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Scaling up Innovative Sustainable Bio-based Products

Case of Spin-offs from Aalto University

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Abstract

Beyond its role in widespread education and research, academia has an important role in driving impact and creating positive changes in society. One vehicle for universities to create impact is through the creation of university spin-offs (USOs). With the global need for more sustainable, better alternatives for the current fossil products on the rise, the focus on exploring bio-innovations as alternatives is imminent. This study uncovers the academic research commercialization process, identifying pathway and the barriers and enablers of USOs manufacturing bio-based products to spinout.

A cross-sectional qualitative study of seven bio-based USOs from Aalto University is done. Inductive-thematic analysis is used to analyze fourteen in-depth interviews with 7 Aalto University's bio-based USOs are selected through the university's research innovation services database. The findings confirms that the development process follows the 4-stage journey of spin-off theory, which includes 4 milestones: research, opportunity framing, finalizing venture projects and launching of spin-off firms. There are twenty-four identified barriers and enablers, with most are dominated by factors related to the business side of innovation commercialization.

Barriers and enablers surround multidisciplinary teams, funding, market entry, and business models. Factors that are special in the case of bio-based innovations are the long development timeline, research and development challenges, and gap of funding for commercialization to scale-up manufacturing. LCA is mentioned as one of the enablers to communicate to investors and to align USOs with sustainable values. Factors that are found to emerge as important bottlenecks to tackle are challenges in IPR handling and funding gap they are correlated other identified barriers, such as hindrance in research and development, scaling up and market entrance. Acknowledging the technical complexity of bio-based innovations, through pre-incubation while supporting the development of technology-driven sustainability assessments is recommended to increase the chances of USOs in overcoming barriers in spinning out.

Keywords: USO, bio-based innovations, research commercialization, scaling-up technology

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Preface and acknowledgments

I would like to thank my supervisor, Luana Dessbesell, who took a generous chance to guide me through the whole thesis journey, and onwards we went. My advisor, Bernadetta, ceaselessly and patiently guided me through my first experience with qualitative research work. To my family and close friends, whom I loved, who have been a great blessing and reliable support through all life's twists and turns. To all interviewees and USOs who had participated and the supportive community at Aalto University who, in their busy schedules, gave me time to sit down and interview them, for without them, this thesis wouldn't have been possible. Acknowledgment is also given to Aalto Scientific Computing (ASC) for their speech2text tool, which greatly helped to transcribe interviews quickly and accurately.

This thesis is written for academics who, with their unwavering bravery, look into taking the leap of faith to spin out their innovations and the hope to make this world a better place one innovation at a time.

Helsinki, 24th July 2024
Vida Hardjono

1 Introduction

Universities have been involved in technology commercialization ever since they were first established. Especially in the field of science and engineering, where academics make commercial use of the technology they developed (Shane, 2004). It is acknowledged that critically important innovations to address the most pressing societal issues are developed in universities and research laboratories (Valenti et al., 2022). Although the importance of transferring scientific research to market is clear, evidence of success in doing this is minimal and literature shows that only a few research projects actually manage to reach the marketplace (Wessner, 2005). The vast majority covers the business aspects of technology commercialization studied through phases from idea generation through fundraising for commercialization once the technology has reached technical viability (Boh et al., 2016). This gap between university IP produced by research and its commercialization is defined by literature as “the valley of death” (Minshall et al., 2007).

In large chemical and biological process companies, there is vertical integration of activities from R&D to commercial implementation and operation of diverse processes, and the technical knowledge to move a process innovation efficiently through the development and scale-up pathway (Berretta, 2021). Such knowledge of commercialization is typically not present for smaller companies, especially in an academic research setting.

More and more, there has been a rise in university programs dedicated to teaching how these business areas should be handled and managed and how they all tie together in the commercialization of technology. Commercialization of technology to the masses also referred to as technology transfer, is usually organized in the university by a technology transfer office (TTO). This is a part of the third mission of the university, which represents the economic and social mission of the university and its contribution to communities (Compagnucci & Spigarelli, 2020).

Limited research has been done to cover academic spin-off innovations of bio-based products. Considering the rise of the bioeconomy and the urgency of the search for better, there is an urgency for the discovery of more sustainable replacements for fossil-based products to be available to the masses in the concerted effort to minimize the overshoot of the planetary boundaries (Richardson et al., 2023).

The existing literature covers mostly the general category of USOs, including the fast-to-deploy IT spin-offs, which follow a faster development milestone than bio-based innovations. Based on (Maine & Seegopaul, 2016) advanced materials, which could include bio-based materials, would need 5-15 years of development time and up to US$ 20 million of development cost. Comparatively, advanced material ventures in comparison to software would take seven times longer and seven times more capital to commercialize, decreasing the chance for discovery to find its way to the masses. Most insights on manufacturing-scale bio-based commercialization remain mostly know-how among industry players and practitioners. There is little academic research on pinpointing factors supporting the likelihood of bioproduct innovations from academia leaving the lab and entering the market.

Having arms in technology, business and design education puts Aalto University at an advantageous intersection where various experts are involved in pushing through for more sustainable innovations in the market. This thesis will dive into the enablers and barriers to commercialization research of bio-based products spinning out from a small subset of Aalto University bio-based spin-offs to answer the driving factors of innovation from the lab to successfully spin off from the university. The practical context for this study is to understand how to support research commercialization by creating high-growth companies in the Finnish context.

1.1 Research question

- What are the stages of development of bio-based USOs?
- What barriers and enablers could be identified for bio-based USOs?

1.2 Research objectives

1. Identify the stages of development of bio-based USOs, comparing literature theories with the case of bio-based USOs from Aalto University.
2. Unveil barriers and enablers for commercializing bio-based innovations from the experience of bio-based USOs at Aalto University

1.3 Scope

The scope of this study entails seven cases of spin-offs, academic ventures, or ventures derived from academic research from a university. Aalto University is chosen as a case study, as it provides a variety of case studies on the development of bio-based innovations, from those that are currently commercialization projects to those that have spun out. USOs are scouted from the publicly available Research Innovation Services (RIS) database of the university. USOs could be in the form of projects/companies that make their business from manufacturing bio-based products derived from renewable biological resources, more outlined in Section 2.2, more on sampling used is elaborated in Section 3.2.

1.4 Structure of thesis

This thesis is arranged in 5 chapters, starting with an introduction, which outlines the background context of the thesis, research objectives, research questions, and scope. Continued by the second chapter, which covers a literature review, setting important definitions of terminologies that are going to be used in the thesis, outlining university spin-offs (USOs), commercialization pathways, sustainable bio-based products, bio-based spin-offs at Aalto, and the research gaps. The third chapter is a deep dive into methodology, including the research context and process from problem definition to how the data is analyzed. Carry through the fourth chapter, where the findings are presented to answer the research questions. Overall, barriers and enablers of the spin-offs are grouped to represent the most important results. The thesis is wrapped up in chapter 5, in which theoretical and practical implications and conclusions are drawn.

2 Literature review

2.1 (Deep Tech) University Spin-Off – and why does it matter?

USOs are defined as ventures formed by university members to transfer research outcomes, technologies, knowledge, and skills created in the university to society (Dorner et al., 2017). USOs are the vehicles for academics to make commercial use of the technology they developed, commonly in the field of science and engineering (Shane, 2004). University spin-offs are an important class of firms because they create economic impact, stimulate economies, and contribute to employment, particularly for the highly educated and wealth creation (Hayter, 2013; Kowal & Szmal, 2022; Rodríguez-Gulías et al., 2016; Shane, 2004).

Besides that, spin-offs are vehicles for knowledge dissemination and play an important role in technology commercialization (Hayter, 2013). Technology would otherwise go undeveloped as it involves tacit knowledge that is too uncertain for established companies to pursue and requires additional inventor involvement to be commercialized successfully (Shane, 2004).

Commercialization of technology hence results in the transfer of university knowledge into application in society (Rasmussen, 2019). This ties into the fulfillment of the third mission of universities of bringing impact to the public (Compagnucci & Spigarelli, 2020). Shane (2004) also argues that spin-offs help with the primary missions of universities, of research and teaching, as it brings additional funding for research. Furthermore, spin-offs also encourage training as professors with knowledge of commercial development of technology, which is valuable to students who are more likely to make commercial use of technology than to make academic use of it.

Attention had been recently brought to the spin-offs due to several push factors, such as the social pressure imposed on universities to create economic growth (Mustar et al., 2008; Tornatzky, 2001). Furthermore, there is also a push from within the university from technology transfer offices to encourage widespread scientific research, supporting the academic community in commercializing the innovations founded in their respective universities (Algieri et al., 2013). This is also supported by policies, especially from within the universities to encourage the creation of spin-offs (Shane, 2004). Including, for example, the offer of exclusive licenses, the possibility of a leave of absence for faculty members to direct their time to commercialize, permitting the use of university resources to develop the technology, and permitting the use of university resources to develop the technology. Other than that, also the availability of public funding to narrow financial gaps that are now made accessible for scientists, which enables them to commercialize (Wright et al., 2006).

The nature of the discovery of technology that leads to spin-offs is usually radical, tacit, and early-stage (Shane, 2004). Descriptors of which falls under "Deep Technology". Deep technology or deep tech is defined according to Siegel & Krishnan (2020) as a technology that is difficult to develop today with the potential to become a pervasive and easy-to-implement basic need in the future. It is common for deep tech ventures to emerge from higher education institutions, given the complexity and the specialized scientific and/or engineering foundations needed deep tech ventures. As remaining close to human capital and infrastructure in the early stages of technical development is essential (Budden & Murray, 2019).

Spin-offs are a lot in common with high-technology start-ups as they faced the same difficulties as any other new technology would (Berbegal-Mirabent et al., 2015; Oakey et al., 1996). However, they are different from other start-ups (Vohora et al., 2004). Mostly due to the fact that the spin-off process is widely done in university settings, therefore, is inherently subject to university protocol (Rasmussen, 2019); not to mention the involvement of third-party stakeholders that are inherent in scene of academia Boardman &

Ponomariov, 2009; McAdam & McAdam, 2008; Mustar et al., 2006), and the fact that spin-offs are formed from teams with academic background (Craig Boardman & Ponomariov, 2009; McAdam & McAdam, 2008; Mustar et al., 2008). All of which might contribute to the hindrance of the progress of the spinning out process (all in blue). More on the barriers will be discussed on Section 2.2.1.

Being deeply rooted in universities, there is a special body, namely Knowledge Transfer Offices (KTOs) or Technology Transfer Offices (TTOs) within the university that manages the creation of spin-offs, among other supporting activities to promote knowledge transfer (KT) (Compagnucci & Spigarelli, 2020). Several ways universities address the complexity of KT include providing services to faculty to enhance innovation and practical use of research results (Bozeman et al., 2015). In the creation of spin-offs from academic innovations, KTOs helped in identifying, managing, and marketing patents and licenses through Intellectual Protection Regulation (IPRs).

2.2 Bio-based Innovations/Innovation in the Bioeconomy

The issues of climate, environmental, and resource scarcity on the rise have pushed priorities in politics, society, industry, and research (Bröring et al., 2020). Among the solutions to address this is the bio-based strategies, which aim to promote the growth of renewable resources, providing more alternatives for production and consumption that are more sustainable (Dietz et al., 2018; SCAR 2015). Outlined by the 2012 document by the European Commission, bioeconomy is the production of renewable biological resources and the conversion of those resources and waste streams into value-added products such as food, feed, and bio-based products, and bioenergy. The bio-based economy also emphasizes enabling new technology to decouple economic growth from environmental degradation Schmid et al., 2012.

One of the ways the policymakers in the EU have done to achieve this is by putting sustainable and circular bio-economy high on their priority with the aim to reduce the use of fossil-based materials, to mitigate climate change, to reduce the dependency on imports of natural resources, and to promote local economies (Kardung et al., 2021). Key policy roadmap for the bioeconomy is the EU Bioeconomy strategy and the supplementary Action Plan. The action plan emphasizes (I) Strengthening and scaling up the bio-based sectors, unlocking investments and markets; (II) Deploying local economies rapidly across the whole of Europe; and (III) Understanding the ecological boundaries of the bioeconomy. This cascades to many EU policy initiatives, among the notable European Green Deal, research programs and the European Circular Bio-Based Industries Joint Undertaking (CBE-JU) (Lühmann, 2020; Wesseler & Von Braun, 2017). CBE-JU operates under the EU's research and innovation program, which aims to advance circular bio-based industries in Europe through project funding formed in partnership between the EU and the Bio-based Industries Consortium (CBE-JU, 2024a).

