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Building a Biorefinery Business

If it doesn't fit, make it fit – strategies for successful commercialization

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Supervisors

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"If you want to move the bioeconomy forward what it needs is success stories; it needs to have companies that are making profitable products derived from biomass. I mean, I have been doing this for 25 years and it's a wasteland of little companies that say they have the ultimate solution and then fail." (participant 3, 2017)

"Who can say anything about the conditions of the markets, when you look at the policy area around transports and decarbonization, electrification of transport. How much of second generation fuel demand will there be around 30 years from now. If we now decide to build a large bio fuel production facility…gasoline investment in Europe is declining even faster than printing paper. So why should we put a lot of investment into fuel markets that we basically believe will be stable or shrinking in the future?" (participant 6, 2017)

"from a technical perspective, generally in the biofuels industry there is a bit of a feeling of once bitten twice shy, so there has been a lot of hype around a number of different technologies that for various reasons just did not work. So, a lot of people are fairly skeptical of … new technology. And so, overcoming that has been a challenge and when it comes to process technology in general I think everybody wants to be first to be second so … nobody wants to build the first plant…" (respondent 2, 2017)

"So, we have to get to a point where we are serious about changing to a bio-based economy. Right now, that's politically very challenging because oil companies are extremely powerful when it comes to politics around the world. So, when it comes to policies in the U.S., money is very powerful and the oil companies have a tremendous amount of money. For every dollar we spend in lobbying, the oil companies are spending 15 till 20 dollars." (respondent 4, 2017)

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Abstract

Due to a combination of economic challenges as well as uncertain policy conditions in the United States and the European Union, the development of (advanced) biorefineries has been slower than anticipated. This has hampered the transition to a more sustainable and less carbon-intensive economy, namely the bioeconomy. In this thesis, the technological innovation system (TIS) approach is combined with the business model (BM) framework to analyze how biorefineries have addressed commercialization challenges and system weaknesses in practice. Hereby, a business-centered perspective is taken, using case study analysis and expert interviews as major means of empirical data collection. The analysis highlights a number of key strategies that have been applied: (1) cooperation, partnerships and networks play a major role for e.g. the mobilization of resources, market formation and knowledge development and diffusion; (2) a high degree of vertical integration, especially upstream, is found to overcome feedstock related challenges (3) product and market diversification into higher values is perceived as key to overcome dependence on oil prices and policy frameworks. Furthermore, prospects for lignocellulosic biorefineries are considered low due to unfavorable economics and lack of policy incentives. In addition to the empirical contribution, the study contributes with novel insights into the role of agency and individual actors as system builders within the TIS framework. The thesis thus suggests that both actor specific activities as well as policy measures are needed to overcome system weaknesses to achieve successful commercialization of biorefineries.

Keywords: biorefinery, technological innovation systems, strategic management, business model, case study

Executive Summary

The concepts of biorefining and biorefineries are largely considered an integral part of the sustainable bioeconomy, as they provide an important pathway to reduce the demand for fossil resources throughout the economy and as such contribute to the mitigation of climate change, fostering energy security and independence, as well as constituting a pivotal role in increasing the efficient use of resources.

Commercialization of biorefineries is hereby clearly needed for the benefits to materialize; however, commercialization and large-scale diffusion of biorefineries requires not only the introduction of new technology, but also sociotechnical changes entailing a variety of actors, interests and institutions. Albeit the envisioned benefits of biorefineries, their implementation in practice remains considerably low.

Firms are considered to play a crucial factor in the commercialization of new technologies, as without dynamic adaption within their strategies and business models, no market introduction would take place. However, firms do not innovate in isolation, but are exposed to their wider socioeconomic context with which they interact. This environment can impose specific barriers on the innovating firm; which need to be addressed. In the context of biorefineries, it is often called for increased policy support towards greater commercial usage. However, the role of firms and how specific barriers can be overcome by them in relation to policy intervention has not been discussed yet. Literature does not explore the strategic responses of biorefinery firms implemented in order to create favorable conditions for themselves and influence the system around them. In addition, an empirical study analyzing how these implemented strategies unfold in practice has not been conducted yet.

Therefore, the purpose of this study is to investigate the strategic responses which have been applied in practice by firm-level actors. The aim is to explore and analyze which barriers to commercialization can be successfully overcome by biorefineries, while other may need the support from further actors in the system.

To guide the study, one main research question was formulated:

RQ: Which biorefinery commercialization strategies have been successfully applied in practice and how?

To achieve the aim of this research and answer the research question, a qualitative research approach was used, consisting of a single case study in combination with complementing expert interviews. The research is based on a triangulation of data sources and collection methods. Data was collected through a literature review, semi-structured interviews, whereby the latter constituted the backbone of the study. Data sources included academics (literature), practitioners (literature, interviews) and other stakeholders (literature).

The data is analyzed using qualitative methods. The analysis and discussion of the results obtained – both from the case study as well as the expert interviews – is guided by an analytical framework that is based on the integration of insights from three frameworks: The Technological Innovation System, a business model framework, and the Multilevel Perspective (to a lesser degree). From within these frameworks the focus is on the analysis of strategies and business model configurations as proxies for responses of biorefineries towards commercialization challenges. These responses are analyzed in relation to their effect on the Functions of the Innovation System. The case study is discussed at first, followed by a comparative discussion in relation to the expert interviews and literature.

The case study under investigation is the U.S. based biotechnology company Amyris, Inc.; the complementary expert interviews were conducted with Lanzatech (USA), Novozymes (Denmark), POET (USA), Storaenso (Finland/Sweden), Sunpine (Sweden), Verbio (Germany);

Analysis found that a range of strategic reponses to commercialization challenges were applied by the entprepreneurial actors to engage in system-building activities. Whereas most companies have started with a focus on biofuels due to a combination of landscape signals that have created favorable expectatons and mobilized resource for the biofuels sphere, focus has shifted over time. Strategies nowadays focus on achieving product portfolio diversification strategies to decrease dependence on oil price developments and policies. Hereby a step-wise development has proven viable, as resource mobilization and market formation have to be secured. In that context, collaboration across the supply chain has also proven to serve as a catalyst to positively influence the functions of innovations system. Further a high degree of flexibility with regards to feedstock, products and processes can also enhance the successful commercialization.

Based on the results, it is suggested that policy needs to establish a clear vision and targets to move the bioeconomy forward and needs to clearly position itself towards both biofuels and biomaterials. Especially in relation to the former market formation needs to be clearly policy-driven. Thus, a revision of current policy approach is urgently needed to provide for a stable a reliable investment climate, the lack of which has hampered developments in the field. Without policies, the bioeconomy will materialize much slower.

The study has also shown that by using strategic responses to overcome challenges, biorefinery businesses can position themselves on the market independent of policies. Thus, when building a biorefinery business it first needs to be decided what kind of strategy and corresponding business model to be implemented. Careful attention needs to be both the ability to mobilize resources and establish supply and demand at the same time. A collaborative approach towards developing and commercializing biorefineries, focusing on markets where the price point is accessible can help, has proven a viable strategic approach.

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Abbreviations

BM	Business Model
Ch.	Chapter
COP 21	Conference of the Parties 21
DOE	Department of Energy
e.g.	exempli gratia
etc.	et cetera
EU	European Union
FiS	Functions of Innovation Systems
GHG	Greenhouse Gas emissions
i.e.	id est
IEA	International Energy Agency
ibid	ibidim
IIIEE	International Institute for Industrial Environmental Economics
Inc.	Incorporation
IPCC	Intergovernmental Panel on Climate Change
MLP	Multilevel Perspective
NREL	National Renewable Energy Laboratory

OECD	Organization for Economic Cooperation and Development
R&D	Research & Development
RQ	Research Question
SMEs	Small- and Medium-Sized Enterprises
TIS	Technological innovation system
UNFCCC	United Nations Framework Convention on Climate Change
U.S.	United States of America
WEF	World Economic Forum

1 Introduction

To reduce greenhouse gas (GHG) emissions into the atmosphere and cope with the challenge of climate change, the need for a transition to a low-carbon economy is urgent (IPCC, 2014). This is reaffirmed by the decision made in December 2015 by The UNFCCC Conference of the Parties, or COP 21, which confirmed the goal of limiting the global temperature increase well below 2 degrees Celsius and established binding commitments that require all parties to make nationally determined contributions and proceed thereafter with domestic measures aimed at achieving them (UNFCCC, 2015).

To meet the ambitious targets, the concept of bioeconomy is sought to represent an opportunity to address these challenges and has gained increased attention within politics and research - in Europe as well as globally (Kleinschmit et al., 2014; Safferman, Liao, & Saffron, 2009). The concept of bioeconomy can be understood as an economy where the basic building blocks for materials, chemicals and energy are derived from renewable biological resources, such as plant and animal sources (de Besi & McCormick, 2015; McCormick & Kautto, 2013).

The concepts of biorefining and biorefineries are largely considered an integral part of the sustainable bioeconomy (Kishna, Negro, Alkemade, & Hekkert, 2012), an understanding widely shared and supported by leading global organizations such as the Organization for Economic Cooperation and Development (OECD) (Arundel & Sawaya, 2009), the International Energy Agency (IEA) (de Jong, Higson, Walsh, Wellisch, & others, 2012) and the World Economic Forum (WEF) (King, Inderwildi, Williams, & Hagan, 2010). Biorefineries as a concept are hereby for utmost regarded as replacement for petro-refineries (Kamm & Kamm, 2004; Langeveld, Sanders, & Meeusen, 2012). In analogy to the development of oil-refineries, starting with fuels – biorefineries are intended to follow a step-wise development pathway from biofuels to an integrated production of energy, fuels, chemicals and other products from biomass. In fact, biofuels are currently the most visible and large-scale output of the existing bioeconomy (Bünger, 2010; Ragauskas et al., 2006; Richardson, 2012). Beyond fuels, there are many other product categories that have been identified, where biorefineries could have a major contribution, e.g. platform chemicals (Bozell & Petersen, 2010), plastics (Shen, Worrell, & Patel, 2010) and other materials (Jong, Higson, Walsh, & Wellisch, 2012). As such, biorefining allows for the production of both high-value low-volume and low-value high-volume products (Hansen & Coenen, 2015).

Hence, in relation to the bioeconomy, biorefineries are seen as an important pathway to reduce the demand for fossil resources throughout the economy and thus contribute to the mitigation of climate change (Kircher, 2012), higher energy security and independence from global dynamics, and striving for the efficient use of resources (Chen, Cline, & Smith, 2016; Keegan, Kretschmer, Elbersen, & Panoutsou, 2013). Beyond these major positive impacts, biorefineries are also seen as a remedy for struggling industry sectors such as the forestry sector, providing answers to an increasingly competitive environment (Kleinschmit et al., 2014; Ollikainen, 2014) in addition to helping with rural development and job creation (Sonnenberg, Baars, & Hendrickx, 2007); the list of potential benefits is immense.

1.1 Problem Definition

For these benefits to materialize, commercialization and large-scale diffusion of biorefineries is needed (Hansen & Coenen, 2015). Such a transition not only involves the introduction of the new technology, but also sociotechnical changes including a variety of actors, interests and institutions (Geels, 2002; Langeveld et al., 2012; Rip & Kemp, 1998).

However, while there is a large technical potential for biorefineries to facilitate the transition to a bioeconomy with an impressive number indicating that over 90% of oil-based products could be replaced by biomass-derived alternatives (Bünger, 2010), the scale of activities remains considerably low. In 2012, bio-based products replaced only 0.2% of petroleum-based goods and many biomass markets, e.g. for solid biofuels, rely on policy support and incentives (Richardson, 2012); The difficulties with scale-up are especially reflected in the delays and/or severely reduced volumes commercialized in comparison to the initially announced capacity (Sanford, Chotani, Danielson, & Zahn, 2016). In fact, most biorefinery projects in Europe and North America have only reached pilot, demonstration or semi-commercial status (Bacovsky, Ludwiczek, Ognissanto, & Wörgetter, 2013). While the experimental verification through the development of demo- and production-scale facilities has helped to overcome important technical constraints (Bozell, 2008; Wellisch, Jungmeier, Karbowski, Patel, & Rogulska, 2010), other sociotechnical barriers to commercialization, e.g. economic, continue to exist (Palgan & McCormick, 2016), not least with the dependence on oil price developments.

There are various strategies different actors in the sociotechnical system can deploy to overcome the prevailing challenges. In the context of biorefineries, it is often called for increased policy support towards greater commercial usage (Ragauskas et al., 2006; Schieb & Philp, 2014). Yet, firms are considered to play a crucial role in the commercialization of new technologies, "as they experiment with ideas, concepts, and innovations and they can turn the potential of new knowledge, networks and markets into concrete actions to exploit new business opportunities and thus facilitate that the commercial potential is leveraged" (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007). Without firm actors, their strategies and business models, technologies would not make it to the market (Boons & Lüdeke-Freund, 2013; Boons, Montalvo, Quist, & Wagner, 2013). As Chesbrough (2010: 354) notes, "the economic value of a technology remains latent until it is commercialized in some way via a business model." (Chesbrough, 2010: 354). However, as stressed earlier, firms do not innovate in isolation, but are embedded in a specific environment – the innovation (eco) system which they obtain resources from (Hekkert et al., 2007; Kishna, Negro, Alkemade, & Hekkert, 2012). Firms thus do need specific strategies to deal with the barriers – e.g. to commercialization – in their environment (Kishna et al., 2012). The system barriers are considered to be especially high when radical innovations are intended to replace incumbent and mature systems (Kishna et al., 2012), which is the case with the biorefineries in relation to the mature petroleum industry with its more than 50 years of industry experience.

Yet, the way biorefining business respond and influence the system surrounding them through their pursued strategies has not been explored yet. Recent literature has either analyzed the wider system to identify system weaknesses for policy intervention (Bauer, Coenen, Hansen, McCormick, & Palgan, 2017; Carriquiry, Du, & Timilsina, 2011), concentrated on the identification of barriers (Fernando, Adhikari, Chandrapal, & Murali, 2006) or discussed individual aspects such as supply chains (Ekşioğlu, Acharya, Leightley, & Arora, 2009). A recent review actually finds that the vast majority of biorefinery-related publications seem to be concerned with the development of biorefinery technologies and processes, while less than 5 % of them can be categorized as 'social sciences', 'economics, econometrics, and finance', or 'business, management and accounting' (Bauer et al., 2017).

Therefore, to support the development of biorefinery technologies, research is needed to gain a thorough understanding of strategies firm-level actors (biorefineries) can follow in relation to the various commercialization barriers they face; this is where this study fits in. The aim is not only limited to contribute to research on biorefineries and the work of the IEA, but also to support practitioners – policy as well as business actors – through facilitating learning processes in terms of the aspects that need careful consideration when building a biorefinery business.

1.2 Research Questions

Against the identified research gap, the aim of this study is to gain insight into strategies used by biorefinery businesses in practice to influence the system they are embedded in and to determine which barriers to commercialization can be successfully overcome by them, while other may need the support from other actors in the system. The thesis thus revolves around the one research questions, which is outlined below; three steps are identified that are required to be taken for obtaining the necessary results to answer it.

Table 1-1. Research questions and prerequired research steps

Research Question	Which biorefinery commercialization strategies have been successfully applied in practice and how?
Step 1	Review of the commercialization challenges that biorefineries have to overcome.
Step 2	Review of theoretical reflections on commercialization of new technologies.
Step 2	Integration of both perspectives for the deduction of a theoretically sound and practically relevant framework for a) the systematic and structured data collection and analysis of the strategies that have been applied in practice; and b) the delineation of the role business actors can assume in relation to the wider sociotechnical system.

Source: author's own depiction

1.3 Overview of Methodology

In the following section the methodological approach used to fulfil the research aim is presented briefly, with a more detailed description found in Chapter 3.

The study follows a qualitative single case-study approach combined with complementary expert interviews. As case, a biorefinery is selected and analyzed. As experts, representatives from biorefineries and biotech companies are selected and their contributions analyzed.

A triangulation of data sources and collection methods is employed. Data is collected through the review of different literature sources, conducting semi-structured interviews and email correspondence. Data sources include academics such as journal articles and practitioner's contribution in "grey"- literature and interviews. The conducted interviews with practitioners from biorefinery/biotech companies constitute the backbone of the case study analysis and discussion.

The analysis and discussion of the strategic responses in relation to the commercialization barriers is combined and structured according to a conceptual framework developed for the systematic structuration – not explanation – of the former. The framework is presented in Chapter 2.2 and defines the aspects to be considered in the analysis. Different conceptual frameworks and theoretical streams informed and were integrated into the framework. Each dimension is applied to the case study and the expert interviews respectively.

1.4 Scope

This thesis focuses on the whole value chain of the biorefinery business and the respective strategies for commercialization in relation to them at the intersection of the firm itself and its innovation system. As strategies for commercialization, all strategies are summarized which are directed towards achieving successful market introduction of the resulting products from biorefining processes, including those for upstream supply development and downstream demand development. However, processes happening inside the biorefinery business of behavioral nature are treated as "black box"; the discussion of technological matters is also kept to a minimum necessary for the analysis. In addition, the terms biorefinery business/firm/biorefinery are used interchangeable throughout the thesis.

As will be elaborated on in the following chapter (Ch. 2), the focus of the analysis is reasonably chosen to be on biorefineries following a multi-product pathway beyond biofuels. However, challenges to commercialization are considered to resemble to certain degrees, thus literature on biofuel is included, too. Apart from that, as it is not yet known what type of biorefineries will emerge in the future with regards to feedstocks, technologies and processes, an inclusive broad definition is intentionally used. The definition is also elaborated on in the following chapter.

Regarding geography, the analysis is limited to biorefinery development in North America and Europe, as these regions have been among the most active in the development of biorefineries and analyzed in the research literature (Bauer et al., 2017). However, the different regional or sectoral differences within these geographical contexts are not distinguished further.

With regards to time, the research focuses mainly on phenomena that occurred within more or less the same time frame, as for comparability – policy framework and sociotechnical environment – this is sought to be important. There are few biorefineries – in e.g. Sweden and Norway – which have thus not been considered for analysis as they have been developed decades ago with very different motivations which are not considered comparable to more recent activities.

Further specific scoping issues and limitations are discussed in the Chapter 2 (Background and Theory), Chapter 3 (Methodology) and in Chapter 5 (Conclusion).

