LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY LUT
School of Engineering Science
M.Sc. Biorefineries

Antti Tiilikainen

ADDED VALUE OPPORTUNITIES FOR BIOREFINERIES: A STUDY ON BUSINESS MODELS FOR GREEN CHEMICALS

Examiners: Professor Satu-Pia Reinikainen
D.Sc. (Tech.) Eeva Jernström

TIIVISTELMÄ

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Biojalostamoiden lisäarvomahdollisuudet: Tutkimus vihreiden kemikaalien liiketoimintamalleista

Diplomityö

2020

73 sivua, 20 kuvaa, 3 taulukkoa ja 1 liite

Tarkastajat: Professori Satu-Pia Reinikainen
TkT Eeva Jernström

Hakusanat: business mallit, biotuotteet, koivun kuori, vihreä kemia

Metsäteollisuus tuottaa vuosittain suuria määriä puunkuorta sivuvirtanaan. Nykyään kuori poltetaan pääasiassa energiaksi, vaikka puunkuori on kemialliselta rakenteeltaan rikas ja monipuolinen. Kemiallisesta koostumuksestaan johtuen kuori on potentiaalinen uusiutuvien kemikaalien lähde. Vaikka akateemista tutkimusta on tehty koivun kuoren mahdollisuuksista kemiantuotteiden raaka-aineena, löytyy teollisenmittakaavan sovelluksia kuitenkin vain vähän.

Tämän opinnäytetyön tarkoituksena on tutkia koivunkuorenpohjaisten uusiutuvien kemikaalien markkinamahdollisuuksia ja antaa yleiskuva liiketoiminnan näkökulmasta. Tämä työ antaa yleiskuvan kemikaalimarkkinoista, vihreän kemian ajureista ja esteistä, kemian teollisuuden liiketoimintamalleista, ja biopohjaisten kemikaalien menestystekijöistä. Esimerkkisovelluskohteena koivunkuorenpohjaisten kemikaalien liiketoimintapotentiaalin analysoimiseksi työssä käytetään tekstiilien vedenhylkykemikaaleja.

Tekstiili- ja vaateteollisuus on yksi saastuttavimmista teollisuudenaloista. Työssä arvioitiin esimerkkitapauksena liiketoimintamahdollisuuksia, jos koivunkuoresta saatavia kemikaaleja käytettäisiin ympäristöystävällisempänä vaihtoehtona nykyisille menetelmille tekstiilien vedenhylkyominaisuuksien saavuttamiseksi. Kirjallisuustyön lisäksi kehitettiin Excel-pohjainen Monte Carlo simulaatio työkalu ehdotetun loppukäytön taloudellisen toteutettavuuden ja markkinoiden alustavaan analysointiin.

Lisätutkimusta tarvitaan kuoripohjaisten kemikaalien teknisestä toteutettavuudesta vedenhylkykemikaaleina teollisessa mittakaavassa. Lisäksi perusteellisempaa tutkimusta tarvitaan kuoripohjaisten kemikaalien markkinakysynnästä ja niiden hinnoista teollisessa mittakaavassa.

ABSTRACT

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Added Value Opportunities for Biorefineries: A Study on Business Models for Green Chemicals

Master’s Thesis

2020

73 pages, 20 figures, 3 tables and 1 appendix

Examiners: Professor Satu-Pia Reinikainen
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Keywords: business models, bioproducts, birch bark, green chemistry

The forest industry produces large quantities of bark each year as a by-product. Today, bark is mainly burned for energy, although the bark is rich in chemical structure and a versatile material. Due to its chemical composition, bark is a potential source of renewable chemicals. Although academic research has been conducted about the potential of birch bark as a raw material for chemicals, there only few industrial applications exists.

The objective of this thesis is to study the market opportunities of birch bark based renewable chemicals and to give an overview from business perspective. This work provides an overview to the chemicals markets, drivers and barriers of green chemistry, business models in the chemical industry, and key success factors of bio-based chemicals. As a potential end use case, when analyzing business potential of birch bark based chemicals, is used water repellent chemicals in textiles.

The textile and clothing industry is one of the most polluting industries. As a case example in the study was assessed economic feasibility, if chemicals from birch bark would be used as a more environmentally friendly alternative to current methods to achieve water-repellent properties on textiles. In addition to the literature work, an Excel-based Monte Carlo simulation tool was developed for studying preliminary markets and economic feasibility of proposed end use.

Further studies are required and proposed on technical feasibility of bark based chemicals as water repellents in industrial scale. Also, more thorough studies are needed on market demand aspects of the birch bark based chemicals and of their prices in industrial scale.

"A man who dares to waste one hour of time has not discovered the value of life"
Charles Darwin (1809 - 1882)

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1 INTRODUCTION

Large amounts of bark is produced each year in the forest industry as a side stream. Currently the bark is mainly burned as energy in the production processes, anyhow at the same time bark is very versatile chemically compared to other parts of the tree. This means that bark is readily available potential source for renewable chemicals. Although lot of technical studies have been done about extraction of biochemicals from bark, there is no bark-based chemicals widely produced in industrial scale. The objective of this thesis is to study the market opportunities of birch bark based renewable chemicals and to give an overview from business perspective. In this work is provided an overview to the chemicals markets, drivers and barriers of green chemistry, business models in the chemical industry, and key success factors of bio-based chemicals. Additionally, one goal of this work is to study a potential use case, and evaluate its business feasibility, for birch bark based renewable chemicals. The research of thesis is based on qualitative literature research. An overview to writing process and frame of the study results is presented in figure 1.

This work has the following main segments of content. First in this work is given overview to chemical markets and market potential of renewable chemicals. On second main theme, the drivers and barriers of green chemistry and circular economy are studied to understand obstacles why bark-based chemicals are not yet in the markets. On third segment, business models in chemical industry and key success factors of biobased chemicals are studied. This segment is to understand business logic of biorefineries, and the key economic factors related. After these more academic literature focused parts, on fourth segment a business case framework is constructed for a possible end use case of bark-based chemicals.