Despite the growing attention and growth, bioeconomy is still in the early stages and needs innovation to strengthen and increase its value (Levidow et al., 2013, 2012). Existing research on how to make the bioeconomy more competitive recommended an increase in investment in R&D, policy incentives and driving innovation (Levidow et al., 2013; Philp, 2018). Innovations play an important role in a bioeconomy, as the "transitory economy" is dependent on the pressure from the current technological regime dominated by fossil-based industry (Bröring et al., 2020). Change and disruption can only be brought about by radical innovations, which face the biggest barrier to the market due to the existing regime (Nagy et al., 2016). In the bioeconomy context, the R&D of bio-based products and processes are cost and risk-intensive; in order to compete with the established fossil-based dominated system needs foresight and strategic management (Aguilar et al., 2018).

In bio-based innovation, the most frequent innovations are development of production methods, followed by innovations in goods and services (Lovrić et al., 2020). Research by (Bröring et al., 2020) classifies innovation types in the bioeconomy into four categories, substitute products, new processes, new products and new behavior summarized in Table 1.

Table 1. Innovation Types in the Bioeconomy, adapted from Bröring et al., 2020.

	I: Substitute Products	**II: New Processes**	**III: New Products**	**IV: New Behavior**
Description	Old function, new resources, new value chains	Allocation of biomass	New products with disruptive applications in many industry sectors, new value chains	Reuse of already exploited biomass, new value chain connections
Examples	Bioplastic from PLA, Drop-in solutions	Lignocellulose conversion by algae, bio refineries	Renewable construction materials, novel nanotechnological sensors	conversion of residual cellulose to bioplastics, extraction of valuable compounds for new value chains
Ecological Potential	reducing carbon footprint and fossil/based resources	resource efficiency, reduced GHG emissions and pollution	Improving recyclability of products, cost and eco/efficiency	resource efficiency, reduce waste
		Change triggered in which aspect?		
Product	Yes	No	Yes	Yes
Process	Yes	Yes	No	Yes
Organization	Yes	No	No	Yes

2.3 Commercialization pathway

2.3.1 From Lab to Market

Based on the current literature, the expression 'lab to market' is often used in association with deep tech ventures to emphasize its journey from the academic research lab (Ruiz de Apodaca et al., 2023). Transitioning new technologies from lab to impact means translating research and development (R&D) investments into new technologies needed to tackle big global issues such as climate change (Valenti et al., 2022). In order for research of new technologies, herein referred to as “invention”, to create societal impact, it is crucial for these inventions to exit the lab and enter the masses.

The process of commercialization of an invention happens when a product entering the market is what sets apart invention and innovation (Godin, 2012) – this is the concept assumed in the context of this thesis. Following this statement, recent literature argued that for an invention to be called an innovation, it should offer a solution to an existing market or fulfill a certain demand in the market (Rambaran & Schirhagl, 2022).

The journey to transition from lab to market in the context of innovations made in academia, there have been several studies on the journeys of USOs (Boh et al., 2016; Clarysse & Moray, 2004; Ndonzuau et al., 2002; Rasmussen, 2019; Shane, 2004; Vohora et al., 2004), summarized in Table 2. Current literature on university spin-off commercialization timelines differ from one another, demonstrating how the commercialization journey of spin-offs doesn’t follow a well-defined standardized milestone pathway. All studied timelines start with academic research, relying mostly on public funding for more application-focused research.

The simplest pathway theory elaborates a simple 3-step milestone of invention-transition-innovation (Clarysse & Moray, 2004). The generalization of arguably the most important phase under the word “transition” gave this commercialization framework the advantage of flexibility. Since it makes it possible to fit with a lot of the empirical cases of USOs.

Another theory on timeline by Rasmussen, 2011 builds up a timeline, by lending concepts of previous theory. Rassmussen uses Clarysse & Moray (2004) three-step theory further and to split the pre-start-up/transition phase into two opportunity framing and proof of viability. This split is inspired by Vohora et al. (2004) borrowing the idea of opportunity framing as a crucial stage to transform the unstructured ideas for structured venture creation from research through identifying opportunities in the market. This phase is then followed by the proof of viability phase, where prototype development begins to validate the viability of technology for commercial use. This phase marks a more structured venturing process just before spinning off and enters the mature post-start-up phase.

2.3.1.1 Innovation Commercialization in Aalto University

As a higher education institution, creating societal impact is naturally on its core strategies (Shore & McLauchlan, 2012). To this end, their planned actions are cultivating an environment of innovation, developing global and local networks, and building a sustainable and thriving campus. To carry out their innovation program, universities usually have a TTO (Compagnucci & Spigarelli, 2020).

The commercialization pathway from research idea to technology transfer is shown in Figure 1 and is done by the Research Innovation Services in concert with the Startup Center under the Ideas to Impact® Program (Aalto University Innovation Services, 2024a). Aalto University TTO provides support in different stages of the process, including innovation, business relations, financial, and legal services. The journey starts with the disclosure of the invention, where the novelty aspect of the innovation is reviewed, followed by a multi-stage patenting process. This process aims to strengthen the utilization path of the invention. Once the concept is ready, the technology transfer process will start, the invention will then be transferred for use by a start-up of an existing company. Many of the commercialization projects at Aalto utilize Business Finland's funding, namely the Research to Business (R2B) (Aalto University Innovation Services, 2024d).

R2B is a special funding program by Business Finland intended for public research organizations, which includes universities that aim to develop their research into new businesses and commercialize (Business Finland, 2023).

This funding is mostly focused on the very early stage of commercialization, covering feasibility studies, business model identification, market surveys, and protection of intellectual property rights.

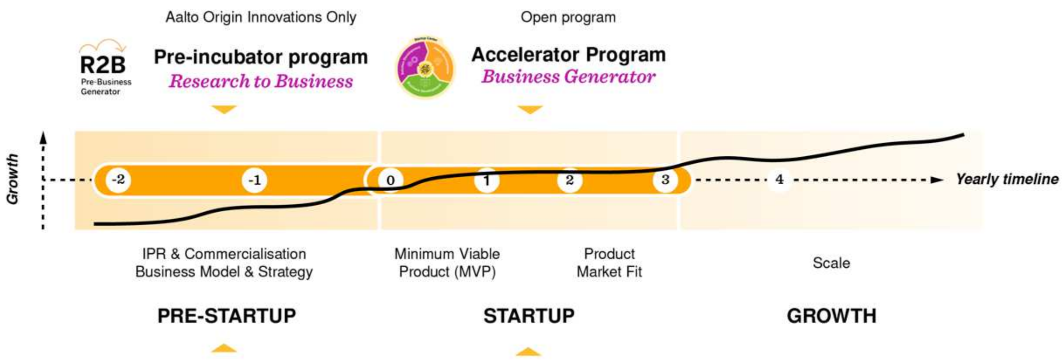

Figure 1. Commercialization process at Aalto University
Source: (Aalto University Innovation Services, 2024a)

Table 2. Comparison of Spin-off phases

<table>
<tr><th>Ndonzuau (2002)</th><th>Research</th><th colspan="4">Generating business ideas</th><th colspan="2">Finalizing venture projects</th><th colspan="3">Launching spin-off firms</th></tr>
<tr><td>Clarysse and Moray (2004)</td><td>invention</td><td colspan="6">transition</td><td colspan="3">innovation</td></tr>
<tr><td>Shane (2004)</td><td>use of funded research</td><td>creation and disclosure of invention</td><td>decision to seek IP protection</td><td colspan="2">marketing the technology</td><td colspan="2">licensing decision</td><td colspan="3"></td></tr>
<tr><td>Vohora, Wright, and Lockett (2004)</td><td>research</td><td colspan="4">opportunity framing</td><td colspan="2">pre-organisation</td><td colspan="2">re-orientation</td><td>sustainable returns</td></tr>
<tr><td>Boh (2015)</td><td>idea generation</td><td>commercialization decision</td><td colspan="2">prototype generation and commercial viability</td><td colspan="2">founding team formation</td><td colspan="3">strategy and commercialization process</td><td>fundraising</td></tr>
<tr><td>Rasmussen (2011)</td><td>research</td><td colspan="4">opportunity framing</td><td colspan="3">proof of viability</td><td colspan="2">start-up / spin-off</td></tr>
</table>

2.3.2 Scaling up in chemical engineering

Innovation is achieved through the application of new technologies, which comes with a great deal of uncertainty and risk of its capabilities, limitations, and development trajectory. For this, an understanding of technology maturity is essential in making decisions in especially complex engineering projects (Olechowski et al., 2015).

Technology Readiness Level (TRL) is widely used by organizations, especially the ones in the chemical engineering domain, to assess technology's maturity, also enabling comparison with other technologies (Yfanti & Sakkas, 2024). The TRL scale was first developed at NASA in the 1970s to measure technology maturity during complex system development through a 7-point scale (Sadin et al., 1989). The first version of TRL was then refined with a detailed description of each stage in 1995 to become a 9-point scale (Mankins, 1995). It was founded to tackle differing perceptions of researchers and mission planners towards intended and actual proof of readiness of technology in development. TRL scale is widely adopted as it provides a shared understanding of technology and risk (Sadin et al., 1989) as well as marking milestones and establishing gates in a development process (US Department of Defense, 2023) and projecting which technologies would finish on time and on budget by the start of system development (US Department of Defense, 2023).

Today, the TRL approach is being used in multiple industries and serves broader goals than originally intended (Olechowski et al., 2015). To be applied in many industries, including in chemical and biological process companies (Berretta, 2021) to map integration activities from R&D to commercial implementation and operation. The mapping of typical scale-up and development phases of novel process technologies in chemical and biological processes are classified into nine stages, from idea phase up to fully commercialized technology, elaborated in Table 3.

Table 3. TRL Descriptions for Chemical and Biological Processes. Adapted from (Berretta, 2021).

Stage	Name of Stage	Description of Stage
0	Idea Phase	An innovation idea has been generated and stated. This is the start of the Idea Phase.
1	Bench-Scale (smaller, lab-scale experiments)	Experimental work and proof of the innovation has been started or completed. This remains part of the Idea Phase and moves into the Bench-scale Phase.
2	Bench-Scale cont. (integrated process concept)	An integrated process concept for the innovation has been proposed and investigated at a high level. This forms part of the Bench-scale Phase.
3	TEA Evaluation	The innovation has been analyzed, within the proposed integrated process concept, through a detailed techno-economic assessment (TEA), and further bench-work has been completed to de-risk some of the technical challenges identified through the TEA. We are now in the TEA Phase.
4	Pilot Phase	The process has been experimentally validated by integrated larger experimental set-ups. This is the start of the Pilot Phase.
5	Technical de-risking of pilot plant	Process validation and completion of technical de-risking has been done in larger prototypes or pilot plants. We are still in the Pilot Phase.
6	Commercial Plant Analysis	R&D results and data have been translated into a complete engineering plant design package. We are now in the Engineering and Commercial Plant Analysis Phase.
7	First Demo Plant	First demonstration plant for the technology has been commissioned. We are now in the Demonstration Plant Phase.
8	First commercial plant	First commercial plant has been commissioned. This is the start of the Commercial Scale Phase.
9	Commercial product	The technology has successfully penetrated the market. We are at the end of the Commercial Scale Phase.

In the context of scaling up bio-based innovations, the CBE-JU also uses the TRL scale to mark the milestones shown in Figure 2 to evaluate the development of circular, bio-based technology innovations and funding allocation from EU partnership with the Bio-based Industries Consortium (BIC). The development phase occurs from scales 1-4, where research and innovation actions occur. The following scales leading up to 9, where scaleup, demonstration of technologies up to establishing a large-scale first-of-its-kind product facility done by the help of innovation action or flagship programs. The projects that are funded by CBE-JU are usually a consortium between industries, research agencies and higher education institutions. Funding granted are higher in later stages of TRL development compared to earlier stages (CBE-JU, 2024a).

