1.2 Role and definition of green hydrogen

Hydrogen can be created by a multitude of processes, which markedly give each production method a typical GHG-emission footprint, based on either the source of H_2 or the production process. For simplicity, a color-coding system has been created to distinguish between different types of produced hydrogen, listed in Table 1 below:

Table 1 *Colour coding of differently produced hydrogen and CO_2 emission characteristics.*

Colour coding	Hydrogen source	Production method	CO_2
Grey	Fossil, natural gas	Steam methane reforming, SMR	High, without CCS
Blue	Fossil, natural gas	Steam methane reforming, SMR	high / medium with CCS
Green	RES-electricity, H_2O	Electrolysis	Low / none
Pink/Red/Purple	Nuclear-power, H_2O	Electrolysis/catalytic splitting	Low / medium
White	Naturally occurring H_2	-	-

By an overwhelming percentage, today's demand of hydrogen is created from SMR, so called grey hydrogen. Green, or low GHG-emission hydrogen can also be produced by less mature or advent technologies, such as biological production, but they are currently in their infancy regarding industrial scale technological maturity. They are disregarded in this study and focus is on electrolysis using three primary electrolysis technologies: alkaline, proton exchange membrane and solid oxide electrolysis, often abbreviated AE or AEL, PEM and SOE or SOEC respectively. The three technologies are compared in table 2 below.

Table 2 Comparison of the three major electrolysis technologies' characteristics. Edited from (Buttler & Spliethoff, 2018; Grigoriev et al., 2020).

Types of water electrolysers	Alkaline	PEM	Solid Oxide
Technology status	mature technology		lab-scale, R&D
T range (°C)	ambient - 120		700–1000
Charge carrier	OH^-	H^+	O^{2-}
Conventional current density (A/cm^2)	0.2–0.5	0–3 (up to 20)	0–2
Nominal efficiency (%, LHV)	51-60	46-60	76-81
Capacity (Nm^3/hour)	1–500	1–250	1
Durability (hours)	100,000	10,000–50,000	500–20,000
H_2O specification	liquid	>10 MΩ.cm	steam
Transient capability	medium	fast	slow

Hydrogen, and especially green hydrogen, is seen as one of the most promising components in achieving truly net-zero CO_2 energy future. Many countries have laid out specific hydrogen roadmaps or strategies in an effort to coordinate transition pathways towards 2050 and beyond, which in EU legislation has been determined as the timeframe-target for carbon-neutrality. (European Commission, 2019)

1.3 Context and objective of research

This study is done under Wärtsilä's X-Ahead project, aimed at researching both the technical and business potential of Power-to-X, which will be used to promote carbon-neutral business development and serve as a basis to define Wärtsilä's role in the Power-to-X (P2X) field. The aim in this study is to map a value chain for electrolyser-focused business ecosystem, and to identify key actors in green hydrogen production. The following research questions arise from the goals of this study:

1. *RQ 1*: Who are the key actors in green hydrogen business ecosystem?
2. *RQ 2*: What resources or capabilities are needed or lacking for reaching industrial-scale business feasibility?
3. *RQ 3*: Who are the potential off takers for green hydrogen?

The scope of research does not have a focal case project since the green hydrogen market is still nascent in nature. Ergo, to seek answers to these questions, the research objective is to map current business ecosystem actors, companies, and through characterization of their roles in the value- and supply-chain, to create an understanding of the evolutionary phase of the ecosystem.

The research process is two-fold. First, we map the existing green hydrogen business structure for most successful or prevalent companies, define what kind of role or position they are holding based on their product and service offering in the value chain to delve into RQ1. Second, we hypothesize missing actors, resources or bottlenecks based on the researched value-chain and test these hypotheses via semi-structured interviews with interviewees having knowledge of hydrogen market's demand side, in order to find answers to RQ2 and RQ3.

1.4 Structure of thesis

The thesis is divided in six chapters, following a scientific structure. The first chapter is introduction where research questions and general background are defined. Chapter two conducts a literature review on the relevant theoretical background, business ecosystems and sustainable competitive advantage.

Chapter three presents the research design: research philosophy, methods used and data gathered, as well as how the data is analysed. Chapters four and five present the results gleaned from collected data and connects these to the wider environment presented in introduction and the theory used. Finally, chapter six summarizes key contributions, limitations of the research and further research suggestions.

2. THEORETICAL BACKGROUND

This chapter discusses relevant literature and theory for analysing value chain and ecosystem actors used in this study. Primarily these comprise of business ecosystem framework with various roles, and value analysis framework of RBV, Resource-based view, as well as dynamic capabilities. The aim is to provide the reader information on the development of these frameworks and their evolution, as well as primary characteristics.

First, business ecosystem is defined, and an overview of its evolutionary phases is provided, then ecosystem roles and finally the resource-based view and dynamic capabilities before presenting a synthesis of primary points.

This should provide the reader a clear understanding of chosen perspectives which are used to analyse results and formulate the foundation of the research methods, namely the themes used in semi-structured interviews.

2.1 Business ecosystems

What is a business ecosystem? It is important to highlight the ecosystem terminology: innovation, business, service, and knowledge ecosystems all create confusion about what kind of framework best suits the situation. As a construct for strategy and management, literature often uses the terms *business ecosystem* and *innovation ecosystem* interchangeably due the premise of an ecosystem habiting that of a new innovation whence the ecosystem is built up on (Dedehayir et al., 2018). Depending on the authors focus, also *entrepreneurial ecosystem* has been used in management literature (Boutillier, 2021).

The paradigm of ecosystem stems from analogy of biological or ecological structures and environment. Original business-centric definition by Moore in 1996, an ecosystem is *an economic community supported by the organisms of the business world, a foundation of interacting organizations and individuals* (James F Moore, 1996). Past this, a widely acknowledged definition by Ron Adner is: *the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize* (Adner, 2017). Both these definitions have an actor focus which is relevant to this study, but lacking in evolutionary perspective, so a more recent definition proposed in literature, which involves focus on value propositions or outputs and so successfully synthesizes above views, is chosen as a starting point for this study: *an ecosystem is consisted of a* *community of multiple co-evolving actors that organized around specific value propositions/focal offerings/outputs* (Shi et al., 2021)**.**

This definition is chosen, because it is the foundation for more recent developments to the scientific framework, and due the focus being on value-creation within a multitude of actors co-operatively, which is a more direct conceptual evolution from Porter's value-chain of that focuses only on a single firm's value creation. (Porter, 1998)

Regardless of the definition chosen, the foundations of a business ecosystem remain the same. It consists of business independent actors of various roles, each working interdependently towards a common value proposition. Figure 3 illustrates a generic view of ecosystem structure, surrounding a focal firm, where complementors supplement the customer-perceived value in some way that the focal firm could not do alone.

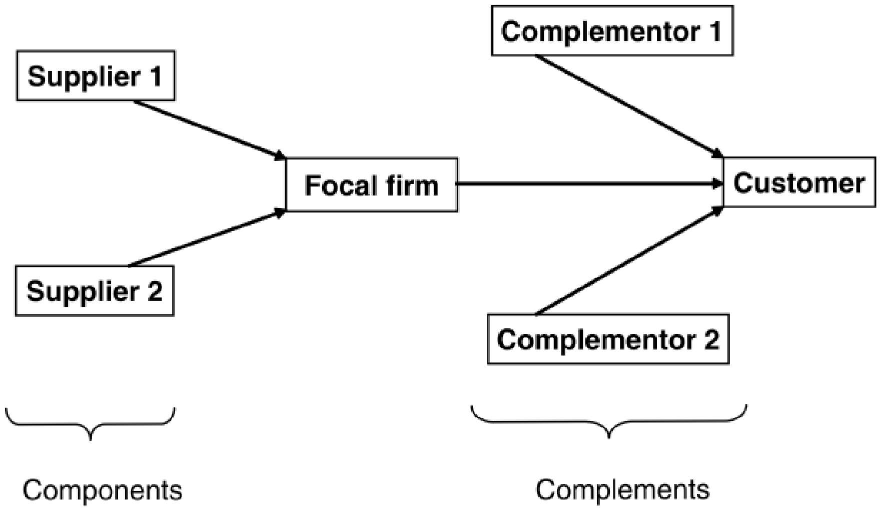

Figure 3 *Ecosystem illustration around a focal firm* (Adner & Kapoor, 2010)*.*

Each actor in the schema is linked by a value chain, which is *a sequence or a process of value creation activities to deliver products.* According to this structure, we can surmise that value chains are building foundations of business ecosystems, because they are a primary vessel for value co-creation, and that each individual actor is part of at least one value chain depending on their role.