1.5 Ethical Considerations

Some ethical consideration need to be taken into consideration here, as the study is partially based on interviews. It was important to make sure that interview partners participated voluntarily and to the knowledge of the author, this was always given. In addition, approval needed to be obtained that interviewees agree with being referred to by name and also approve with the correctness of the statements used on their behalf. Interviewees were provided a draft version of the thesis prior to publication.

Finally, the author confirms that common academic standards are honored and ownership is clearly attributed to foreign texts and ideas. The author applied good academic practice to reach a high level of objectivity, however, influence of the author's subjective point of views can never be fully eliminated. This is briefly addressed in the introduction to the methodology section where the author elaborates on the epistemic view followed.

1.6 Audience

The research at hand has been written as part of the Master of Science program in Environmental Management and Policy at the International Institute for Industrial Environmental Economics (IIIEE) at Lund University in Lund, Sweden. It aims to contribute to the ongoing research biorefineries and the bioeconomy. In particular, the thesis contributes to the work of the International Energy Agency Bioenergy Task 42, which it is part of. Further, the study may be of interest for the actors involved into biorefining, especially those that have contributed to the study, but also beyond. At the same time, other practitioners from the policy sphere may also benefit from the better understanding of commercialization strategies and the issues that remain unresolved.

1.7 Disposition

The remainder of the thesis will progress as outlined in figure 1-1. Some more background is provided in Chapter 2.1 where biorefineries and the literature on commercialization challenges is outlined. This will serve the purpose of providing the necessary understanding of the sources of complexity associated with building a biorefinery business and commercializing it.

The second half of chapter 2 (2.2) is dedicated to looking at commercialization from a theoretical perspective and reviewing frameworks and approaches that are relevant and useful for structuring the analysis later on.

In Ch. 3 the methodology is presented starting with the research design and approach in 3.1. and continuing with the analytical framework which is constructed for the purpose of analyzing the findings. As depicted in figure 1-1 below, the visual representation and aspects included in the framework follow a mixed approach of deductive-inductive iteration. The review in Ch. 2 as well as the findings both informed the final framework.

In Ch. 4 the findings are presented and discussed following – in its structure – the analytical framework. The section concludes with a summary of the most important highlights before chapter 5 concludes with answering the research questions, identifying further research needs, deriving implications – theoretical as well as practical – and discussing limitations to the study.

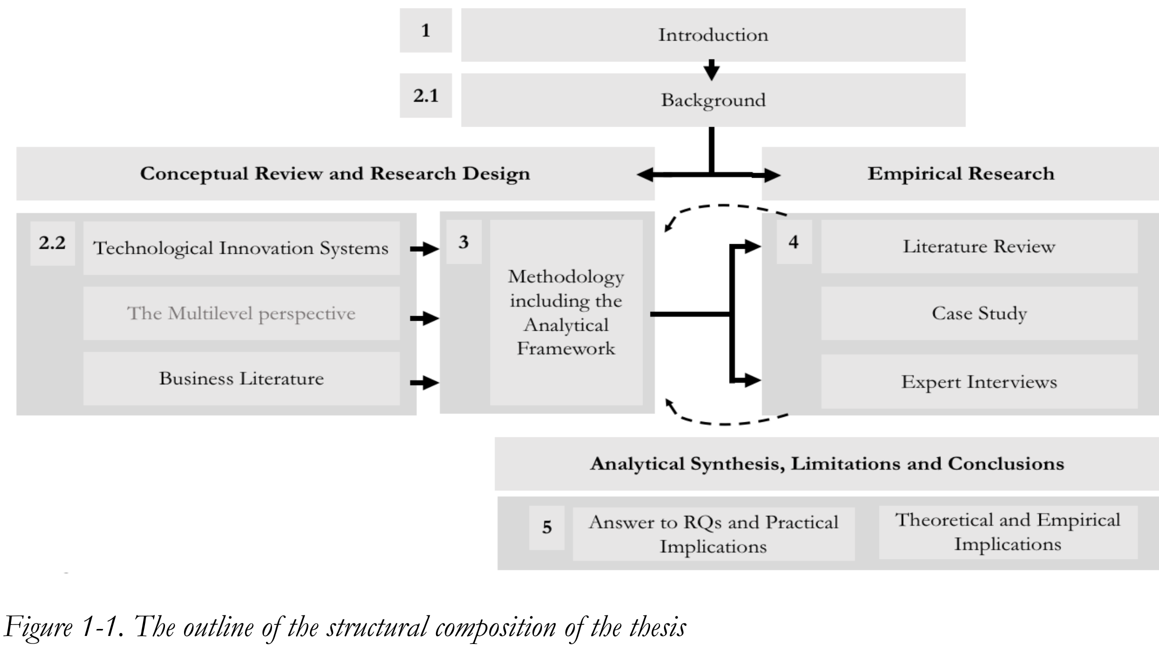

Figure 1-1. The outline of the structural composition of the thesis

Source: author's own elaboration

2 Commercialization of Biorefineries: Background and Theory

The aim of this chapter is twofold. Firstly, it aims to introduce biorefining and biorefineries for the illustration of the complexity associated with them. This includes one section reviewing and summarizing the commercialization challenges of biorefineries as identified by the research community. By doing that, the necessary background information is provided for the understanding of the origins of the discussion and the sources of challenges relevant for commercialization. Secondly, the review will turn to the theoretical review necessary to develop a conceptual framework later on as part of the methodology. For that purpose, frameworks and concepts are examined which were developed to systematize the analysis of relevant structures and processes around the deployment and diffusion of new technologies from a theoretical perspective. The review in that regard was always guided by the desire to utilize them in a conceptual model that captures all relevant aspects to be considered when analyzing the commercialization of a biorefinery business.

2.1 Biorefinery Concepts and Commercialization Challenges

2.1.1 Concepts and Definitions

While the concept of biorefining is not new – aspects of the approach can be found in conventional converting technologies used in the sugar, starch and pulp and paper industry (Sonnenberg et al., 2007) – as a research field it is still in an early stage; this is reflected in its terminology. There is no single accepted definition, but rather a series of definition which all serve to partially understand (aspects of) the subject (Schieb, Lescieux-Katir, Thénot, & Clément-Larosière, 2015). A selection of recent and some of the most prominent definitions of biorefineries is presented below:

“Biorefinery is an overall concept of a processing plant where biomass feedstocks are converted and extracted into a spectrum of valuable products. Based on the petrochemical refinery.” (US DoE, 1997)

“the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat). This means that biorefinery can be a concept, a facility, a process, a plant, or even a cluster of facilities.” (IEA, 2009)

“A biorefinery is an overall concept of a processing plant where biomass feedstocks are converted and extracted into a spectrum of valuable products. Its operation is similar to that of petrochemical refineries.” (Kamm, Gruber, & Kamm, 2007; Kamm, Kamm, Gruber, & Kromus, 2005)

“A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power and (organic) chemicals from biomass. The biorefinery concept is analogous to today’s petroleum refineries, which produce multiple fuels and products from petroleum.” (NREL, 2000)

“Biorefineries are emerging industrial systems that aim at sustainable and efficient utilization of biomass, valorize potentials lying in biomass resource and deliver multiple useful bioenergies and bioproducts.” (Budzianowski, 2017: 794)

“A biorefinery system is described as a conversion pathway from feedstock to products, via platforms and processes.” (Cherubini et al., 2009)

As the quotes indicate, some common denominators exist, but also differences. Some of the definitions apply a wider scope viewing biorefineries as larger production systems operating throughout the entire value chain from feedstock to final goods, whereas other definitions focus on a (single) factory. Bauer et al. (2017) identify that among the factory-focused definitions, some view biorefinery as an add-on to an existing facility – such as pulp and paper mills – whereas others are not limited to processing options for specific biomass. The authors further point out that the intensified use of biomass resources is a theme emphasized in some definitions (Bauer et al., 2017). The (set of) process technologies to produce certain products from biomass are usually not outlined as part of the definition.

Common characteristics found across definitions is the analogy to petrorefineries. Langeveld et al. (2012) emphasize that biorefineries operating in a similar way to petrorefineries to achieve the production of multiple products may be the only way for reaching the optimal utilization of limited biomass resources (Langeveld et al., 2012). In fact, most definitions include the production of multiple products produced by biorefining, with both bioenergies and bioproducts as part of the portfolio. Bioenergies include low-value, but high-volume biofuels (e.g. biodiesel, bioethanol, biogas, bioelectricity, process bioheat) while bioproducts (e.g. pharmaceuticals, cosmetics, nutrients, chemicals, fertilizers, materials) are preferably high-value, but occur in lower volumes (Budzianowski, 2017; Fernando et al., 2006; Taylor, 2008). The discussion around the different volumes and values is motivated by the intend to use biomass as efficiently as possible which is a prerequisite for achieving economic, but also environmental sustainability (Budzianowski, 2017). Further, one reason for why definitions as well as discussion often revolves around fuels is the high imbalance between commodity chemicals needs and transportation fuels (Ragauskas et al., 2006). In the past, the focus has been on transportation fuels and thus predominately biofuel-driven biorefineries can be found on the market (Sonnenberg et al., 2007).

Yet, while the transportation sector offers the largest potential for the reduction of GHG emissions, bioenergy and biofuels have been subject to heated debates worldwide and especially in Europe (Börjesson, Ericsson, Di Lucia, Nilsson, & \AAhman, 2009; Solomon, 2010). In Europe but also the US policies have been major drivers to biofuels with mandatory targets and blending mandates. However, numerous stakeholders expressed their concerns which Edwards et al. (2008) and Croezen et al (2010) summarize as issues regarding economic costs, feedstock availability, GHG emissions associated with indirect land-use changes, sustainability of the respective production system and potential impacts on food supply and biodiversity (Croezen, Bergsma, Otten, & Van Valkengoed, 2010; Edwards, Szekeres, & Neuwahl, 2008). The issues will increase in significance as bioenergy systems continue to expand.

This debate has led to the introduction of sustainability as one of the divinatory criteria, e.g. in the definition proposed by the IEA. It has also fueled the discussion on the desirability of certain biorefineries, stimulating another discourse – closely linked to the definatory one – which has not been answered with consensus: classification. There are several different classifications available, where some have a pure describtive notion while others entail a connotation indicating the desirability of the respective biorefinery type. The latter can be found to have been largely applied especially in the context of biofuels, which are classified into generations; The first generation captures those fuels that use edible feedstock like corn, whereas the second generation entails biofuels produced from cellulosic feedstock such as agricultural and forestry residues (Golecha & Gan, 2016). This classification was also applied to biorefineries (Balan, 2014). In addition to classifications based on feedstock, classifications have also been reached according to the biotechnology deployed (Jungmeier et al., 2009; Naik, Goud, Rout, & Dalai, 2010). In addition, technological implementation status has also been used as a classification basis (de Jong & Jungmeier, 2015).

Cherubini et al (2009) have come up with a classification approach, which may be more suited. The authors distinguish four main features by which biorefineries can be classified: (1) platforms, (2) products, (3) feedstocks, and (4) processes. The table below provides an overview of the different features and relative subgroups:

Table 2-1. Example of a biorefinery classification approach

Platforms	Products	Feedstock	Process
1. C5 Sugars 2. C6 Sugars 3. oils 4. biogas 5. syngas 6. hydrogen 7. organic juice 8. pyrolytic liquid 9. lignin 10. electricity and heat 11. ..	**1. energy products** a. biodiesel b. bioethanol c. biomethane d. synthetic biofuels e. electricity and heat f. … **2. Material products** a. food b. animal feed c. fertilizer d. glycerin e. biomaterials f. chemicals and building blocks g. polymers and resins h. biohydrogen i. …	**1. dedicated crops** a. oil crops b. sugar crops c. starch crops d. lignocellulosic crops e. grasses f. marine biomass g. … **2. Residues** a. lignocellulosic residues b. oil based residues c. organic residues and others d. …	**1. Thermochemical** a. combustion b. gasification c. pyrolysis d. … **2. biochemical** a. fermentation, b. enzymatic processes c. … **3. chemical processes** a. catalytic processes, b. pulping c. hydrolysis, d. … **4. mechanical/physical** a. extraction b. pretreatment, c. …

Source: adapted from Cherubini et al., 2009

The process by which these different elements are combined can be described in relation to the petrorefinery supply chain. The petroleum-based fuel supply chain is often discussed relative to three major subdivisions: *upstream, midstream* and *downstream*. *Upstream* is used to describe the origin of the fuel: petroleum extraction and transportation to refineries. *Midstream* describes the refining process, thus captures the refinery itself. *Downstream* refers to processes linked to the steps following refining, that are related to storage and distribution to customers (An, Wilhelm, & Searcy, 2011) These terms can be applied to biorefineries as well. *Upstream* then covers aspects such as harvesting, collection and transportation of the feedstoock to the pre-processing facilities and conversion plants. *Midstream* refers to biomass conversion into one of the platforms – intermediates – described above which are subsequently converted into final energy and material products using different conversion processes (Cherubini et al., 2009). *Downstream* resembles to the supply chain of petroleum.

As the literature above illustrates, there is a vast number of different (possible) biorefinery systems. Yet, two types of specific biorefinery concepts/classifications have received major attention in the public domain but also in the academic debate: 1) the lignocellulosic biorefinery within the class of advanced biorefineries, and 2) the integrated biorefinery. These two types are not mutually exclusive, yet the first referes to the feedstock used whereas the second has the emphasis on whether the efficient utilization of the feedstock is achieved. Both are introduced along the next paragraphs.

The Lignocellulosic biorefinery has received attention based on the fact that it is considered to provide a large potential for the sustainable scale-up of biorefineries. Lignocellulosic biorefineries, as the name indicated, use lignocellulosic biomass as feedstock. These can vary from agricultural residues such as corn stover, wheat straw, sugarcane straw, bagasse, etc. to forestry residues (woody biomass) and municipal solid waste or energy crops planted in nonproductive areas (Valdivia, Galan, Laffarga, & Ramos, 2016). The reason for why lignocellulosic biomass is that it 1) does not pull biomass away from food purposes, 2) has a higher emission saving potential and 3) lignocellulose is the most abundantly available raw material on earth.

Whereas biorefineries nowadays mostly use only one type of feedstock, one specific technology and produce a limited portfolio of products, the integrated biorefinery is envisoned to use multiple feedstock, technologies and produces multiple outputs exhibiting the highest degree of flexibility possible (Kamm & Kamm, 2004). It has in fact been highlighted that integrated biorefineries could be an answer to the sustainability debate (De Jong, Van Ree, Sanders, & Langeveld, 2010; Kamm & Kamm, 2004). Through the combination of several conversion technologies, overall costs could be reduced and more flexibility in feedstock, product and power generation be achieved. The integrated biorefinery is considered a major goal in the advanced bioeconomy (Fernando et al., 2006; Octave & Thomas, 2009). Wagemann et al. (2012) summarize the vision of the future biorefinery as being "characterized by an explicitly integrative, multifunctional overall concept that uses biomass as a diverse source of raw materials for the sustainable generation of a spectrum of different intermediates and products (chemicals, materials, bioenergy/biofuels), allowing the fullest possible use of all raw materials components".

Yet, whereas lignocellulosic biorefineries as well as the vision of an integrated biorefinery have received wide-spread recognition the concrete implementation is still to be decided. Together with the previous sections and supported by review illustrates and is also supported by Bauer et al. (2017), the biorefinery discourse clearly lacks a definition that is commonly accepted. The lack of conceptual clarity paired with the different possible technologies, feedstocks and the associated controversies as well as products show the degree of complexity building a biorefinery business entails. However, for the purpose of this paper the definition introduced by the IEA is used as 1) this paper is part of the work of IEA bioenergy and 2) according to Sanden (2012) the definition is one of the most frequently applied (Sandén & Hedenus, 2012). In addition, the definition can be described as being rather broad and holistic in its scope, which fits to the current state of development of biorefineries. As the technologies and ways forward are not conclusively defined it seems reasonable to use a rather wide scope.

The succeeding chapter will discuss the commercialization challenges that result at different ends with special emphasis on the ones attributable to the supply chain.

2.1.2 Commercialization Challenges

Commercialization can be understood as the process of moving a technology from the concept stage, to the production of a product and from there, to market acceptance and subsequent use (Reddy & Balachandra, 2012).

So far, commercialization processes have been rather slow, both in the US and Europe (Nguyen et al., 2017; Valdivia et al., 2016), with only few second-generation biofuel facilities having reached commercial operations, while some plants where closed or suspended at the same time (Nguyen et al., 2017). Most of the projects are set up mainly for the purpose of reducing bottlenecks and processing costs to prove the viability of the respective companies' technologies with the aim of engaging in licencing later on (Balan, 2014). Especially those projects that can be considered "true" biorefineries, meaning they produce a signicant range of marketable products, are rarely realized. This slowdown is attributed in particular to oil price developments. Biorefineries – mostly biofuel production – have received a major upcurrent between 2006 and 2014 when oil prices rose to US$ 105 per barrel. When oil prices dropped again by over 50% in subsequent years, so did the positive prospects (Lamers, 2016). Nowadays, the overall challenge biorefineries face is that of achieving economic profitability while oil prices are low.

It can be observed that most literature reviewed for this section concentrates on sector specific analysis (e.g. the forest sector) and on supply chain aspects predominatly; a well-designed and well managed supply chain is a key condition for economic profitability, irrespective of the type of biorefinery (Ekşioğlu et al., 2009). This is especially true, since biorefineries are envisioned to replace petro-refineries. Petrorefineries obviously have a clear cost advantage due to e.g. their existing and fully depreciated infrastructure. In addition – as will become clear in the succeeding sections – the biorefinery supply chain is subject to additional complexity.

It must be noted, however, that while this chapter refers to biorefineries in a rather general way with no distinction between the different kinds of biorefineries, the extent to which the challenges affect one or another varies. A general tendency that the literature conveys is that a number of the challenges are intensified for lignocellulosic biorefineries, e.g. due to the larger dispersion and variability of biomass, the costs of conversion due to the difference in biomass characteristics, the infrastructure, which may not be in place compared to conventional feedstock, to name a few.

Consequently, after the introduction of some general aspects, the structure of this chapter is chosen according to the subdivision of the supply chain introduced in the last section, which is upstream, midstream and downstream aspects. The boundaries are not strict and often overlap in practice. A separate section is dedicated to political aspects as they have also been highlighted to play an important role.