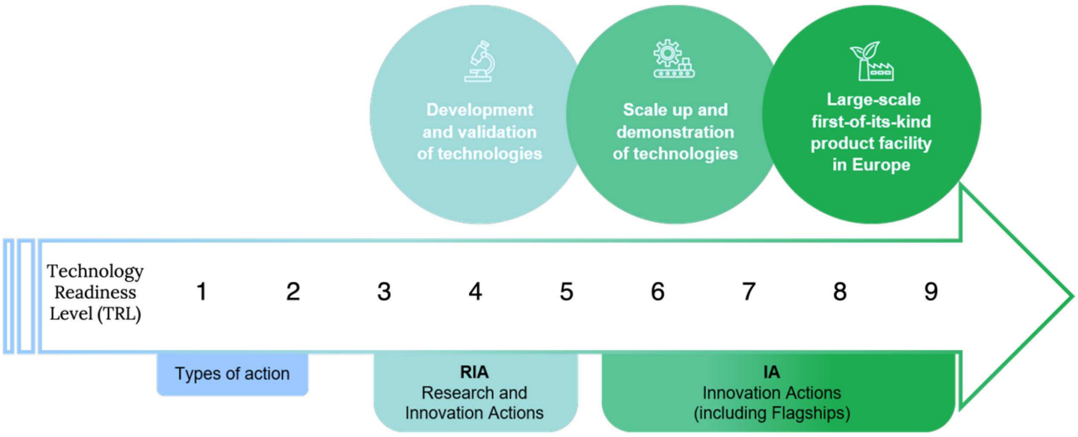

Figure 2. CBE-JU Funding and Actions along the TRL Levels
Source: (CBE-JU, 2024b).

2.4 Barriers and drivers of research commercialization

Borrowing the definition from Hueske & Guenther (2015) who studies the broader innovation context, barriers defined in this thesis, in the context of commercialization in this thesis is defined as any factors that hamper, delay, or block innovations to be scaled up commercially. While enablers are defined as the factors that drive, support, and accelerate the commercialization process.

There have been several existing research on the barriers and enablers of USOs and general innovation commercialization, summarized in Table 4. Although the field of research has been growing through the decade, most research is scattered, with only a handful that resulted in a categorization of both the barriers and enablers. One of which is a literature review that summarized from 193 articles barriers and enablers and classified them into three categories: factors on the micro-, meso- and macro- levels (Hossinger et al., 2020).

Studies on barriers and enablers of USOs in general have been based on a subset of the general category of innovations (Calderón-Hernández et al., 2020; Hossinger et al., 2020; Hueske & Guenther, 2015; Jonsson et al., 2018), with no concentration on certain industry, start-ups that require manufacturing scale-up along its commercialization journey, more over bio-based innovations. The scale-up journey is different than those of more mainstream IT-software startups, which dominates the current literature as it is more mainstream in the market. The available research on innovations in manufacturing is available in a more general industry context, not specified to include innovations in an academic context (Abdullah et al., 2016; Hartono & Kusumawardhani, 2019).

Considering the imminent need for better alternative replacements of fossil-based product in the market, bio-based products served as a promising potential (Bröring et al., 2020). This thesis is written to fill in the gap in current literature to anticipate the imminence of growth of bio-innovations, along with the evident that there is a lack of academic insight regarding barriers and enablers, specifically in a USO context, to help accelerate and push the survival rate of bio-based USO innovations to spin-out to manufacture or license their technology for the masses. The discussion around barriers and enablers are elaborated in Table 4, ranging from the micro-meso-, macro-level classification (Hossinger et al., 2020), EOGI (external, organization, group and individual) framework (Hueske & Guenther, 2015) and internal/external barriers and drivers (Abdullah et al., 2016).

Table 4. Previous literature on barriers and enablers of innovations and academic spin-offs

Paper	Focus of Study	Scope of Sample/Subject of Research	Methodology	Findings
(Hossinger et al., 2020)	Drivers, barriers and success factors of academic spin-offs (ASO)	General, no categorization of ASOs, based on 193 articles covering 28 countries with mostly focused in European countries and the US	Systematic literature review	Identification of drivers, barriers and success factors, categorized into micro, meso and macro-levels
(Calderón-Hernández et al., 2020)	Barriers to university spin-off creation in emerging market	Based on a Colombian context, emerging market with low levels of innovation and entrepreneurship	Qualitative studies, thematic analysis of semi-structured interviews	Barriers to spinning out in an emerging market context include limitations of the understanding of spin-off concept, trust, perception of university, academic culture, and incentives.
(Jonsson et al., 2018)	Longitudinal analysis of university spin-offs (USOs) created through the holding company of a university	Study takes place in Uppsala University, Sweden, during the nineteen-year period between 1998 and 2016, 50 spin-offs were studied	Longitudinal study using descriptive statistics	The two major barriers to overcome for a USO during its development: commitment in the founding team of researchers and to overcome the so-called 'threshold of credibility'
(Hueske & Guenther, 2015) –	Barriers to innovations	Citation analysis based on 188 empirical studies on barriers	Systematic review of empirical barrier research	Identified barriers and classification following the EOGI barrier model: external environment, organization group and individual

2.5 Sustainable? Bio-based spin-offs

This thesis studies seven cases of spin-offs, all coming from various departments at Aalto University, mainly from or in collaboration with members from School of Chemical Engineering (CHEM). Spin-offs are focused in the production of bio-based products, as the EU Commission outlines: products are wholly or partly derived from materials of biological origin (such as plants, animals, enzymes, and microorganisms, including bacteria, fungi and yeast) (European Commission. Directorate General for Research and Innovation., 2018). Additionally, they do not include materials that are embedded in geological formations and/or fossilized.

It is important to note that even with literature that states bio-based products as a better alternative for fossil-based products (Bröring et al., 2020).It is important to note that bio-based refers to the type of raw material used to manufacture a product, not how the feedstock has been cultivated, nor about the product itself: therefore, not automatically more sustainable fossil-based products (CORDIS-EU, 2023).

A bio-based product's impact could be way lower than a fossil-based one if the process and feedstock used are more sustainable. Feedstock selection, shifting from laboratory to commercial-scale production and end-of-life treatment of bio-based products may introduce sustainability trade-offs (Hottle et al., 2013). In order to minimize such trade-offs to ensure bio-based products as viable economically, socially and environmentally alternative to fossil-based products, it is important to identify and reduce potential environmental impacts via a systematic assessment (Ögmundarson et al., 2020). Reliable judgment of an environmentally preferred and more likely sustainable product can be achieved via validated assessments, such as life cycle assessment (LCA) (Vinodh & Rathod, 2010).

LCA aims at capturing environmental impacts from material extraction and manufacturing end-of-life (Ögmundarson et al., 2020), pinpointing hotspots for the prevention of environmental impacts, used to reduce the total life cycle cost of the products and ensure sustainability. Taking into consideration the good spirits of researchers to integrate sustainability in the invention of their discovery, claims of sustainability in products would only be valid after proper assessments are published.

In this study, we prefer not to use the word sustainability vaguely and therefore we focus on the fact that these USOs use bio-based feedstocks. Description of the USOs are summarized in Table 5. Cases are anonymized through the analysis of interviews due to the disclosure agreement with the interviewers.

Table 5. Interviewed USOs

USO	**Description**
IONCELL	Technology that turns used textiles, pulp or even old newspapers into new textile fibers sustainably and without harmful chemicals. The process converts cellulose into fibers which in turn can be made into long-lasting fabrics.
WOAMY	Exploring cellulose-based materials as suitable alternatives to replace plastic. Bio-based, lightweight, and strong material mould-free and fast-drying foam manufacturing process without the need for any chemical additives, extreme pressures, or temperatures.
Lignosphere	Hardened lignin nanospheres use for adhesives, coatings and composites.
Nordic Bioproducts Group (NBG)	Hydrolyzed ligno cellulose used to manufacture MCC through the Aalto Cell ® process
WUUD	Durable embossed wooden panels against the weathering against the fungi growing against the other that aging
CirPa (Circular Panels)	Bio-based circular panels, with tailored surface patterns that maximize noise control and provide aesthetic value as a decorative element. “Circular” by exploiting locally available forest resource side streams.
Bubbles with Benefits	Cellulose-based and biodegradable bubble wrap replacement. This innovation is a completely wood-based material that can replace plastic-based bubble wrap in packaging.

3 Methodology

This section starts with the research context and continues with the discussion of the research process, which includes the justification behind the research design of the thesis and the discussion on the methodology of research used to answer research questions.

3.1 Research Context

This thesis is of interdisciplinary nature and conducted as a part of the Sustainable Bio-Innovations and Bioproduct research group under the Department of Bioproduct and Bio-Innovations, School of Chemical Engineering in collaboration with the Entrepreneurship Unit of Aalto Business School. The research aims to clarify the stages of development and identify the barriers and enablers of bio-based USOs. This thesis is written to gather insights from current spin-off projects and companies to help aspiring spin-off teams who want to commercialize sustainable bio-based products developed in the lab in all stages of the journey.

3.2 Research Process

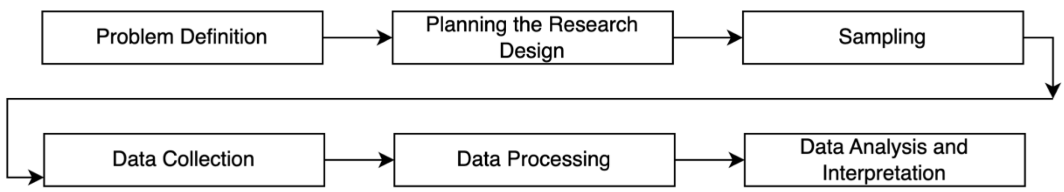

Figure 3 Research Process Flow Diagram.

The research process follows Figure 3. The process is similar to the typical flow of qualitative research (DiCicco-Bloom & Crabtree, 2006). It starts with problem definition, where the research gap is identified and research questions are formulated. Aiming to answer the research questions, the research design is set. Sampling is done to scope down primary data sources from available databases to find USO teams that are relevant to the research. Next, data collection is performed, where interviews are performed. Prior to the interviews, research questions are cascaded to interview guidelines. Next, data processing is performed to identify highlighted themes from the interviews, which later would provide the basis for data analysis and interpretation.

3.2.1 Problem Definition

This research intends to fill in the gap in the lack of studies pinpointing bio-based innovation commercialization. Considering the rise of the bioeconomy and the urgency of the search for better, there is a need to accelerate the commercialization of more sustainable replacements for fossil-based products in the concerted effort to minimize the overshoot of the planetary boundaries (Richardson et al., 2023). Based on (Maine & Seegopaul, 2016) advanced materials, which could include bio-based materials, would need seven times longer development time and up to seven times bigger development cost than a typical IT venture, decreasing the chance for discovery to find its way to the masses.

Maine's research leaves out the nuance of innovations in an academic setting, considering the amount of public funding allocation and the expected return of their research to create an impact on society. Aalto University makes an appropriate case study for this, as it is a Finnish public university with 200+ current and past commissioned innovation projects (Aalto University Innovation Services, 2024c) from various domains, including in bio-based innovations.

3.2.2 Planning the Research Design

To answer the research question, the research design is set. The design of the research is based on the research onion framework (Saunders et al., 2023). First, the research philosophy will be discussed, followed by the approach to theory development. As shown in Figure 4, the choices made in the earlier 'layers' of the onion provide the reasoning for the later layers.

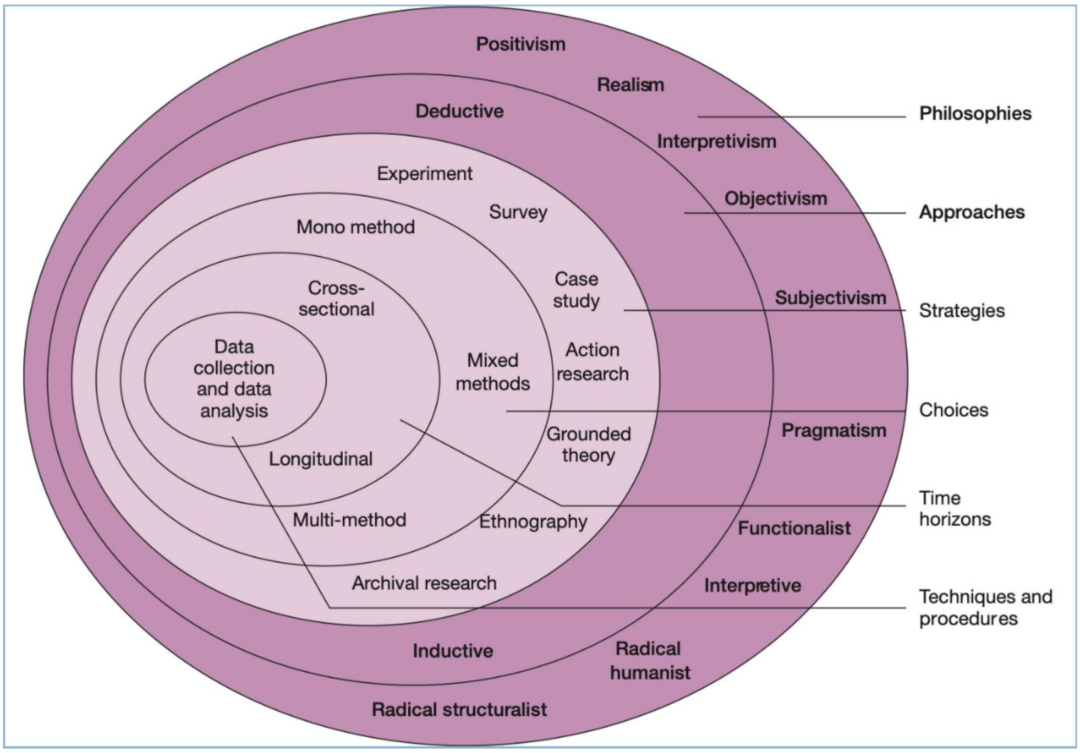

Figure 4. Research Onion (Saunders et al., 2023).