Regarding roles in an ecosystem, it's paramount to note that ecosystems are not static in nature, and each ecosystem member can hold a multitude of different roles during the ecosystem's lifecycle. Next, we will look at different phases of ecosystem during its evolutionary cycle.

2.1.1 Evolution of business ecosystems

The original introductory evolution framework as presented by Moore in 1993 recognised four phases: birth, expansion, leadership and self-renewal or death. If the ecosystem is unable to reconfigure itself a when faced with challenges to it's core value proposition, be it technological, competitive or otherwise disruptive challenge. (J. F. Moore, 1993)

Extant literature on ecosystem evolution has some variance in different phases based on what kind of ecosystem is in question. The original concept, including evolution and roles, has extended to research of innovation and industry topics as well (Adner, 2006; Dedehayir et al., 2018; Thomas & Autio, 2019) and they offer slightly different perspectives to the generic phases due changing value propositions which can be case-specific. This is likely due the fact that as business ecosystem as a framework was developed to analyse competitive business strategy and related phenomena. Therefore it is only natural that the framework itself must evolve as lenses to depict real-life strategic decision-making or value-creation changes, for example with more focus on technological foresight or disruptive innovation, or industries themselves evolve via e.g. digitalization (Adner & Lieberman, 2021). In Figure 4 below is an illustration of the stages in ecosystem lifecycle.

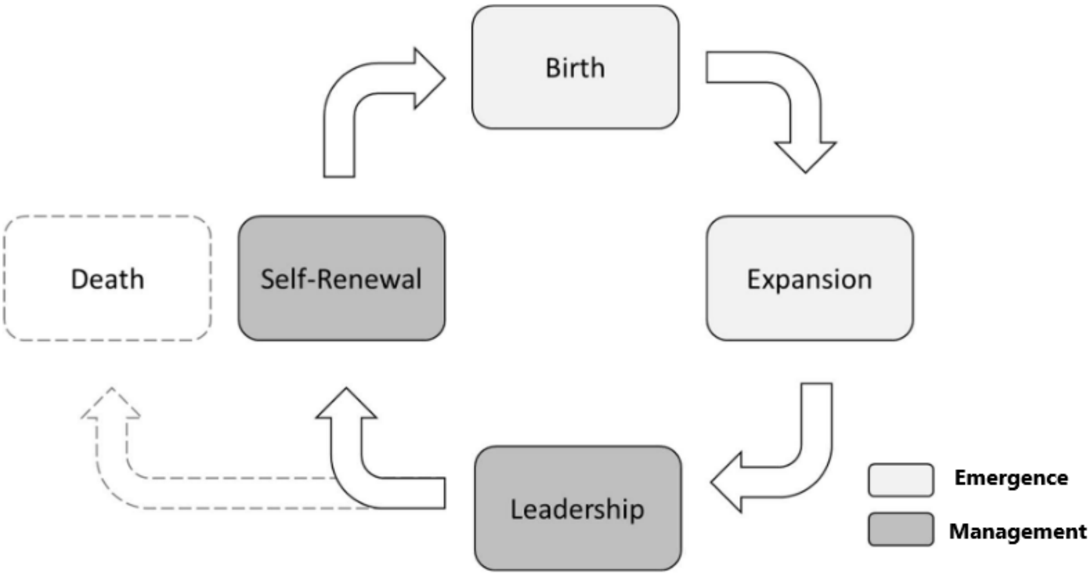

Figure 4 *Evolutionary stages of a business ecosystem, edited from (Welin, 2019)*

The birth or emergence stage begins with a seed innovation, a value proposition defined with other actors and customers by potential ecosystem leader-actor (J. F. Moore, 1993). This creation and building stage of the ecosystem is in nature more iterative and chaotic than later stages, as the suggested value proposition, customer segments and potential supply chains are refined and new actors come into the ecosystem (Dedehayir et al., 2018). This is what Moore (1993) calls co-operative challenges, which in latter literature has been synonymised by term co-evolution especially in the case where the ecosystem is moving to the emergence phase via self-renewal of an existing ecosystem (Wieninger et al., 2020). Competitive challenges in this phase, from the focal firm's perspective, revolve around protecting one's own ideas from competing, similar offerings or competitive solutions to the same customer demand, and in securing potential partners such as lead customers and key suppliers over the competition.

The second stage begins where the emergence begins: with the first commercialization of the value proposition, bringing it to market with suppliers and partners. This phase is characterized by the existence of many alternative solutions or even rival ecosystems providing similar value offerings. Thus the co-operative challenges within one's partners and suppliers consist of capturing market share, and the attention turns from refinement of the value proposition to competing in in the market with a clearly defined offering (J. F. Moore, 1993). Competitive challenges entail chasing a leader-position in the market, which marks the transition to the next stage, where the focal company's ecosystems value offering becomes, using a technological analogy, a 'dominant design' or a perceived standard. This phase has in later literature been divided into two categories, which depict the features of the framework phase: *diversifying* and *converging*, wherein diversity refers to the number of solutions and flexibility of actors present, and converging refers to the selection of a network-widely accepted and integrated solution with partners, which is aimed to become a dominant design (Rong & Shi, 2015, p. 137).

The third stage begins when one ecosystem prevails over the others around a focal company that provides its value-cooperative partners a compelling, clear vision to encourage them to continue within the ecosystem design through its course. This means that the leader- or dominator role maintains strong control or bargaining power over other ecosystem players, especially as it comes to retaining value capture pathways, which is the focus of competitive challenge during this phase. (Adner, 2017; J. F. Moore, 1993)

Moore's fourth and final stage is self-renewal, which requires either an external ecosystem, innovation, customer demand, or idea to threaten the mature ecosystems value proposition, or configuration of existing value chains. This phase is in nature tightly linked to the more diverse birth-phase, and similar cooperative challenges emerge as the focal firm is once again required to work with innovators to assimilate new ideas to the existing structure, or to completely change the value proposition created to match the new paradigm. (J. F. Moore, 1993)

Naturally, as businesses evolve and become more complex, ecosystems will also evolve in unpredictable and more varied ways than what Moore’s framework describes. It is notable that the original ecosystem theory was constructed during an era where value chain theory (Porter, 1998) and value creation was less complex than today. In last years, as literature has taken a renewed approach in ecosystem dynamics and strategy, value creation and the study of ecosystem competition, ecosystem evolution has also gained a new perspective, which is summarized in Figure 5 below. (Adner & Lieberman, 2021; Jacobides et al., 2018)

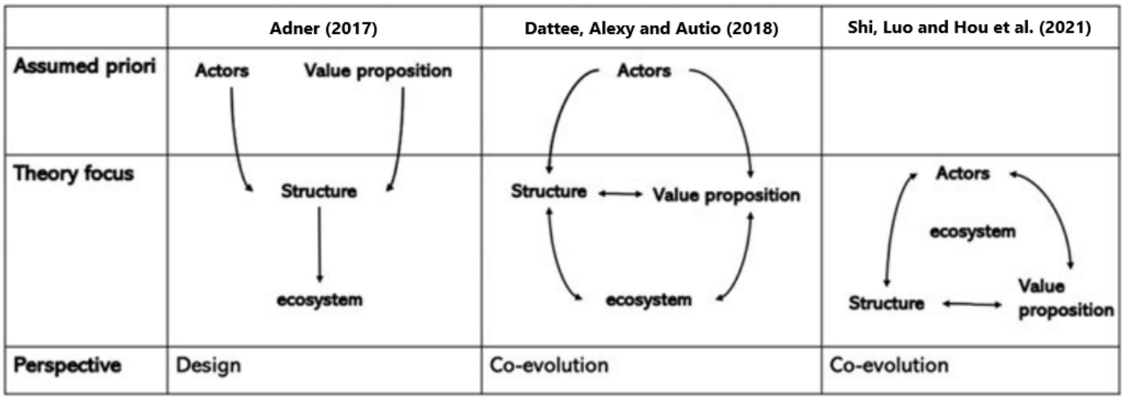

Figure 5 *Literature perspectives on ecosystem emergence, adapted and edited from* (Shi et al., 2021)

It’s worth noting that Adner’s perspective reflects that of Moore, where actors define value propositions, seeking to devise a favourable structure design for value appropriation, preferably becoming a focal actor or leader themselves.