Upstream Aspects

As described before, upstream challenges are those that relate to the supply chain steps until the feedstock reaches the biorefinery. In general, depending on feedstock, upstream supply chain steps may include collection, storage, preprocessing and transportation (Sokhansanj & Hess, 2009; Sultana, Kumar, & Harfield, 2010). All these steps affect the cost of delivery. Every step is however again affected by the specific characteristics of the respective feedstock.

Biomass availability – in both, the right quantity and the right quality – is generally required for any biorefinery to enter into operations and for the potential scale-up (WEC, 2010, Star-COLIBRI, 2011). With regard to quantity: Biomass is not evenly distributed and must be grown in regions that offer suitable conditions in terms of soil, weather, growing as well as harvesting seasons, all ultimately affecting biomass yield. Biomass is grown typically far from industrial clusters and product demand locations. This requires infrastructure for moving the biomass along the supply chain; here large volumes of biomass are required relative to final output as biomass is characterized by high moisture and low-energy contents. Hence, the feedstock also directly affects the choice of location for the biorefinery facility (An et al., 2011). The moisture content additionally affects storing as specialized storage systems are frequently required to preserve the feedstock quality (Golecha & Gan, 2016).

With regard to quality: In comparison to oil, biomass is characterized by larger variability between, but also within feedstocks. This is considered one of the main challenges facing biorefineries (Menrad, Klein, & Kurka, 2009). This aspect is accelerated when it comes to lignocellulosic biomass (Golecha & Gan, 2016). Lignocellulosic biomass requires pretreatment steps due to its complex matrix comprised of cellulose, hemicellulose, lignin, and other minor components (Mood et al., 2013). It has to be noted that biomasses from plants are naturally persistent. The decomposition is hence rather slow but the pretreatment steps are needed to accomplish the process in the biorefinery in a much shorter period of time. Consequently, additional costs are added for lignocellulosic biorefineries due to the necessary preprocessing steps making it even more difficult to compete (Amidon, Bujanovic, Liu, & Howard, 2011; Balan, 2014).

Balan (2014) finds that feedstock costs significantly influence the overall production costs; biomass can contribute up to one third of the production costs (Balan, 2014). The author also identifies harvesting and transportation as major cost drivers, which is affected by not only the distance to the biorefinery facility but also the availability of sufficient infrastructure, on-site technology and the general mode of transportation (Balan, 2014).

All the above-mentioned challenges can be summarized as challenges of choosing the *right* feedstock, the *right* location and the *right* supply chain configuration for a cost-effective and reliable biomass supply.

Midstream Aspects

Midstream challenges are those that are related to the the biorefinery facility specifically and are interrelated with the upstream aspects discussed above but entail also plant specific matters.

The location of the biorefinery is usally determined by the feedstock supply which is required to be located in a radius of not more than 200 miles (Valdivia et al., 2016); some authors even see a 50 miles radius as required for the economic operation of a biorefinery (Balan, 2014). To this requirement, most biorefinery facilities are placed in remote areas, which in turn increases the remaining production costs (utilities, personnel, downstream logistics), due to the missing proximity to cities or engineering suppliers (Valdivia et al., 2016).

Closely related to the choice of location is the choice with regards to the type of biorefinery to be set up. Whereas for existing industries the integration of biorefining technology may be easier, often that does not fall within their core competencies, while R&D and asset investments are substantial. Thus, it may be challenging to acquire the knowledge and respective technology to integrate biorefining. On the other hand, setting up greenfield plants requires additional funds to be mobilized, posing a challenge for new players on the market. Due to high investment requirements small- and medium-sized enterprises (SMEs) may find it particularly challenging to become involved with biorefining (Hansen & Coenen, 2015).

In fact, for any commercial plant one of the main challenges is obtaining financial backing and having a bankable project in place (Sanford et al., 2016). Often (commercial) biorefinery projects can cost up to 300 million euros. Acquiring the needed investment funds is obviously a challenge as new technologies often entail a high degree of uncertainty when it comes to markets, customers, policy frameworks, competition, technology, cost structure and revenue prospects. Biorefineries are hereby no exeption (Giarola & Bezzo, 2015). In fact, lenders are hesistant to invest into a technology that has not proven economically viable without subsidies yet (Nguyen et al., 2017).

One major challenge that has been identified and deemed critical to prove the economic return of the project, is assuring long-term feedstock supply; this is considered critical to prove the economic return of the project. However, long-term contracts are new for farmers and biomass suppliers as it is common for them to work on an annual basis (Valdivia et al., 2016). Thus, a major challenge is to collaborate with upstream actors to secure the supply. Valdivia et al (2016) addtionally find that this challenge is more severe for lignocellulosic biomass in the EU vis-à-vis the US, as in the former case a larger number of farmers have to commit to biomass production, being induced by the overall smaller parcels in Europe (Valdivia et al., 2016). In addition, real but also perceived technological risks have been identified as challenges affecting associated capital costs (Stephen, Mabee, & Saddler, 2012).

Thus, the challenges attributable to the midstream stages can be summarized as revolving around the *mobilization of funds*, *securing supply*, *acquiring knowledge* and *capabilities* and *optimizing the technology*.

Downstream Aspects

In addition to securing the supply upstream, demand downstream also needs to be assured, preferably simultanously, which poses a challenge in itself.

So far, the main focus has been on the development of the conventional and later on the advanced biofuel production processes; the development of processes that maximize the valorization of the raw material following a multi-product pathway has received less attention (Van Ree, 2011). This observation supports findings from Menrad and colleagues who conducted a survey among European sector stakeholders identifying that the highly efficient production of a portfolio of biobased products is mostly still outside the core business of the industrial actors; focus is largely on one product only (Menrad et al., 2009).

Also, neither lignocellulosic biofuels nor products have received competitive cost levels yet (Nguyen et al., 2017; Valdivia et al., 2016), due to low oil prices as described earlier. Estimates of biofuel production costs show that second generation biofuels are two to three times more expensive than petroleum fuels on an energy equivalent basis (Carriquiry et al., 2011). Most biobased products nowadays are either direct substitutes/replacement or functional substitutes to oil-based products; products that are no substitutes at all are far less produced (Petersen & Fitzgerald, 2015). Companies have also started to realize that in most markets there is no “green” premium for their goods and that they must compete on conventional metrics in addition to environmental ones (Petersen & Fitzgerald, 2015). Hence, bringing the costs of biobased products down is the major challenge that permeats from the very first stage of the supply chain to the downstream market introduction (Amidon et al., 2011). To achieve independence from petroleum-derived products, it is a challenge for biorefineries to develop products that may compete on other markets (Budzianowski, 2017). As has been generally recognized, the co-product generation is very essential for producing cost competitive biofuels (Balan, 2014; Budzianowski, 2017; Chandel, Singh, Chandrasekhar, Rao, & Narasu, 2010; Lange et al., 2016; Sandén & Hedenus, 2012).

In essence, the challenges attributable to the downstream stages can be summarized as revolving around the *offering a competitive product, mobilizing demand* and *identifying* and *targeting the right markets.*

Political Aspects

The lack of unity in the concepts and definitions as the above-review revealed adds to commercialization challenges paired with the numerous challenges identified, increases the difficulty for policy maker to identify policy instruments that could be directed toward development and diffusion of biorefinery technologies (Bauer et al., 2017).

While biofuels have received significant public support in recent years through the introduction of tax credits, blending mandates and state incentives, biobased products have received hardly any support (Lamers, 2016; Palgan & McCormick, 2016; Snyder, 2015). Palgan et al. (2016) further highlight that no policies in the EU directly target the support of integrated concepts such as biorefineries but are restricted to individual products such as biofuels and -energy. In addition, the "food-vs.-fuel" that sparked in relation to the negative impacts associated with first generation biofuels has decreased public support (Petersen & Fitzgerald, 2015). This is also reflected in the absence of targets or incentives in the EU beyond 2020, directly impacting the climate for investment around biorefinery projects (Palgan & McCormick, 2016). Also in the US expectations of vigorous new policies for second-generation biofuels remains uncertain, largely driven by uncertainties around future political efforts towards sustainability. In addition, annual revisions of the US volumetric mandates for cellulosic biofuels has further added to the uncertain institutional setting. As the perceived political stability and support is low, confidence has eroded and risk perception levels increased (Peck, Grönkvist, Hansson, Voytenko, & Lönnqvist, 2015). A general lack of security for biorefinery investments has been recognised as a key constraint for biorefinery development in Sweden and beyond (Menrad et al., 2009; Palgan & McCormick, 2016).

Against the unfavorable market conditions for biobased fuels and products, paired with the high production costs of advanced biofuels, numerous authors identify the lack of policy support a major challenge to biorefinery commercialization (Van Ree, 2011; Vandermeulen, Van der Steen, Stevens, & Van Huylenbroeck, 2012).

The literature review shows that commercialization entails a lot of uncertainties: numerous alternative pathways, process equipment, supply chains and coordination challanges as well as limited learning across projects. This creates a so-called 'chicken-and-egg' problem as few investments are made due to the high risk and uncertainty, inhibiting learning effects to take place due to too few plants (Huenteler, Anadon, Lee, & Santen, 2014). The findings of the review support the results presented in a study by Chen and Smith (2017). Accordingly, the main challenges to commercialization can be summarized as revolving around high production costs, policy uncertainty, competition vs. petro-fuels, feedstock costs, capital availability, technological availability, logistics, and consistent feedstock supply; competition versus corn-grain ethanol is highlighted as an additional challenge with regard to cellulosic ethanol in particular (Chen & Smith, 2017).

2.2 Commercialization of Biorefineries: Conceptual Review

As the previous section revealed, the commercialization of biorefineries is characterized by a high degree of complexity, which can be summarized as follows: first, market prices play an important role; second, policy is discussed to excert a prominent force, too; third, far-reaching changes are required to make biorefining happen; fourth, there are numerous challenges and pathways that can be chosen and numerous variables to be selected (feedstocks, technology, product portfolio) when building a biorefinery business, thus successful commercialization comes with a lot of organizational challenges and potential bottlenecks to be considered. Throughout the initial review it became apparent that upstream and downstream processes and how biorefineries are organized to manage them is particularly critical. These points need thorough reflection in the framework to be developed hereafter.

Against this backdrop, the aim of this section is to provide a literature review on concepts and frameworks that can help to construct an analytical framework for modelling the biorefinery business for organizing ideas and enabling a systematic analysis of the factors that have contributed to successful commercialization from a business-centered perspective; the actual framework will be proposed in the methodology section.

The review will start with the rationalization of why specific frameworks were chosen before turning to reviewing them one-by-one. However, the goal of this work is not to develop a unified theory, but still to contribute with complementary insights within the chosen literature streams. However, the analysis is not to be understood as providing for a comprehensive discussion of the theories, but stays at a level appropriate to accomplish the aims of the thesis.

2.2.1 Rationalizing the Choice of Frameworks

As outlined in the introductory section to this thesis, radical systems innovations like the one needed if the transition to a bioeconomy is to be achieved involve "innovations that are directed to redesigning entire systems of practices and provisions, instead of individual products or processes" (Sterrenberg, Andringa, Loorbach, Raven, & Wieczorek, 2013: 9) Thus, numerous authors emphasize that the analysis of radical systems innovations and how they diffuse involves interactions between technology, politics/policy/power relations, economics/business actors/markets, and culture/discourse/public opinion and takes place in the context of a wider system (Geels, 2011; Geels & Schot, 2007; Hekkert, Negro, Heimeriks, & Harmsen, 2011; Planko, Cramer, Hekkert, & Chappin, 2017). However, it has also been stressed that actors such as firms, fulfill a central role in the diffusion of innovations; yet, innovation systems' studies have commonly been criticized for focusing predominatly on structures downplaying the agency and the role different actors, e.g. firms play in them (Flanagan, Uyarra, & Laranja, 2011).

Therefore, the review of suitable frameworks is guided by the premise that both perspectives need to be incorporated: 1) the systemic nature of the diffusion of technological innovation and the sources of influence originating in the larger system on the one hand, and 2) the role of agency in the form of business actors on the other. While working on the conceptualization, the author came to realize that it is not possible to follow only one literature stream or framework; none sufficiently covers all aspects that deemed relevant.

Hence, for identification of a suitable and meaningful framework, or a set of frameworks, the thesis draws on insights from two distinct yet related literature streams: 1) innovation studies and 2) business studies. Innovation studies help to map out the wider system context, whereas business studies help with mapping the micro-level, firm-centered perspective. From the multitude of theoretical frameworks and concepts derived from the two literature streams, three were eventually identified as relevant, with major focus on two.

Within innovation studies, in particular the *technological innovation system* (TIS) framework (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008; Hekkert et al., 2007) and the *multilevel perspective* (MLP) (Geels, 2002) have been developed to analyse the development and deployment of new technologies from a sociotechnical system perspective. These two frameworks dominate the analysis to understand the different elements that play a role in sustainable transitions in terms of the various drivers and barriers that can exercise influence. While being developed rather indepently of each other, their respective focus is on the same phenomena while also several key concepts are shared (Coenen, Benneworth, & Truffer, 2012; Markard & Truffer, 2008b). Even though these frameworks have not been developed for any specific technology, they have been applied to renewable energy technologies and biorefining likewise (Bauer et al., 2017; Negro & Hekkert, 2008; Peck et al., 2015; Sandén & Pettersson, 2013).

There are still some differences worth mentioning concerning the analytical levels and perspectives taken (Markard & Truffer, 2008b; Planko et al., 2017). The TIS framework was originally developed to analyze barriers and drivers at different stages of development, production and deployment of a new technology with the purpose to understand how increased uptake of the technology can be supportd by policy (Dewald & Truffer, 2011; Jacobsson & Bergek, 2011; Suurs & Hekkert, 2009). The MLP framework, on the contrary, is relatively more focused on niche applicatons or regimes less on different intermediate stages of development such as the commercialization stage, for example (Markard & Truffer, 2008b). Compared to the TIS, the MLP is hence more suited when an explanation of broader transformative changes is desired, whereas the TIS is better suited when technology-specific matters are of interest (Markard, Suter, & Ingold, 2016; Weber & Rohracher, 2012). These differences suggest that the TIS framework is a more appropriate choice for the purpose of studying the deployment and thus commercialization of biorefining; The MLP will nevertheless serve to model the wider system context the biorefining technological innovation system is nested in. Authors such as Walz et al. (2016) have recently proposed that the innovation system of a specific technology can be interpreted as a niche in the context of the MLP (Walz, Köhler, & Lerch, 2016). Consequently, the TIS framework and the MLP to a far smaller extent are chosen to guide the analysis from the innovation studies' literature stream.

The relative wide scope that the TIS proposes in its systems' perspective on innovations implies that details on parts of the sociotechnical system are swallowed by an aggregate whole, the TIS framework is criticized for lacking a micro-level foundation and neglecting the role of agency (Markard & Truffer, 2008a). However, actors have been assigned the key role in the innovation concept, and the influence of strategic decisions of particular actors empirically proven to be relevant (Carlsson, Jacobsson, Holmén, & Rickne, 2002; Carlsson & Stankiewicz, 1991; Jacobsson & Johnson, 2000; Malerba, 2004). The TIS, however, does not provide guidance on which other frameworks to use when intending to study market actors such as firms in greater depth. In fact, the author did not find specific anchor point of the TIS literature to other literature streams when it comes to different actors involved in technology commercialization and some of the 'functions' or key processes. An analysis performed by Foxon (2011) does, nevertheless, identify business strategies as one of the key co-evolving subsystem among three others (ecosystems, technologies and institutions), relevant for analyzing sustainable transitions (Foxon, 2011). This study provides additional support for strengthens the case of zooming onto the firm-level.

Hence, as business strategies apparently lack coverage in the described literature, they remain an interesting potential field that can add the missing piece for the desired model to be developed. This leads the discussion over to the second literature stream that is reviewed as part of the analysis: Business studies.

Within the business studies literature, it is widely accepted that business strategies and in particular business models play a crucial role in commercializing sustainable technological innovation (Baden-Fuller & Haefliger, 2013; Boons & Lüdeke-Freund, 2013; Chesbrough, 2010; Lüdeke-Freund, n.d.; Teece, 2006, 2010; Zott & Amit, 2008). Whereas business strategies describe how companies intend to fulfil their socio-economic purpose, business models are the application of these strategies in terms of organisational and financial architecture (Andreini & Bettinelli, 2017).

A typical frameworks proposed in the context of studying business strategies for the commercialization of technological innovations is the business models' framework (Amit & Zott, 2001; Shafer, Smith, & Linder, 2005). This framework is, nonetheless, paired with complementary aspects from Porters' generic strategies typology as well as supply chain management (Mentzer et al., 2001; Porter, 1980); the latter is meant to bring out the focus on upstream and downstream factors, identified to accommodate major challenges in the context of biorefinery commercialization. Hence, by using a business model framework – or an adapted version of it – it is possible to introduce firm-level activities in response to and in interaction with the wider TIS into the overall analysis, thus zoom in on real-world phenomena covered by the TIS literature. In fact, the business model centered analysis can be comparatively easily placed within the TIS literature as there is a clear relation to key TIS concepts such as 'actors', 'entrepreneurial experimentation', 'resource mobilization', and 'market formation' as will become apparent in the subsequent sections. The business models' literature is yet much more detailed on the phenomena of interest.

To accomplish the aims for this chapter, the remainder is organized by the two frameworks, the TIS and the business model, resepectively, complementary insights from the concepts introduced above are added in case of relevance.

2.2.2 The Technological Innovation Systems' Framework

The TIS has been defined as "a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilisation of a technology" (Carlsson & Stankiewicz, 1991: 111). While the TIS usually focuses on the development of a single technology and biorefining is rather a concept that captrues a multitude of different technologies and processes, Bauer et al. (2017) have proposed that the TIS perspective can contribute "(…) valuable insights into the development of biorefineries from a systemic perspective, as the challenges facing renewable energy technologies are very similar." (Bauer et al., 2017: 3)

The application of the TIS approach has not been characterized as a theory but rather as a "heuristic attempt" (Hekkert et al., 2007) that focuses on particular aspects in the development of novel technologies as well as the organizational and institutional changes required for emerging technological innovations (Bergek, Jacobsson, et al., 2008; Hekkert et al., 2007). It is primarily developed to identify the source of success or failure of a specific technology on the basis of its performance (Twomey & Gaziulusoy, 2014). For this purpose, newer TIS literature (Bergek, Hekkert, & Jacobsson, 2008; Hekkert et al., 2007), has differentiated between structural components and functions (Hekkert et al., 2011).