Research Philosophy

Research philosophy concerns how the researcher develops knowledge and the nature of the knowledge (Saunders et al., 2023). The view/assumption will later cascade to the research strategy and method that the researcher as a part of the strategy. This thesis will adopt an interpretivism view. This view focuses on understanding human roles as social actors, where the researcher had to adopt an empathetic stance, understanding the world from their point of view (Saunders et al., 2023).

Approach to Theory Development

The way in which a research develops a theory or answer its research question is usually through three approaches, deduction, and induction, and in some cases, also a combination of both. Usually, the research approaches are attached to a certain research philosophy. This thesis adopts an interpretivism approach to theory development, which favors an inductive approach using data analysis to develop a theory (Saunders et al., 2023). This thesis aims to identify the barriers and enablers of bio-based USOs, a niche phenomenon, and alternative explanations that are essential to complement current theories in other contexts. For this reason, an inductive approach was used in this thesis, over deductive approach, as it allows the anticipation of phenomena (Collis & Hussey, 2014), limits the discovery of alternatives, having an 'air of finality' (Saunders et al., 2023).

Methodological choice

In order to achieve the research aims, the methodology used is the qualitative methodology. This method allows for exploratory study through opinions to gain an in-depth understanding of the human dimensions, such as perceptions, experiences, opinions and knowledge in depth (Pathak et al., 2013). This is valuable for addressing questions that are difficult to address using numerical measurements of quantitative methods.

The majority of the previous research listed on barriers and enablers of USOs, including articles they reviewed in Table 4, are based on empirical studies analyzed through quantitative methodology. There have been a noticeable shift away from qualitative methodologies over time (Hossinger et al., 2020). One possible reason for this is that university spin-offs/academic entrepreneurship fields of research have matured enough that there have been sufficient theories and frameworks to be used to carry out a quantitative analysis. Qualitative methodology is usually used in the early stages of research since it is effective in describing phenomena and exploring influencing factors (Rothaermel et al., 2007). As a relatively less-researched overlapping subcategory between the rising research on bio-innovations and university spin-offs, this thesis uses a qualitative method to explore the phenomenon.

Primary data collection in this thesis is done through in-depth semi-structured interviews to answer the research questions of the thesis. Such interviews are organized where the interviewer has a set of predetermined open-ended questions, with several additional questions that emerge from the dialog as the interview progresses (DiCicco-Bloom & Crabtree, 2006). This method is used in both individual or group settings, usually planned at a scheduled time and in a location outside of everyday events (DiCicco-Bloom & Crabtree, 2006).

Strategies

Under qualitative research methodology, the strategy used in this thesis is case study. A case study is a study of a single unit, or having a small sample size (Hollweck, 2015) with an aim to generalize across a larger set of units (Gerring, 2004). This fits the thesis case as the USO under study, the manufacture of sustainable bio-based products, is currently a very limited subset. Case study provides an exploratory approach to the research (Hollweck, 2015) of successful and failures in business-context research (Glette & Wiig, 2022), which is suitable for answering the research question.

Time Horizon

The time horizon of this research is cross-sectional, meaning data is collected at one point in time rather than a continuous one, in the case longitudinal study. Each USO, with a total of seven, involved in this study is interviewed twice, with one interview focusing on the business activity of the USO and the other focusing on the technical/research and development side with a total of 14 interviews. The interviews take place in between July 2023 to May 2024.

3.2.3 Sampling

Sampling in this research is done to scope the informants of the research. This is done by looking into the publicly available database Aalto Research Innovation Services (Aalto University Innovation Services, 2024b) on spin-offs that are currently under their assistance and past projects. The criteria for informant USOs are those who utilize bio-based feedstocks to manufacture their products. Sampling is purposive; interviewees are chosen by going through a list of keywords using bio-based materials such as “wood,” “pulp” of wood-derivative products, “cellulose,” and “lignin”. Seven out of eight of the informants fit the criteria of the research and are willing to be participants in the research. The sample size of the research is deemed representative of the population as 8 USOs are identified from the database, and 7 agreed to participate in the thesis research.

3.2.4 Data Collection

Data collection was performed intentionally and specifically for this research purpose through a series of interviews. Fourteen interviews are performed, with two interviews done with each USO; one interview will focus on the business side of the spin-off, then another focused on the technology development/more scientific perspective. The focus between the two is adjusted based on the interviewee's position in the USO, although the separation of roles (scientist/business developer) in most cases is not very clear.

The research questions are cascaded to questions in the interview to prepare for the interviews, forming the interview guides. The breakdown of the research question is presented in Table 6. The interviews, as explained in the research design section, are semi-structured. During the interview, the investigator takes short notes while observing and questioning the informants (Agar & Agar, 1993). In practice, the investigators could adjust the interview guide as needed as the interview progresses, in which the sequence of questions could be rearranged, and interview questions could be added if an interesting point is brought up in the interview. Interviews are both done in an individual and group setting. The researcher interviews one informant at a time, and some are done in groups of two or more people, depending on the interviewee's availability.

Table 6. Interview guideline.

Topic	Research Questions	Questions in the Interview
Spinout Journey	What are the stages of development of bio-based USOs	What is the timeline/milestones so far in the establishment of the company? How long do you think it will take for your innovation to become commercial?

Enablers	What are the enablers for accelerating bio-based deep tech spin-outs?	What advantages/ease did your company have that you think helped in the process?
Barriers	What barriers could be identified for bio-based deep tech spinouts?	What has (have) been the main challenge(s) your company has had to face in the current and in the past?
		What's the biggest challenge of getting to a TRL of 9?

3.2.5 Data Processing

Data processing involves transcribing the interviews into text format. The interviews are partially done by automated Microsoft Teams transcription for meetings, along with manual correction to the transcript by listening to the interview recording. Some interviews are transcribed using the product of Aalto Scientific Computing's (ASC) new transcription speech2text tool using the Whisper Model.

3.2.6 Data Analysis and Interpretation

When doing data analysis through the qualitative method, the researcher becomes the instrument for analysis, making judgments on coding, theming, decontextualizing, and recontextualizing the data (Starks & Brown Trinidad, 2007).

The thematic analysis is done by the inductive approach, where the themes identified are strongly linked to the data themselves (Patton, 2015) instead of being driven by theoretical interest. In inductive analysis, coding is not based on a pre-existing frame or preconceptions (Braun & Clarke, 2006).
This is a useful method to examine the perspectives of different informants, identify similarities and differences, and generate unanticipated insights (King, 2004). Qualitative Data Analysis Software (QDAS) is used to support data management and analysis (Woods et al., 2016). ATLAS.ti is used as QDAS in this thesis to document, highlight, code, group codes, build code structures, and make connections between the codes.

Primary coding is done mostly by verbatim, the coding process is semi-open, focused on the research questions, but also leaving enough room for the research question to evolve. A total of 969 codes are made from the 14 documents from the 14 interview transcripts. These codes are used to answer the first and second research questions. The first research question is answered through content analysis, using (Rasmussen, 2011) the four-stages model in the academic spin-off creation journey as a reference. This paper is used as a reference is because it summarizes the previous literature on the journey theory, has a clear division between stages, and general enough to flexibly fit the variations in journeys of the USO interview. Keywords are used as a reference when coding the interview transcript. The key phrases in the interviews are recorded.

The second research question is analyzed as shown in Figure 5. First; the main code group division classifies the 969 primary codes into a total of 42 groups. Codes are then reviewed, selected to answer research questions, documents are recoded, and double codes are eliminated, resulting in 433 codes. Code groups are reviewed, merged, and eliminated, resulting in 16 code groups. Throughout the coding process, connections between cross-cutting themes are also marked. From those code groups, 55 subgroups of enablers and barriers are identified and classified into 2 categories: internal and external. This list is then analyzed, and connections between the codes are explored. Some direct quotations are included in the analysis to give nuance and context to the analysis.

Coding guidelines closely follow the research questions. To answer the second research question, important internal means factors that exist within the organization within the USO projects/companies, whilst external means factors outside of the organization, such as, but not limited to, the market and academic environment in which the spin-off operates up to national levels legislations. The term 'barrier' is defined as a factor that prevents or hinders, while an ‘enabler’ is defined as a factor--of competence or ability to attain a certain goal.

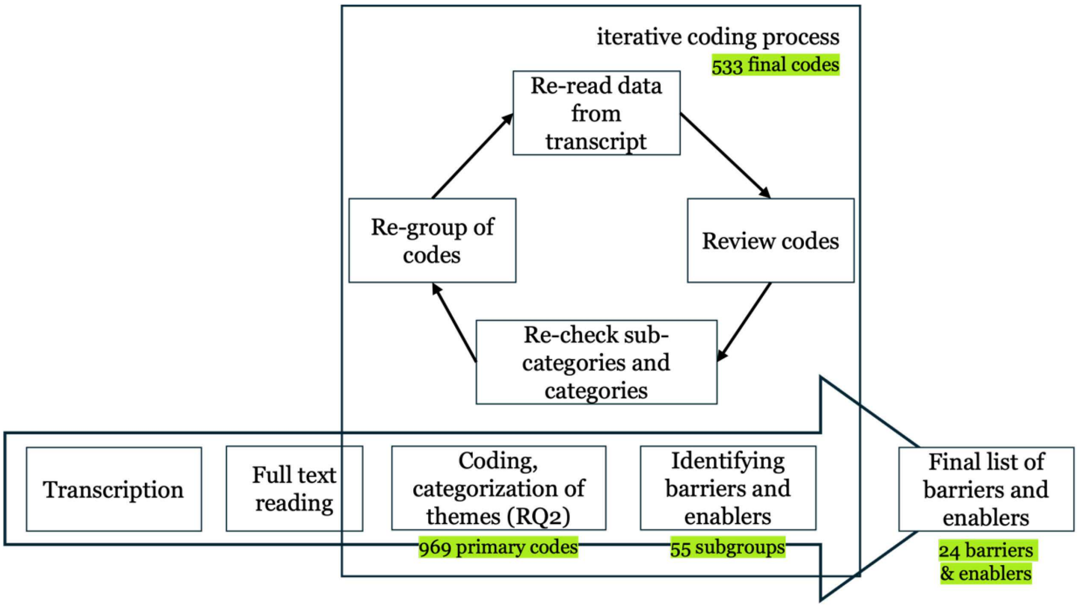

Figure 5. Iterative coding process for RQ 2.

4 Results

4.1 Bio-based USOs at Aalto

To put the case studies into context, a profile of the USOs is shown in Table 5. The profiles of the USOs are elaborated through the business model they are currently operating with and/or planning in the future (in the case they haven't spinout), innovation types, time from initial research idea to start of project, whether the innovation product is commercialized due to market-pull or technology push, ownership of intellectual property (IP), project/company founders, major funding source, self-reported TRL and current status of USO.

All the USOs studied make their business based on bio-innovations, deriving their innovations from renewable, biological resources, in this case, all derived from wood products (more on this in Section 3.2.6). The feedstocks of the USOs studied in this thesis are products derived from wood or wood itself. Although all USOs are in the business of manufacturing products, some opted for licensing instead of sales or considered licensing further down the line, in the case of USOs 4, 6, 7. One of the reasons for this is that it allows the widespread of the technology to bigger markets without having to be burdened with all the costs.

Following the bio-innovation types as elaborated in Section 2.2, the USOs' products could be classified as either new products, new processes, or substitute products. Similar to results in advanced material innovations, most of the USOs studied took quite a long time from research idea to the start of a project or initial commitment to commercializing; most took 5-10+ years.

The span of years listed on the table is mostly taken for doing the research for product development and feasibility studies of commercializing the technology. The mark of initial commitment to commercializing is when they initiated to beneficiaries of the R2B funding/and/or were in touch with Aalto

University's RIS to start the go through with the commercializing of their product. Exceptions to this are USO 2 and 5, which take only 2 years of research, in which research was based on the founder's thesis and course project work. USO 2 expressed that the relatively short research timeline for them was due to leaving out the research on chemical modifications, which they projected to take at least a decade to develop.