The perspective of co-evolution has developed in challenging the focal-firm aspect and controllability or creation of a well-defined value proposition. It might not always be clear, especially in nascent markets, what the valid value propositions might be, and the actors seeking to engage in the emerging ecosystem must therefore create an *innovation ecosystem* in order to figure out a valid ecosystem strategy (Adner, 2006). This co-evolution perspective was further elaborated by Dattee et al. (2018), where they highlighted novel ecosystem creation involving a systematic process of organizations counteracting a nascent ecosystem ‘drifting away’ from intended points of value capture. (Dattee et al., 2018)

The dynamics of a newly constructing or emergent ecosystem are of major relevance for this case study, so more focus will be given to strategic roles and functions within this phase going forward.

2.1.2 Ecosystem strategic roles

As ecosystems emerge, different actors face questions how they want to be a part of them, who to partner with, in what capacity, and what kind of role to play in the ecosystem. Possible roles of course depend on the structure of an ecosystem as well as the value proposition inherent to the particular market. For example, Holmström Olsson & Boch (2017) study of software-heavy industries recognised up to 23 different co-operative strategies across their three ecosystem configurations, which were innovation, differentiating and commoditizing ecosystems. These three configurations were thus characterized based on the actor whose perspective an ecosystem strategy was looked at: customers and third-party developers often work in innovation function, keystone player (synonym for leadership player/actor) in differentiating function to seek and maintain control, and suppliers, competitors and followers who are within less value adding functions operate in commoditizing ecosystem. (Holmström Olsson & Bosch, 2017)

Moore (1993) focuses the strategy mostly from the perspective of an actor seeking a leadership status, so it is not sufficient as a base for analysis. Later research literature has brought up emergence dynamics and related roles more in-depth in various case analyses, e.g. (Mäkinen & Dedehayir, 2012) literature review recognized three roles (keystone, ‘wannabe’ and ‘niche player’) with specific strategies, which were expanded on a later study on ecosystem emergence roles (Dedehayir et al., 2018) where four role-categories (leadership, direct value-adding, value support and entrepreneurial roles) were analysed based on typical activities. These categories are aptly synthesized in Figure 6 and Figure 7 below, depicting a theoretical framework of a business ecosystem on a generic level, and typical activities during ecosystem genesis for different roles or strategies.

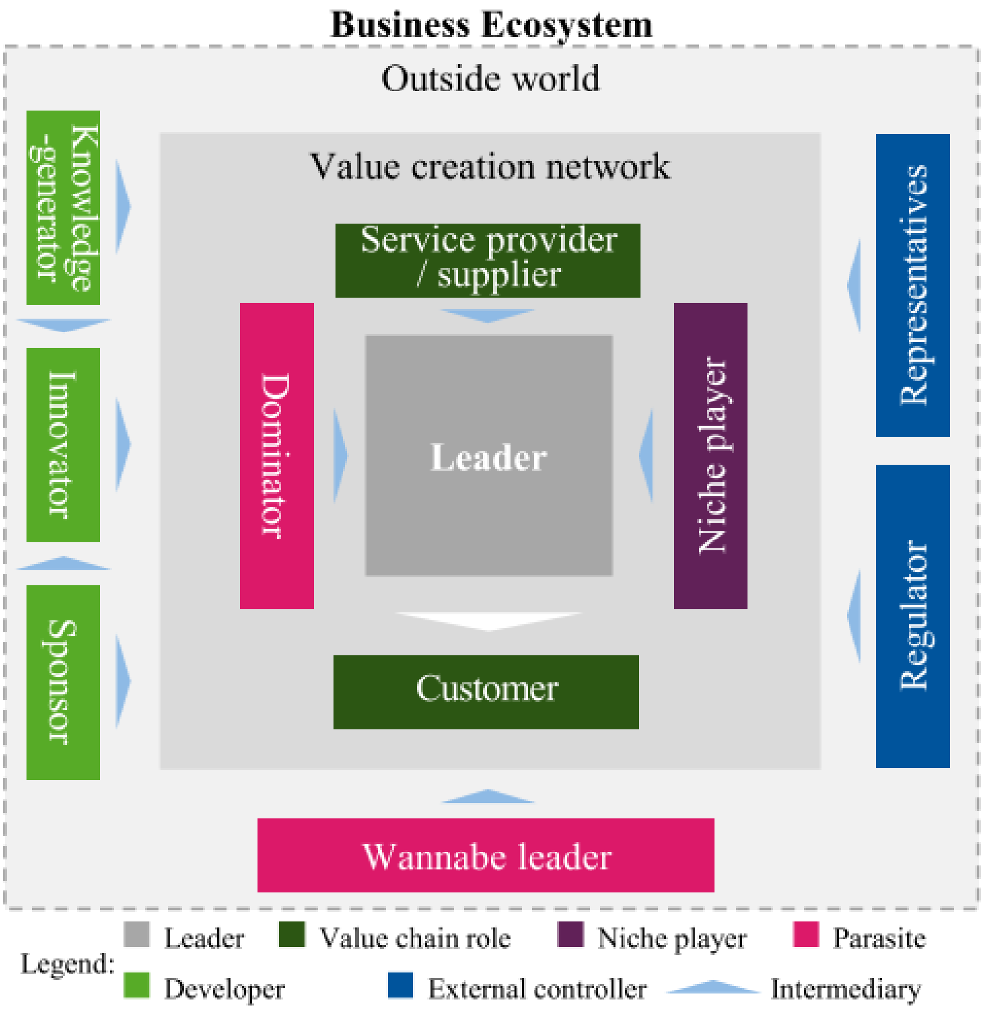

Figure 6 *Framework for characteristic roles of an ecosystem, adopted from* (Wieninger et al., 2020).

		Preparation	Formation	Operation
Leadership	Ecosystem leader			
	ecosystem gov.	decipher roles	coordinate interactions	orchestrate resource flows
	forging part.	attract & link partners	create collaboration	stimulate complementarity
	platform man.	build platform	open platform	orchestrate complementors
	value man.		decipher bases of value	create & capture value
	Dominator			integrate actors
Direct Value Creation	Supplier			supply components
	Assembler			assemble components
	Complementor			provide complementarities
	User	define need	provide ideas	purchase and use
Value Support	Expert	generate knowledge	provide expertise	transfer technology
	Champion		build connections	provide access to markets
Entrep. Ecosystem	Entrepreneur	co-locate	set-up network	
	Sponsor	give resources	co-develop offering	link to other actors
	Regulator	provide favorable conditions		

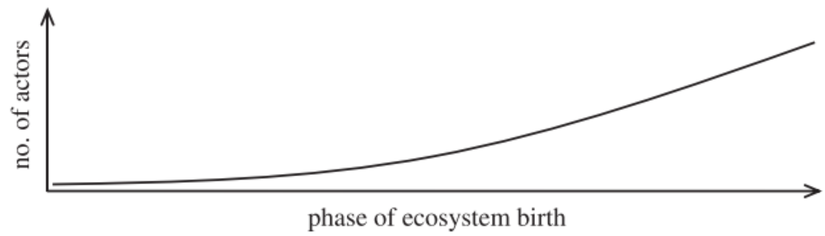

Figure 7 *Roles and activities during ecosystem genesis. These roles were identified specifically for early innovation ecosystem. Adopted from* (Dedehayir et al., 2018).

It is important to note that each actor may change their role in the ecosystem during its lifecycle, and that it is often a dynamic decision-making process, especially at the birth stages when competing ideas and innovations are on the table. Innovation ecosystems are seen as a building phase of an ecosystem, and one recent study even acknowledges ecosystem strategy to typically have typically two layers regarding actor-specific view: an explorative and an exploitative layer, depicted in Figure 8 below. (Visscher et al., 2021)

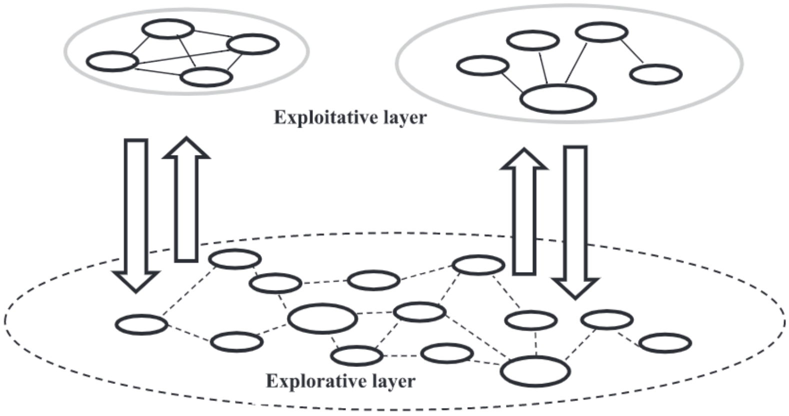

Figure 8 *Innovation ecosystem multi-layered strategy approach. Adopted from* (Visscher et al., 2021).