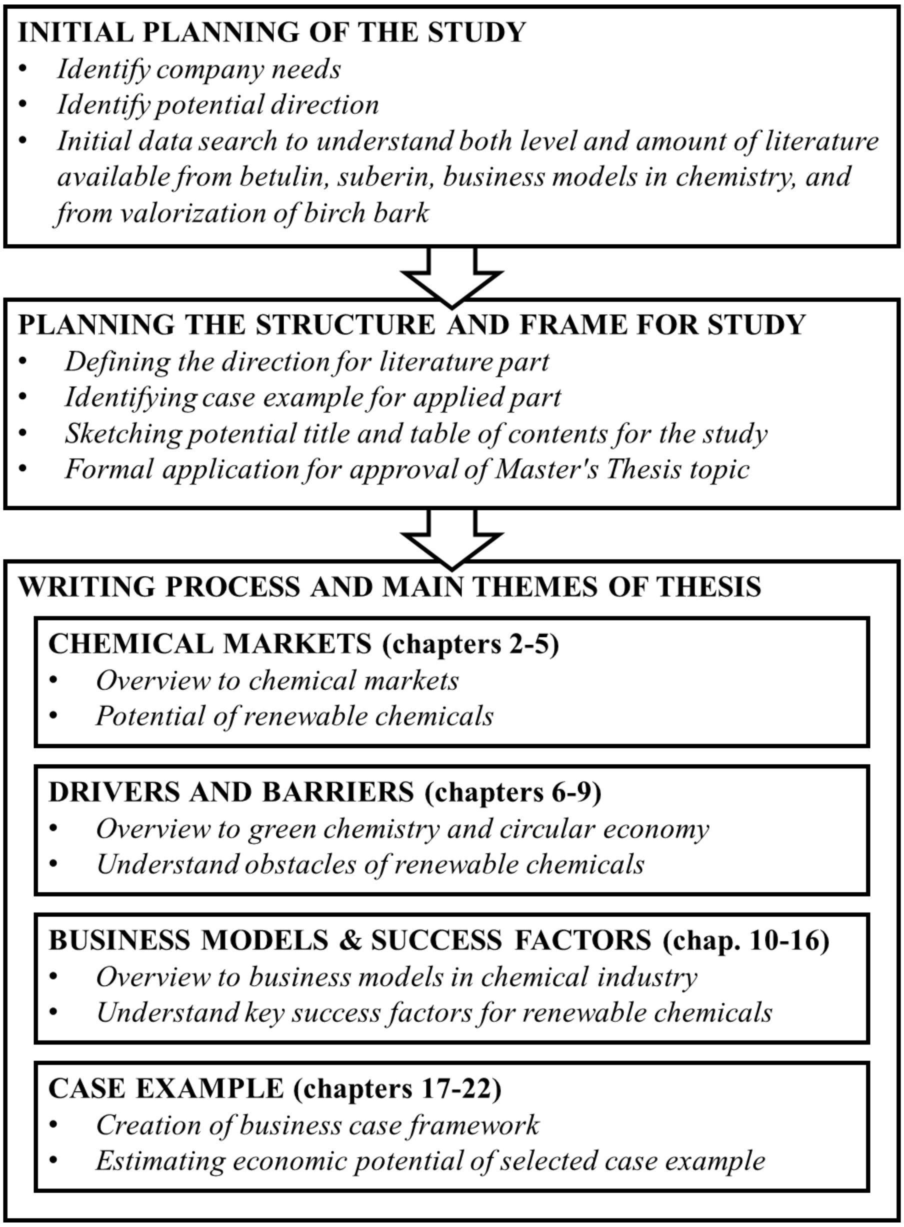


Figure 1. Writing process and the main themes of the thesis

2 CHEMICAL MARKETS AND MEGATRENDS

The global chemical sales are around ~3 350 billion EUR a year. The world chemical sales is presented more in detail on figure 2. China is the dominant country in chemical industry and covering almost 1 200 billion EUR, over a third, from the global sales. North America and European Union are also significant players in chemical markets, both covering over 500 billion EUR (over 15 %) from global sales. (Cefic, 2020)

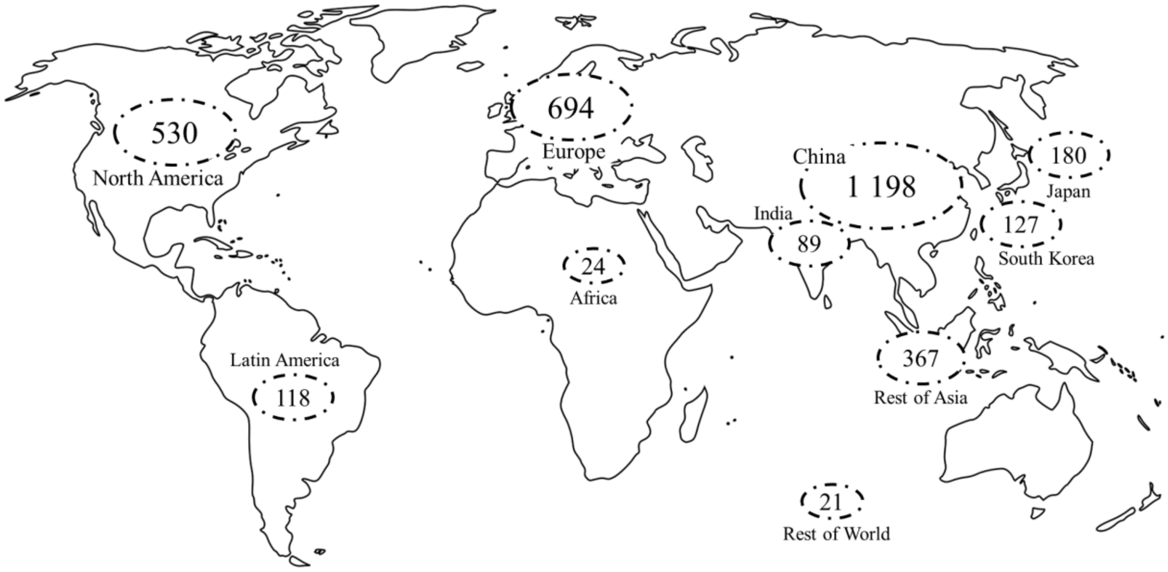


Figure 2. World chemical sales in year 2018 in billion EUR (Cefic, 2020)

The global megatrends impact the chemical sales. Especially how we try to mitigate and stop global warming, will have an impact to chemical industry (Spekreijse et al. 2019). The current economic models, that are based on linear "take-make-waste" value chain, are challenged. It is acknowledged that many environmental problems exist and that we have limited resources on Earth. There is need to replace current economic models with models where focus is on closing material loops and keeping them in use for long as possible. Furthermore, increased value through services and smarter solutions are needed to overcome Earth's resources overload issues. (Antikainen & Valokari, 2016) Therefore, one interesting megatrend impacting global chemical markets is digital transformation. There is potential to significantly improve efficiency in manufacturing processes and logistics with digitalization. New digital business models create opportunities, to those who are capable to apply those.

New data-driven value-add services create business potential for the chemical industry to widen its service offering beyond traditional chemical sales. (Bock, 2017)

When looking to near future, it is expected that chemical production will continue to grow faster than global GDP until 2025. Beside climate change challenges and resource scarcity, one of the main drivers for the growth of chemical industry is population growth and urbanization. (Bock, 2017) According to estimates of United Nations (2019) there are currently ~7,8 billion people in the Earth, and it is expected that population growth continues until around 2100. It is expected that in 50 years time, by 2070, there is around ~10,5 billion people. This would mean population growth of ~2,7 billion people, or ~35 %, just in five decades. Another item is urbanization. Currently based on estimates of United Nations (2019) about ~58% of population lives in urban areas, and it is expected that by 2050 about ~68% of population lives in cities. Based on the United Nations (2019) estimates, it can be assessed that possibly >2,6 billion people more will be living in cities by 2070.

The population growth and urbanization will set high demand for energy and food on coming decades, and will increase Earths resources usage. As chemicals are needed in wide range of products and technologies, population growth and urbanization will drive future chemical markets. As summary, chemistry is needed to mitigate and enable solutions to energy scarcity, climate change, food waste minimization and providing clean water. (Bock, 2017)

3 BIOREFINERIES

Biorefineries are industrial systems that aim at sustainable and efficient utilization of biomass by valorizing biomass resources and delivering multiple useful bioproducts and energy. (Budzianowski, 2016) The International Energy Agency defines biorefining as "*sustainable processing of biomass into a spectrum of bio-based products (food, feed, chemicals, materials) and bioenergy (biofuels, power, heat)*" (Sillanpää & Ncibi, 2017; Budzianowski, 2016).