The product/process of the USOs studied was discovered through research groups, university research or inter-university research. Most spin-offs come from or in collaboration with the Department of Chemical Engineering, of Aalto University. All of the spin-offs expressed interest in commercialization driven by technology or on the basis of technology push, as opposed to market pull.

In all of the cases interviewed, most of the innovative product comes from years of academic research, in which having a product in the market might not be the main motivation the researchers have in mind starting out. This type of innovation is when a particular discovery is made and one looks out at the world to find applications where it may have an impact (Tranquillo et al., 2023). The research started out as a technology push, but soon as they commercialized, USOs would inevitably have to adjust their capabilities to the market demand.

Naturally, the founders of USOs are mostly members of academia, mostly with technical background: professors, post-doctoral researchers, doctoral researchers, and students. Those who are in the founding team of the USOs that are not coming from the university are people in charge of commercialization, usually with a managerial background to develop the business, usually appointed by the university/research innovation services. This is unsurprisingly a common practice (Clarysse & Moray, 2004), especially when no one in the current team has managerial experience.

The major funding source for these USOs is from public sources, mostly utilizing Business Finland's R2B funding and university funding. This is especially true for those USOs who are early in their development process, self-reporting a 4 or below on the TRL scale. Naturally, USOs who are in later stages on the TRL scale, more mature USOs, outsourced their funding from external funding such as VCs and partner companies. The status of the USOs varies and is true during the time of the interview period, elaborated in Chapter 3 on methodology. As shown in Table 7, the status of USO as of the time this thesis is written, 3 of which are still holding the status of R2B project, in which IP is either still owned by the university or isn't registered because it is not applicable. Two of the USOs have terminated their R2B phase but aren't spin-outs, with one of them discontinued and another one still holding a title of company under the university. Two of the USOs that have advanced in TRL scale of 7 or more hold the status of start-ups and have already had IPR transferred to their companies.

Table 7. Profiles of USOs.

Spin-offs	USO 1	USO 2	USO 3	USO 4	USO 5	USO 6	USO 7
Feedstock	Lignin	Wood	Lignocellulose	Cellulose	Cellulose	Cellulose/Fibers	Cellulose/Fibers
Business Model	N/A	B2B Sales	B2B Sales	Technology Licensing	B2B	B2B Sales/Licens-ing	B2B Sales/Licens-ing
Innovation Type	New Product	New Process	New Process	New Product	Substitute Product, for packaging	New Product	Substitute Product, for foams
Time from initial re-search idea to spin-off project	5 years	2 years	10+ years	10+ years	2 years	10+ years	10+ years
Source of initial idea	Research Group	Thesis Pro-ject	Unversity re-search	Research Group	Course Pro-ject	Research Group	Research Group
Market-pull or Technology Push	Technology push	Technology push	Technology push	Technology push	Technology push	Technology push	Technology push
University-owned intellectual property	Yes	No patent rights	Transferred	Yes	Yes	Yes	Transferred
Project/Company founders	Research Group	Thesis Re-seacher, Business De-veloper	University Pro-fessor, Current CEO	Current CEO and Univer-sity Professor	Technology founders, professor, PhD students	Technology founders, student project wrokers	Technology founders, student project wrokers
Major funding source	Public	Public	Private	University	Public	Public	Private
Self-reported TRL	3	4	9	4	3	3	7
Current Status (June 2024)	Discontinued	R2B Project	Startup	Company, under univer-sity	R2B Project	R2B Project	Startup

4.2 Commercialization pathway

In order to answer the first research question on the stages of development of bio-based USOs, the journey of USOs is plotted on Table 8. The timeline journey is taken from the USO's founding team's perspective through the interview. More on the methodology is elaborated in Section 3.2.6. Using a previous study to benchmark the milestones of USO formation, shown in Table 2, Rasmussen's study (Rasmussen, 2011) is chosen as a reference, as it summarizes theory on USO milestones from previous studies and provides a general enough division that could be a good guideline to make sense of the timelines in the literature reviewed (see section 2.3.1.). According to Rasmussen, commercialization is divided into 4 steps: research, opportunity framing, proof of viability, and start-up/spin-off. These keywords are used as a reference when coding the transcript of the interview. The occurrence of the key phrases in the interviews is tabulated and marked on a table.

As seen in Table 2, it is evident that the timelines for each of the USOs vary; there are a set of milestones none USO takes in the commercialization journey that is exactly like the next. Mechanisms might change from time to time, but considering that all USO journeys went through a pipeline of Aalto University's Innovation Services programs, the commercialization milestone is alike, although the pathway might not be exactly the same.

Naturally, since the studied subjects are USOs, research is the starting point of the journey. Research in this context is application research regarding the development of the product/process innovation that the scientists have discovered. Once the founders of the innovations have the intention to commercialize, the opportunity-framing phase starts. This begins the first step of commercialization. This phase is where business plans are generated and the intent to commercialize the technology by disclosing the invention. This process is normally aided by RIS, as the TTO of the university.
Six out of seven USOs are reported to have dealt with invention disclosure as they are creating a novel product/process. Only one USO reported not going

through invention disclosure/IPR, as they were not applicable to their case. One of the USOs mentions that this phase is also the start of the pre-incubation phase, a program made by RIS at Aalto to prepare start-ups. The most important milestone in the generation of business ideas phase is the enrolment to the USO's first public funding, in most cases, R2B, which is also a big part of one of the pathways Aalto University's RIS offered, especially for deep-tech/innovations coming from research.

The R2B funding prerequisites, to an extent, also govern the timeline of commercialization. This includes requiring USOs to form teams, a milestone mentioned by almost all USOs, noting its significance in the process of generating business ideas. One USO also mentions doing TEA analysis as a part of the generating business ideas phase, as financial feasibility is a requirement to receive R2B funding.

The next phase of development is finalizing venture projects, where the presumption of the economic potential of the innovations as a business project is validated (Ndonzuau et al., 2002). Some of the interviewed USOs are still in their R2B phase; therefore, they are just at the beginning or towards the completion of this phase (USOs 2, 5, and 6). This phase is followed by invention disclosure, where IPRs are registered. This process is important as the protection of the development of the idea is an essential step to transform research into business (Ndonzuau et al., 2002). This process is normally aided by RIS, which functions as the TTO of the university.

All USOs reported to have dealt with invention disclosure as they are creating a novel product/process. Following this is proof of the viability of the products, which includes testing, validation, prototyping, and proof of concept. At this stage, it is expected for a team to be formed to start marketing the product and raise sufficient funds to move forward with the technology.

In terms of funding, this phase is primarily funded by the R2B funding. To be able to have the funding approved, some sense of potential for business success must be demonstrated. For this, they might already have some samples of products, application ideas, and business plans. However, in order to prove market viability, they would need proof of concepts (of products and their application or the process of manufacturing itself). Production is pushed to upscale from lab to pilot/demo at this phase. Based on the interviews, 3 USOs reported that their self-reported TRL is a 3 during the R2B phase. In order to go up the TRL scale, to a 4-5, they would need to do so by building pilot/demo scale production. This would require funding other than the R2B, which is only possible when USO has completed R2B. Tension of funding will be explored next in section 4.3.

The 2 USOs that have moved past the R2B phase next in the timeline entered the launching to the spin-off stage. To begin this stage, USOs secured raising funds from other sources to launch the spin-off firms phase for the next leg of commercialization, the launching of the spin-off, The final stage happens once the products pass the prototyping and regulation requirements and, in most cases of spin-offs, have licensed their technology from the university. From then on, the company will raise funds for the scale-up of their manufacture. Funds are primarily used for IPR transfer and scaling up of technology to meet customer's requirements. Only 2 USOs in this research have reached the launching spin-off firms phase.

Table 8. Commercialization Journey of 7 Bio-Based USOs.

Rasmussen, 2011	**Research**	**Opportunity framing**			**Proof of viability**			**Launching spin-off firms**
USO 1	research	TEA	team formation	IP discussion	R2B	Raising funds		
USO 2	research	In contact with RIS, team formation	pre-incubation			R2B		
USO 3	research	In contact with RIS	team formation	IP discussion	University Funding, R2B	IPR transfer, raising funds	Demo plant	establishing a company
USO 4	research	In contact with RIS	team formation	IP discussion	University Funding, R2B	Pilot production	team formation, raising funds	
USO 5	research	pre-incubation	team formation	IP discussion		R2B		
USO 6	research	In contact with RIS, IP discussion	team formation	R2B				
USO 7	research	In contact with RIS, IP discussion	Team formation	R2B		Pilot production		IPR transfer, raising funds

4.3 Barriers and Enablers

Based on the case study, the discussion on barriers and enablers to USOs is grouped into two categories. Internal and external factors differ based on the point of influence. Internal factors have to do with the ones that come within the organization, whilst external factors are sourced from outside the organization. Enablers and barriers, respectively, refer to the positive and negative factors that affect the development of USOs. Elaboration on the definitions outlined in Section 3.2.6.

Barriers and enablers are identified through the coding of interviews, with no causational relationship pulled in between barriers and enablers to form problem-solution relations. Barriers and enablers identified are dominated by business-leaning themes, surrounding teams, market entry, and funding, and less technical-leaning themes, such as technical complexity of scaling up.

4.3.1 Internal Barriers

Internal barriers identified by the informants encompass the lack of insight into the commercialization pathway, research and development (RnD), and team dynamic challenges. Table 9 lists the barriers, which are further explained below.

Table 9. Internal Barriers.

Internal Barriers
Lack of insight on commercialization pathway
Research and development challenges
Long research timeline
Technical challenges to scaling up
Team struggles
Hard to find team members
Tensions within multidisciplinary teams
Talent gap within teams

Lack of insight on commercialization pathway

"So, looking back, there could have been a lot of improvement in that and also really having a crystal clear part on how to commercialize." – USO 1

The lack of insight into the commercialization pathway is mentioned as one of the internal struggles. In all cases of USOs interviewed, the commercialization process is driven by the scientists' vision of widespread their innovation beyond the invention they found in the lab. For this, take the example of the case of USO 1 above, the founding team early on is dominated by technical personnel/researchers who are experts on innovation. As much as they are experts in the technical know-how of the inventions, they might not have the experience or the proper training in commercialization, transforming the invention into innovation. When asked further what it is exactly the kind of insight they felt lacking, they responded mostly about the business aspect that goes into commercialization.

"How to build a business and how to build a team... understanding how a successful team could be founded and how to set up the company and how to share the shares or divide the shares and responsibilities and tasks and so on." – USO 1

Navigating business and team dynamics are the two areas they lack in insight, which are barriers for these USOs to commercialize as USOs are a form of academic entrepreneurship where business and team dynamics are essential.

Research and development challenges

a. Long research timeline

One of the hallmarks of bio-based innovation is the long research and development timeline. USO businesses discussed in this thesis are built upon deep-tech innovations based on application research, which easily takes one decade of research despite some years of basic research backing them up.

Similarly, this is also the case for the field of advanced materials (Maine & Seegopaul, 2016), which requires 5-15 years of development time.

"Prior to that, there was already, let's say, a very long time in academic research behind it... I think the timeline is something that the idea came in 2006 – USO 3"

The long research timeline is a hindrance, as time is essential when it comes to the projection of the chances for the USO to spin out and make economic returns. The innate long payback period wouldn't be a good incentive for founders to thrive in their endeavors nor for the funders to be able to trust financing the project due to the uncertainty that comes with such long timelines. The USOs often face funding gaps due to the long development timeline. More discussion on the cross-cutting barrier to funding will be discussed in Section 4.3.2. on external barriers.

"The new method with new chemicals takes easily like 10 years – USO 2"

In the case of USO 2, they decided to leave out part of their innovation plan due to the long development timeline. Although there has been quite some foundational basic research to back their application idea, they reported that it would take them at least a decade of research on its application on their current product, which isn't feasible based on their current timeline and funding options.

b. Technical challenges to scaling up

A long time to develop the technology itself is one thing, the scaling up of technology is another issue. Most of these technologies started from bench-scale production in the lab, which normally runs in batch processes. This is the case, especially for USOs with technologies of TRL stage 4 and earlier. USOs at this TRL level are those who are in the R2B incubation stage.