Structure

The TIS differentiates between three structural elements - institutions, networks and actors, which are briefly outlined below with some examples; a more in-depth description follows thereafter.

Table 2-2. Description of the structural elements of a TIS with examples

Structural element	Description

Actors	Any organization or individuals relevant for the development and deployment of the technology. **Example:** policy maker, suppliers of biotechnology and services, supplier of feedstock, customers, other supply chain actors …
Networks	Linkages between actors through which information is exchanged. **Example:** Associations for organizations providing and deploying biorefining, informal networks between adopters, advocacy coalitions for lobbying; …
Institutions	Any humanly devised rules (formal or informal) affecting the development and deployment of the technology; **Example:** laws, standards (technology standards, blending quotas etc.), practices, collective mind frames; legitimacy through popoular perceptions…

Source: author's own depiction but content found in Bauer et al., 2017; Bergek, Jacobssion, et al., 2008; Jacobsson & Bergek, 2004; Walz et al., 2016

Institutions embrace legal and regulatory aspects, norms and cognitive rules that affect the decisions, activities and learning processes of actors (Bergek, Jacobsson, et al., 2008; Markard et al., 2016; Wirth & Markard, 2011). They are particularly relevant for emerging TISs as competition takes place between firms not only over the marketplace but also for gaining influence over institutions (Bergek, Jacobsson, et al., 2008). In this competition, incumbent firms are often in a stronger position than newcomers introducing a new technology, which is why in the early stage of a TIS the institutional set-up is usually misaligned to the emerging technology or even missing.

Compared to actors, institutions have a more passive role and are linked to the behavior of actors (Markard & Truffer, 2008b). The institutional framework puts constraints on some and favors other sets of activities, thus influences the behavior of actors in the TIS. However, actors can actively influence the institutional set-up of a system through their strategic choices (Kishna et al., 2012).

Turning an invention into a marketable product or service involves a number of actors (Planko et al., 2017). Thus actors can be individuals and firms along a value chain, but also other organisations such as universities, industry, intermediary organisations, other stakeholder groups and government bodies (Dewald & Truffer, 2011; Wirth & Markard, 2011). In the context at hand, actors can be all kinds of organisations such as biotechnology companies, farmers, investors, and biorefinery companies, with the later being central to the analysis. In an emerging TIS key actors might be missing.

What is understood as networks can take various forms, such as "learning networks" that link firms with other firms or users, companies with research institutions, thereby creating important bonds of knowledge transfer; 'policy networks' can be e.g. coalitions of actors sharing the same beliefs and engaging in activities to influence the political agenda (Sabatier, 1998). As a diverse range of actors and organisations can interact within the TIS, both types of networks have to be considered (Bergek, Hekkert, et al., 2008). In an emerging TIS, networks are often lacking.

Functions

For analysis of technological innovations, the structural approach proved insufficient, hence, the functional perspective emerged highlighting the processes (not just structure) that are important for the performance of (technological) innovation systems (Bergek, 2002; Bergek, Jacobsson, et al., 2008; Hekkert et al., 2007; Johnson, 2001). In comparision to the structure which provides insights on who is active in the system, the system functions enable the analysis of what the actors are doing and if the activity level is sufficient in degree and direction to develop successful innovations (Hekkert et al., 2011). Hence, the so-called functions of innovation systems (FIS) can be understood as the dynamic processes between the structural components of the system. Each key process contributes to establishing a favourable 'ecosystem' around a new technology (Jacobsson & Bergek, 2011; Musiolik & Markard, 2011). Even more importantly, the interaction between system functions stimulates the emergence and growth of an innovation system in virtuous cycles, contributing positively to the likelihood of market success (ibid.). Hence, the FIS can be understood as proxies to determine how well innovation systems perform (Bergek, 2002; Bergek, Jacobsson, et al., 2008; Hekkert et al., 2007; Johnson, 2001).

The functions that are commonly identified – with some variations – are knowledge development and diffusion, entrepreneurial experimentation, influence on the direction of search, market formation, building up legitimacy and resource mobilization (Bergek, Hekkert, et al., 2008; Hekkert et al., 2007; Suurs & Hekkert, 2009). Their meaning is described below:

Knowledge development and diffusion, encompassing different processes of learning among key actors. Regarding commercialization firms, policy makers and potential customers need to gain an understanding of how to implement, market (technology as well as the resulting products), regulate, support and use the technology. Thus, this function is used to describe the depth of knowledge existent and how well that knowledge is diffused in the system.

Influence on the direction of search, captures the incentives for e.g. firms to enter and participate in the TIS. The strength of this function is to a great extent determined by present and future market formation as perceived by relevant actors. Incentives to enter a system may come from regulations and policy, technological advances and actors' visions and expectations. Signals from the so-called landscape level as described in the MLP can also influence the direction of search (Walz et al., 2016).

Entrepreneurial experimentation, including various activities of firms. When it comes to commercialization, market activities in terms of the variations and application tested can serve as an indicator for this function. Entrepreneurial experimentation can take the form of R&D activities, pilot and demonstration plants etc.

Market formation, referring to activities that contribute to the creation of demand for the technology. Market formation is a crucial part of the commercialization process and a prerequisite for diffusion. Barriers to market formation are often found in the institutional set-up (for example as a lack of standards or misaligned legislation) or in a poor price/performance as have been observed for biorefineries. For a TIS to establish itself and become competitive often niche markets or regulated markets are needed.

Building up Legitimation, referring to changes in the social acceptance of a technology, or how good or desirable the technology is perceived to be. Legitimation through activities performed by advocacy can have tremendous effects for implementation of a technology. In previous chapters legitimation and acceptance concern have been described as pushing for the development of lignocellulosic feedstocks and advancing second generation biofuels.

Resource mobilization, the TIS's availability of social and financial capital e.g. through education, venture capital, government investment in R&D etc.) as well as complementary assets necessary for the TIS to perform well. With regard to the commercialization of biorefining technologies, the mobilization of capital has e.g. been described as a major challenge.

The importance of one or another function can vary with the stage of development of a TIS. By identifying and strengthening poorly performing functions, policy intervention can facilitate the dissemination of desirable technology. This can be achieved by strengthening or adding drivers of by weakening or removing barriers (Bergek, Jacobsson, et al., 2008). In fact, the perspective taken on innovation systems and their functions is from a policy intervention one. However, this thesis is concerned with using a firm-centered perspective and thus looks at the functions from a different perspective; which is on the interaction of firms with the FIS. Actors in the TIS can influence the functions to increase the support they gain from the innovation system (Kishna et al., 2012; Underwood, Blundel, & Lyon, 2012).

2.2.3 Business Studies and the Business Model Framework

This chapter does not aim to be an exhaustive literature review of business studies, but rather an introduction to the basic concepts that will be used in the development of the analytical framework of this research.

Business Studies

As discussed earlier, the TIS framework considers the 'business ecosystem' of an innovating firm (Edquist, 2004). The focus is on the wider context, with a less detailed depiction of individual elements. Business studies bring the micro-level firm centered perspective into the analysis and let the author introduce agency in the form of individual choices into the TIS approach. In fact, business studies focus on individual actors and their choices. As argued in the beginning, for turning an invention into a marketable product or service a number of actors are required (Reddy & Balachandra, 2012). Firms, who are usually key actors in technology deployment need to deploy specific strategies to overcome barriers to the deployment of radical innovations. To profit from the technology, these new strategies are needed to provide value for their customers and capture value for the firm itself – that is, new business models are required (Baden-Fuller & Haefliger, 2013; Chesbrough, 2007; França, Broman, Robèrt, Basile, & Trygg, 2017). As highlighted above, to introduce agency to the discussion – individual decisions by actors in the innovation system – strategies and the choice of business models serve as proxies in the discussion to model them (Markard & Truffer, 2008a).

In line with Kishna et al. (2012), the author also follows the assumption that firms engaged with developing radical innovations need specific strategies to deal with the opportunities and barriers in the environment they are embedded in, meaning in the innovation system discussed above (Kishna et al., 2012). It is thus expected that entrepreneurs developing radical innovations have to have strategies aimed at overcoming specific barriers by enhancing the fit between innovation and environment, that is strategies related to the key processes (or functions) of innovation systems (ibid.). This argument follows the main idea conveyed by one of the major theoretical lense to view organizations, namely the contingency theory (Donaldson, 2001). The essence of this paradigm is that organizational effectiveness results from fitting characteristics of the organization, such as its structure, to contingencies – the environment, organizational size and strategy – that reflect the situation of the organization (Burns & Stalker, 1961; Lawrence & Lorsch, 1967; Pennings, 1992). The underlying assumption is that fit leads to superior performance, which is why an organization seeks to attain fit.

Strategic Management

The strategic management literature follows the basic idea that strategic activities emerge as an outcome of the tangible and intangible resources held by firms. Firm resources manifest in the control of rare, valuable, and imperfectly imitable resources that offer differentiation and competitiveness to companies (Barney, 1991; Demil & Lecoq, 2010; Peteraf, 1993). This means that success is determined by how a business manages to obtain and create resources it can exploit that provide them with a competitive advantage, a concept that refers to the ability of an organization to outcompete its competitors (Porter, 1996).

The literature on strategic management and thus the explicit emergence of business strategy has its origins in the 1950s. Alfred Chandler was the first to present a comparative and systematic account of growth and change in companies (Chandler, 1962). He highlighted the importance of a long-term strategy that encompasses all activities and gives structure, focus and direction. According to him, strategy can be understood as the determinator of the basic long-term goals of an enterprise, and the adoption of courses of action and the allocation of resources necessary for carrying out these goals (Chandler, 1962). Mintzberg (1979) later developed an understanding of strategy as the mediating force between the organization and its environment; thus, as the consistent patterns in streams of organizational decisions to deal with the environment (Mintzberg, 1979). Prahlad (1993) emphasizes that strategy is more then just fit and allocation of resources. It is stretch and leveraging of resources (Prahlad, 1993). Porter (1996) understands strategy as being different. It means deliberately choosing a different set of activities to deliver a unique mix of value (Porter, 1996). According to him, strategy is about making choices (ibid.).

Based on these definitory approaches, strategy consequently defines to a large extent a firm's choices in terms of the way their activities are organized, resources allocated and responses to the external environment are chosen; all to fullfil their business purpose. It very well connects to the discourse in previous sections: It means that a company is *actively* seeking to leverage resources and decide to carry out activities that lead to a fit with the organization's environment, that is the wider (innovation) system it is embedded in.

The business strategy concept has been included in the empirical analysis and analytical framework of this research to serve as a proxy for intra-firm agency, an element arguably under-acknowledged in the TIS (and MLP) approaches. Porter proposed a typology of generic strategies and will be followed ere. These strategies are adopted by firms to create and maintain their competitive advantage. A firm can deploy three strategies to develop its competitive position: cost leadership, differentiation and segmentation; cost leadership referes to targeting price-conscious customers with high-throughput, low price offering, meaning economies of scale and experience curves, lower operational costs (through standardization) and control over the supply chain through e.g. vertical integration; here, the firm tries to work on the efficiency of its operations to obtain market share by producing at a cost lower than average. Differentiation refers to developing products and services that have unique attributes different from others available on the market. Potential customers have to recognize the added value brought by these attributes and be willing to pay a premium price for them. Firms that adopt this strategy need to have access to technological expertise, own protected intellectual property, implements successful marketing and have a good reputation for quality. Segmentation is the third option, according to the typology proposed by Porter, and it means narrowing the firm's focus into serving specific specialized market segments (Porter, 1996).

Business Models

Casadesus-Masanell and Ricart (2010) suggest that the business model is a way to put a strategy into practice and argue further that a business model is a reflection of the firm's realized strategy (Casadesus-Masanell & Ricart, 2010). While earlier literature suggests that business models are "variations on the generic value chain underlying all businesses" (Magretta, 2002: 4) this view has been criticized as too simplistic to analyze the value capturing process by firms (Teece, 2010; Zott & Amit, 2013). It is argued that the business model chosen also determines which activities in a value chain are performed by a specific firm (ibid.).

More recent business model literature goes beyond the value chain idea that remains centered on the focal firm (Chesbrough, 2007; Zott & Amit, 2013). As suggested by Zott et al. (2011), researchers have begun to converge on a number of common themes. Accordingly, business models are perceived to center around the logic of how value is created for all stakeholders, not only on value capturing for the focal firm. The activities performed by the focal firm as well as partners, suppliers and even customers play an important role; business models take a system-level, holistic approach in explaining how firms conduct business (Zott, Amit, & Massa, 2011).

While no general definition exists (Andreini & Bettinelli, 2017), in their widely cited paper, Zott and Amit (2010) have conceptualized a firm's business model as "a system of interdependent activities that transcends the focal firm and spans its boundaries" (Zott and Amit 2010: 216). The authors have further developed their definition conveying an understanding of a business model as "a bundle of specific activities, an activity system, conducted to satisfy the perceived needs of the market, along with the specification of which parties (a company or its partners) conduct which activities, and how these activities are linked to each other" (Amit & Zott, 2012: 42).This representation remains still firm-centric but also identifies all relationships a firm can develop outside its boundaries (Andreini & Bettinelli, 2017).

Unlike more structural definitions that concentrate on the delination of specific elements of a business models, the representation of a business models as a system allows for a more dynamic perspective on interconnections between components beyond the firm (Andreini & Bettinelli, 2017). The definition corresponds very well to the understanding in this thesis, as especially the upstream and downstream activities that are performed, meaning how the focal firm interacts and connects with its network, are of interest. However, for the analytical purpose later on, it is still valuable to depict specific elements of a business model. The following elements are found – with some variation or different terminology – in most definitions (Andreini & Bettinelli, 2017; Morris, Schindehutte, & Allen, 2005):

Table 2-3. The structural elements and descriptions of a business model

Elements	**Description**
Value proposition	The products and services offered to customers
Customer interface	The overall interaction with customers, including customer relations, customer segmentation ans distribution channels
Infrastructure	The company's inner structure for their value chain, including assets, know-how and partnerships
Revenue model	The relationship between the costs and revenues of the value proposition

Source: Andreini & Bettinelli, 2017; Morris et al., 2005

It is recognized in the literature that business model innovation (the development of new business models or the adaptation of existing ones) can facilitate the deployment of new technologies (Boons & Lüdeke-Freund, 2013). A new technology may not only come with inherent attributes that require a new or changed business model, but also the newness in itself might entail barriers that could be addressed through business model configuration (ibid.) In the case of biorefineries, for example, the business model has to accommodate for the difference in feedstock – among others – compared to a petrorefinery.

Consequently, successful business models allow the entrepreneur or firm to overcome uncertainties and incompatibilities with existing institutions through e.g. the transfer of risks and reduction of transaction costs by distributing them across supply chain actors, or to neutralize particular institutional barriers (ibid.). This can be achieved by means of entering into partnerships for leveraging resources to build a web of favorable system components; the business model needs to be configurated in a way to achieve an alignment with the evolving socio-technical environment reacting to dynamic changes in the system levels (e.g. institutional framework and regime structures) (Bolton & Hannon, 2016).

3 Methodolody

The overarching aim of this chapter is to present the research design and analytical framework. This will include justifications for specific choices made and assumptions followed with the aim of making the process by which the author derived her cognitions, transparent and traceable.

As point of departure, the research follows the post-positivist paradigm to scientific inquiry which – from an ontological point of view – assumes that reality can be approximated but never fully known (Bunge, 1993; Denzin & Lincoln, 2008). One of the most common forms of post-positivism is critical realism. Although, the positivist view on the existence of natural order in social events and in discourse is recognized, the critical reasoning claims that the underlying order must be discovered through the process of interpretation; the detection of patterns of events through mere observation is not possible (Walliman, 2015). However, through rigor in carrying out the research, the ideals of objectivity and generalizability of results are still embraced (Ellingson, 2013). Consequently, emphasis is placed on using multiple methods with triangulation to avoid errors and approximate reality as close as possible (Lincoln, Lynham, & Guba, 2011). These principles are followed in later steps and reflected in the research design.

With regard to the appropriateness of the epistemological stance taken, critical realism has in fact received increased recognition throughout numerous disciplines, among them in the field of economics (Fleetwood, 1999), organization theory (Easton, 2002, 2010; Fleetwood & Ackroyd, 2004; Tsang & Kwan, 1999), and sociology (Sayer, 1997).

The remainder of the methodology section continues as follow. The first section (3.1) explains the chosen research design as well as the methods used for data collection and analysis thereof. The second section (3.2) continues with the development of the analytical framework. Limitations will be presented in the conluding chapter (4.4).

3.1 Research Design

To answer the research questions, the study revolved around a case study approach. Qualitative research methods were used to collect and analyze the data as it 1) deemed more fluid and flexible than quantitative research and thus particularly well suited for the phenomenon of interest being characterized as a not yet mature research field and 3) the emphasis of qualitative research on the discovery of novel or unanticipated findings and the possibility to alter research plans in response to such serendipitious events (Schramm, 1971). In this study, the qualitative approach helps to explore the commercialization of the biorefinery business seeking to identify aspects of practical relevance. The analytical framework developed in 3.2 has guided the presentation and discussion of the findings in Chapter 4.