In high conceptual level biorefineries are similar to petrochemical refineries, both produce wide range of fuels, products and chemicals. As the oil and gas reserves are depleting, the biorefineries are becoming more important. They are needed to help to mitigate food crisis, global warming and environmental threats. The technological configurations of biorefineries vary depending on feedstock available and type of end products produced. The availability, type and quantity of feedstock is important for cost-effectiveness of biorefineries. Furthermore, development of biorefining technologies that are efficient, robust and cost optimized is key aspect for success of biorefineries. Full process optimization is often key to make biorefineries more profitable. (Sillanpää & Ncibi, 2017) On figure 3 is presented examples from different bioproducts and bioenergies that can be produced in biorefineries. The products are arranged in value vs. volume axis. It is suggested in literature that valorization of biomass resources into range of products with maximum total value and good business models would improve economic feasibility of biorefineries, instead of them just focusing on one or two products. (Budzianowski, 2016)

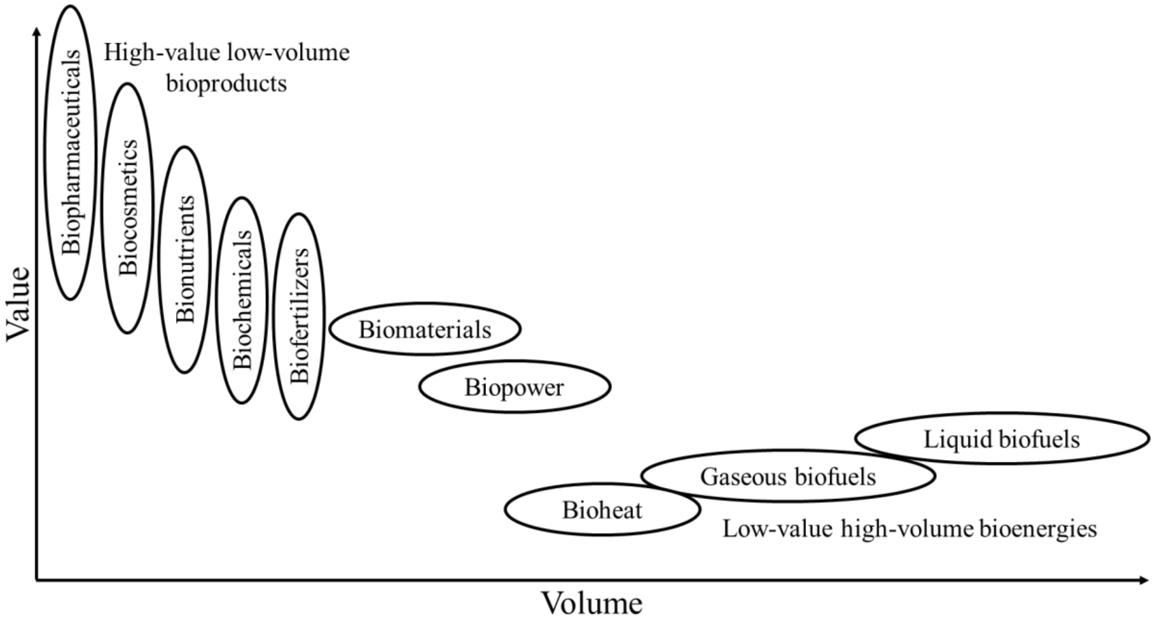


Figure 3. Schematic representation of values and volumes for various bioenergies and bioproducts from biorefineries (Budzianowski, 2016)

4 BIOMASS VS. FOSSIL FEEDSTOCK BASED PRODUCTION

Biomass feedstock contains more polymerized aromatics compared to fossil oil, which is mostly alkanes. The complex structures available on biomass, that are not easily synthesized from fossil based feedstock, may provide real benefits and price competitiveness to biorefineries, over fossil derived materials. In the biorefinery pathways should be considered, could these naturally occurring biomolecules be valorized, instead of breaking them just into energy. It is reasonable to consider cascading approach, where first high-value compounds are separated and synthetized to products, before using rest of biomass for energy production. Anyhow, this kind of approach requires advanced technological solutions and business models, to be economically competitive with fossil-based products. (Budzianowski, 2016)

Currently biorefineries need to compete against fossil-based production, which is economical challenge especially for production of biofuels, biopower and bioheat. Often conventional petroleum refineries only fractionate oil into marketable transportation fuels, and the other petroleum products are then produced on separate facilities. Aiming for full valorization of biomass feedstock on biorefineries, will make them more complex compared to petroleum refineries. As outcome biorefineries need to integrate themselves more strongly with existing fuel, chemical and energy value chains. The performance of biorefineries depend on whole value chain integration, including economic, environmental and social dimensions. When setting up biorefineries, the various variables of feedstock need to be carefully analyzed (i.e. harvesting sites, availability/price, chemical composition), the possible conversion and processing routes need to be assessed, and the targeted bioproducts and their market conditions analyzed. Typically, biomass has low energy density and high water content, which means that feedstock of biorefineries need to be available locally in sufficient quantities. It is more economical to transport the end products than biomass long distances. Consequently, biorefineries are often more unique and localized compared to fossil-based refineries. (Budzianowski, 2016)

Compared to inorganic fossil-based feedstock, the organic biomass consists of unique complex chemical structures, which cannot be easily artificially synthesized. As nature provides ready-made complex molecules, it should be considered to convert them to chemical products while keeping aspects from their original structure, instead of taking structures completely apart and putting chemicals together from scratch, or by wasting complex molecules found in biomass just for metabolites and energy production. (Budzianowski, 2016; Dusselier et al. 2014)

These complex structures have potential to be employed in different end use applications. Therefore, it is argued in academic literature that biomass disintegration, combustion or fermentation are not utilizing biomass feedstock in the full extent. Therefore, it is recommended that high-value bioproducts should be produced first, and coupled with full valorization of the rest feedstock potential. Biochemicals are high-value bioproducts, that are possible to be produced in biorefineries. Biochemicals derived from biomass are often unique, and have specific applications where they are used the industry. Anyhow, currently the separation and conversion technologies are still developing, and the lack of techno-economical capabilities restrict in some cases biochemicals production in biorefineries. Another challenge is, that the application specific chemicals may require modifications or new technologies to customers processes also. Therefore, market adoption of new biochemicals can be slow and require also capital investments. (Budzianowski, 2016)

Integrating carbohydrate chemistry successfully to biorefinery concept will depend highly on the availability and price of biomass feedstock, and on its fractionation costs. As biomass is limited by collection volumes and it has low density, biorefineries have stronger limitation on production volumes compared to fossil feedstock refineries, and therefore usually more localized closer to feedstock and smaller in size than traditional oil refineries. Therefore, it can be argued bit contrary to full chemical structures valorization, that biorefineries should focus on specific chemicals to produce meaningful volumes of products, instead of too wide portfolio of products. (Dusselier et al. 2014)

The benefit of lignocellulosic biomass as raw material for biorefineries is that its relatively inexpensive and its possible to cultivate on marginal lands, which are not competing with food production. The bioproducts made from biomass are often made as biodegradable, non-toxic and durable, which potentially enhances business potential of biorefineries. Anyhow, not all chemical products are suitable for biorefinery production. The aspects like feasibility of industrial scale production, and coupling of bioproducts and bioenergy production, need to be considered. (Budzianowski, 2016)

When considering lignocellulosic biorefineries, there are two technological aspects required to be in place. Firstly, fractionation of biomass into its components needs to be sustainable and cost-efficient. Currently separation and fractioning processes often focus on only separating only one or few fractions, instead of all available fractions. Secondly, process technology needs to be robust and have high efficiency in industrial practices scale also, not only in theory & laboratory level. The high efficiency and robustness of technology is required to be able to compete with petrochemistry pathways. (Dusselier et al. 2014)

As a summary, when planning biochemicals production, the application dimension of the chemical, production and market volumes possible, fractioning/separation technology aspects, and availability of biomass feedstock (incl. collection, storage & logistics) need to be considered. (Dusselier et al. 2014) Complementary, according to Budzianowski (2016) when planning a biorefinery, the following criteria should be considered on bioproduct selection:

1. *"the cost of required feedstock*
2. *material processing cost*
3. *current and expected future bioproduct market price*
4. *market capacity*
5. *and technical characteristics fitting market needs".*