“The maturity of the technology development has been in a laboratory condition, so in a batch mode” – USO 4

In order to commercialize, the upscaling of the process would require not only an increase in feedstock flow and capacity of production but also a change in the way these USOs manufacture. Upscaling means moving from lab to pilot and/or to demo plant, which means a major change in the mode of production, from batch to continuous mode, as operational parameters might need to be entirely reconsidered to adjust to the new process.

”10 years of research and lab work [...]. In total, ten plus ten years, a total of 20 years. – USO 3

In the case of USO 3, it was projected that despite the decade of research and lab work, it would need another ten years to ‘break away from university’ or to establish its own company, to commercialize. In the case of USO 3, the research and development process spans more than a decade, as it is still an ongoing active research in parallel to the current scale-up activities. This adds another layer of how lengthy the development timelines are for bio-based innovations as mentioned about the long research timeline. Relating to this barrier is also the issue of funding during this critical stage of commercialization, further discussed in Section 4.3.2 on funding barriers.

“Very viscous material which makes it very, very difficult to run through a process machine and of any kind so we need to go down, which is one of the assignments for [personnel of USO 5], try to go down with the viscosity to the level that it actually can be processed.” – USO 5

Scaling up innovations in bio-based products comes with its own set of challenges, one of which is the optimization of the process, which is necessary due to the different nature of batch and continuous mode. In continuous production, there are limitations in operational parameters that are heavily dependent on unit operations used and vice versa. Availability of unit process in the market as well as cost to procure unit processes out of the market option in the case that it is necessary. Not to mention the consideration of the cost of utility needed to procure a continuous process, which might not matter much in lab-scale production. Drastic alterations are necessarily done; as in the case of USO 5 quoted above, the viscosity of the current recipe is not optimized for the continuous production mode. Other unit operations also would need to suit the process parameters.

Team struggles

The barriers to USOs working in teams can be divided into three distinct subgroup struggles: difficulties in finding team members, tensions within multidisciplinary teams, and talent gaps.

a. Hard to find team members

Struggles in team dynamics have been a recurring theme that has appeared to be a barrier for all USOs interviewed. An interviewee from USO 6 expressed concern about the challenge of finding a 'good team'.

"But we have problems finding a good team for the startup. [...] It's not a straightforward for example right now it's true. It's right now it's two of them. They're both still studying. They're both still studying their bachelors at Aalto, and they would then be responsible for, for doing this." – USO 6

Originating from the university, it is natural for the founding team members to have tensions as they juggle their responsibilities as active faculty members. In the light of the quotation from the interview above, the interviewee from USO 6 views this as a concern as their team members are still students and will be taking a huge role in the early stages of establishing the USO. The challenge of finding team members who is both dedicated and has the level of experience that fits the role of the team is a barrier, as teams are essential in academic entrepreneurship and are widely researched in the wider context of entrepreneurship (Harper, 2008).

b. Tensions within multidisciplinary teams

Aside from its long development timeline, another hallmark of a bio-based USO identified through interviews is the multi-disciplinarity nature of teams, which could create tensions.

"I think this is a challenge for many university spin-outs that people who have been working in a university for a short or a long time, they're not the same people usually who are too entrepreneurial minded." – USO 6

Scientist/s and engineer/s who are experts in developing the technology in all cases of USOs are often paired with personnel with the competence to make a business out of the product, making such teams inevitably multi-disciplinary, formed by members from different fields of expertise. This pairing of researcher-business developer could occur out of the main inventors of the technology's conscience to bridge the lack of expertise in the business aspect when they form the teams.

In other interviewed cases, hiring a business developer in the team was based on the advice of Aalto University's RIS team when they discussed the possibility of commercializing their invention. This phenomenon is not new and aligns with findings in research on academic venture formation (Clarysse & Moray, 2004). Working in teams with members with different backgrounds is perceived as a barrier to 6 out of 7 USOs interviewed. The barrier of communication and different viewpoints on priorities of issues in teams were highlighted during the interviews.

"It's like uh, communication as a I think a big issue....between the disciplines, because so (the engineers), for them it's just important that the foam is good [product]. And then there's also designers. There's also

designers who wants, of course, to make it a good product service system so that it sells good and that it's attractive. And then of course, if you want to get some money out of it.” – *USO 6*

“Issue that we have to discuss something that may not be that important for longer because everyone has a different idea on what the obvious way to go to would be… we literally speak different languages in many like kind of figuratively and literally as well so it's more work to understand each other” – USO 5

Although it seemed like team members in these USOs wanted something in common: to successfully be able to spin out from university, the different viewpoints in multidisciplinary teams are perceived as taxing. USO 5 mentioned that it takes more work to understand individual team members' perspectives and that it is challenging to work as a collective as they view the same issue from different perspectives, causing a diverge in the discussions—what was obvious for some is not as obvious for others. USO 6 mentioned how a designer views priorities differently from how an engineer sees them, and this can cause disagreements and tension, which could be more counterproductive than coming up with a resolution. In these situations, these team members are bringing to the table their individual expertise and experiences. This could play out differently, as good team experiences, in turn, could be an enabler for USOs, elaborated in enablers of teams in Section 4.3.3.

c. Talent gap within teams

It has been previously established that researchers often team up with people with more business developer backgrounds and competence when it comes to invention commercialization. However, this is not the case for all the USOs in this research; 3 out of 7 USOs reported that they have a talent gap in commercializing competence. Two interviewed USOs reported that they have a talent gap in team members with business competence and one USO reported a talent gap in more technical competence.

“none of us has ... (a) business background like we have business experience and some business studies on like a behind but not like education or a lot of like actual degree or working in business positions for a long time. So I would say that well it's just difficult when you have to have to learn everything from scratch. So in that sense, it might have been helpful to have someone on board from the business background.” – USO 7

One of the two most developed from the cohort of USOs reported in this research, which shows that it’s not completely impossible to spin out without a member with a business background. Business competence is an important skill for commercializing USOs, as USOs are ultimately ventures based on research. Research would naturally be a huge part of it, but a lot of commercialization and scaling up has to do with ensuring that the research itself would have economic return to convince customers, investors and stakeholders alike. Therefore, a talent gap does serve as a barrier for these teams having to learn the business side of the work of USOs. For USO 1, on the other side, the talent gap is detrimental, as it was one of the contributing factors to why they weren’t successful in spinning out their innovation.

”I could have searched for those things myself and better prepared myself. However, you can't Google things you don't know exist, which makes it a bit difficult.” – USO 1

From USO 1’s case, the talent gap in business competence couldn’t just be fixed by talking to more people or simply searching. In other words, the experience of someone who has a business management role in teams is valuable and irreplaceable by other means. So, the only way to alleviate the barrier is by recruiting a new team member whose competence suits what was missing from the team to put the USO in a position with the best possible chance of survival.

” We are looking for business talent to include in our team. But for that to fill the lack of talent.” – *USO 7*

4.3.2 External Barriers

External barriers identified in this thesis are communication barrier, reluctance of collaborate, lack of funding, difficulties in navigating IPR transfer and market entry struggles. Table 10 lists the barriers, which are further explained below on Table 10.

Table 10. External Barriers.

External Barriers
Communication is not open
Reluctance of industrial partners to collaborate
Gap in funding for commercialization
Difficulties in navigating IPR transfer
Struggles of market entry
Constraints of regulations
Current production unable to capture economies of scale
Existing competition in the market

Communication is not open

“But this was never straight or communicated to us.” – USO 1

“People always also tend to be a bit more secretive when it comes to business, which I understand in a way. But on the other hand, that everything is sort of in shadows, that doesn't help anyone right now.” – *USO 1*

The matter of the communication barrier was brought up by USO 1, especially during negotiations on IPR rights. Although the informant understood that communication in negotiations couldn’t be as open as they wished it to be, which was crucial in order for their team to function. This is a barrier to commercialization as it is counterproductive and doesn’t help resolve issues USOs face along their journey to commercialization.

Reluctance to Collaboration

Bio-based innovations, like most emerging industries, are associated with radical and/or disruptive technologies, which might generate the interest of researchers (Lubik et al., 2012), a view that companies and potential external collaborators might not share. Two USOs, interestingly, one that did spin out and one that didn't succeed in doing so, expressed the reluctance of partner companies towards collaborating and, in general, aversive view towards new innovations proposed by the USOs.

"Scandinavic companies are so rigid." – USO 1

It is widely accepted in innovation literature that emerging industries are those without a clear or established value chain. For this, they would have to cause a change or reorganize within the existing value chain (Leifer et al., 2001). To do this, they would need to collaborate with existing stakeholders in the value chain, including incumbent companies in the market the USO operates in.

"Conservative companies that are the key holders of the change itself and then it's like oh it doesn't it's not compatible at all great innovation but you know they would need to have capex of changing the whole setup by hundreds of millions and they're not willing to do that kind of an investment just to get this one product out." – USO 3

It is acknowledged by USO 3 that although companies are interested in the innovation they offer, it would take more than mere interest to be able to collaborate and/or integrate their products, as it would take a whole lot of CAPEX to include new innovation in, a risky cost especially when the product/USO doesn't demonstrate a good enough potential for economic returns. This aversion towards taking chances on innovations is a barrier to commercialization as USOs are newcomers and would need trust and establish collaboration with incumbent players in order to integrate themselves into the existing value chain in order to sustain their survival in the market.

Gap in funding for commercialization

"Now we are also pursuing [new market products] now we need more funds in to actually fund the research so that we can open up these markets in the future and this is there's a gap until we get revenue from the actual production how are we financing. And that's kind of the interesting situation that how companies will survive this Death Valley of innovation." – USO 3

The widely accepted notion of gap in funding for innovations, more famously referred to as "Valley of Death", is an identified barrier in all cases of USOs participating in this research. Valley of death is a hindrance due to lack of funding and support during the early stages of science-based innovation at the transition between invention and innovation (Ellwood et al., 2022). Through interviews, the gap in funding that most of the USOs are experiencing could be pinpointed to fund for employing the team and building the pilot/demo plant.

"In order to start to demonstrate that action we have viable commercial viable product and that would be the like the first phase in order to be able to set this kind of manufacturing this kind of piloting manufacturing with at least money as possible" – USO 2

USOs also reported that the financing gap puts them in a chicken-and-egg situation, where they needed access to funding to scale up to a pilot/demo manufacturing plant but in order to access that funding, they would need to demonstrate a commercially viable product, which could only be achieved through procuring such pilot/demo plant. The tension between funding as both the means and end in the survival of the transitional period of invention-innovation is somewhat of a conundrum that all USOs must inevitably face in order to spin out.

"So they require a lot of CAPEX to build the first piloting and then validating getting all the kind of approvals for the product and if it's a novel or legislation and everything it might take five to ten years and you still need the funding for that and start building the actual with the high risk and then you know where do you find that sort of money" – USO 3

The requirement to prove commercial viability is more than just the capital needed to erect the plant but also the approvals necessary to even initiate the project. This is especially tricky for novel products and processes, where it might need longer approval time; USO 3 claimed that their estimate ranges from 5-10 years, which adds yet another layer of the previous point on long development time. The approval process is lengthy, uncertain and costs a lot, which adds to the capital required.

"This step that we are in right now I think would be the hardest at the moment we are in the stage where we don't have any research project going on regarding the commercialization." – USO 1

Considering that all USOs are concentrated heavily on research; naturally, a lot of the funding in the discovery/invention phase utilizes funding for research. It becomes a problem when currently there are no research projects that would fund the research to develop the product. This is especially true as the product might be niche, and so the funding for the specific research might not be available all through the development phase, just as the case for USO 1, which has been established previously to be able to span over a decade. Research funding isn't suitable for developing technologies to be commercialized.

"A challenge in such a short project development process. This year in and a half, in order to develop a commercially viable, new [product manufacturing] technique during this time is really challenging, and therefore I

believe that during this year and a half, this chemical technology development is not commercially viable yet." – USO 2

Other than research funding, all of the USOs have been granted research-to-business (R2B) funding. Although it has aided in bringing deep-tech research to business, it might not be suitable in some cases of USOs, which require a longer development process, as is the case of USO 2. R2B funding generally only spans for 18 months, which is somewhat of a short time to develop the product ready enough to be commercialized. A USO can only do so much in 18 months; research on the product and application should already be mature enough before starting the R2B project funding.

Difficulties in navigating IPR Transfer

"*The other problem was that the patent was all the universities and the newly established company needs to pay a lot of money for that patent to be transferred to the company And it's a lot of money as a startup. How do you finance that transition of that IPR?" – USO 3*

Challenges in the current mechanism for IPR transfer have been a recurring theme mentioned by 5 out of 7 USOs. Taking the insight from USO 3, IPR transfer is so far too big of a cost for new startups. The challenge in IPR handling is not only a barrier in transitioning the USO project to an official business entity. The issue with IPR transfer also extends to other barriers, causing challenges in gaining market validation, tension in employing teams, and scaling up production.