This multi-layered approach builds on the work of Adner (2017) who depicted ecosystem with two distinct views: ecosystem-as-affiliation and -as-structure. Ecosystem as affiliation sees ecosystems on a macro level where strategy (of a focal firm or actor) tends to focus on increasing bargaining power through introduction of ecosystem actors and increasing network density which would increase the ecosystem centrality and value creation through direct and indirect network externalities which the actors collectively provide. This view is notably lacking in tools to analyse direct value creation processes and insight is limited to general governance and community level, so it is not selected as perspective here. (Adner, 2017)

Ecosystem-as-structure lends itself better for interpreting strategic positioning, value creation and appropriation, as it starts the strategy formulation from a value proposition which is formulated in the explorative layer through selection of proper partners and identification of value appropriation pathways, after which the strategic approach moves onto exploitative layer in in the chosen configuration. The structural perspective consists of four basic elements which define the configuration of actors and resources that enable the materialization of the value proposition:

1. Activities: discrete actions for value creation towards the value proposition.
2. Actors: entities to undertake the activities either singularly or cooperatively.
3. Positions: location of actors in the flow of activities (value chain position), which specify who hands off to whom.
4. Links: transfer paths across actors, wherein the content of transfers may vary (material, information, funds etc.) and need not link to the focal actor.

Competition, and thus strategies of actors, operate in two distinct levels from these elements, within and across ecosystems. On one hand firms seek to maintain or gain competitive advantage by searching a suitable alignment within the ecosystem, aimed at securing activities, positions and roles which determine value capture potential, and on the other hand, ecosystems compete with rivalling constellations of actors, which Figure 8 depicts: explorative layer can spawn many constellations of actors from a similar innovation source, separate ecosystems operating in shared competitive environment. (Adner, 2017)

Next, we will look at traditional dynamics of how competitive advantage is formed in academic literature, to link together specific value creation strategies and the larger ecosystem.

2.2 On sustainable competitive advantage

According to Oxford Dictionary (2022) definition, competitive advantage is “a condition or circumstance that puts a company in a favourable or superior business position” (Oxford Dictionary, 2022). Extant literature on defining the characteristics and building blocks these conditions or circumstances have mostly focused on value creation, especially where the advantage is sought to remain sustainable.

One of the dominating perspectives for studying competitive advantage is that of resource-based view, abbreviated RBV, was introduced by Barney in 1991. RBV has since diffused widely into strategic management and received much development and empirical testing (J. Barney et al., 2001), which offered theoretical extensions to come forth, such as the framework of dynamic capabilities by Teece et al. (1997) which aims to explain organizational capabilities in usage and organizing of resources.

These two frameworks will be briefly introduced, as they provide a good foundation for analysing emerging value creation activities and organizational considerations regarding business ecosystem strategy and formulation of an ecosystem’s value proposition.

2.2.1 Resource-based view RBV and VRIO-framework

The resource-based view of the firm was first introduced by Wernerfelt in 1984, and further refined into an analytical framework for defining the characteristics a resource must have for it to sustain competitive advantage for the company by Barney in 1991. The characteristics are defined by the VRIO, an acronym of initials that describe the resource: *valuable, rare, inimitable,* and *organized*. Originally, Barney introduced his RBV perspective with a VRIN-model, wherein the last letter of the acronym concerned *non-substitutability* of a resource. VRIO-framework of analysis is an evolution of this, where the organizational aspect refers to the company’s ability to exploit the resource or capability.

The framework is depicted in detail in Table 3 below. (J. Barney et al., 2001; Wernerfelt, 1984)

***Table 3** The VRIO framework for resource analysis, adopted from* (J. B. Barney, 1996, p. 163, 2007, p. 70)

Is a resource or capability . . .					
Valuable?	Rare?	Costly to imitate?	Exploited by organization?	Competitive implications	Economic performance
No	—	—	No	Competitive disadvantage	Below normal
Yes	No	—		Competitive parity	Normal
Yes	Yes	No		Temporary competitive advantage	Above normal
Yes	Yes	Yes	Yes	Sustained competitive advantage	Above normal

The VRIO framework is useful in identifying critical or bottleneck resources towards specific competitive goals, not only for company level but also across companies, such as in an ecosystem. It is notable that the resources themselves do not offer competitive advantage, but it is correctly timed deployment of the company's resources such as physical capital, human resources, technological or reputational resources that create the advantage compared to competitors. Correct timing is of major importance within a changing business landscape, as any newly found advantages tend to be limited in usable time, as it diffuses across the market. This temporal dimension means that companies need to be dynamic in recognizing and utilizing their resources. (D'Aveni et al., 2010)

2.2.2 Dynamic capabilities

Dynamic capabilities were first introduced by Teece et al. (2010) during the 90's and can be seen as a continuation or expansion of the RBV framework. The rationale by which it was developed was that RBV alone could not explain companies having competitive advantage in unpredictable and rapidly changing environments, where value propositions, customer demands, or technological progress are constantly shifting valid business environment. (Eisenhardt & Martin, 2000; Helfat & Peteraf, 2009; Teece et al., 1997)

According to Teece, dynamic capabilities are companies' enablers to create, deploy and protect their assets, competences and complementary assets that reinforce their superior long-run business performance (Teece, 2007). The dynamic capabilities refer to organizational and strategic routines, reconfiguration and expansion of existing assets and resources, with focus in forces of change. They are of major importance for companies operating in international, open competition where business environments are prone to rapidly diffuse major innovations, and where most ambitious companies not only sense and respond to the changing landscape, but also drive the change themselves. (Helfat & Peteraf, 2009)

2.3 Synthesis of background

Chosen ecosystem definition is: an ecosystem is consisted of a community of multiple co-evolving actors that organized around specific value propositions/focal offerings/outputs (Shi et al., 2021). From this definition we can recognize that if green hydrogen is the chosen offering, its business ecosystem consists of and serves many separate networks or ecosystems depending on the end-user segments (such as synthetization of e-fuels or industrial usage), or where the electrolysis inputs, water and electricity, are generated.

As a conclusion of the presented theory, ecosystems consist of actors, value chains and an ecosystem-specific resource-pool in the explorative ecosystem level, which houses various actors, value creating processes and linkages whence a more defined value proposition is created through a chosen ecosystem configuration, which then emerges to the exploitative ecosystem-layer. In these aforementioned phases, a company must first determine, find or create the proper resource and partner pool from which to start configuring an ecosystem. In this the role of RBV analysis for sensing bottlenecks in emerging value propositions, as well as dynamic capabilities to create these value propositions or change existing ones, come to the forefront of management.

These theoretical frameworks are used as basis for data gathering and analysis, detailed in the next section: the roles within the nascent green-hydrogen ecosystem actors are mapped form most prevalent companies across the hypothesized value chain, and RBV and dynamic capabilities provide the basis for semi-structured interview phase of qualitative data gathering.

3. DATA AND METHODOLOGY

This chapter discusses the research methodology and research design used in this thesis. First, the philosophical premises of the research, and how this affects the chosen research approach, are discussed and justified for this thesis. Second, methods of data collection are presented, which include selection guidelines and profiles of interviewees.

3.1 Research philosophy and methods

Research philosophy refers to the 'system of beliefs and assumptions about the

development of knowledge (Saunders et al., 2019, p. 130). It is important to recognise how the researcher's assumptions and nature of available data affects the interpretation of research questions, and by extension also results. The common research philosophies in business and management studies, and different levels of research methodology, are adeptly summarized in the below Figure 9, a so called 'research onion', where the outermost layer defines the research's philosophical viewpoint, and innermost section is aimed at the data and analysis.