5 MARKET POTENTIAL OF BIOMASS BASED CHEMICALS

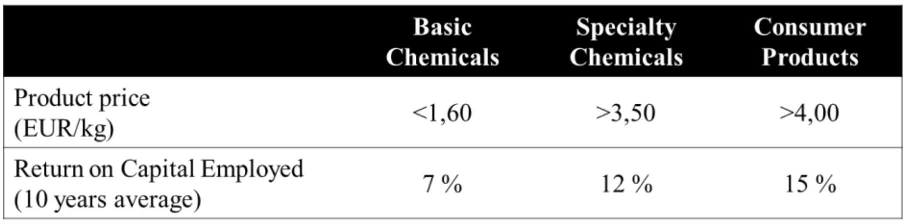
Biobased products can be defined as products that are wholly, or partly, derived from materials of biological origin. Basically, biobased products refer to non-food products derived from biomass (i.e. plants, algae, crops, trees, animals, biological waste). Biobased products can be ranging from high value fine chemicals to chemical biopolymers. Anyhow, traditional pulp, paper, wood products and energy use of biomass are typically excluded when using term bioproducts. (Spekreijse et al. 2019) When discussing biobased chemical products, it is important to distinct two archetypes according to Spekreijse et al. (2019) that are:

1. *“drop-in biobased products, i.e. chemically identical versions of existing products that have established markets (e.g. ethylene, polyethylene (PE), polypropylene, polyethylene terephtalate (PET))*
2. *dedicated biobased products, i.e. can be produced only via a biobased pathway and do not have an identical fossil-based counterpart (e.g. lactic acid, levulinic acid, succinic acid, polyhydroxyalkanoate (PHA), polylactic acid (PLA))”.*

For biobased chemicals production in EU has been estimated compound annual growth rate (CAGR) of ~3-4% on overall level for coming near future. There are some areas where growth rate is estimated to be higher, e.g. biobased platform chemicals and adhesives with CAGR ~10%. The platform chemicals are starting materials for manufacturing of broad range of products. Ethylene is one example from platform chemicals, it can be used to produce e.g. different polymers and compounds like styrene and synthetic fatty acids. Respectively, growth in products like biobased solvents is expected to be much smaller, CAGR ~1%. Overall, currently the market share of biobased products in chemical industry in EU is rather small, only around ~3%. (Spekreijse et al. 2019) The near future market share of bioproducts is dependent highly from technological development and regulation/policies supporting the shift from fossil feedstock to bioeconomy (Budzianowski, 2016).

The average prices of bulk chemicals, like platform chemicals and solvents, is currently typically around ~1-2 EUR/kg. The prices of specialized products, like cosmetics, personal care chemicals and plasticizers, are typically somewhat higher, but often chemical prices are anyhow below 10 EUR/kg. (Spekreijse et al. 2019) On table 1 is presented the typical prices of chemicals on different segments and the average profitability of the different segments.

Table 1. Typical prices of chemicals on different segments and the average profitability of segments (American Chemistry Council, 2019)



	Basic Chemicals	Specialty Chemicals	Consumer Products
Product price (EUR/kg)	<1,60	>3,50	>4,00
Return on Capital Employed (10 years average)	7 %	12 %	15 %

In near future it can be expected, that drop-in biochemicals will proceed faster to markets, while for novel biochemicals it will take longer. Novel biochemicals will require further technological and market efforts to be taken into full commercial use. In order to be competitive with petrochemicals, in the biobased production should be exploited the advantageous chemical properties of biomass feedstock. (Dusselier et al. 2014) Generally, it can be commented that many bioproducts are on the early phase of development and markets maturity. For the bioproducts that have technical function or complex supply chain, the market entrance can be time taking long process. For the drop-in chemicals that do not have technical functions, the market entrance is easier, but in these cases price and environmental impact can be limiting factors. Anyhow it is typical, that drop-in chemicals have relatively low selling prices, and therefore price competitiveness of these biorefinery bioproducts is a challenge. The opportunities for high value bioproducts should also be looked from areas of completely new products, that do not have competition with existing fossil-based products. Creating and opening new markets is a challenge, but it may provide path for sustainable economic development and allow expansion to new areas with less competition. (Budzianowski, 2016)

When assessing potential benefits of bioproducts compared to traditional fossil products, there can exist e.g. following beneficial properties like improved biodegradability, lower toxicity, lower greenhouse gases production, and improved safety. Similarly, as challenges of biobased products can be seen e.g. lower / inconsistent quality, technology requirement of purification and fractionation processes, and higher costs compared to fossil-based alternatives. Furthermore, biobased products have higher land use due to their feedstock. This can be seen as negative aspect from environmental impact perspective, but this aspect also creates local jobs. The willingness of consumers to pay premium from green chemistry products depends on the market sector. The awareness of general citizens about biobased products differs between product categories. Public awareness about biobased products is higher e.g. on bioplastics and lubricants, whereas less so e.g. on surfactants and adhesives. It has been considered that regulatory sustainability measures could be used to restrict the use of fossil-based products, and to create demand for bioproducts. For example, in EU there are some regulations already existing to support competitiveness of biobased products like e.g. lubricants, surfactants and plastics. (Spekreijse et al. 2019)