"We would have liked that our customers would have bought the products so that just not give them away for free because that's not good business but they would have bought them to run on tests but we couldn't do that because the IPR were still at Aalto which It felt very frustrating when we realized that this is what's happening." – USO 1

IPR transfer was a challenge in market validation as it is required for selling sample products for the customers to run tests on, leading to the possibility of purchase.

“We can't hire the person because of IP rights, need a licensing rights to hire some people to continue the development.” – USO 3

IPR transfer is also required for licensing rights to do technology development under the flag of an official spin-out separated from the university, which was essential to hire a technical expert and employ the necessary headcount for the spinout to develop.

“We also wanted to make the first pilot scale, so outside lab. We had the patent issue with Aalto, so the patents were still at Aalto. So we had difficulty just trying to get to the larger scale.” – USO 1

Aside from that, issues with IPR transfer also cause challenges in scaling up the process, as the rights were necessary to build a pilot scale production under the flag of the USO, without affiliation to the university.

Struggles of market entry

Market entry for novel products is difficult to navigate and poses a barrier for USOs as new players. There are three reasons why this could be a challenge: for one, the constraints of regulations, the disadvantage of not being able to manufacture at the economy of scale, and existing competition in the market.

a. Constraints of regulations

“The regulatory things are very difficult to get past, and it takes a long time” – USO 6

“I (the new regulation) just takes some options away or makes them more difficult” – USO 5

In order for products to enter the market, they would have to have approval and certifications regarding the product, process and materials used in the product that abide by the market it operates. In this thesis context, USOs must abide the EU requirements, which includes lengthy approval process, this is especially true for USOs whose innovations are new materials. This in turn could cause a delay in bringing new product in the market. Not to mention that these regulations could change at any point of the process, as mentioned by USO 5 in the interview. Taking into consideration the limitation of resources of time and resources these USOs have access to puts USOs in a lesser competitive advantage to enter the market with their innovations.

b. Current production unable to capture economies of scale

”*Biggest problem is the size of the lab scale and the minimum order quantity of industry. So there is a huge gap and to kind of find the good path that you can produce so much that is so expensive that covers the cost.*” *– USO 6*

The transition from small-scale lab to pilot/demo/industrial scale production is a critical change for USOs. USOs that already have their scaled-up production facility are faced with the challenge of meeting the minimum order quantity requirements from clients with their current limited production capacity. Scaling up poses a challenge to meet market demand while also optimizing for the lowest possible price point based on their current production capacities. USO 6 elaborated the challenge to meet the economies of scale, tension of wanting to sell in bigger volumes and lower price points to serve the bigger market, but is bounded by their current capacity, which only allows for them to serve smaller niche customers who could afford a higher premium pricing for production at low capacity. Without a feasible path to scale up, USO will continue to face barriers to market entry due to the high price point.

c. Existing competition in the market

"Yes, that we have is a very competitive market, is very thin margins. So we had to like smart and strategy." – USO 6

A highly competitive market with a very thin margin also poses a threat for USO to thrive and be competitive in the market. As mentioned above, especially due to the current limited production capacity, the price point is inevitably going to be high, putting them at a competitive disadvantage, especially in comparison to competitors, old players in the market with more mature processes, which captured economies of scale through mass production. The narrow profit margins might disincentivize USOs from entering new markets.

4.3.3 Internal Enablers

The identified internal enablers of USOs are the internal drive of founders, suitable business models, diversifying funding, market entry strategies, evaluations for process improvement, and favorable team dynamics. Table 11 lists the enablers, which are further explained below.

Table 11. External Barriers.

Internal Enablers
Internal drive of founders
Adopting suitable business model
Fundraising strategies
Start fundraising for spin-off during R2B
Diversifying sources of funding
Building rapport to raise funds
Market entry strategies
Market creation by considering end-users of product
Market pull as sustainable alternative products
Showcases to promote market entry
LCA for process improvement and regulatory compliance
LCA for process improvement
LCA for regulatory compliance
Favourable team dynamics

Good communication within teams
Strengths of a multidisciplinary team

Internal drive of founders

"If you start something like that, you need to stay convinced that it's possible." – USO 1

Internal drive and positive attitude of the funding team are critical for the commercialization of USOs. Taking into account the lengthy process of spinning out and the barriers to transitioning research out of the lab, it is important that the founders stay convinced with the technology. Having a strong positive attitude and internal drive is a huge enabler to persevere through the stunted progress and failures along the commercialization process.

Adopting suitable business model

"Well, we have a couple of revenue models that we are actually, we built this R&D center here. So this needed to be built so that we can build the factory. And now that we have this, we are selling the time of these researchers and this facility to other companies as an R&D for service. So we sell R&D projects for other companies." – USO 3

The lengthy scaling-up process of USOs and the long approval process for a business to trust and approve the innovation, let alone change suppliers to manufacture existing products could hinder new innovations from entering the market. For this reason, it would take quite some time for USOs before they could generate revenue from the manufacture of their products. For this, an alternative revenue-generating business model is crucial for survival, ensuring financial stability and support through the costly and lengthy scaling-up process. One strategy that USO 3 brought up is selling R&D services, offering the competence and know-how of their research employees.

Fundraising strategies

a. Start fundraising for spin-off during R2B

"And then we started the company in June or something like this. So it was like we just switched to switched gears – USO 7

"During the university project, we already had [big industrial company] and [design specialist] on board." – USO 7

From the USO's experience, we learn that USO will only be able to gain the status as its company after the period of R2B, which means that it might be tricky for them to gain support from other funds and collaborations with partners as they aren't an official business yet then. Receiving R2B funding through the transition might be a temporary lifeline for USOs, but it doesn't promise its continuity of survival after. For this, USO 7 shared that their enabler of securing funding is already having on board a big company player during R2B phase in order to secure funding right after R2B ends. They do this by pitching to potential companies and partners as early as they can.

b. Diversifying sources of funding

"Wanted to have an industrial partner, you know, a corporate finance, and then after that only VC, so venture capitalist." – USO 3

"*We utilized all the publicly available fundings, like everything." – USO 3*

"I mean, for example, my funding is I'm getting paid by by Aalto for my research. So that's basically my doctor." – USO 1

Diversifying funding is crucial to ensure the financial stability and development of USOs. Utilizing publicly available funding, such as academic funding and R2B, could be safe to secure early-stage development, but it shouldn't be the only source. USOs are dependent upon, especially as they transition to separate from the university, spinning out as their own company. To leverage different financial support and dependency on a single source, USO 3 shared how they combine industrial partnerships, corporate finance, and VCs in their funding strategy.

c. Building rapport to raise funds

"They need to see that the company can run for a certain amount of time that there is some money coming in and there is a team that's credible". – USO 6

"One of our investor happens to be, let's say, as they call it, what is it, the dark green investor. And portfolio investors. So they needed really that (LCA) one." – USO 3

There are several ways that USO could do to build rapport to attract funding, one of which are identified in the research is having a good team. This backs the current literature that an entrepreneurial team is the main criterion for considering investment (Clarysse & Moray, 2004). Having capable personnel behind the founding team is a great enabler in high-tech start-ups, especially those with managerial is one of the biggest reasons why research-based spin-offs do not receive funding (Clarysse & Moray, 2004). Other than good team, some investors, especially portfolio "dark green" investors as referred to USO 3, also have LCA evaluations as a mandatory pre-requisite to apply for funding.

Market entry and creation for products

a. Market creation by considering end-users of product

"Applications where these can be used very effectively and where you can get even better properties than you know what you can get with possible options of that would be" – USO 1

"You really need to make sure that the innovation fits the market need and the end user's need" – USO 7

The majority of participants of the research, 6 out of 7 USOs, reported that they benefit from expanding their product portfolio by considering applications for the end-users of products. The expanded product applications enable USOs to penetrate multiple markets and increase their chances of sales across different types of customers and industries providing multiple potential revenues. Diversifying the product portfolio for USOs and putting end user's demands first is useful to mitigate the risk of relying on a single market, enhancing the chances of market penetration across multiple segments. Focus on product applications with better properties or high-value applications, as mentioned by USO 1, also an enabler for market entry as it plays to the competitive advantage of new innovations, useful to attract early adopters.

b. Market pull as sustainable alternative products

"What the industry is expecting is that, first of all, you need to have a sustainable product or process or technology....in our case and our business sustainability uh the key aspect of sustainability is circularity because because at the moment there are no circular solutions uh in the market" – USO 4

With the industry's increasing attention on sustainability, makes the claim of products as a sustainable alternative, and or manufactured sustainably is increasingly attractive. This could be a big competitive edge for USOs that could justify their product as sustainable solutions to issues that aren't available in the market yet. In the quotation by USO 4 above, they leveraged circularity claims as a factor to enabler to access the market.

c. Showcases to promote market entry

"Helsinki Design Week [industry event exhibition] is one good option to see the people and the potential clients are to like the our solutions or not and then what is the kind of a demand from the market" – USO 2

"Advantages from the marketing that comes from Aalto. A lot of big brand market are interested in collaborating" – USO 4

Marketing of products through relevant industry event showcases and exhibitions is among the most intuitive strategies for market entry. USOs in this research have mentioned several notable events that are relevant for the Finnish market for bio-based products which are Design Weeks and Slush, among other events relevant for start-ups. USO 4 also brought about also how having Aalto University's brand under the brand name of the USO to facilitate market acceptance as the university's brand is widely known for customers and to potentially forge many partnerships from the university's connections.

LCA for process improvement and regulatory compliance

a. LCA for process improvement

"LCA's like everything can look very good, but in an LCA you can see something. Where you could do some improvements just to have a more sustainable process." – USO 1

LCA is mentioned by USOs not only to build rapport for investors but also is used to evaluate the ways in which process improvement could be done in the manufacture of the product to ensure the sustainability of the product. As quoted from USO 1, and mentioned by 5 other interviewed USOs, sustainability in the way they manufacture is something they value, more than just to tract investments. One of the ways be able to evaluate sustainability is through LCA studies, which could, for instance, be used to identify hotspots to optimize for energy and material use, which is important when upscaling the lab to a continuous pilot/demo scale process, where utility use is multiplied.

b. LCA for regulatory compliance

"I think it (LCA) will be important to do these tests to really see how could we label the materials. How should it be recycled or composted in home compost or as bio waste or paper waste or whatever it would be. We are planning on getting these statements." – USO 5

Life Cycle Assessment (LCA) is a valuable assessment to identify the impact of the manufacturing of products. It was previously mentioned how LCA is beneficial to build rapport for investors, but also, as USO 5 points out, it is important for regulatory compliance, making sure that their products, claims, and labelling comply with the standards in the market. Labels are important not only for compliance but also for marketing to customers. LCA assessments, in this case, are useful to justify the claims, which is important for USOs, like the case of USO 5, which are concerned with greenwashing—making false claims to customers regarding their product.

Favourable team dynamics

a. Good communication within teams

"We are quite strong, I would say, that we have already discussed before this start of the project about our values, our mission, visions. – USO 5

"Since this barrier of understanding sometimes and then also just a very clear communication barrier when it comes to, yeah, we have to, uh bi-weekly meetings." – USO 6

Communication within teams is essential to set the foundations of collaborations. Considering that all teams in this research consist of members from different fields of expertise, alignment, and constant communication are important to ensure alignment to set the basis of day to day execution of USOs.

USO 5’s strategy for establishing communication is through discussing their values, mission, and vision, while USO 6’s strategy is a bi-weekly check-in.

b. Strengths of a multidisciplinary team

“For many researchers, when they're passion is research, I think it would be good for them to find the people who are passionate about the best business side so that they can focus on the research and let the people who are a little bit better in that like do that and then also I would say like one of our strengths has been the fact that we have designers on board.” – USO 7

USO 7 offered an alternative point of view of team dynamics, where instead of a barrier, multidisciplinary teams bring together diverse sets of skills and perspectives, which are essential to team success. As research-based start-ups, it is natural for scientists/researchers themselves to be actively involved in the start-up, contributing their expertise and insights. However, barriers that USOs have to face in commercialization often require a wider set of skills to be able to translate invention to marketable innovative products. In USO 7’s case, they leveraged their team member’s range of perspectives by benefiting from having designers on board. Designers, as they elaborated, are used to considering the end-users of the product, giving the product the best chance to have a market once it is commercialized.