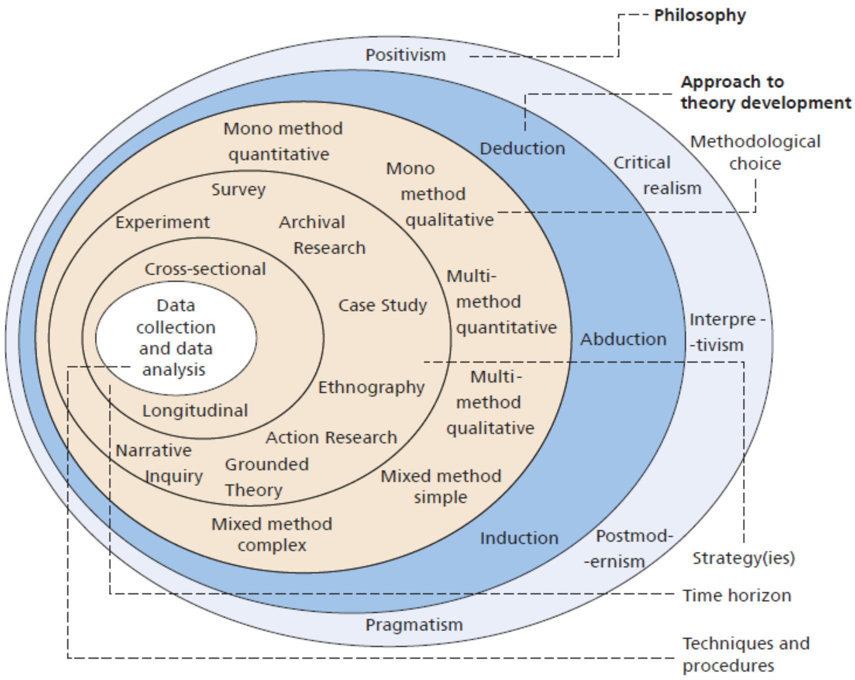

Figure 9 'Research onion' depicting research methodology perspectives. (Saunders et al., 2019, p. 130)

This study's chosen philosophy is interpretivism. Interpretivism assumes that the nature of viable information studied is socially structured and therefore subjective, instead of being governed by objective theoretical laws, so humans as social actors and their interpretations are recognized as valid information sources. Ontologically, interpretivism sees the nature of reality, or observable information, to be complex, changing and potentially having multiple meanings or interpretations. From an epistemology perspective, acceptable knowledge includes subjective meanings and perceptions, and interpretivism seeks to focus on the reality behind these details. This typically promotes an inductive research method, which creates new theories or knowledge based on collected data, over the deductive method which first defines existing theories from literature and then empirically tests them (Saunders et al., 2019, p. 144). Thus, interpretative philosophical approach lends itself well towards qualitative research and handling qualitative data, which semi-structured interviews provide.

The research subject, green hydrogen business ecosystems, do not yet exist or they are in fast-changing nascent phases, so detailed information about them is not available to be analysed. Therefore, this study adopts an *abductive* research approach, which combines deductive and inductive approaches: first, data is collected, a theory or hypothesis created from this data, and lastly tested empirically. This thesis conducts a mono-method qualitative study, the primary method being semi-structured interviews, which also dictates the next layer of the research onion that the research strategy is qualitative interview research with the time horizon being tied to the thesis project. Namely, this means that the thesis is a cross-sectional study, focusing on relevant phenomena at the time of the thesis research. (Saunders et al., 2019, pp. 152; 212)

Lastly, the final layer of the research onion defines the main data gathering and analysis, which will be looked at in their own sections next.

3.2 Data gathered

This section defines the data gathered in detail, including company data acquisition and selection of interviewees.

3.2.1 Key actor mapping

The main data gathering method for mapping the key actors was usage of in-project data, which had preliminary listings of companies, and supplementing this by exploring company websites, press releases, and a database search on Crunchbase. The purpose for exploring the companies' offering was to determine their potential roles in the ecosystem, and to theorize how the ecosystem competences and resources might develop.

Focus for company offering was given to the chosen technology, which gives some indication of potential customer segments in the future.

This data collection was specifically aimed to answer RQ1, and to further hypothesize answers for RQ2-3, to see if the companies researched indicated lack of resources or capabilities that would need to be added or rectified by other parties or partners.

3.2.2 Semi-structured interviews

The semi-structured interviews were chosen as the means to tackle research questions 2 and 3. The purpose of the interviews was therefore to find resources and capabilities for ecosystem development, and potential off-takers based on themes that were theorized from the key actor value chain as well as those suggested by literature.

Chosen interviewees were based on suggestions from X-Ahead team that had already worked with the power-to-x scene, with the aim to cover various stakeholders in P2X scene and across the value chain, within and outside Wärtsilä.

The interviewees were approached by email and respondents were given indicative interview themes ahead of the scheduled interviews, which were conducted in either Finnish or English according to the respondent’s preference. A total of 9 interviews were conducted between January and February 2022. The interviewed parties, anonymized, are detailed in Table 4 below.

Table 4 Interviewee titles, areas of expertise and durations of interviews.

Interviewee	Title	Duration
Interviewee A	Senior Manager P2X	47 min
Interviewee B	Senior Project Manager, Sustainable Fuels & Decarbonization	42 min
Interviewee C	Development Manager, Environmental Solutions	32 min
Interviewee D	General Manager, Business Intelligence	50 min
Interviewee E	General Manager, Strategy & New Business	55 min
Interviewee F	Principal Scientist, Fuel cells and hydrogen	38 min
Interviewee G	Director, Growth & Development	53 min

Interviewee H	General Manager Research Coord & Funding	51 min
Interviewee I	Professor, Electric Engineering	60 min

Each interviewer was given the same interview themes prior to the interviews, to familiarize themselves with the subject and to prepare discussing the themes according to their own specific areas of knowledge. The interview material which also defines these prepared themes is attached in appendix A. The interviews were conducted via remote connection, recorded, and transcribed.

3.3 Data analysis

Companies mapped in the first data gathering phase was mainly categorized into the electrolyser-supply or value chain, with the distinction of chosen electrolysis technology. The purpose of this formatting was to hypothesize possible ecosystem roles for the mapped companies, to determine potential leader, follower, integrator, or other roles that business ecosystem theory suggests.

The gathered data from the interview, being qualitative in nature, was gathered and summarized by the researcher with the help of transcripts, then categorized by the interview themes to compare the respondent's answers to find common or recurring sentiments.

The synthesis of both analyses is discussed in the results and discussion chapters.

4. RESULTS

This chapter presents the results from utilizing the chosen methodology to answer the research questions, which define the sections of the chapter from RQ1 to RQ3. This chapter focuses on presenting the data, whereas the following chapter 5 will discuss potential meanings and conclusions that can be derived from the results. For a clearer overview, key takes from interviews for research questions 2-3 are gathered in a SWOT format in Table 5.

Table 5 *SWOT-summary of semi-structured interview results for RQ2-3, regarding green hydrogen feasibility and off-takers.*

Green hydrogen feasibility	
Strengths **Industry**: guaranteed market in replacing fossil based (SMR) H_2 in steel making, oil refining Strongly supported by **policy** and **regulation** to achieve rapid scale-up (in Europe), which bring cost benefits in electrolysers and green H_2 Synergy with **RES**-electricity competitiveness, green H_2 cost structure implies that roughly 70% costs is from electricity price	**Weaknesses** **Energy sector**: not competitive with battery-based solutions; BESS/EV is already benefiting from economies of scale with better efficiency - P2X-X2P cycle efficiency is low with H_2 and troubled with storage concerns **Transport sector**: battery-based passenger vehicles (EVs) looking to become the dominant design Reliant on RES costs and availability to drive down production costs **Storage** is difficult and costly: main concern for wide adoption
Opportunities Hydrogen economy is highly versatile in usage possibilities and if scale is reached, H_2 is likely to diffuse to many sectors through derivatives (synthetic fuels). Any industrial scale green H_2 suppliers should seek to drop-in some production to large-margin transportation segment. Continued internalizing externalities of GHG emissions should level the playing field for alternate fuels and energy carriers.	**Threats** Unclear whether green H_2 will be the cheapest decarbonization path and become sufficiently market-driven Many competing technologies: direct electrification in transport, energy storage, bio-fuels If natural rock caverns are not available for LRC large-scale storage due competing uses (CO_2 storage), volume and scale benefits may crumble.

4.1 RQ1: Who are the key actors in green hydrogen business ecosystem?

The key actor companies along the value chain were mapped from previous x-ahead project material and database search on crunchbase, with filtering description keywords ‘green hydrogen’, ‘electrolyser’, ‘electrolyzer’, ‘water electrolysis’ and ‘clean hydrogen’ as well as company industry ‘renewable energy’, ‘clean energy’ and ‘energy’, to accumulate a list of prevalent electrolyser manufacturers and technology providers. These lists were cross-referenced with each other to determine the most capable in separate offering categories. The most prevalent companies operating in today’s market were categorized into value chain roles related to a theorized electrolysis system supply chain, depicted in Figure 10 below.