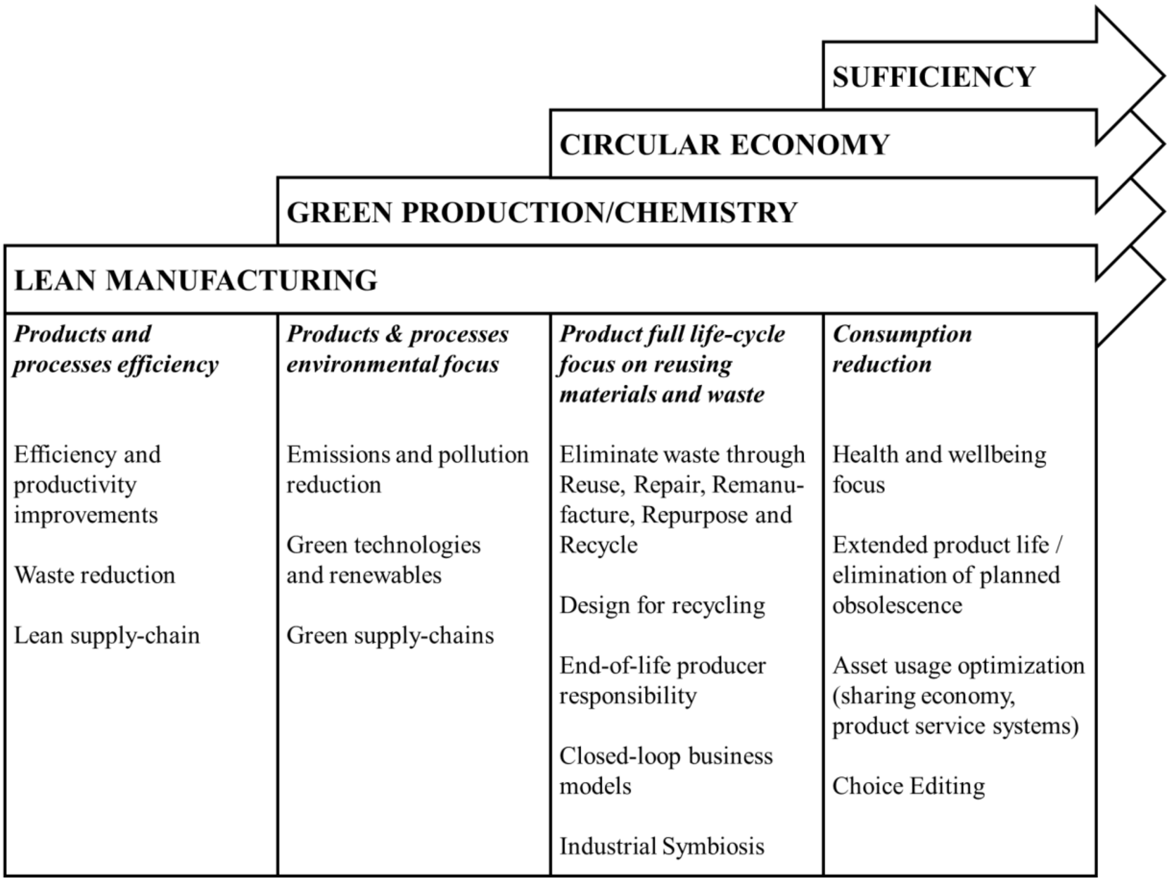
6 INDUSTRIAL SUSTAINABILITY

In order to achieve sustainability in the biorefinery concept, the production need to utilize the raw material feedstock in cascading way. First, the most easily accessible high value bioproducts should be extracted, then the other valuable biofuels or bioproducts should be produced, and finally only the remainder residues should be used as bioenergy or as fertilization on biomass cultivation. The materials loops should be closed in biorefineries to achieve high value products and high sustainability standards. (Budzianowski, 2016) From economic systems perspective, according to Bocken et al. (2013), the route to a sustainable economy would be:

- *"A system that encourages minimizing of consumption, or imposes personal and institutional caps or quotas on energy, goods, water, etc.*
- *A system designed to maximize societal and environmental benefit, rather than prioritizing economic growth*
- *A closed-loop system where nothing is allowed to be wasted or discarded into the environment, which reuses, repairs, and remakes in preference to recycling*
- *A system that emphasizes delivery of functionality and experience, rather than product ownership*
- *A system designed to provide fulfilling, rewarding work experiences for all that enhances human creativity/skills*
- *A system built on collaboration and sharing, rather than aggressive competition".*

According to Bocken & Short (2019) the industrial sustainability theories have evolved from lean manufacturing, efficiency and productivity, to current circular economy initiatives and managing with less actions. In their work Bocken & Short (2019) identify distinctive progressive steps in industrial sustainability, which are lean manufacturing, green production, circular economy, and sufficiency. These steps identified by Bocken & Short (2019) are presented in figure 4. With lean manufacturing is meant producing products with efficiency focused manner. In the green production furthermore the environmental impacts of emissions and production technologies are taken into account. Beyond the green manufacturing, in circular economy is also considered the products full lifecycle and closing the material loops. When going beyond circular economy, further actions are needed in order to manage challenges of climate change, biodiversity losses, population and urbanization.

Therefore, the next step in sustainability beyond circular economy, needs to be consumption reduction and assets sharing, in other words sufficiency and managing with less. (Bocken & Short, 2019)



Products and processes efficiency	***Products & processes environmental focus***	***Product full life-cycle focus on reusing materials and waste***	***Consumption reduction***
Efficiency and productivity improvements Waste reduction Lean supply-chain	Emissions and pollution reduction Green technologies and renewables Green supply-chains	Eliminate waste through Reuse, Repair, Remanufacture, Repurpose and Recycle Design for recycling End-of-life producer responsibility Closed-loop business models Industrial Symbiosis	Health and wellbeing focus Extended product life / elimination of planned obsolescence Asset usage optimization (sharing economy, product service systems) Choice Editing

Figure 4. Progression of industrial sustainability (Bocken & Short, 2019)

In green production (in some literature called also green engineering, technology, or chemistry) the main idea is to eliminate the use and generation of hazardous materials, reduce waste and produce in sustainable manner (Veleva et al. 2019). For example, in textile industry the term green production can be looked at in two ways according to Pal (2017):

1. *“manufacturing of green products: using renewable resources and energy systems or resources having reduced environmental impacts*
2. *greening of manufacturing: reducing pollution and waste by minimizing natural resource use, recycling and reusing what was considered waste, and reducing emissions”.*

According to Veleva et al. (2019) green chemistry is defined as "*the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances*". For example, in textile industry green production might mean replacing dyes with organic and benign dyes (Pal, 2017).

The difference of improving efficiency / productivity and circular economy is that circular economy extends the focus beyond single firm or supply chain, it encompasses resource use, manufacturing, consumption and disposal from a holistic perspective (Bocken & Short, 2019). According to Werning & Spinler (2019) a circular economy describes an economic system that "*is based on business models which replace the end-of-life concept with reducing, alternatively reusing, recycling and recovering materials in production / distribution and consumption processes*". And according to Tura et al. (2018) the circular economy should be "*understood as a system in which value is created by minimizing waste and the use of energy and natural resources*". Respectively according to Bocken & Short (2019) the "*circular economy seeks to enhance resource efficiency and reduce waste through closed loop industrial systems that make use of recycling and reuse to keep resources in play for as long as possible*". Circular business then again refers to solutions (products and services) and business models, which aim to enhance circular economy, respond to resource scarcity, minimize environmental impact, and provide economic benefits (Tura et al. 2018). It has been argued on academic literature that sometimes with circular economy can be achieved "win-win-win" situation from perspectives of business, economy, and environment. According to Werning & Spinler (2019) this "win-win-win" situation is result from four principles of value creation and capture, which are:

1. *"circulate in the inner loops*
2. *circulate longer*
3. *cascade used assets along industries*
4. *use pure, nontoxic, easier to separate inputs".*

In their framework of circular economy Werning & Spinler (2019) furthermore identify micro, meso and macro levels. When discussing about circular economy on micro level products, companies and consumers are the operators, on macro level cities, nations and regions are having the aim of sustainable development. In the between is meso level, which can be e.g. industrial parks. (Werning & Spinler, 2019) According to Tura et al. (2018)

especially the possibilities provided by information technology play a central role in the economies transformations towards circular economy. According to Manninen et al. (2017) the characteristics of circular economy are

1. *"less input and use of natural resources*
2. *increased share of renewable and recyclable resources and energy*
3. *reduced emissions*
4. *fewer material losses/residuals*
5. *keeping the value of products, components and materials in the economy".*

The closed loop and recycling-based business models are being more and more extended with design for longevity, repair and reuse, product service systems, and with shared economy initiatives. These developments are looking benefits from perspective of full utilization of resources and assets. Anyhow, regardless the good development by circular economy, it can be argued that circular economy does not yet lead to complete solution to problems caused by mass consumption. Additionally, there are some areas where closed loop business models cannot be applied due to economic costs, degradation of material, or energy demands of collection and recycling. One example being full recycling of concrete. Furthermore, the population and wealth growth demand even more virgin materials regardless of closed loops and circular economy, the material demands anyhow surpasses the availability of recyclable materials. Therefore, sufficiency is also needed in the future. (Bocken & Short, 2019)

7 DRIVERS AND BARRIERS ON GREEN CHEMISTRY

There are multiple internal and external factors pushing to reduce environmental impacts of manufacturing. Examples from these are e.g. stakeholder pressure, cost saving targets, reputation considerations, market positioning, and ability to retain / attract talent. (Veleva et al. 2019) On figure 5 is presented common drivers, barriers, and opportunities of advancing green chemistry adoption globally.