4.3.4 External Enablers

The identified external enablers of USOs are the benefits of having a benchmark technology, ecosystem support, and ease in market entrance. Table 12 lists the enablers, which are further explained below.

Table 12. External Barriers.

External Enabler
Benefit of having benchmark
Ecosystem support
Finnish ecosystem support
University ecosystem support
Ease of market entrance due to existing demand

Benefit of having benchmark

"We have a space what's right next to [USO 7] so their office is here the space is here so there's nice collaboration there I know the people who are doing the actual foam in our project they are they know how it's done they have been doing it for years now" – USO 6

Leveraging benchmarks from existing, more mature processes is an enabler to ease the commercialization journey for especially new technologies. This could be learning from similar USOs who are further along the development process, or from existing, more mature processes. As quoted above, from USO 6's experience, they benefit from the expertise, experience, and resources from USO 7. Adopting mature benchmarks helps avoid potential pitfalls, reducing uncertainty on the pathway to scale up and accelerating USO to the spin-off.

Ecosystem support

a. Finnish ecosystem support

"I mean advantages that the ecosystem. It was system here and Finland, yeah, with business Finland and innovation service, all those kind of I mean even Slush and all it's always like it's very easy to get funding for things. It's like they'll Business Finland literally dying to get startups to spinout. So it's it's crazy easy to get this to money and to actually get something going." – USO 6

The support from the Finnish ecosystem towards start-up creation is identified to be among the enablers for USOs to commercialize. R2B funding was initiated by Business Finland for the purpose of encouraging more inventions from labs to turn into innovations in the market. Research-to-business funding not only does this through monetary funding but also, in collaboration with academic institutions like the university, provides access to other enablers, such as mentorship and networking opportunities. Other than R2B, yearly hallmark events within the Finnish start-up ecosystem such as Slush also is a good platform to gain insights, network and market their products.

b. University ecosystem support

"An advantage of being here in Aalto like you can kind of like easily find those people. Uh, and have this support system, so that is very nice"– USO 7

"At the same time I started to talk with innovation services at Aalto and and some other people and then and then kind of this plans about the commercial possibilities or developed and then [business developer's name] stepped into the picture" – USO 2

"Innovation services place really central role in in all of this. That's where it all kind of started and that's that's when you apply for this R2B funding [...] they're kind of facilitating this whole thing. And they're and they're guiding, guiding us like through the whole process as well." – USO 2

The university ecosystem also plays a huge role in enabling USOs to spin out through the broad network of expertise, resources, connections, even curriculum, and the involvement of research innovation services (RIS) to provide incubation support through the commercialization process. The RIS team facilitates the USO's journey through several ways, as mentioned in the interviews: organizing R2B, mentorship, connecting USOs with experts within their network, hiring teams, and encouraging participation in events to market USO's products. The university ecosystem support itself plays an important role in equipping USOs and enhancing the likelihood of their commercialization.

"From my point of view they (Aalto University), have established quite good curriculum of this kind of course in order to be able to understand for instance, what is what are the issues related to commercialization" – USO 2

Aalto University had placed an "entrepreneurial mindset" as one of their three approaches for the university strategy, which, as mentioned by USO 2, supports the education on the commercialization process. Entrepreneurial education isn't only an enabler in preparing USOs with the know-how to bridge the gap to bring research to the market but also a platform to connect like-minded individuals to build things together. In some cases of USO, they recruited their current team from being involved in practical, hands-on, project-based courses. University's strategies on entrepreneurship are enablers in commercialization through providing education and opportunities to network within the academic community.

Ease of market entrance due to existing demand

"The way the green transition as such is also helping us as there's a quite huge global demand request for these solutions to help countries, companies to decarbonize their production." – USO 3

"We haven't yet reached a point where we have to reach out to new customers because there's so many people reaching out to us because that people are really looking for this kind of solution." – USO 7

The global transition towards decarbonization and sustainable solutions are great enablers for USOs developing sustainable bio-based innovations. The market pull from customers and businesses for such products signals product acceptance. The product could do so in two ways: as a completely new product that disrupts the market and as a better substitute for what is currently available in the market. More on the innovation types of USOs are discussed in Section 4.1. Without having to extensively market the product, the existing demand eases product acceptance even in the early stages of product introduction to the market, as mentioned by USO 7.

5 Discussion

This thesis aims to answer two research questions:

1. What are the stages of development of bio-based USOs?
2. What barriers and enablers could be identified for bio-based USOs?

This section will discuss how these two questions are answered and how the thesis has aligned and explored gaps in the existing literature on USOs.

5.1 Implication for theory

A reference from Rasmussen's (2011) study is used as the benchmark to answer the first research question on the stages of development of USOs. Based on the results, it can be concluded that to its grain, different USOs take different pathways to commercialization (Figure 6). However, in essence, each of the USOs that participated in this research went through four similar stages (Figure 2), which confirms Rasmussen's 4-stages theory: research, opportunity framing, proof of viability, and launching of the spin-off. In retrospect, based on the interviews, the milestone does fit the framework; in practice, there is much more variance in the timeline, as elaborated on in Section 4.2.

The research stage doesn't start and end at the beginning of the journey, but rather, in some cases, quite often extends through the rest of the milestone, as the product applications are developed to be able to capture new markets and as the process scales up, and so research needs to be done to configure process parameters. Extending this argument, the timeline is fitting to make sense of the USO's first entry into the market, which is discussed in most literature (Boh et al., 2016; Clarysse & Moray, 2004; Ndonzuau et al., 2002; Rasmussen, 2019; Shane, 2004; Vohora et al., 2004). As the USO development progresses, there are bound to be iterations, USOs could go back and forth along the timeline every time they develop a new product or expand to new markets. Impediment of one stage of development could impact the future trajectory of the development timeline, sometimes even causing oscillation of going back and forth along the timeline.

In answering the second research question on internal and external barriers and enablers, twenty-four unique points are identified. Most of the identified barriers and enablers are dominated by factors related to commercialization's business side, including themes surrounding teams, funding, collaboration, market, and business model. The technical aspect of commercialization was discussed, but less frequently than business-leaning factors (Calderón-Hernández et al., 2020; Hossinger et al., 2020; Hueske & Guenther, 2015), even in interviews with personnel with a technical background and/or holding a technical role in the USO.

The technical aspect of commercialization identified in this thesis has also been discussed in the literature on green innovative manufacturing, such as the case study in Malaysia (Abdullah et al., 2016). This thesis contributes to novelty by discussing barriers and enablers from taking a case of a specific type of innovation, academic start-ups in bio-based innovations. Available current literature studies mostly the broader context of academic innovation commercialisation. Compared to other technology commercialization, the exceptionally long development time of around ten years is distinctive to the nature of bio-based innovations, which is also shared with advanced materials innovation (Maine & Seegopaul, 2016).

5.2 Implication for practice

Innovation commercialization might have a straightforward definition but certainly not a straightforward pathway, as each USOs are bound to experience. For this, the list of identified barriers and enablers could be the first step to open discussions on ways to improve the commercialization process both for the USOs and the academic community and ecosystem that supports the USOs, specifically for bio-based USOs.

The findings in the thesis demonstrate that the characteristics of bio-based innovations, long development timeline, research and development challenges, and gap of funding for commercialization to scale-up manufacturing correlate to barrier factors identified in the study. The long development timelines and research and development challenges further lag the product from market entry and cause barriers to proof maturity of technology to access funding necessary to survive through the transitional period of commercialization. Findings also show how the two factors affected relate to one another. In order to access funding, USOs should demonstrate market viability through, for instance, having several promising potential buyers. This demonstrates that the barrier and enabler factors are often mostly correlational with multiple factors.

Further, the findings also are evidence of how some identified barrier and enabler factors, team dynamics and IP handling issues are intertwined with other factors. A good team is not just beneficial for the day-to-day operations but also helpful in building rapport to attract investments. With issues with IPR transfer to USOs, which were found to be correlational to barriers such as market validation difficulties, challenges to attracting funding, hiring a technology expert, and scaling up the process. This is because, without IPR transfer, USOs have a hard time legally establishing themselves as a business separate from the university, which hinders them the clearance to be able to market their technology, develop further the technology, and sell their products to customers. Access to funding and negotiating with potential customers is limited due to its status as a university project. Better IPR handling is recommended to debottleneck this issue.

On the upside, this study has identified that the majority of barriers identified have a counter-enabler. I.e., a perceived barrier to one USO had already been 'resolved' by another USO that is further in their development - which is identified in the data as an enabler. An example of this is the case of funding and market entry barriers, which are major barriers shared by all USOs. On the enabler side of the data, some USOs already have a strategy to anticipate this by diversifying funding and expanding market categories by involving end-users of the products in the development. In both cases, diversifying, both funding and product application, is a good mitigation strategy. When USOs diversify, they do not depend on one pathway to success but look for other possible opportunities, both in terms of funding and when finding a space in the market.

The extent of experience USO could make a factor perceived negatively (as a barrier) or positively (as an enabler). This is true for themes such as multi-disciplinary teams, which both could be a detriment and the core success factor of a USO, suggesting that one factor could go either way, according to the point of view and, more importantly, experience in debottlenecking issues relating to the barriers. Ultimately, shared learning, connecting the more experienced to the less-experienced USOs, is important in order to guide USOs earlier in the process to spin out.

5.3 Conclusion

Beyond its role in widespread education and research, academia plays an important part in driving impact and creating positive changes in society. One vehicle of impact are bio-based USOs. With the global need for more sustainable, better alternatives for the current fossil products on the rise, the focus on exploring bio-innovations as alternatives is imminent. This gargantuan quest for finding alternatives puts the university as one of the important part of the solution. Having arms in technology, business and design education puts Aalto University at an advantageous intersection where various experts are involved in pushing through for more sustainable innovations in the market. The collaboration of experts at the university led to the creation of seven USOs specializing in bio-based innovations.

All USOs interviewed have gone through their unique journey in their pathway to commercialization, but all in all, they have gone through four similar big milestones: research, opportunity framing, finalizing venture, and launch of spin-off. Through their journey, they have faced barriers from within their company that are hallmarks of bio-based innovations, which are the long timelines and iterations, lack of commercialization insight and struggles in working with an interdisciplinary team. Like many other innovations, the main barriers external to their company or teams include the funding gap—having to thrive through the 'valley of death', reluctance to collaborate with the current incumbent players in the market and struggles with market entry. Barriers in bio-based USOs are amplified with the long development timeline, which leads to uncertainty of success and hinders the chances of spinning out. This study identified that most barriers are counter-enabling factors, which shows just how much agency the USOs have been able to tackle hindrances to thrive. These enablers include the internal drive of founders, suitable business models, diversifying of funding, market creation through product application, and favorable team dynamics. Not to mention that factors that help these USOs thrive also come from the ecosystem; having support from the public sector and university is crucial, and so is having a more technologically mature benchmark.

With the drive for innovation coming from a technology push, it is important that USOs look beyond focusing on the development of technology and also take into consideration the market demand and adjust towards the market needs so that they can survive. There have been several ways in which USOs strategize to survive through the valley of death: adopting a suitable business model, diversifying funding, and expanding the current target market by taking into consideration end-users. Aside from that, the thesis also suggests the importance of teams and the successful handling of IPR as the precursor to other barriers identified, such as difficulties with market entry, access to investments, and technology development. Therefore, better guidance on navigating these issues is recommended to be done and included in incubation programs in universities.

Universities have the most influence early on and can still support and accelerate the development and increase the potential of achieving full commercialization (TRL 9). Acknowledging the technical complexity of bio-based innovations, a suggestion to universities is pre-incubating while supporting the development of technology-driven sustainability assessments. These pre-incubators should help USO researchers and teams in building technical, business, market, and environmental knowledge capacity to better prepare a value proposition for fundraising.

5.4 Limitations and recommendations for further studies

This study is mostly focused on identifying barriers and enablers, as well as observing USO's journey/pathway to commercialize bio-based innovations. The case study of Aalto University studied in this thesis might not be able to be extrapolated to similar USO cases in other universities. Results are made from the lens of the university and the academic research context in Finland, which is too small of scope to suit other universities' contexts. Further investigation to broaden the scope could be done by looking into more cases in leading universities in the bio-based produces innovations domain.

Although identifying barriers and enablers is the key step to identifying bottlenecks to spinning off, further studies is recommended to pinpoint how barriers and enablers present themselves through TRLs to better equip future USOs in their journey. Aside from that, this thesis has explored the interviewing roles of scientific experts/technology developers and business developers without much exploration of the different perspectives. It would be interesting for future studies to dive into the two sides of the perspective, especially considering that multidisciplinary teams are found to be a major theme in bio-based USOs.

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