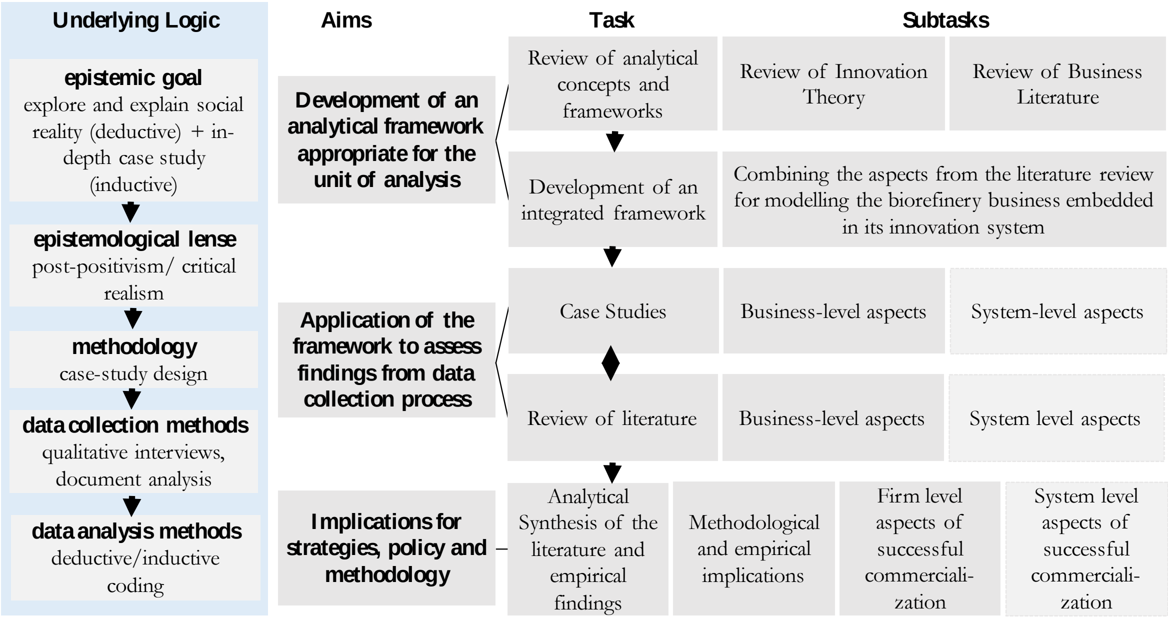

Figure 3-1. Overview Research Design

Source: author's own depiction

3.1.1 The Case Study Approach

Case studies are described as empirical in-depth inquiries in single settings (Eisenhardt, 1989; Yin, 2009). They can be based on qualitative or quantitative methods, or a combination of both; as pointed out earlier this study will follow a qualitative approach only.

This qualitative case-study research approach is according to i.e. Patton (2002) appropriate for investigating issues that are complex and difficult to quantify (Patton, 2002). As such, this approach is especially well suited to shed light into 'how'- or 'why'- questions regarding a contemporary phenomenon of which little is known, over which the researcher has little or no control and for which contextual conditions matter (Yin, 2009). These types of questions are guiding the research at hand ("how can we model a biorefinery business for analysis"; "how are the commercialization challenges overcome in practice?"). In essence, case study research can serve as means to derive descriptions, identify themes, patterns and concepts for the understanding of the phenomenon as well as to test or generate theories (Patton, 2002; Yin, 2009).

Case studies can be classified as either within-case studies or cross-case studies. The former means focusing only on a single case in order to familiarize with the patterns within this one unit and provide a holistic understanding (6 & Bellamy, 2011; Eisenhardt, 1989). In fact, the author has chosen to use a single case study for both instrumental and exploratory purposes. Instrumental in so far as the case study serves the purpose of testing the applicability of the conceptual framework; instrumental also, as the single case study is used as contrast material for the comparative discussion of findings (Stake, 1995). Exploratory, as the author has interviewed experts from successful companies engaging with biorefining, thus, also seeks to explore findings that are specific to them. In addition, case studies are considered to represent a methodology that is well-suited to create knowledge with relevance from a managerial point of view, as they are carried out in interaction with practitioners (Amabile et al., 2001; Leonard-Barton, 1990). This argument also aligns with the overall goal of this thesis.

In conclusion, since the aim of this research was to develop a conceptual model of biorefineries for the systematic identification of key drivers of successful commercialization and apply the model in practice, the single case study analysis in combination with expert interviews is considered appropriate. The in-depth single case study served both the aim of testing the conceptual model as well as identifying and contrasting the specific aspects within the comparative discussion with both expert interviews and against the background of the literature review. This dual purpose allows for the holistic understanding of the complexity of the exemplary case while providing the possibility to identify patterns and differences in relation to the experts.

3.1.2 Sampling, Data Collection and Analysis

Sampling

To identify a suitable case, purposeful sampling was chosen. This is described as a technique widely used in qualitative research for identifying and selecting information-rich cases with aim to use limited resources most effectively (Maxwell, 2008; Patton, 2002). This requires the identification and selection of informants that are especially knowledgeable about or experienced with the phenomenon of interest (Creswell & Clark, 2007). Furthermore, beyond knowledge and experience, the availability and willingness to participate was identified as important criteria (Bernard, 2011; Spradley, 2016).

Hence, as a first step, potential cases had to be identified. This was based on the working definition introduced in chapter 2. This definition was broken down into a set of criteria to be fulfilled:

Table 3-1. Sampling Criteria

Criteria	**Description**
Commercialization	The biorefineries need to have passed the demonstration and pilot phase and run at commercial scale
Product Portfolio	Biorefinery that produces at least two different products, with biofuels one of them
Access to information	biorefinery that provides access to information through both interviews and other data sources such as annual reports, articles and corporate presentations;
Depth of information	Biorefinery that allows to gather the extent of detailed information required to test the conceptual framework

Source: other's own depiction

Suitable cases were identified by searching different generic (*google*) and specific databases (*lubsearch*), internet searches, initial recommendations from researchers and contacts at the IEA as well as screening journal articles and market studies. An exhaustive list of possible cases was created, which then required further investigation to validate the information and status quo; some of the information proved to be outdated. In addition, the author had to make sure that the cases would qualify in relation to the criteria presented above. The initial sample included 53 different organizations, but several of them had to be dropped as they neither qualified for the definition nor could contact be established and the information accessible through other sources did not suffice. Throughout this iterative process, a differentiation was made between potential cases fulfilling the criteria and companies that would qualify to be used for the complementary *expert interviews* being either biorefineries with (planned) multi-product operations or biotechnology companies not running plants themselves. As the analysis takes a business-centered stance, further stakeholders from (policy, consumers, suppliers) were not considered.

Table 3-2. List of Informants for the Semi-Structured Interviews

	Company *C: case; E: expert;*	**Classification**				**Interview**
		Platforms	Products	Feedstock	Processes	
P1	Novozymes *(E)* *- biotechnology* Denmark	-	Largely diversified portfolio	Wheat straw rice straw	Enzymatic and micro-biological processes	Contact: N. Amrani, Role: lobbyist Date: 2017/07/17 Duration: 24:56
P2	Lanzatech *(E)* *- biotechnology* USA	-	Ethanol others	carbon-rich gases	Enzymatic processes	Contact: D. Meyer, Role: Senior Business Development Manager Date: 2017/07/07 Duration: 40:19
P3	Amyris (C) *- biorefining* USA	farnasene	Lubricants jet fuel emollients	sugar cane	Enzymatic processes, fermentation	Contact: J. Cherry, Role: Head of R&D Date: 2017/07/12 Duration: 01:00
P4	POET *(E)* *- biorefining* USA	-	ethanol	Corn grain Corn Straw	fermentation	Contact: D. Berven, Role: VC Public Affairs Date: 2017/07/11 Duration: 39:21
P5	Sunpine *(E)* *- biorefining* Sweden	-	crude tall diesel rosin bio-oil	Crude tall oil from woody biomass		Contact: M. Edin, Role: CEO Date: 2017/07/10 Duration: 19:03
P6	Storaenso *(E)* *- biorefining* Finland/ Sweden	-		woody biomass		Contact: M. Hannus Role: Head of biorefinery R&D Date: 2017/08/07 Duration: 38:14
P7	Verbio *(E)* *- biorefinery* Germany	-	Ethanol Biodiesel Glycerin Biomethan Fertilizer	Rape seed oil Wheat grain (non-feed/ food) Straw	esterification	Contact: K. Sauter Role: founder/CEO Date: 2017/08/02 and 2017/08/08 Duration: email correspondence

Source: author's own depiction

Final Selection: Amyris Inc. as Case Study

The final sample resulted in Amyris, Inc. (Amyris hereafter) being chosen for the in-depth analysis due to the access to information criteria, amongst others. As the company is publicly listed and has received media attention combined with the possibility to have an in-depth interview, the holistic and in-depth analysis was possible due to the access to information.

Amyris is an industrial biotechnology company and chosen as a reference case to be analyzed in-depth and guide the presentation of the additional findings and discussion. Although Amyris does not describe itself as a biorefinery company, but as an industrial biotechnology company, it still does qualify as a case as they also deploy the technology themselves.

Amyris was founded in 2003 by a group of scientists from the University of California, Berkeley and completed their initial public offering in 2010 (NASDAQ). The company is headquartered and has productions in both California and Brazil. With 404 employees, Amyris is a leading company within the field of integrated industrial biotechnology applying its technology platform to engineer, manufacture and sell a portfolio of products. The company's first major milestone was achieved in 2005, when they received a grant from the Bill & Melinda Gates Foundation to develop a technology capable of creating microbial strains to produce artemisinic acid – a precursor of artemisin – an effective anti-malaria drug. In principal, the company uses microbes such as yeast as a catalyst to convert sugar through fermentation into high-value molecules. Whereas the company is able to use a variety of feedstocks for production they have focused their sourcing activities on assessing Brazilian sugarcane due to cost considerations among others. Amyris' main portfolio of commercial products is based on Biofene®, their brand of renewable farnesene, a long-chain hydrocarbon, which is produced in their plant in Brotas, Brazil. While in the beginning the company focused on fuels, in 2016, Amyris fully transitioned beyond their biofuels business to focus on high-value markets: Health and Nutrition, Personal Care and Performance Materials (including fuels). Until the stage they have reached now the company went through turbulent times and still faces high debt levels and numerous risks leaving them under critical views from auditor's regarding their going concern. However, sales figures as well as debt levels show positive developments, with total revenues almost doubled from $34.2 million in 2014 to $67.2 million in 2016.

While it is not clear yet if Amyris will prosper and reach profitability in the upcoming years, the company has come a long way to reach the stage they are in. It is actually considered fairly typical for biorefineries to have a long time to market. Thus, the case is chosen as it illustrates very well, how bottlenecks and challenges with regards to feedstock supply, funding, market development, pricing pressures and many more, can be met by emerging companies. Amyris had to deal with several of the challenges reviewed in the literature and has done so by adjusting both their strategies and business model to overcome them. Thus, the chosen case is suited in relation to the underlying research interest.

According to the classification approach used, conventional feedstock is used which would classify them as a first generation biorefinery. However, the feedstock is sustainably sourced which qualifies them according to the selection criteria applied within this study. Lignocellulosic activities are not part of commercial activities yet.

Data Collection

A case study typically make use of a variety of multiple sources of evidence, including documents, artefacts, interviews, and observations (Eisenhardt, 1989; Yin, 2009); due to research practical reasons the research here relies mainly on expert interviews as well as document analysis. By triangulation the external validity can be increased as well as the substantiation of results (6 & Bellamy, 2011; Eisenhardt, 1989). For this research, triangulation was achieved through the use of different empirical approaches including literature reviews, online resources, and semi-structured interviews.

The literature review covered the relevant background information on biorefineries and their definitions as well as the different commercialization challenges discussed in academia. Together with the review on frameworks and concepts that are widely used to structure the analysis of the commercialization of technological innovations from both a systems' as well as a business-centric perspective, the conceptual model was developed as part of the methodology section. For that purpose, academic articles, books, conference papers, as well as grey literature was reviewed. Further, an initial literature review of the case as well as the experts was conducted as preparation for the in-depth interviews and was mainly based on online resources such as websites and corporate reports.

The case itself was largely informed by expert interviews combined with information from websites and documents published on the company's website. Corporate reports and articles found were used to complement and also triangulate the results obtained from the expert informants.

While the literature review provided background information and the contrast material, the interviews constituted the backbone of the case study and the study as such. The interviews were carried out in a semi-structured manner, meaning an interview guide with a set of questions was prepared in advance – derived from the literature review and conceptual framework – but was not necessarily followed strictly. The interview guide can be found in Appendix I. The semi-structured approach allowed the interviewer to vary the order of questions and ask follow-up questions to any (unforeseen) answers (Bryman, 2012). This helps to focus attention on the interviewee's point of view and adapt the direction based on what the interviewee considers particularly relevant (Bryman, 2012).

In total, six interviews were performed as well as one correspondence solely based on email communication. Four interviews were conducted with representatives from biorefining companies. In addition, two interviews were completed with representatives from biotechnology companies. Interview partners were identified by browsing through the websites of the respective companies, through referrals from researchers, and through referrals from company representatives that were asked to forward the request to an appropriate informant. Site visits were not included, due to distance, sustainability and simply research practical reasons such as time.

Potential interview partners were contacted via email or telephone; the interviews themselves were conducted via skype throughout a period of one month (July 2017/August 2017). They started with an introduction of the research background and objectives and typically lasted for 20-45 minutes. They were all audio-recorded with the consent of the interviewee. Soon after the interview, respondents were contacted if clarification was needed. The list of the interviewees is provided in Table 3-2 above.

Analysis

The interviews were then transcribed and coded for analysis using *Maxqda*, a software program that facilitates data tarnscribtion, coding and analysis. The analysis itself was led by the conceptual framework which provided the initial coding categories. A directed approach to content analysis was used to identify patterns within the case and in relation to the other findings (Hsieh & Shannon, 2005). The conceptual framework will be described in the following section.

3.2 The integrated framework

The analytical framework proposed in this section is based on the literature review in chapter two; both the review of the commercialization challenges of biorefineries as well as the conceptual review were considered; in the later part of the review, the author established the links and rational for choosing the frameworks which are integrated in this chapter to model the biorefinery business in its wider system context. The framework can serve as an instrument that can be used for reasoning and enquiring and as such as a tool that allows the author to explore ideas conveyed by the findings (Morgan & Knuuttila, 2012; Morrison & Morgan, 1999). As Porter emphasizes, "frameworks seek to help the analyst to better think through the problem" (Porter, 1991: 98). Therefore, proposed framework serves as a heuristic that will guide the collection and analysis of empirical data in meaningful way with respect to the research aims. By way of refreshing the argumentation, a brief summary of the review is given before the framework is presented thereafter:

Based on the review, the author has inferred that the MLP can serve to model the wider system context the TIS is nested in. In relation to the MLP, the TIS can be interpreted as a niche in the context of the MLP (Walz et al., 2016), which is assumed to apply for most advanced biorefining technologies. In addition, the TIS is better suited when technology specific matters are of interest (Markard et al., 2016; Weber & Rohracher, 2012), which is also the case in this thesis. However, it has been argued that the comparatively wide scope the TIS proposed in its systems' perspective on innovations leads to a high degree of aggregation; the micro-level foundation is lacking and with that the role of agency is disregarded (Markard & Truffer, 2008a). Hence, a business model framework – or an adapted version of it – in combination with other insights from strategic management can introduce the missing micro-level perspective to the TIS. By doing that a zoom-in is possible on biorefineries as actors within the TIS (Markard & Truffer, 2008a). The resulting framework is presented below and presented subsequently.

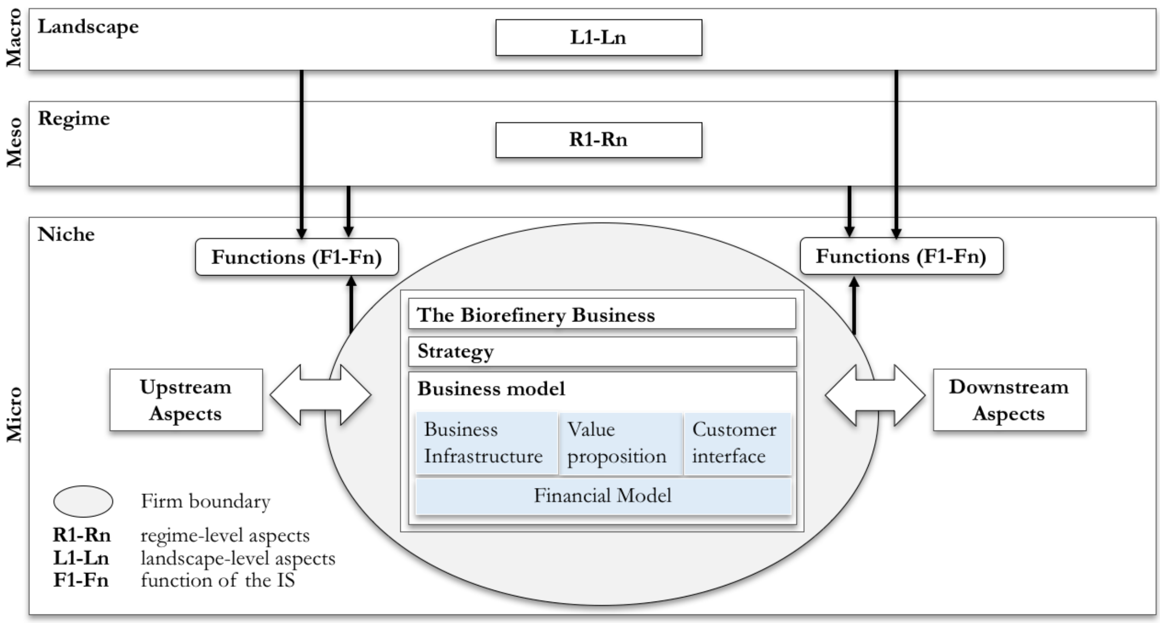

Figure 3-2. The Integrated Analytical Framework

Source: author's own depiction, but content based on Andreini & Bettinelli, 2017; Geels & Schot, 2007; Hekkert et al., 2011; Porter, 1996; Porter et al., 2011

Starting with the broader perspective, the MLP is adopted for the fundamental structure of the framework; accordingly the differentiation of the sociotechnical system into landscape, regime and niche is proposed (Geels, 2002; Geels & Schot, 2007). The landscape refers to the overall socio-technical setting that encompasses both the intangible aspects of social values, political beliefs, and worldviews and the tangible facets of the built environment including institutions and the functions of the market place, such as price, costs, trade patterns, and incomes. In the case at hand, it represents the exogenous environment in which firms operate and which changes only slowly. The abbreviation (L1-Ln) functions as spaceholder for all potential landscape-level aspects that represent it. The regime-level of the sociotechnical system constitutes the mainstream, and highly institutionalized, way of currently realizing societal functions, that is the fossil fuel dominated system of energy and materials production. The abbreviation (R1-Rn) functions as spaceholder for all potential regime-level characteristics that represent it. Regime level aspects are existing rules, practices and instututions as well as incumbent technologies supportive of the dominant sociotechnical regime. Niches form the micro-level of the sociotechnical system and are the most unstable configurations. They are responsible for the generation and development of radical innovations (Geels, 2002). Within the micro-level the biorefinery TIS is interpreted as a niche (Walz et al., 2016). The biorefinery and with it the firm-level perspective is placed into the niche level, as most of the advanced and lignocellulosic technologies have not reached mature stages yet; the same goes for multi-product biorefineries. First generation biofuels have entered the regime level somewhat more as they are accepted on the market. As Geels et al (2007) propose that niche innovation can be regarded as fully developed when their share in the market covers at least 5% (Geels & Schot, 2007). This can be regarded as not applicable. From a TIS perspective the biorefinery business is one actor in the TIS.