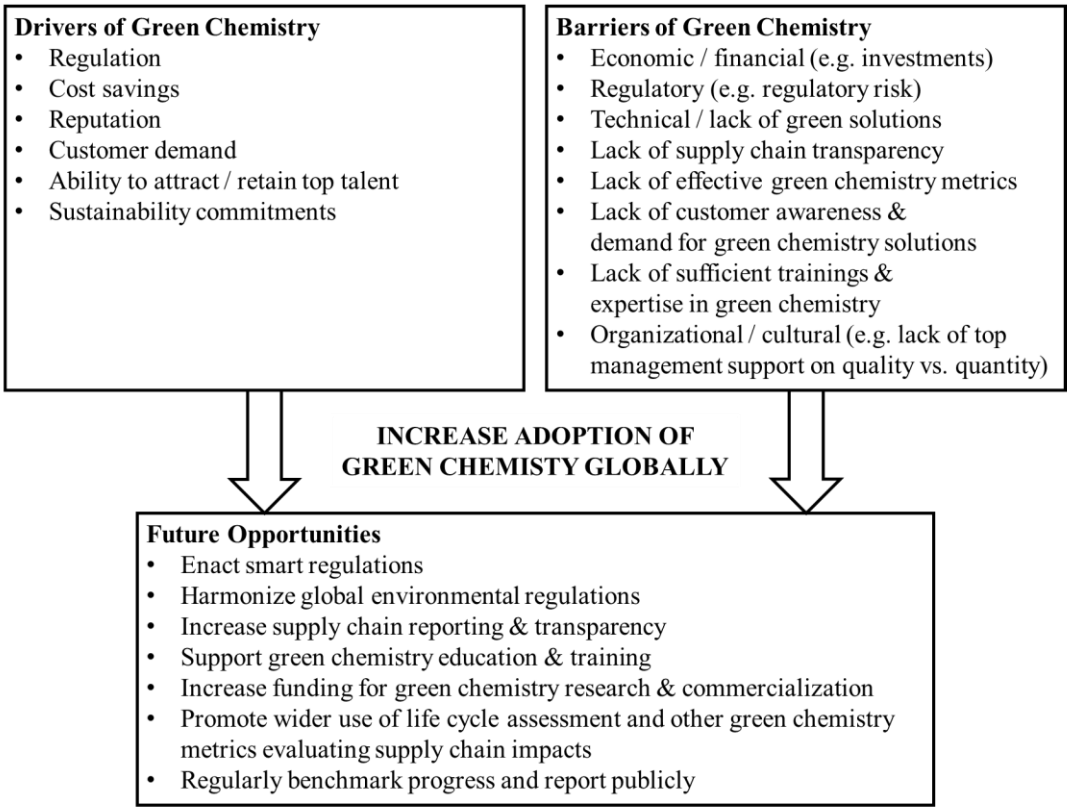


Figure 5. Key drivers, barriers, and opportunities for advancing green chemistry adoption globally (Veleva et al. 2019)

The most prevailing barrier for bioproducts is the cost of producing them compared to fossil alternatives. Anyhow, it is good to note that in some product categories consumers have willingness to pay premium from biobased products, like in cosmetics and personal care. It is argued in some academic literature that fossil-based products are priced too cheaply, as they do not internalize cost of their environmental impact to same extent as bioproducts do. Some experts claim that fossil carbon tax could be seen as method to create level playing field to all products, or even to promote the more sustainable products. (Spekreijse et al. 2019) It can be stated that the rate how new biochemicals enter market depend on high extend about technology development and implementation of regulation and policies (Budzianowski, 2016). Beside the fact that bioproducts can substitute, or at least reduce dependency from fossil-based production, and make the economy more sustainable, furthermore they also have potential to bring new functionalities to the markets (Spekreijse et al. 2019).

The typical barriers to the development and implementation of green chemistry according to Matus et al. (2012a) found in the literature are:

1. *“economic, financial and market barriers*
2. *barriers from path-dependency*
3. *regulatory barriers*
4. *technical barriers*
5. *organizational barriers*
6. *cultural barriers*
7. *barriers from disagreements regarding definitions and metrics”.*

7.1 Economic and financial barriers

The new products in chemical industry need to have both economic and environmental performance. Typically, it is not enough that green chemistry requirements are fulfilled, but simultaneously the products should be profitable to producer and not sacrifice efficiency and quality requirements of the end user. Furthermore, the economic and financial barriers mean, that possible upfront costs need to be covered with potential operational cost savings. (Matus et al. 2012a) When looking green chemistry on macro level, according to Matus et al. (2012b) the most crucial barrier to green chemistry e.g. in China is the competing priorities of economic growth and environmental protection. The economic and financial barriers arise from the capital constraints of firms. There are also costs beyond traditional product development, that hinder expected payoffs of product innovations. The market barriers should also be considered when discussing economic and financial barriers. These barriers of green chemistry arise if market has many competitors, then it is more difficult for the innovators to win back their investments. (Matus et al. 2012b)

7.2 Barriers from path-dependency

The chemical industry is highly capital intensive, which means that companies are tied up to previous investments and cannot easily abandon them. When capital resources are bound to existing investments, then less is left to reinvest to new technologies. (Matus et al. 2012a)

Another aspect of path-dependency is interfacing with existing infrastructure. New innovations need to interface with existing technology platforms, processes and infra, these also set barriers to new innovations. (Matus et al. 2012b)

7.3 Regulatory barriers

Environmental regulations have impact to chemical industry. When companies producing chemical products aim to global markets, they need to cope with different regulations of each region. The green chemistry is interested in reducing hazards of chemicals. Respectively environmental, health and safety regulations are focusing to reduce risk of exposure. This leads sometimes to conflicting situation, where companies need to use their resources to adhere to day-to-day regulations, instead of investing more to R&D of safer products. When the regulatory focus is on risk control over risk prevention, this can be a barrier to green chemistry. In this situation also firms are forced to focus their resources to risk control over the risk prevention. (Matus et al. 2012a) Furthermore, sometimes regulatory barriers occur, when taxation structures or technological approaches do not favor investments or innovation (Matus et al. 2012b).

The chemical regulation can act both as driver and barrier for green chemistry. Regulation may in some cases stimulate innovations, but it also often imposes additional costs for companies. The chemicals regulation in European Union is built upon to four key elements, which are registration, evaluation, authorization, and restriction of chemicals. The commonly referred REACH acronym in EU regulation is derived from these key elements (Registration, Evaluation, Authorization and restriction of CHemicals). The basic components of chemical risk assessment are the intrinsic properties of substances and the exposure conditions. The challenge for regulation is to prove and mitigate unacceptable risks also on circumstances when only limited not perfect data and knowledge is available. Although both REACH regulation and green chemistry aim for innovation, environmental and health protection, there are clear differences between them. REACH promotes generation of data and knowledge. Although this fosters less hazardous and safer chemicals, REACH is also resource consuming and slow for industry, and it does not promote renewable feedstocks. Therefore, it is sometimes argued in academic literature that REACH is only a weak driver for green chemistry. (Karlsson & Börjeson, 2019)

7.4 Technical barriers

The technical barriers to green chemistry arise from general complexity and multidisciplinary of chemistry. Furthermore, developments in chemistry are often protected as trade secrets due to reasons of competitive advantage. Technical barriers arise from new knowledge or pathways simply not being readily available to the chemists within industry. (Matus et al. 2012a)

7.5 Organizational barriers

Organizational barriers to green chemistry inside firms may occur in situation, when a division is required to do actions that would lower their own profitability but would potentially improve overall corporation performance. This phenomenon can happen in organizations e.g. when new solution costs are happening locally, but benefits are in division level. Furthermore, there can be situations where development of greener production in one part of company will lead decrease in sales in other division. Organizational barriers to green chemistry may also occur, when producers of new technology or products are not in positions of power. Power struggles and conflicting priorities may hinder implementation of green chemistry, which may lead to difficulties to secure resources inside organization. Absence of common goal across the organization is a hurdle for green chemistry implementation inside the organization. (Matus et al. 2012a)