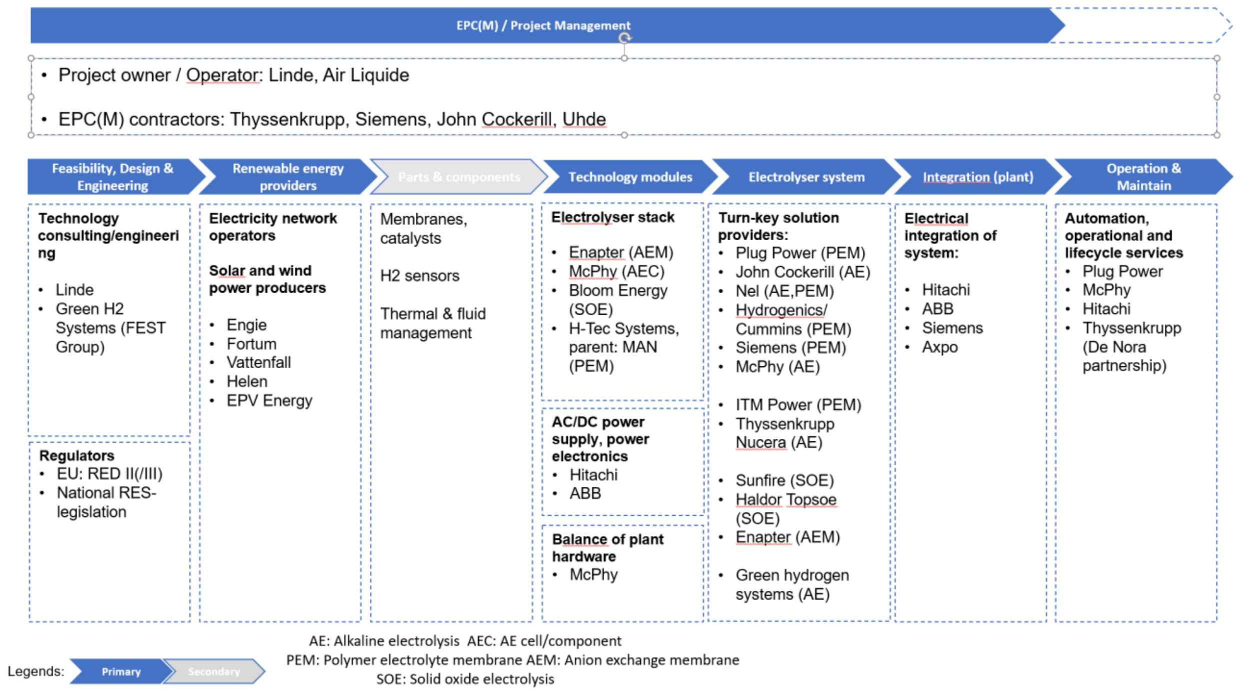

Figure 10 Electrolyser value chain with active companies, divided by supply chain activities.

In Figure 10, the main focus regarding key actors is on the electrolyser system provider section, which houses several large companies that provide turn-key scalable solutions.

Looking at the listed companies through the lens of business ecosystems, it is difficult to determine which company is currently an ecosystem leader, or whether there is one at all. The company landscape is constantly in a flux where individual module suppliers seek to scale up their production through joint ventures or are acquired by larger companies looking to diversify their business, such as MAN Solutions acquisition of H-Tec Systems.

One could argue that, from business ecosystem perspective, each individual electrolysis technology (AE, PEM, SOE, AEM) seem to be separate value proposition configurations, because they are targeting different end users or customer segments based on the various technology characteristics. PEM and AE are the most mature technologies, while SOE and AME remain R&D heavy technology. Figure 11 defines various technology readiness levels (TRL) of the primary electrolysis technologies.

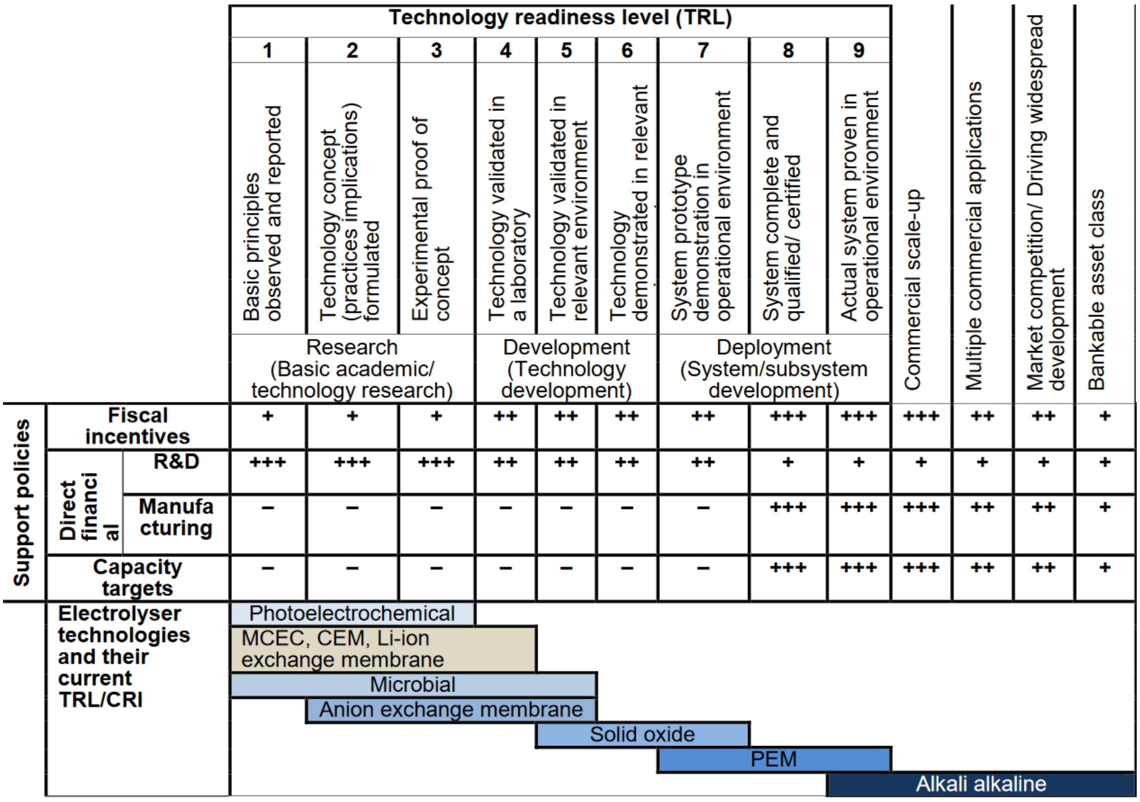

Figure 11 *TRL and support policies for electrolyser technologies. Edited from (Patonia & Poudineh, 2022).*

This graph distinguishes alkaline electrolysis to be at the forefront of commercial activity, but both AE and PEM having similar support as it comes to support policies regarding manufacturing and capacity targets. Both are depicted to be in TRL level 9 that defines the technology to be proven in system level operation. Therefore, both technologies seem to have the potential to become dominant in green hydrogen ecosystems, and it follows that the one to scale up production faster within a valid customer segment or off-takers will reap the benefits and assume a local business ecosystem leadership. Due higher energy efficiency, SOEC could in future become a competing technology in large-scale applications such as baseload-production or on areas where RES is abundant, but as of 2022, it's unlikely to carry the technology take-off.

4.2 RQ 2: What resources or capabilities are needed or lacking for reaching industrial-scale business feasibility?

The second research question's primary data source were the interviews where one lead question was specifically aimed at it. The first leading question was about phase the green hydrogen business ecosystem and its potential next steps, which supported the follow-up question of resources or capabilities needed to achieve these steps. It is notable that for the interviews, 'industrial-scale business feasibility' was supplanted by finding a successful value configuration (or a leader-role) to factually create a green hydrogen business ecosystem as depicted by the theoretical model presented in the background theory.

Not all respondents gave clear answers directly but were regardless hinting at next steps needed for ecosystem to evolve. Common notion across all respondents that directly addressed this question, was that knowledge-sharing or innovation ecosystems must be created and nurtured via pilot projects to create a functional base for finding valid business cases. Following this, policy and legislation both locally and region-wide (EU/internationally) should properly incentivize a chosen technology to guide businesses into choosing between competing technologies. Similarly, it was seen as important that these knowledge or information networks involve educational facilities so as to enable capable workforce going forward with hydrogen technology.

To cement this regulative resource's or actor's importance, interviewee I commented that '*regulation tends to lag behind actual customer and producer demands or ambitions for green values, such as for food industry regarding drop-in ammonia*', which suggests that there is increasing pressure towards clear regulation not only for industries that use hydrogen today, but also for its derivatives. Other common notes regarding demands towards regulation across most of the respondents (B, C, G, H and I) was that to gain benefits of scale, necessary hydrogen infrastructure (pipelines) and additional RES must be supported and built for hydrogen and its derivatives to become competitive.