The biorefinery business is represented by using strategy and the business model elements as proxy; firm-internal processes are regarded as a black box because the interest of this thesis is to look at the intersection of the firm with its external environment. While according to the understanding followed in this thesis the value chain is captured by the business model, the author decided to depict the upstream and downstream aspects separately. This acknowledges that many challenges identified in the review section (Chapter 2.1) concern the upstream or downstream aspects of a biorefinery explicitly and thus it seemed relevant to emphasize them particularly. Upstream and downstream here serve as umbrella dimensions, which refer to actors as well as aspects that the biorefinery business engages with. Examples of actors include e.g. suppliers and customers; aspects include e.g. feedstock, transportation, preprocessing, distribution.

To further model the interactions of the biorefinery business with the TIS and the wider sociotechnical system, the functions of innovation systems are denoted with the abbreviations F1-Fn. It is of interest to identify how the biorefinery business interacts with its external environment and by that affect and are affected by the functions.

By way of concluding, the author thus has constructed a framework that puts the business model central while still considering its system embeddedness. Thus, it can be used for analyzing how biorefinery businesses seek to attain fit with their sociotechnical environment through their strategic choices and business model. The framework is deliberately held simple and open and is not be considered to be static and neither as strictly hierarchical (Geels, 2011).

4 Findings and Discussion

The section describes and discusses the results obtained from the data collection process described in the chapter before. As also already introduced, the analytical framework serves to guide the discussion so that the subsections are chosen accordingly. Within each subsection first the analysis of Amyris is presented and thereafter the insights gained on the same aspect as obtained through the expert interviews. After the presentation of the findings the contrasting discussion follows right away. The summary of the discussion as a last section is helping to wrap-up the main findings and highlights.

The findings will be organized as follows: The sections are chosen according to the framework proposed and interactions with the wider system are discussed as part of these subsections. In Addition, the sections start with Amyris and the presentations of the findings in relation to them, followed by an account on the expert interviews in relation to the findings. Lastly, the findings are discussed and contrasted with the literature. The presentation and discussion of the findings will be limited to the aspects that are considered relevant and thus does not seek to provide a holistic analysis but derive themes without getting lost over small details.

4.1 Commercialization Strategies: Case Study

This chapter presents the findings of the case study on Amyris, Inc., focusing on the strategic responses the company has chosen towards overcoming commercialization challanges. In the discourse, the strategies are discussed in relation to functions of innovation systems; by that the interaction of the case company with its wider system is illustrated.

4.1.1 Upstream Strategies

Regarding the upstream challenges, Amyris has deployed various strategies to address them. The initial feedstock selection (direction of search) was largely driven by considerations surrounding feedstock availability and steady as well as reliable supply at low costs (Amyris Annual Report, 2012). In addition, Amyris made sure that the sugar is sustainably sourced to ensure the legitimation of the feedstock used. Thus, the informant does not see sustainability issues such as the food vs. fuel debate as applicable to their business. He noted “if there were markets they could expand capacity 10-fold without impinging on rain forest and moving anywhere near that sensitive areas.” (Amyris, personal communication, 2017). Apparently, the topic is also not sensitive from their customers’ view as sustainability is part of Amyris’ value proposition (Amyris Annual Report, 2016).

However, compared to the degree of diversification and entrepreneurial experimentation reached in products and markets, the feedstock is the part of the business Amyris has not deeply engaged with, mainly because the company does not see the necessity as long as they can reliably source low cost sugar (Amyris, personal). In fact, they have not identified any other source of biomass derived sugar that is equally attractive in price and as reliable as sugar sourced from Brazil (ibid.). In general, feedstock diversification is seen as an option, but Amyris has not engaged much with it, as it is outside their core competence (ibid.). This is also the reason why lignocellulosic feedstocks have not been focal to the agenda. Although Amyris is part of a joint project, funded by the U.S. Department of Energy (DOE), with Renmatix for the production of farnasene from cellulosic sugars – which Renmatix produces – the respondent emphasized, “we have converted our existing farnasene strains to be able to use lignocellulosic sugar like cellulose and glucose successfully but you know so we are steadying on that technology, but because we don’t have anybody that can supply us the sugar at a cost that is equivalent to the sugars we buy in Brazil you know that has nothing to do with the technology.” (Amyris, personal communication, 2017).

The informant further adds "in many cases … we cannot just purify sugar and put it into our engines. There is a conversion process that also adds costs…. if we compare starch based or sugar cane based to lignocellulose well you know in a plant those compounds in a sugar cane or in corn plant in corn kernels are meant by nature to be degraded to energy compounds for the growth of the plant. Lignocellulose on the other hand is made to be resistant to degradation and hold the plant together erect. And we want those to be comparable. And the problem is this is not how nature designed them. And we use nature's tools to break them down," the informant further stresses "…when oil goes to 200$ a barrel at least some of these processes become competitive. At some point that may happen but you know I would not bet my business on it anymore." (Amyris, personal communication, 2017). What this illustrates is that the choice of feedstock is not necessary driven by technology readiness but by the cost of sourcing the respective feedstock; in addition, landscape signals (oil prices) pull the direction search in relation to feedstock away from lignocellulose.

To secure the market access to low cost sugar (market formation), in 2012, Amyris entered into a long-term sugar supply contract with sugar mill in Brazil, instead of engaging into market trading (Amyris, personal communication, 2017). As part of this decision, Amyris built a manufacturing plant for their most important platform molecules, farnasene, in Brazil (Amyris, personal communication, 2017). As the informant describes, "our facility is located in Brotas, Brazil and it is on a piece of land that is adjacent to an existing sugar mill so when they crush the sugar cane and then make the sugar cane syrup the mill concentrates that sugar and sends it through a pipe that connects us to the mill. So, we are physically connected to the production site for the sugar." (Amyris, personal communication, 2017). Amyris is solely responsible for operations and maintenance of their biorefinery. By collocating with an existing sugar mill, sugar supply could be guaranteed. Further, the infrastructure for producing, gathering and processing sugarcane is already in place (ibid, 2012), and thus did not have to be built anew, which would have required additional resource mobilization. However, Amyris also experienced the challenge of seasonality in feedstock supply, but managed to find a substitute for the off-season. The company entered into another agreement with their supplier to buy molasses and high polarity sugar and we blend it together to use it as a replacement for cane syrup (Amyris, personal communication, 2017). To increase capacity, Amyris has planned the completion of their second plant in Brazil, following the same principle as the first, by 2017 (Annual Report, 2016).

With regard to the market formation for the supply of sugar, the value proposition towards their suppliers is that of providing a hedging means against price fluctuations as well as convenience and steady revenues, which is summarized by the informant as follows: "our cost for sugar is a formula that is based on the current cost of ethanol and sugar and so for them it is a so-to-say hedge against fluctuation in price. And it is you know we are a steady consumer and frankly it is really easy for them because they do not have to do any transport or shipment they just put it into the pipe and send it to us."

After the conversion into farnasene, shipment (tanker trucks and ships) to the U.S. and worldwide takes place for further processing (Amyris, personal communication, 2017). As such Amyris has managed to avoid biomass transportation over long distances and related costs; no large quantities of sugar need to be shipped. International trade of feedstock does not play a role in the case at hand. In fact, to secure supply, Amyris has decided to pursue a strong vertical integration with close collaborations throughout the supply chain.

By way of concluding, upstream has proven successful for Amyris to pursue a high degree of vertical integration, access to a reliable source of low cost biomass and avoiding transportation by collocating with an existing facility; the decisions upstream are purely driven by the ambition to keep costs as low as possible, while maintaining a high degree of reliability and predictability in supply.

4.1.2 Business Model and Midstream Strategies

The responses towards the upstream challenges originate from the overall business strategy Amyris pursues; this strategic approach is focused around the direct commercialization efforts of higher-value, lower-volume markets. Lower margin, higher-volume commodity products, which includes fuels and base oil lubricants products, are moved into joint ventures with established industry leaders. This approach is considered to permit access to capital and resources necessary to support large-scale production and global distribution of large-market commodity products. The strategy is implemented into a business model that is heavily based on partnering (network creation). These collaborative technology-based partnerships provide Amyris with insights and access to markets (market formation) and help them to channel their direction of search towards molecules that have corresponding demand when being introduced (Amyris Annual Report, 2016). Amyris builds their value proposition around the access to their technology with which leading consumer brands can develop products made from renewable sources that offer equivalent or better performance and stable supply with competitive pricing.

However, one major issue that accompanies the company since inception is the mobilization of resources, especially financial resources. While, the business model entails a highly integrated supply chain (vertical), which is considered a cost-intense strategy, the company generally seeks to deploy a capital-light business model, which is reflected in the decision to build a bolt-on, instead of a greenfield plant, as described in the section before (Amyris Annual Report, 2016). This strategy materializes in the high dependence on partnerships. In fact, partnerships are largely used for contract manufacturing activities for further processing of their initial target molecules into finished products, in both the U.S. and Brazil. This strategy shall be further deployed to access flexible capacity and an array of services as product development progress (Amyris Annual Report, 2016). In addition, their proprietary platform to design microbes serves as living factories in established fermentation processes, which adds additional flexibility to use contract manufacturing (ibid.)

Yet, since inception, Amyris has mobilized numerous different resources, ranging from equity and debt financing from investors obtained from affiliates of Total Energies Nouvelles Activités USA, formerly known as Total Gas & Power USA, SAS (or Total), the international energy company, and Temasek Holdings (Private) Limited, the Singapore sovereign wealth fund, to leading U.S. venture capital and private equity investors such as Kleiner, Perkins, Caufield & Byers and TPG Biotechnology Partners. Amyris has also acquired financial resources through the issuance of stocks in the initial public offering in 2010 (Amyris Annual Report, 2016). In addition, the company received around $38.5 million in subsidies between 2004 and 2016 (reference). However, with increased diversification, resource mobilization and with that their financial model is now largely driven by partnering with leading companies. Collaborations provide Amyris with payments for technology access and research and development, subsequent sales of the target molecules to the partners and participation in the cost/benefits the partner derive from the molecules (value-share agreement). By that, access to capital and resources for large-scale production is secured (Annual Report, 2016).

Collaboration is also used to influence knowledge development and diffusion. Amyris is a member of the National Advanced Biofuel Consortium under the Department of Energy (DOE) and NREL, as well as a recipient of an Integrated Biorefinery grant from the DOE. Furthermore, Amyris engages in research collaborations in Australia, Brazil and the U.S. As founding member of the Advanced Biofuel Association, Biotechnology Industry Organization and Diesel Technology Forum, among others, Amyris actively engages in network building activities.

The high degree of collaboration further influences the entrepreneurial experimentation as well as knowledge development and diffusion. For the companies that Amyris is partnering with it would be hardly possible to reach the stage of development they reached; as the informant puts it, "you know we have got an investment into Amyris of about 1.3 billion dollars and huge amount of that effort has been focused on engineering the yeast strains and optimize production of farnasene so the cost at which we can produce farnasene is far superior to anything else out there. So, no one can even – even if they could copy the technology – get to the point we are at would take them years and its patent-protected" (Amyris, personal communication, 2017). This illustrates the magnitude of investment required to commercialize a biorefining technology as well as the long time to market, which poses a high entry barrier to firms seeking to develop a biorefining technology internally.

Accordingly, entrepreneurial experimentation can only take place through these collaboration agreements as then Amyris acquires the necessary funds to do so and their partners do not need to develop the technology internally anew. Hence, due to patent protection, knowledge development and diffusion is tightly connected to collaborative arrangements. Companies that seek to use the technology have to either develop a different technology for reaching the same outcome or engage into licensing or other forms of partnerships. However, as Amyris possesses the technology and their core competence is around it, they are also similarly dependent on their partners to providing complementary assets such as market knowledge access. Amyris considers this to help with aligning the incentives of the partners to the collaboration (Amyris Annual Report, 2016).

While partnerships are considered integral part of their approach, licensing is only envisioned to play a role in the future. This is largely based on the fact that the technology is still under development and close partnerships are required, especially the transferability is considered an issue: "You know we spend a lot of money and a lot of time understanding how the performance of a yeast strain in a two-liter fermenter compares to the performance of the same strain in a 200.000-liter fermenter; knowing what is a transferable process and what isn't is really important." (Amyris, personal communication, 2017). In addition, the informant perceives companies to be reluctant towards building an own plant on someone else's technology: "if it costs you say a 100 million dollar to build a fermentation facility to run it on someone else's technology and you don't have any data at commercial scale or even at a demonstration scale that is a lot to ask. You know, who is going to write a 100 million dollar check on an unproven technology?" (Amyris, personal communication, 2017). Hence, the collaboration approach is chosen as business model as licensing was not considered viable.

The direction of search is also influenced by the collaborative approach. However, over the years, the direction of search received different impulses from within the socio-technical system. In the beginning, the funding received was tied to the development of artemisinin. When the initial project was terminated, an alternative use of the technology was to be found; the company used the same technology to focus on fuels. The informant remembers "... in 2008, oil was at $130 a barrel and everybody was very concerned about the end of oil and you know any company that was working in the biofuels spaces was a hot commodity. People wanted to invest; we were in the process of raising money to support the company and investors involved, …, they were very interested in the biofuels space because it is a huge market with huge potential to grow and now what happened between 2008 and 2010 is shale oil came online, the price for oil started to drop and basically our ability to profitably make fuels disappeared. So, as a consequence we started looking and working pretty hard internally to identify higher value compounds we could make that would have higher margin to support the company…. the original decision to go into fuels was really driven by venture capitalists who were funding the company saying we want to go for the big thing." The expectations were created by general public perceptions, as the informant summarized, "…everything was pointing towards biofuels would going to be a big thing, so it was policy, it was the price of oil, it was just the general public perception that biofuels would be going to be a big deal. But nobody really foresaw the price of oil dropping to $35 a barrel." (Amyris, personal communication, 2017).

Hence, different impulses coined the direction of search throughout the company's development. However, the current strategy is largely driven by landscape signals which do not make a business case for relying solely on biofuel markets, but rather pursue a differentiation in markets independent of oil prices and policy incentives (Amyris, personal communication, 2017; Amyris Annual Report, 2016). The differentiation strategy itself with regards to the products and markets is driven by both market developments and customer needs articulated, which drives the molecules Amyris is focusing on. The ability to adapt to the changing signals from within the sociotechnical system, is largely attributable to the flexibility Amyris has achieved through building a platform technology but also developing a platform chemical (Amyris Annual Report, 2016). The informant emphasizes this key aspect stating, "If I was to give advice to somebody and that is ten years behind Amyris…build a technology platform as flexible as possible so that you can respond to changes as they happen." (Amyris, personal communication, 2017).

The overall strategy and the corresponding business model have affected the way upstream processes are organized and – as will become apparent in the next section – have also largely affected how downstream processes are managed. The whole business model – across the value chain steps – exhibits a large degree of integration and collaboration; whereby the decisions are largely driven by concerns around resource mobilization as well as diversification to become less dependent on single markets and especially oil prices and policies.

4.1.3 Downstream Strategies

Amyris deployed a diverse range of strategic responses to position themselves in the market and reach legitimation as well as credibility of their technology; the direction of search, resource mobilization and knowledge development and diffusion played hereby an important role in influencing how the business was developed downstream.

As described before, Amyris started off with biofuels after the project targeted towards the development of artemisinin ended, however realized that market formation around biofuels is largely dependent on policies and landscape developments such as oil prices; pressures from the landscape level (policies, visions, and expectations) which have formerly pulled Amyris into the biofuels sphere and created windows of opportunities for technologies in the field, have vanished over time. For an overviewe on oil price developments see Figure 4-1 further down. Nowadays, biofuels are only a minor part of the business and are outsourced into joint ventures. However, the shift away from biofuels to biomaterial follows a step-wise strategy around five different markets: cosmetics, flavors and fragrances, performance materials, renewable lubricants (and fuels).

According to the informant, the motivation for the development of bio-based materials is based the fact "…that bioproducts tend to be expensive products, so trying to get to commodity markets from biomass derived fermentation products is extremely difficult, so I think that most companies have realized or moving to realize that targeting higher value smaller market compounds is a much better business proposition", thus, in comparison to biofuels, the shift towards biomaterials is largely industry-driven; in fact, the informant considers policies in that field largely ineffective: "I would say policy is extremely ineffective... if you look at… the US government purchasing policy around government purchases of any products – they have an obligation to source bio-based products over other product –…the problem is that the bio-based products have to be at comparable price, if they are more expensive there is no obligation. And the problem is that the products that have been targeted are all more expensive and people are expecting, the businesses are expecting people, companies, government to pay more because it is a bio-based product. And they won't. They won't. You know in fuels you see a number of policies around trying to increase the content of renewable fuels in jet fuels for instance but when it comes down to it, because the cost is significantly higher for the bio-based fuels – ours included –, there is very little motivation by the people actually purchasing the fuels to do that because there is no economic benefit to them. They have to spend significantly more money." (Amyris, personal communication, 2017)

Hence, disincentives in the biofuel market lead to the repositioning of Amyris to target markets where they can realistically compete on price (Amyris Annual Report, 2016). As the informant underpins, "If I was to give advice to somebody and that is ten years behind Amyris, I would say the (two) things you really want to make sure is that you can be competitive on price. Cause nobody is going to pay for green at least not as much as you need them to…" (Amyris, personal communication, 2017). With regard to the choice of focusing on other markets, but biofuel, the informant further reflects "… if you think about what we are trying to do. We have a completely depreciated infrastructure pumping oil up out of the ground and refining it into fuel. We are trying to build an entirely new industry that has a very high capital cost for the initial investment and in many cases the work it is a conversion process like it is not that we can just purify sugar and put it into our engines. There is a conversion process that also adds costs. Expected to be competitive with fully depreciated industry is just not realistic at the current prices." (Amyris, personal communication, 2017).