7.6 Cultural barriers

Cultural barriers to green chemistry arise, when nations, industries, firms or academia is resistant to new technologies, or simply lack incentive to support adoption of new cleaner technologies (Matus et al. 2012b). Important aspect in cultural barriers is lack of basic awareness about green chemistry concept. Furthermore, misconceptions regarding green chemistry may also hinder its progress. Sometimes it is even labelled just as greenwashing, instead of set of science-based practices. (Matus et al. 2012a)

7.7 Barriers from disagreements on definitions and metrics

One barrier to green chemistry is lack of clear metrics, definitions and certifications about what is really environmentally friendly in big picture. The green chemistry is highly contextual term and the metrics how to define what really is green chemistry are debatable. Furthermore, among the actors in chemistry, the term green chemistry is used often interchangeably with chemical sustainability, which highlights the fuzziness of even term itself. (Matus et al. 2012a)

8 DRIVERS AND BARRIERS IN CIRCULAR ECONOMY

When looking the drivers and barriers of circular economy, they can be classified to seven categories according to Tura et al. (2018); *environmental, economic, social, political and institutional, technological and informational, supply chain, and organizational factors*. These are presented in more detail throughout examples given on table 2. On the work of Tura et al. (2018) is highlighted that the biggest barrier for circular economy is the economic uncertainty. This arises from the fact that defining and measuring long-term benefits of circular economy is extremely challenging.

Barriers and drivers of circular economy can also be looked from the whole bioeconomy perspective. In work of Reim et al. (2019) is presented the barriers of circular business models in framework that is derived from business model canvas concept. It can be summarized from their work, that main barriers in value propositions are inappropriate business models, that focus too little on circularity aspects. Respectively main barriers in value creation are arising from lack of collaboration among partners. On value delivery, the main barriers are deriving from lack of communication / education and from lack of understanding the customer demands. Beyond the above discussed barriers, expenses of investments / operations and unsecure revenues create significant barriers on value capture. The barriers discussed by Reim et al. (2019) are presented in figure 6.

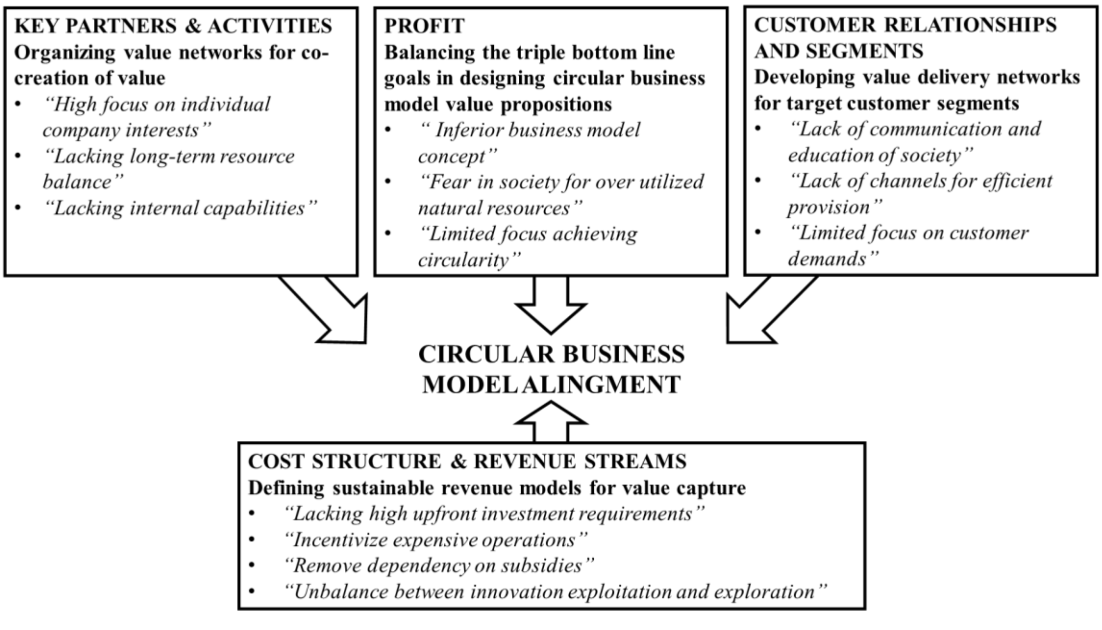


Figure 6. Barriers for developing circular business models (Reim et al. 2019)

Table 2. Framework of circular economy drivers and barriers (Tura et al. 2018)

Category	Drivers	Barriers
Environmental	• Resource constraints and potential for preventing negative environmental impacts • *"Global trend to minimize negative environmental impacts"* • *"Resource scarcity (fossil fuels, waste material)"*	
Economic	• Potential for improving cost efficiency, finding new revenue streams and gaining profit • Potential for new business development, innovation and synergy opportunities • *"Cost savings"* • *"Potential to create value from waste and production side streams"* • *"Potential for new service business development"*	• High costs and lack of financial capability and support • Lack of tools and methods to measure (long-term) benefits of circular economy projects • *"High initial investment costs"* • *"Scarcity of raw material, assets or infrastructure"* • *"Dominance of economic indicators in decision making"*
Social	• Increased internationalization and worldwide awareness of sustainability needs • Potential to increase workplaces and vitality • *"Increasing awareness of sustainability needs"* • *"Increased external demand for sustainability"* • *"Societal development projects e.g. industry roadmaps supporting sustainable development"*	• Lack of social awareness and uncertainty of consumer responsiveness and demand • Lack of market mechanisms for recovery • Lack of clear incentives • *"Region-specific and (local) cultures hamper the implementation of new solutions"* • *"Conservativeness in business practices (e.g. waste management industry)"* • *"Lacking or uncertain customer needs"*
Institutional	• Directing regulations and standard requirements • Supportive funds, taxation and subsidy policies • *"Directing laws and regulations create a demand for new solutions"* • *"ISO -standard development for solid recovered fuels"*	• Complex and overlapping regulation • Lack of governmental support • Lack of circular economy know-how of political decision-makers • *"Region-specific laws and regulations against circular economy solutions"* • *"Conflicts of interest and fluctuations in taxes and governmental subsidies - high future uncertainty"*
Technological & informational	• Potential for improving existing operations • New technologies • Increased information sharing through enhanced information management technologies, e.g. platforms • *"Emerging process technologies support circular economy business"* • *"Enhanced information sharing and management technologies support the creation of new services, increase transparency and enable more efficient processes"*	• Lack of information and knowledge • Lack of technologies and technical skills • *"Increased technical difficulty in handling circular economy material flows (lower homogeneity of raw material)"* • *"Lack of compatible technologies and high technological uncertainty"* • *"Lack of practices and systems for collecting, sharing and utilizing circular economy information"*
Supply chain	• Potential for reducing supply dependence and avoiding high and volatile prices • Open collaboration and communication practices • Multi-disciplinarity, increased availability of resources and capabilities • Management of (reverse) networks • *"Increasing the transparency of the supply chain"* • *"Increased availability of knowledge and technological resources through collaboration"*	• Lack of network support and partners • Strong industrial focus on linear models • Lack of collaboration and resources • *"Conflict of interest, values and modes of operation between different stakeholders"* • *"No clear responsibilities and ownerships in circular economy projects"* • *"Validating and verifying all environmental effects is a challenge for transparency and analytics"*
Organizational	• Potential for differentiation and strengthening the company brand • Increased understanding of sustainability demands • Circularity integrated in company strategy and goals • Development of skills and capabilities for circular economy • *"Circular economy innovations foster a sustainable company brand"* • *"Changed organizational structure, strategy and culture to support circular economy"* • *"Development of skills and capabilities for circular economy"* • *"Flexible decision making and product/service development models"*	• Incompatibility with existing (linear) operations and development targets • Silo thinking and fear of risks • Conflicts with existing business culture and lack of internal cooperation • Heavy organizational hierarchy and lack of management support • Lack of circular economy knowledge and skills • *"Incompatibility with existing (linear) operations and development targets"* • *"Conflicts with existing business culture"* • *"Silo thinking and fear of risks"*

9 SUCCESS FACTORS OF BIOBASED CHEMICALS

The commercial success and competitive advantages of biomass-derived chemicals rely on the three factors; *economics, performance, and environmental factors*. These success factors are presented in figure 7 below.