Regarding green hydrogen competitiveness and lowering costs, several respondents (F and G) mentioned that for a true market-driven ecosystem to occur, there should first be a regionally tied large storage site, namely a lined rock cavern (LRC), that would serve as a hub for non-industrial usage of hydrogen to grow around. Non-industrial use was specifically mentioned because industrial process-feedstock hydrogen does "not need storage as it can be hybridized depending on the current need on the go". This large-scale storage to benefit from economies-of-scale is seen as a necessity for green hydrogen to get a foothold in high-margin volume-driven segment of transportation, over that of competing technologies such as direct electrification.

4.3 RQ3: Who are the potential off-takers for green hydrogen?

Like the second research question, the third was also specifically aimed at within the semi-structured interviews, with theme one being an inquiry about off-takers as-is. The respondents' answers were more harmonic than for RQ2 and each one had an opinion regarding potential off-takers.

The most common off-taker segment all EU-centric interviewees agreed on, one supported by both research of IEA and actual EU policy, was that of industrial feedstock and replacing the existing grey hydrogen supply with drop-in green hydrogen. This industry-segment includes chemical industry (ammonia, methanol production) and steel production (direct reduced iron, DRI), which is separated from oil refinery usage where hydrogen is used for hydrocracking and removing impurities. (International Energy Agency, 2021, pp. 51, 55)

Following this, for transportation sector and specifically marine which is among the so-called hard-to-abate sectors, green hydrogen derivatives such as methanol or ammonia were seen as the most prominent off-taker segments. Notably, the potential in transportation sector was specifically limited to those applications where direct electrification, such as passenger vehicles, cannot compete yet due to limitations in range or the weight of batteries. According to interviewee I, these limitations might be overcome even in heavy road transport with battery-switching stations or similar measures, and only marine and aviation transport could be seen as truly certain off-takers in the long run.

Most other off-takers were seen to be reliant on policy which should dictate 'internalizing externalities of GHG' (respondent H), meaning assigning proper price to societal costs of not only grey hydrogen, but also to other supply chains in other segments such as power generation. In other words, if green hydrogen is seen primarily as a decarbonization measure, it needs to be competitive or supported to become such with other direct decarbonization measures such as fossil sources coupled with carbon capture and storage (CCS).

IEA recently, at the time of writing, published a global hydrogen overlook that was referenced by several interviewees as a source for their latest opinions regarding likely off-takers. Below Figure 12 depicts two scenarios of hydrogen demand increase, the left one 'Announced Pledges' depicts currently government-issued pledges of hydrogen use, such as EU's proposed Fit-for-55 package (European Commission, 2019) and the right one depicts targets that would bring about a net-zero GHG emissions by 2050, which is in line with the Paris Agreement's 1.5°C target to global temperature increase.

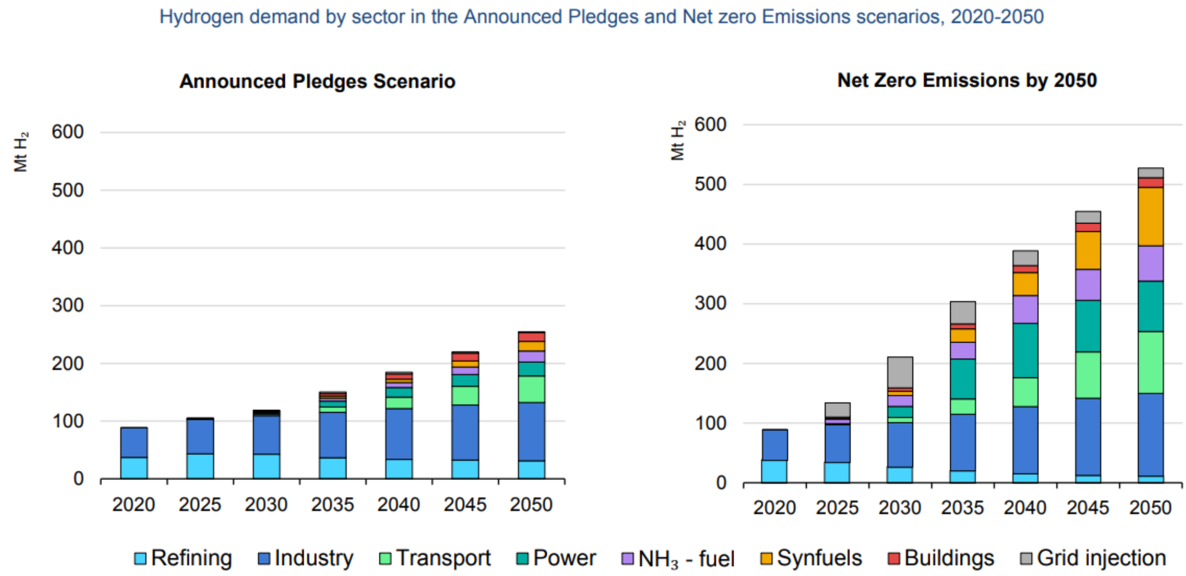

Figure 12 Potential hydrogen demand by sector. (International Energy Agency, 2021, p. 44)

As one can surmise from the graph, it is likely that green hydrogen will have a guaranteed demand in many sectors over the currently grey hydrogen using oil refining and industry, which will be replaced first with cleaner hydrogen varieties, blue and green. Notably, the 2020 demand in the graph is almost entirely grey H_2, so green hydrogen already has a base demand in green transition of today's use cases and will only increase in these scenarios. At first, the demand is focused within the industry and refinery sector, but in the net zero -scenario all other uses would in the long run surpass them in demand.

5. DISCUSSION

The discussions chapter's purpose is to connect the results gained to the relevant theory and discuss how they connect to the wider environment. Regarding the mapped companies or key actors today, it's clear that there is not yet a developed ecosystem and the theory's suggested leader role has not yet been reached. Several larger companies that have over-arching EPC (engineering, procurement and construction) capability or several value chain segment activities are potential candidates for this role. Companies such as Thyssenkrupp or Siemens have, by size alone, more scaling-power of electrolyser production. Other companies such as McPhy, are already active in most parts of the value chain and prepared to offer complete product and service configurations, which might make them local or niche leaders depending on their capability to compete with bigger conglomerates or groups seeking to become integrators in electrolyser business.

Regardless, the ecosystem phase is still in an uncertain, nascent preparation and formation phase characterized in figure 6. This is based on the interviews' common resource-needs being methods or platforms to crystallize market-driven business cases, namely networks of knowledge sharing, workforce education or training, and finding relevant partners.

In the interviews, a theme regarding ecosystem roles (theme 3) fit for different companies was brought up and opinions of how green hydrogen would affect different industry segments were given by several respondents. Most respondents were familiar with either energy or marine business, which somewhat divided opinions somewhat of a potential role that a technology-provider company like Wärtsilä could seek. Some saw that green hydrogen will become such a major energy vector in the future that electrolyser business would eventually commoditize and become low-margin business for technology-provider role (as it comes to electrolysers or their components). Thus it would be better to focus on hydrogen end uses and technologies related to the demand side instead of supply side if remaining in a technology-provider status.

6. CONCLUSIONS

6.1 Key contributions

The aim in this study was to map a value chain for an electrolyser-focused business ecosystem, and to identify key actors in green hydrogen production. On top of that, exploring the potential business environment through identification of likely off-takers and bottlenecks for business scaling were determined as relevant areas to gather information on. The results purpose was to support business strategy development within X-Ahead and Wärtsilä in the P2X field, and so this thesis is written with managerial perspective as the target group.

Main contribution along answering research questions, with the use case in mind, was to promote ecosystem thinking in strategic development process, whereby the literature review of ecosystem theory rose as an important aspect of the research because research questions were acknowledged to be very wide and challenging to analyse without an actual case which to find specific data on.

6.2 Research assessment and limitations

The study conducted in this thesis is limited in generalizability as the data gathering of interviews was limited to certain parts of the value chain, which was due time limitations and the very general research questions which necessitated a narrower focus nearing the end of research time frame.

The results were also purely qualitative in nature and furthermore, tied to the particular time when the research took place. The semi-structured interview themes were also set and unaltered throughout the interviews, yet there was room for improvement to them based on feedback from the interviewees. This could have been rectified by using multiple interview rounds or multi-method qualitative approach in the research, but it was not possible within the allotted timeframe.

These in tandem mean that the research results leave many questions open which might become clearer later as the ecosystem and knowledge of green hydrogen develops.