Consequently, the company developed a value proposition that allows them to compete in existing markets and which the informant describes as follows: "We have a line that our products are no compromise products; there is no compromise on price - it is at least equal or even better in price - there is no compromise in sustainability - it is going to be at least as sustainable if not more sustainable then the current product - and the performance is at least going to be equal or better. No compromise on those three areas. And when we target customers what we target are products where they have a lot of volatility in price. And we are their supply on sustainable you know shark livers from deep water sharks to make a face cream is not a very sustainable process." Hence, sustainability is seen as a value proposition on top of providing a competitive offer on purely economic concerns. The importance of this approach is further emphasized by the informant in that he recommends other companies who want to engage with biorefining "… to target markets where the price point is accessible, you know if they are trying to make commodity products and you know, I think there are many of them actually thinking about commercial production, they are mostly technology companies that don't have any scale of capability; unless they are targeting higher value compounds they are very unlikely to be successful." (Amyris, personal communication, 2017).

The value proposition supports the legitimation and acceptance of their technology in the market and is further supported by the characteristics of farnasene, which is "…a branch chain alkane, the chemistry to convert it into other things is very well known; it is a typical component of petroleum feedstock and it looks like something from petroleum; so, chemists who grew up working on alkanes from petroleum know what to do with the chemistry. So, what we did is create a whole series of markets where we use this as a base molecule which then gets converted into other compounds." (Amyris, personal communication, 2017). Thus, Amyris can offer drop-in substitutes for existing molecules, making the integration in existing processes comparatively easy. Thus, their *no compromise value proposition* helped to gain acceptance and support by surrounding actors, especially customers, which positively affects the ability for resource mobilization through e.g. stimulation of customers' articulation of demand (market formation).

In this light, Amyris is not engaging with market formation in the sense that a development of new markets is aimed at, but targets markets where they can replace a supply source for an existing market that is well understood and is growing faster than current supply can support from either a volume or pricing perspective (Amyris Annual Report, 2016). However, to reach legitimation and access to existing markets, the high degree of collaboration, which permeates through the whole value chain, is is also seen as a major driver in that regard. By pursuing a diversification strategy, Amyris is active in several different markets, which all require specific market knowledge and knowhow as well as assets which the company mobilizes through their collaboration. By that Amyris has gained access to brands and companies which have already built reputation in the respective markets. The informant summarizes the role of partnerships for market development: "It is critical. It is critical. Because we sell into so many different markets that are very different from each other you know – flavors and fragrances and fuels, health and nutrition, personal care – these are all really different businesses with very different concerns about the product. Knowing all their concern is impossible we need the partners to tell us what do they care about when we deliver the fragrance to them (…) We can't possibly know all that" (Amyris, personal communication, 2017).

In exchange for this access to their partners' knowledge, Amyris offers on-demand product development of products to cater to their customers' needs and thus reduces their internal R&D requirements. This collaboration approach is sought to align incentives for success, and allows them to mobilize the resources to support large-scale production and global distribution of their products (Amyris, Annual Report, 2016). Furthermore, due to the flexibility of their technology platform and platform molecules (e.g. farnasene) Amyris realizes comparatively fast times to market which allows them to react towards changing dynamics in their environment. It also enhances the acceptance reached in the market when competing with well-established incumbent processes and products.

Lastly, as above-noted, collaboration is not only helping market formation and knowledge development, but also stimulates entrepreneurial experimentation, as it de-risks R&D activities. Hence, these activities create – what has been described by (Geels, 2002) - protected niches around the technology for experimentation and further development. In fact, the biofuel business is largely focused around bringing the costs of production down to make the current price point accessible (Amyris, Annual Report, 2016).

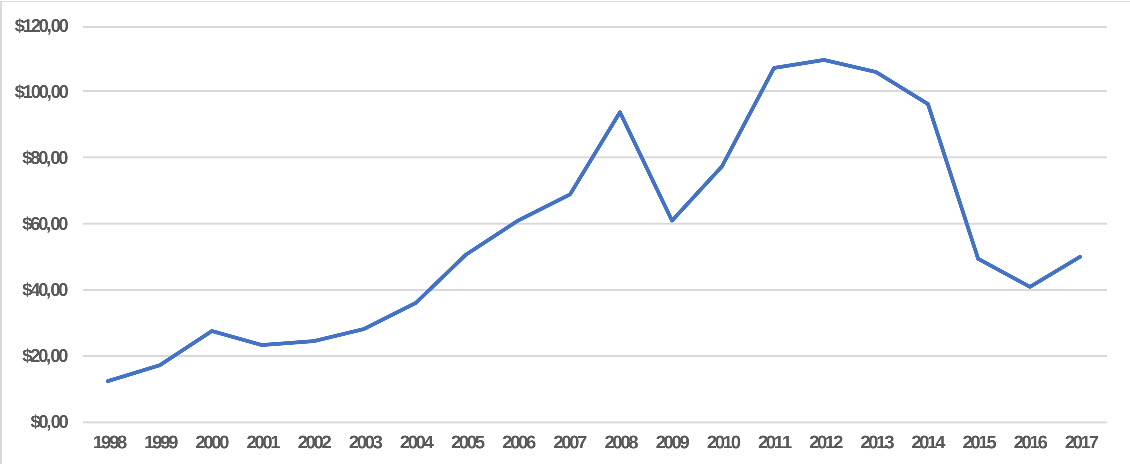

Figure 4-1. Oil price Development 1998 – 2017

Source: author's own based on information derived from Statista

4.2 Commercialization Strategies: Comparative Discussion

Having presented the case study above, the findings will now, in a following step, be discussed and contrasted with the insights gained from the additional expert interviews as well as existing academic discourses in this field. Thus, the findings are put in perspective to provide for a critical account. Hereby, the same general structure as in the previous chapter is used. Every chapter starts with a brief summary of the findings from the case study, followed by the discussion.

4.2.1 Upstream Strategies

In relation to the upstream challenges, Amyris has chosen to pursue a high degree of vertical integration to secure the supply of low-cost biomass. This is reflected in the choice of location – bolt-on to an existing sugar mill –, use of existing infrastructure and long-term supply contract. Amyris uses only one type of feedstock, whereby the choice of feedstock is purely driven by cost considereations and availability. These strategic responses are also somewhat reflected in the results obtained from the expert interviews, however, differences are also identified, as the companies engage in different ways and to varying degrees with biorefining.

Securing supply and market formation upstream has been an issue identified by all, but one, as critical. As one respondent notes "…the major issue would be first to secure the supply to have enough raw material from wherever you should start" (Sunpine, personal communication, 2017). Raw material in fact, often constitutes a major cost driver in relation to the overall production costs.

Yet, Through the use of waste gases as feedstock, Lanzatech is "… able to utilize a feedstock that is low-cost and will remain low-cost and provide certainty in the cost structure." (Lanzatech, personal communication, 2017). In fact, part of their value proposition towards their customers is to provide a technology that can turn a cost center into a profit center (ibid.). Yet, Lanzatech is the only company which does not have to consider the cost of their feedstock. In comparison for Sunpine "…the cost for crude tall oil is the single largest cost that ... the company has. It is a huge part of the cost." (Sunpine, personal communication, 2017). Also for POET the corn grain "will make up, I don't know, maybe 80 percent of our expense in producing the ethanol." (POET, personal communication, 2017).

Similar to Amyris, all companies have chosen a location close to the feedstock, however to varying degrees. To reduce additional production costs, POET relies on biomass which is locally grown (30 miles radius around the plant) in the U.S. and benefits from an exiting infrastructure in place. (POET, personal communication, 2017). International biomass trade does not play a role. Yet, the degree of integration varies with feedstock, which the informant describes, "on the cellulosic side, we have contracts with farmers and we have contracted prices and delivery times. On the grain side, we just put, corn is a global commodity, … a price out that we will pay every day and farmers will choose to deliver or not, whatever it might be." (POET, personal communication, 2017). Accordingly, integration here helps when biomass supply is not warranted otherwise. In the case of Lanzatech, colocation with existing plants for feedstock sourcing is mostly required as "…when you are talking about utilizing industrial off-gases. You know, gases are by their nature not energy-dense, so it is important to be co-located with the facility because it is not really economical to transport the gases." (Lanzatech, personal communication, 2017). Sunpine exhibits an equally high degree of vertical integration as Amyris, as the owners comprise the full value chain, thus supply is secured (Sunpine, personal communication, 2017).

In relation to the value proposition upstream, similar to the case of Amyris, "…farmers really like investing in ethanol plants because the theory has always been that, if grain prices are really good, I am going to do very well on the farm. If grain prices are low, my ethanol investment will help me through any losses of the farm." (POET, personal communication, 2017). Whereas in the case of Amyris, the contract serves as a hedging means, in the case of POET farmers can also diversify their business by investing into ethanol either through sales, equity or both. As has been described before, in the case of Lanzatech, the value propostion is that of mitigating emissions, while generating an additional revenue stream.

The initial choice of feedstock was motivated "… to soak-up surplus grain, provide a market for farmers, because yields in the United States - for corn especially - are just going through the roof. The demand is stagnant. We are having no market for that grain, we are running the family farm out of business in this country, and we are going to flood the world with very cheap grain, which is not good for agriculture around the world." In fact, the founder of POET has been a farmer himself and has started the business to diversify his own farm initially.

Lanzatech's motivation to chose the feedstock is described as "…when you look at the market opportunities we have in terms of addressing waste gases and it's huge and couple that with a strong focus on sustainability and people start to get pretty interested. So, I think that is definitely a good part of it." (Lanzatech, personal communication, 2017).

Whereby the cases above do not have a problem (yet) with competing demands but have actually chosen their feedstock deliberately due to its abundance and little problem with competing demands and interests, in the forest sector implementing a biorefinery, especially when aiming at large scale poductions to produce biofuels, proves challenging due to different competing demands. As an informant evaluates "…the thing is that there is an existing use in the Nordic area of the available harvest, economically available volumes of timber or solox, pulp wood, and energy as ornaments from the forest. And the higher the utilization rate is, the more local the market will be. So, in order to make biofuels economically interesting, you need to build a very large facility and then the cost of the biomass delivered to the facility will be far too high due to the fact that you have local uses close to the biomass sources that are able to pay more than what the big bio fuel focused refinery will be able to do. To have a, say 300 to 500 thousand metric ton per year production unit, you will need to fight yourself into the market with very high biomass prices. And because the forest owners are not stupid, they are not selling valuable solox or pulp food at a value of harvesting residues or energy assortments. There is still a lack of understanding how well the wood raw material markets are optimized by existing market mechanisms without policy instruments. So, policymakers should understand that, if they go in, require an existing functioning market to be distorted... It will have consequences for how the actors are behaving." (Storaenso, personal communication, 2017)."

In essence, while the feedstock availability as such is less of an issue, accessing it for low value products such as fuels is challenging. Thus, an integration/collocation with existing pulp and paper mills is often discussed to provide a way of implementing a biroefinery in the forestry sector.

Thus, the upstream strategies, exhibit varying degrees of integration, albeit the tendency to have an integrated supply chain either through physical integration, contract agreeements or ownership can be identified. Only for local commodity biomass such as corn grain, formal arrangements are not necessary. In order to establish markets upstream (supply) the value proposition is often a diversification and price volatility hedging for farmers or utilization of feedstock that otherwise has no market value.

4.2.2 Business Model and Midstream Strategies

In relation to the midstream challenges, a high degree of collaboration is characteristic, which helps Amyris to mobilize financial resources most of all. The financial model is largely supported by R&D upfront reimbursements, allowing for a high degree of entrepreneurial experimentation. Amyris' technology is characterized by flexibility, which allows them to adjust to changes as they come.

Across the experts a high degree of variability is seen in the way the businesses engage in biorefining. While Lanzatech, Amyris, and Novozymes are most of all biotechnology companies, Storaenso is a pulp & paper manufacturer, Sunpine a renewable products (fuel) company, and POET an ethanol producer most of all. Hence, also the way they structure their business models is different. While Lanzatech, Amyris, comparatively small in size, engage in partnerships and licencing activities and have the biotechnology at the heart of their business, Novozymes caters to a large variety of markets, with biofuels one of them, StoraEnso has established a designated biorefinery business unit within their company and Sunpine is fully owned by all value chain participants.

In addition, all companies use their own technology, only Storaenso acquired a technology not developed internally. While for Storaenso, engaging in biorefining is another way to diversify their business and hence has to be integrated, others have their business model build around biorefining technology. The fact, that most companies developed their own technology, is an interesting observation and will likely influence the way biorefining will diffuse, as most companies have dedicated large funds and long time to the development of their technologies and seeked patent protection eventually. Indeed, one informant states "We have raised well over 200 Mio. dollars to this point of funding from various sources…that's a lot of money for one company of any size to commit to a technology like this." (Lanzatech, personal communication, 2017). Another respondent confirms "…and it has been an investment of more than 20 years from a research and innovation perspective here at Novozymes to get at a stage, to get to the point where we had something that was working well." (Novozymes, personal communication, 2017). Also in the case of Sunpine "the three owners put up with 100 Mio. SEK each" (Sunpine, personal communication, 2017).

Consequently, developing a technology internally will be difficult for a lot of companies as biorefining is not part of their core competencies and thus unlikely to be developed internally: "… the technology … we have developed is not one that…could be developed inside one of these companies. The steel sector knows about making steel. They know nothing about making ethanol, or selling ethanol or like anything like that. So, this technology certainly would not have been developed within a steel mill." (ibid.)

In addition, both Lanzatech and Amyris – being SMEs in size – stress the importance of following a capital light business model and mobilize resources by way of partnering with larger companies with stronger balance sheets. As one informant points out "If you look at the people that we are partnering with…these are much larger companies, with much larger balance sheets. So, from a financial risk perspective, it's much easier for them to raise capital because they have stronger balance sheets than we do." (Lanzatech, personal communication, 2017). Hence, from a resource mobilization perspective, this has helped both companies to expand faster and deploy their technology faster than otherwise possible. The informant further emphasized "If we had taken a build-own and operate approach, at best we could have one commercial project that we develop. So, having the licencing approach does give you the ability to deploy the technology more quickly without devoting as much capital internally to those commercialization efforts." (Lanzatech, personal communication, 2017) However, it also "created some additional challenges and creates an additional layer of people that you have to convince to come on board. But first we had to convince Soregun and Arscom Metal, they have to go out and convince their people, financers and things." (ibid.)

Yet, for any new technology "…being able to demonstrate the technology at larger scale than just in the lab definitely goes a long way to providing that comfort that we actually know what we are doing and the technology does actually work." As has been argued, pilot and demonstration plants are very important in that they create trust and legitimation in the technology (Frishammar, Söderholm, Bäckström, Hellsmark, & Ylinenpää, 2015; Hellsmark, Frishammar, Söderholm, & Ylinenpää, 2016). Due to the comparatively higher costs of building a cellulosic ethanol facility, POET is also considering the licencing approach and has build their first cellulosic ethanol plant for demonstration purposes mainly. As the informant confirms "we have been making really good improvement in the cellulosic process ever since and we are getting to a point now where our confidence level is very, very high. But we haven't decided to build the second plant. Once we decide to build the second plant, we will license the technology for another plant. That is when we will really have cracked the code of cellulosic ethanol and we are still looking at optimizing that process right now." (POET, personal communication, 2017). Also in the case of Novozymes, deploying their lignocellulosic ethanol technology, required entering into a partnership (Novozymes, personal communication, 2017).

What has been further observed by some of of the inverview experts is the importance of mobilizing the required capabilities needed for the commercialization of a technology, as emphasized by one respondent "another thing that we have done very well, is we have managed the science, the engineering and the business aspects of what we do holistically well I think." (POET, personal communication, 2017). This is supported by Lanzatech in "…so that this is one thing that has helped lanzatech be successful is that we have coupled a very successful science team with a robust engineering team and so we have been able to marry not only the underlying science advancements from a science perspective but also developed the process necessary to bring that to commercial scale." (Lanzatech, personal communication, 2017).

Hence, the findings confirm the proposition by several authors that the business model is largely important for the diffusion of new technologies (Baden-Fuller & Haefliger, 2013; Chesbrough, 2007).

4.2.3 Downstream Strategies

Downstream, collaboration once again plays a crucial role for market development, acceptance and legitimation. As Amyris has developed a value proposition that strieves to not compromise neither price and performance nor sustainability the company has achieved to generate demand for their products. Amyris targets high value – high margin markets, however, has followed a step-wise diversification strategy, pursuing fuels first and then gradually shifting towards higher value markets. The interest in fuels was largely stired by landscape signals (oil prices, policies and expectations); yet, the company realized that the price point is not accessible for them and seeked oil price and policy independence. Due to their value proposition, Amyris could mobilize complementary assests such as market knowhow, access to existing distribution channels etc. from their partners, helping them to position themselves on the market. R&D collaborations also help with derisking Amyris business model and providing a so-called protected space (niche) for further experimentation and scale-up.

In line with the analysis of Amyris, also across the experts a tendency towards diversification is clear, following a step-wise process, having started from biofuels. The initial interest in biofuels was largly motivated by the same landscape signals pulling companies into biofuels. As one respondent notes "first thing was of course to see what kind of additional revenues can be attained from markets where there was then a hyped bio premium and expected premium price. First it was very much around bio fuels, but soon it was realized that this is not the viable thing in the areas where we are actively running industrial operations due to lack of profitability. There is not cheap enough wood available for making biofuels. So, the focus has switched many many years ago towards different kind of material, intermediates, and chemicals, special chemicals and different kinds of solutions, combinations of these natural polymers that we have in the bio mass." (Storaenso, personal communication, 2017). Yet, Novozymes sees biofuels as a necessity as "you need to first reach economies of scale at big volume with bio fuels. So that's why we have been more focusing on the bio fuels part...chemicals …or bio materials, it's more value added produced per kilo if you want, or per ton, …the technology to get there is more complex… "we see bio fuels as the greatest potential is because the technology is ready to do it, both for conventional and also advanced." (Novozymes, personal communication, 2017).

However, they all have realized that for large-scale biofuel projects, market formation is highly dependent on policy support. One respondent emphasizes "If you want these private investment flows into building new biorefineries you need clarity and stability of the legislative framework is very important." (Novozymes, personal communication, 2017). The respondent further argues "…if you don't have blending mandate demand on the market that is kind of guaranteed, then why would any fuel supplier, fuel blender, buying fuel?" Sunpine also stresses "We are dependent on rewards for the use of tall diesel in the form of different kinds of tax relief. Green fuels are exempt from energy and carbon dioxide tax. Without such tax relief, the SunPine's business operations would not be financially viable. The true price of tall diesel is around twice that of 'dirty' diesel". (Sunpine, personal communication, 2017).