6.3 Proposals for future research

The researcher suggests that ecosystem framework's applicability to green hydrogen and electrolyser business could be explored further through case studies of real-life projects, those of partners or from other empirically accessible sources. This would assist in testing whether next emerging phases of green hydrogen ecosystem follow the theoretical framework and assist in crystallizing viable ecosystem roles, and therefore ecosystem management.

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APPENDIX A: INTERVIEW THEMES

Value chain and business ecosystem analysis of green hydrogen production

The overall aim with the interviews is to form a status check of sorts with the following lead questions:

- **In what kind of phase is the green hydrogen business ecosystem? How might it evolve?**
- **What capabilities or resources are needed / are missing / exist in the ecosystem roles or across the value-chain?**

Theme 1: Potential off-takers and market potential

What kind of potential do you see in green hydrogen and side streams (oxygen, heat)? Who would be the first off-takers? Considering a timeline of present situation until 2030.

Theme 2: Value drivers for a business case

What do you see that would be your company's or organization's value drivers in a green hydrogen ecosystem / business case?

Theme 3: Roles

How do you see your company´s or organization's role (see attached picture) in a green hydrogen ecosystem? Are there important roles to be added or missing?

Theme 4: Regulation

What kind of regulation drivers effect your company´s or organization's role in a P2X ecosystem? Is there important regulation needed or missing?

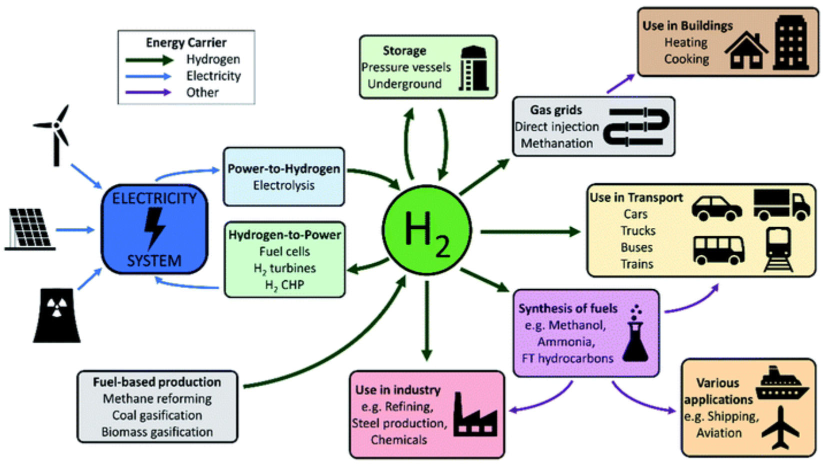

***Figure 133** Source: https://pubs.rsc.org/en/content/articlehtml/2020/se/c9se00833k*

APPENDIX B: HYDROGEN STRATEGIES 2021

CATEGORY	ASIA: Australia	ASIA: Japan	ASIA: South Korea	EUROPE: EU	EUROPE: France	EUROPE: Germany	EUROPE: Hungary	EUROPE: Netherlands	EUROPE: Norway	EUROPE: Portugal	EUROPE: Spain	LAC: Chile	NORTH AMERICA: Canada
Strategy contains timeline for market development with targets	Detailed	Detailed	Detailed	Detailed	Mentioned	Detailed	Mentioned	Mentioned	Not seen	Mentioned	Detailed	Detailed	Detailed
Strategy contains hydrogen cost targets	Mentioned	Detailed	Detailed	Not seen	Not seen	Not seen	Not seen	Not seen	Not seen	Not seen	Not seen	Mentioned	Mentioned
Strategy includes measures to support H2 development													
Direct investments	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Not seen	Mentioned	Detailed	Detailed	Mentioned	Mentioned	Mentioned
Other economic and financial mechanisms	Detailed	Mentioned	Detailed	Detailed	Detailed	Detailed	Mentioned	Detailed	Detailed	Detailed	Mentioned	Mentioned	Mentioned
Legislative and regulatory measures	Detailed	Mentioned	Detailed	Detailed	Mentioned	Detailed	Mentioned	Detailed	Mentioned	Detailed	Detailed	Detailed	Mentioned
Standardisation strategy and priorities	Detailed	Detailed	Detailed	Mentioned	Mentioned	Detailed	Mentioned	Mentioned	Detailed	Detailed	Detailed	Mentioned	Detailed
Research & development initiatives	Detailed	Detailed	Detailed	Mentioned	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Mentioned	Detailed
International strategy	Detailed	Detailed	Mentioned	Mentioned	Mentioned	Detailed	Detailed	Detailed	Mentioned	Detailed	Detailed	Mentioned	Mentioned
Strategy addresses social issues for H2 development	Detailed	Detailed	Detailed	Not seen	Detailed	Mentioned	Not seen	Mentioned	Mentioned	Detailed	Detailed	Detailed	Detailed
Strategy includes review and update	Mentioned	Not seen	Not seen	Not seen	Not seen	Detailed	Not seen	Not seen	Mentioned	Mentioned	Detailed	Mentioned	Not seen
Strategy's H2 target source by 2030	Clean	Fossil-based with CCS	From natural gas	Low carbon	Low-carbon & fossil based	Carbon-free	Low carbon & carbon free	Blue & Green	Clean	Green	Renewable	Green	Low carbon intensity
Strategy's H2 target source by 2050	Clean	CO_2-free	Eco-friendly CO_2-free	Clean / Renewable	Low-carbon	Renewable	Low carbon & carbon free	Green	Clean	Green	Renewable	Green	Low carbon intensity
Import / Self-reliance / Export	Export; Self-reliance	Import	Import; Export (tech)	Depends on Member States	Export	Import; Export (tech)	Self-reliance	Import to export H2 (EU hub)	Self-reliance	Self-reliance; Export	Self-reliance; Export	Self-reliance; Export	Self-reliance; Export
MAIN GOALS / DRIVERS													
Decarbonisation	Lower	Immediate	Lower	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Diversify energy supply	Lower	Immediate	Long term	Lower	Lower	Immediate	Immediate	Immediate	Lower	Immediate	Immediate	Lower	Immediate
Foster economic growth	Immediate	Immediate	Immediate	Lower	Immediate	Immediate	Lower	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Integration of renewables	Lower	Lower	Long term	Immediate	Lower	Immediate	Lower	Immediate	Lower	Immediate	Immediate	Immediate	Immediate
SECTORAL PRIORITIES													
Heating	Immediate	Immediate	Lower	Lower	Lower	Lower	Immediate	Immediate	Lower	Immediate	Lower	Immediate	Immediate
Industry													
Iron and Steel	Long term	Lower	Lower	Long term	Immediate	Immediate	Long term	Immediate	Lower	Immediate	Lower	Not seen	Immediate
Chemical feedstock	Immediate	Lower	Not seen	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Refining	Not seen	Lower	Not seen	Immediate	Immediate	Immediate	Immediate	Immediate	Lower	Immediate	Immediate	Immediate	Immediate
Others (cement, etc.)	Not seen	Not seen	Not seen	Not seen	Immediate	Lower	Long term	Lower	Not seen	Immediate	Lower	Not seen	Immediate
Power													
Power generation	Lower	Immediate	Immediate	Lower	Not seen	Not seen	Lower	Lower	Not seen	Lower	Lower	Not seen	Lower
Back-up services	Lower	Lower	Lower	Lower	Not seen	Not seen	Long term	Lower	Not seen	Lower	Lower	Not seen	Lower
Transport													
Passenger vehicles	Lower	Immediate	Immediate	Lower	Lower	Lower	Long term	Immediate	Lower	Lower	Lower	Long term	Immediate
Medium and heavy duty	Immediate	Long term	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Lower	Immediate	Lower	Immediate	Immediate
Buses	Immediate	Long term	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Lower	Immediate	Lower	Immediate	Immediate
Rail	Lower	Lower	Lower	Immediate	Immediate	Immediate	Lower	Immediate	Not seen	Immediate	Lower	Not seen	Long term
Maritime	Long term	Lower	Lower	Long term	Lower	Long term	Lower	Lower	Immediate	Long term	Lower	Long term	Long term
Aviation	Lower	Lower	Not seen	Long term	Immediate	Long term	Not seen	Lower	Lower	Long term	Lower	Long term	Long term

Source: World Energy Council

[3] *Methodology: National strategies published until 30th May 2021.*

Strategies content: *Detailed* *Mentioned* *Not seen*

Goals and sector priorities: Immediate priority Long term priority Lower priority Not seen

Figure 14 *Country characteristics of published hydrogen strategies. Used by permission of the World Energy Council.*