Hence, companies have started to gradually shift focus towards higher value markets. "…we are diversifying our portfolio that it used to be that we just make ethanol and distiller's grain. Now we make ethanol and distiller's grain and corn oil. We also sell a large amount of commercial grade CO2 to beverage manufacturers…And we are diversifying our portfolio into all kinds of different thing, like chemical building blocks…It is just a matter of economics and chemistry" (POET, personal communication, 2017).

For the market formation downstream, collaboration plays a role to varying degrees. However, Sunpine notes "Yes, that is actually, that has been a big, that has been a key to the success sometime, that … everybody has a stake in the company." (Sunpine, personal communication, 2017). In addition, "…the owners comprise the full value chain. It is also important that I see others lacking that in itself we had the customers along with us all the time, from the very beginning." Also in the case of Amyris, the demand is already secured before a product is developed, hence market entry is less risky. Whereas, Amyris has made the transition away from fuels, Sunpine still has fuels as their major product. This may be stired by the different policy contexts, as in the case of Sunpine, their major customer for fuels is Preem, the largest Swedish fuel company; as Sweden has one of the most ambitious visions for renewable energy, this may be result in a comparatively higher interest in biofuels. Also for Storaenso, collaboration plays a role for market formation in combination with synergies with their existing production: "Having the synergies with our existing bold production unit, but also our existing customer relations. So, it's always easier, a little bit easier, to introduce new products, new concepts, with customers who already know you and trust. We have many long-term customer relationships that we are benefiting from in introducing additional feature. And of course, when we are going to totally new customers that do not know us, it helps that we are a credible industrial operator. So, we can operate and build, we can operate large-scale facilities that we have proof of." (Storaenso, personal communication, 2017) Being an established player on the market thus has a similar affect then when Amyris or Lanzatech enter into cooperations with large players to gain market access. With regards, to horizontal collaboration, this is hardly seen, as Storaenso notes, "In pre-competitive research we do cooperate with competitors, but when it comes to more specific process or product development, we absolutely don't!"

Valdevia et al (2016) also support the findings in that industry must look for win-win agreements with companies having the necessary technology and customers (companies) who can benefit from it. The authors clearly identify that the final market needs will accelerate the product development based on the specification requirements and on-going collaboration between technology providers and final clients (Valdivia et al., 2016).

In relation to the value proposition, the findings from the case on Amyris are confirmed in that, one respondent notes: "it's performance that drives. Performance and price competitiveness and then it should be taking us forward on the sustainability side." (Storaenso, personal communication, 2017). POET also confirms "We have to compete. The economics mean everything to us and it's hard for us to sell a product that is more expensive than what the oil industry can put out. So, we got to make sure that we are competitive with every product we make." (POET, personal communication, 2017).

The overall theme throughout this analysis is that a step-wise diversification approach plays a role to compete in times of low oil prices and policy uncertainty. To develop the market collaboration is needed and in the case of biofuels, policy support is essential for market formation. Chambost et al. (2008) have also highlighted the importance of a stage-wise approach for biorefinery design based on a thorough analysis of the market in the beginning. Different possible price development scenarios (both specific segment and oil price) are important to be considered to assess the competitive position of the own technology. Devloping a product platform can then diversify risks from price volatility. The same consideration can also be applied when chosing a feedstock their their relative competitiveness need to be considered. (Chambost, Mcnutt, Stuart, & others, 2008). As has been highlighted in the literature the diversification is in fact As is widely discussed in the literature the diversification strategy through full valorization of a biomass resource by conversions into a range of product with maximal total value in combination with a good business model can improve economic feasibility of biorefineries (Budzianowski, 2017).

4.3 Summary

By way of warpping-up the discussion above, this chapter is meant to provide a summary of the discussion above, by first recapitulate the underlying theoretical assumptions that were guiding this thesis and in a preceding step relating them to the results from the discussion. By that the theoretical and the practical lenses are reintegrated.

As has been the argument throughout this thesis, to have an impact, biorefinery technologies have to make their way to the market and become commercialized. This process can entail a lengthy, uncertain and painful process of development and diffusion. From a firm perspective, the associated challenges have been discussed in relation to the business model and strategies firms can assume to overcome them and thus have brought the micro-level into the analysis. From a meso perspective, the process of diffusion of biorefinery technologies is reflected in the formation and evolution of Technological Innovation System. Between these two levels, clear interaction takes place: Firstly, new TISs are built "bottom-up" by entrepreneurial activities that develop and introduce new technologies to the market. Secondly, entrepreneurial actors are highly dependent on the formation of a supporting system, as without them they have little chance of succeeding in driving a technological change (Van de Ven, 1993). While the role of policy is to enable a number of different TIS to concurrently move towards a phase of self-reinforcing growth (Jacobsson & Bergek, 2004), there are also numerous reasons for entrepreneurial actors to consider engaging in sector-building activities in an early phase of TIS formation (Suchman, 1995; Van de Ven, 1993), namly through the interaction with the functions of an innovation system (Kishna et al., 2012). Concequently, the implication is that both policy-makers and entrepreneurial actors need to identify appropriate system-building activities. In essence, these activities should be directed towards both increasing the strength of inducement mechanisms and also reducing the influence of various blocking mechanisms (Johnson & Jacobsson, 2001).

In fact, the discussion of the results revealed that companies applied a lot of different strategic responses to overcome some of the most prominent barriers the literature identified. Which are summarized here briefly. This is in line with findings from Planko et al. (2017), who found that entrepreneurs intuitively engage with system-building processes as described by the TIS.

Table 4-1. Summary of Key Findings

	Dimensions	**Key Findings**
Strategy	Focus	partnerships, product portfolio differentiation and cost competitiveness as integral part of the strategic approach to seek independence from oil prices and policy support.

Business Model	networks, partnership and collaboration	Cooperation widely applied and highly important; positively affects all functions (F1-F6); horizontal cooperation (between competitors) hardly takes place.
	Product portfolio	Diversification strategy widely applied, with a step-wise process over fuels;
Supply Chain	Degree of Integration	High degree of vertical integration, especially upstream; horizontal collaboration/integration hardly seen, no international trade with biomass;

Source: author's own composition

Whereas, market formation and resource mobilization are considered to be weak aspects around the TIS of market formation around biorefineries (Hansen & Coenen, 2015), entrepreneurial actors have found various ways to overcome them, namly through diversification from lower value into higher value products. In addition, partnerships and cooperations are particularly important both upstream (feedstock supply security) and downstream (market development and prior funding). Collaboration in the value chain has also been found by the general innovation management literature to be a success factor in commercializing new technologies (Cormican & O'Sullivan, 2004). Musiolik and Markard further found that the coordination of actors and activities in the value chain positively influences the functioning of the TIS (Musiolik & Markard, 2011). Yet, as has been seen in this analysis, coordination serves somewhat as a catalyst to other processes, such as resource mobilization.

A licensing-based business model approach or at least technology-based partnerships is perceived to be the (only) feasible way forward for SMEs (biotech companies) due to financial resource constraints. Partnerships are however only established along the supply chain, but not between companies that all are interested in utilizing biorefining, so only vertically. For companies not engaging with biorefining predominantly knowledge is hard to and hardly developed internally, but acquired through equity investments, licensing or technology-based partnerships. Especially given that all technologies are well protected and substantial funds are needed to develop them from scratch. Hence, replicability will be challenging in a lot of cases.

However, all candidates stressed the importance of policy in relation to predominatly the development of biofuels. This confirmed findings from a recent study conducted by Chen and Smith (2017) on the commercialization challenges for cellulosic biofuels who found policy uncertainty to be the number one barrier for economic/business respondents and the second most important barrier overall (Chen & Smith, 2017). Actually, the strategies applied by the different respondents largly seeked to achieve independence from oil price developments on the one hand and policy support on the others. While landscape signals such as high oil prices as well as climate change debate paired with policy incentives have largely affected and guided the *direction of search*, the same signals also pull companies and financial resources away from investments into the biofuel sphere. Since biofuels do not provide economically viable business opportunities and mobilization of resources in the technological innovation system proves difficult given the high capital investments and uncertainties around the future role of biofuels in both the U.S. and EU, further investments are not expected (ibid.).

5 Reflections and Conclusion

5.1 Answer to Research Question

The aim of this study is to gain insight into strategies used by biorefinery businesses in practice to influence the system they are embedded in and to determine which barriers to commercialization can be successfully overcome by them, while other may need the support from other actors in the system. Having this in mind, the research was guided by the following question:

RQ: Which biorefinery commercialization strategies have been successfully applied in practice and how?

To reach the aim first the challenges to commercialization by biorefineries were reviewed; second, the theoretical discourse on commercialization of new technologies was investigated. The insights gained from overall literature review were then used to design an analytical framework to assess the empirical data in a systematic way. The research thereby followed a qualitative case-study approach in combination with expert interviews; semi-structured interviews and literature analysis were used for data collection. Qualitative content analysis was used for the assessment of the obtained data.

Analysis found that a range of strategic reponses to commercialization challenges were applied by the entrepreneurial actors to engage in system-building activities. Whereas most companies have started with a focus on biofuels due to a combination of landscape signals that have created favorable expectatons and mobilized resource for the biofuels sphere, focus has shifted over time. Strategies nowadays focus on achieving product portfolio diversification strategies to decrease dependence on oil price developments and policies. Hereby a step-wise development has proven viable, as resource mobilization and market formation have to be secured. In that context, collaboration across the supply chain has also proven to serve as a catalyst to positively influence the functions of innovations system. Further a high degree of flexibility with regards to feedstock, products and processes can also enhance the successful commercialization.

5.2 Contributions to Research

The findings of this thesis contribute to the innovation systems literature by providing a stronger entrepreneurial foundation; So far, most innovation system literature has been targeted to identify the role of policy-makers and inform them as well as scholars (Meelen & Farla, 2013). Entrepreneurs and their system building activities and roles have not been analysed in the context of biorefineries, albeit their importances is recognized.

In addition, the thesis addresses the need for empirical research on biorefineries, especially strategies to address the various challenges identified in the literature. The thesis especially well complements recent research by Bauer et al. (2017). The authors conducted a literature review synthesizing current knowledge on the development, deployment and diffusion of biorefineries. Hence this thesis provides the complementing comparison with practice. For example, the authors identified networks to be important, but difficult to develop into business partnerships. However, the findings in this study have identified that business partnerships are found in practice to be highly relevant and deployed, yet not horizontally. In addition, findings could also be confirmed in that experimentation is rare due to high costs. Also, it has been identified by their study that mobilization of resources and a lack of capabilities is a large barrier to firms, however, this research has contributed by showing possibilities to address them.

Lastly, the conceptual findings contribute to research in that they show that the integration of insights from different analytical perspectives can offer a more holistic understanding of the processes affecting innovation dynamics of emerging technologies. By using different perspectives in tandem methodological weaknesses can be overcome. The integrated framework developed, offers a promising starting point for the future analysis of emerging sustainable technologies.

5.3 Practical Implications and Recommendations

Recommendations to businesses

The study has also shown that by using strategic responses to overcome challenges, biorefinery businesses can position themselves on the market independent of policies. Thus, when building a biorefinery business it first needs to be decided what kind of strategy and corresponding business model to be implemented. Careful attention needs to be both the ability to mobilize resources and establish supply and demand at the same time. A collaborative approach towards developing and commercializing biorefineries, focusing on markets where the price point is accessible can help, has proven a viable strategic approach.

As has been seen collaboration has been very important for all companies – not only SMEs – engaging with biorefining and biorefineries. However, the horizontal collaboration between actors is notably less developed. Yet, it has been emphasized that coalitions of actors can present a common face towards institutions and advocate for common interests towards institutions, especially in the realm of policy-making – current policies – are about to be readjusted; thus they can gain sociopolitical acceptance more easily (Aldrich & Fiol, 1994; Palgan & McCormick, 2016).

However, not only businesses and policy makers play a role but the transition to a bioeconomy needs concerted efforts from several parties; this is nicely summarized by one of the interviewees "…there is a lot of things that have to happen as well, including getting the whole culture more resource-efficient and not producing to much waste materials Being much better in recycling, reusing, everything goes hand in hand, so all bits and pieces have to come together to make a bioeconomy possible." (Storaenso, personal communication, 2017)

Recommendations to Policy Makers

Based on the results, it is suggested that policy needs to establish a clear vision and targets to move the bioeconomy forward and needs to clearly position itself towards both biofuels and biomaterials. Especially in relation to the former market formation needs to be clearly policy-driven. Thus, a revision of current policy approach is urgently needed to provide for a stable a reliable investment climate, the lack of which has hampered developments in the field. Without policies, the bioeconomy will materialize much slower.

Policy makers need to work on regaining trust. Big infrastructure proects as the once required in the case of a large-scale transition to a bioeconomy need long term policy stability. Thus, broad political support and stability is needed – also to cross the 'valley of death' towards commercialization. Without policy support, the development will be mostly industry driven, where potential market opportunities evolve. For biorefineries to contribute to the bioeconomy, it either needs a lot of time or policy action. There is some room for manoevre that has been used by some pioneers in the field, but they are far from being successfully active on the market, but still struggle with financing their businesses to refund the large capital investments that were needed to reach the current state in the first place.

5.4 Limitations and Future Research Avenues

Limitations

This thesis sought to gain an understanding of how biorefineries can overcome commercialization challenges in practice. For that purpose, qualitative data collection methods were used. The choice of a qualitative research approach seemed appropriate in light of the exploratory nature of the study. Data was collected through a literature review and semi-structured interviews.

Interviews were conducted with representatives from biorefinery businesses and constituted the major source of information for the study; for the single case study, the interview was complemented by extensive analysis of available company information. In addition, literature from mostly academia, but also grey literature sources were used. The study faced limitations due to the infancy of the industry (limiting the number of possible cases) as well as due to the accessibility of company information. Access to employees within organisations relevant to the study was difficult and often impeded by concerns regarding confidentiality and potential disclosure of sensitive data. Additionally, this difficulty in securing an interview implied an iterative process, resulting in long time lags. Thus, data availability and access to interviewees posed a challenge towards the study.

In that regard, it needs to be clarified that the initial aim of the author was to follow a multiple-case study approach, but this plan had to be abandoned in the course of the research, as the access to material varied to large degrees disqualifiying the varying data base between the cases for an indepth comparative case study. Research practical reasons such as resources available also influenced the decisions.

However, whereas the data accessibility was challenging this did only affect the degree to which the study provides particularistic rather than generalizable results. The author considers the information eventually obtained through interviews and literature to have yielded enough valuable results in width and depth to inform the study to a mostly satisfying degree. Yet, the choice of a case study design, as well as the high degree of diversity across the interview partners in terms of company size and industry, position of the informants in the companies, geographical location and so forth, may have further reduced the degree to which general conclusions can be drawn. In addition, with regards to the choice of interview partners being company representative, confirmation bias may have influenced the degree of objectivity. While some degree of triangulation was applied to rule out any such biases, the access to information was fairly limited.

The developed integrated framework proved useful to guide the analysis of the data collected. Due to the interdependencies and multicausalities of organizational as well as system's processes, the holistic framework yielded quite a degree of complexity, however considered necessary as both the systems perspective and micro-level perspective provided complementing insights. However, due to the high interdependencies and feedback loops in the system, the degree of effect of one or another strategic response could not be determined.

Further Research

This research has been largely exploratory and could not cover all aspects that would have been valuable to bring together for a holistic perspective. Hence, numerous further research questions remain unanswered.

Further research could delineate further where policies so far have contributed positively towards market development and where they have proven ineffective. The general perception among respondents was that policy proves largly ineffective. Also, further delineation of which functions can be best enhanced by which actors could prove an interesting research endevour.

In addition, the expected revisions of policies and potentially dropping mandates for fuels and their respective consequences for the market could be investigated further. Especially against the expiration of biofuel policies in the EU.

Further contrasting, failure and success cases for the purpose of identifying what has worked not and what has in a more differentiated manner could be interesting.

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Appendix I. Interview Guide for the Semi-Structured Interviews

The interview guideline was used to conduct the semi-structured interview; the questions were either posed directly or answered as part of another question. As the length of the interviews varied more or less details could be obtained on the questions. In addition, some questions were skipped and posed in a slightly different manner to accommodate for the difference in business model of a biotech vs. a biorefining company.

Interview Guideline

Section 1: Introduction

Greeting the interviewee and thanking him/her for taking their time; Short introduction of the author herself; short introduction about the project and its aim and the purpose of the interview; short intro about how the proceeding is planned; approval of interviewee to audio-record the interview; question on how much time the interviewee has scheduled.

Q1: I would like to invite you now to introduce yourself and your position in the company, how long have you been working for them?

Section 2: General Information Strategy and Business Model

Q2: Now, if you could briefly sketch what the company is doing and the development of the company? What are specific milestones you consider particularly relevant?

Follow-up questions: where are you located?, what feedstock are you using – why?, what technology are you using?, what products are you producing?, competition with fossil fuel derived products?; what role does biofuel play? how is the company financed/funded?, do you engage with licencing why/why not?, can your business model be copied?, what drove development – industry, investors, policy – and how?

Section 3: Supply Chain Specifics: Upstream

Q3: Can you describe the process from feedstock to final product?
Q4: How do you engage with your suppliers to guarantee supply? What do you consider critical here?
Q5: What is your value proposition to them? What makes it attractive to supply you?
Q6: What do you consider especially critical for your upstream activities?
Follow-up questions: cost drivers, choice of feedstock, transportation means;

Section 3: Supply Chain Specifics: Downstream

Q7: Which markets do you supply and why?
Q8: What drove the decisions to target one or another market? E.g. industry, policy, public?
Q9: How do you engage with your customers? How is demand secured?
- purchase agreements, integration through equity stake, collaborations …

Q10: What is your value proposition to them? What makes it attractive for them to be supplied by you?

Section 4: Closing section

Q11: what do you think makes your company particularly successful and what can be learnt from you? Any key aspects you would like to emphasize?
Q12: As a final question I would like to know your opinion on the future of the bioeconomy and biorefineries: What you think will be key for a successful development?

Thanking the interviewee for the time and interesting insights; asking for permission to send follow up questions for clarification later on. **END**