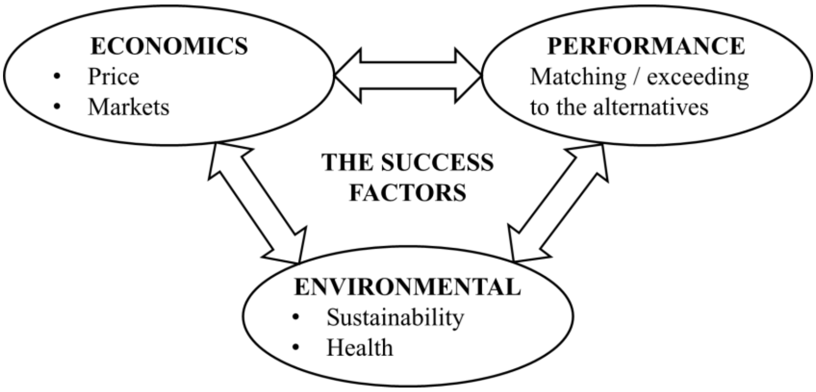


Figure 7. Factors determining competitive advantages for biomass derived chemicals (Erickson et al. 2011)

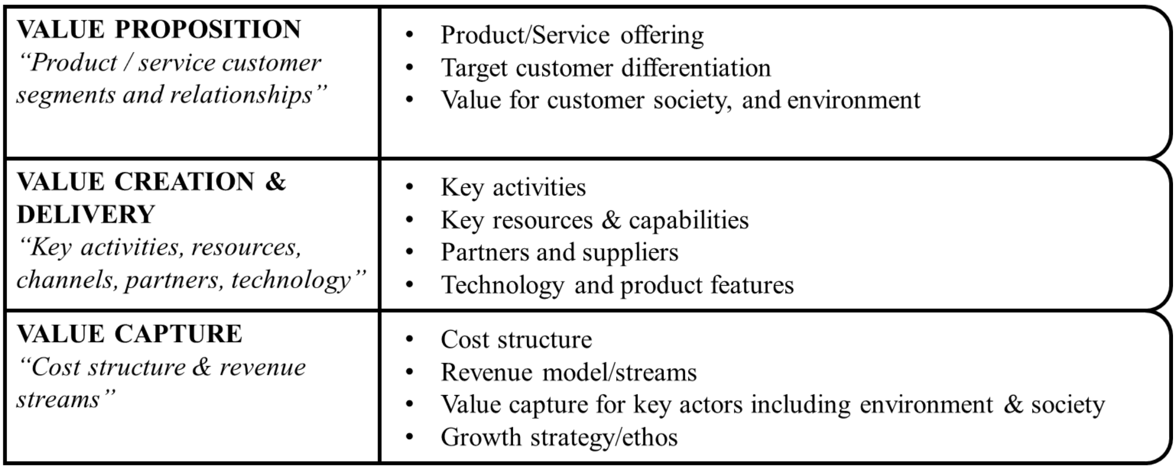
The market price of commodity bioproducts depends highly on two factors, the cost of raw material and the cost of processing technology. In the market entrance phase, it is possible for bioproducts to receive premium price. In some cases, they receive subsidies to be able to compete with fossil-based production. Anyhow, on long term prices of bioproducts are dependent from price and availability of biomass feedstock. The price and availability of biomass feedstock is impacted by multiple topics like variety, pretreatment requirements, land-use, competition with fossil feedstock, and transportation costs. The cost of processing technology has impact to production costs of bioproducts. If conversion costs are high, it is not economically viable to separate potential biochemical fractions from the raw material. Especially in market entry phase the R&D, pilot and demonstration production plants require investments. In the long term, success and market growth of bioproducts is dependent from development of cost-competitive technologies. (Erickson et al. 2011)

Related to economic performance, it is often considered that bioproducts need to offer similar or improved economic performance compared to fossil-based competing products to be accepted widely in markets by customers. In environmental factors important aspects are e.g. CO_2 balance, production processes energy consumption, and environmental impacts of production. (Erickson et al. 2011)

Successful biobased chemical production is highly dependent from economic objectives. Required capital investments, operational production costs, and market adoption are all impacting economic profitability of biorefineries. Processing technologies of biorefineries will mature over time, and typically on mature technology markets the raw material cost tend to become the dominant cost factor. Raw material sources are one advantage of biorefineries, when fossil feedstock sources are depleting, the availability and price of biomass feedstock is expected to remain more stable and predictable compared to fossil-feedstock. (Erickson et al. 2011) As a summary, in order to bioproducts and biorefineries to be sustainable and successful they need to fulfil simultaneously the economic, environmental, and social objectives. Bioproducts need to perform as good as fossil feedstock-based competitors. Sustainable life cycle is critical dimension for bioproducts. Feedstock biomass is renewable and while growing it captures CO_2 from atmosphere compared to fossil-based production which only releases carbon stock to atmosphere. (Budzianowski, 2016)

10 DEFINITION OF BUSINESS MODEL

Business model is a conceptual tool, which describes how a firm does business. It can be used for analysis, comparison, performance assessment, management, communication and for innovation purposes. (Bocken et al. 2013) Basically, business model represents the rationale of how an organization creates, delivers, and captures value (Antikainen & Valokari, 2016). In business models is typically described how the firm defines its competitive strategy. Business model covers topics like what are its products and services, how they are offered to markets, what is the revenue model, how company differentiates itself from competitors, how company integrates its operations to different value chains or networks, and so forth. (Bocken et al. 2013) On figure 8 is represented a conceptual business model framework commonly found in academic literature.



VALUE PROPOSITION *"Product / service customer segments and relationships"*	• Product/Service offering • Target customer differentiation • Value for customer society, and environment
VALUE CREATION & DELIVERY *"Key activities, resources, channels, partners, technology"*	• Key activities • Key resources & capabilities • Partners and suppliers • Technology and product features
VALUE CAPTURE *"Cost structure & revenue streams"*	• Cost structure • Revenue model/streams • Value capture for key actors including environment & society • Growth strategy/ethos

Figure 8. Conceptual business model framework (Reinhardt et al. 2020; Bocken et al. 2013)

Value creation is key concept in business models. This can be done e.g. by utilizing new business opportunities, new markets, or new revenue streams. Value proposition is more focused to how with the available product or service offering can be created economic return, ecological value, or social value. Whereas, value capture is focusing on how the revenue model is set-up against the provision of goods, services or information to customers. (Bocken et al. 2013) Respectively, the four elements on a generic business model concept according to Manninen et al. (2017) are:

1. *"Value proposition. What value is embedded in the product/service offered by the firm.*
2. *Supply/value chain. How upstream relationships with suppliers are structured and managed.*
3. *Customer interface. How downstream relationships with customers are structured and managed.*
4. *Financial model. Costs and benefits from points 1, 2 and 3, including the distribution across business model stakeholders."*

11 BUSINESS MODELS AND COMPANY STRATEGY

Strategies are needed to capture business opportunities and growth. First companies should decide what kind businesses they want to have in their portfolio, after that they can start to work on their business model to create and strengthen their competitiveness. The businesses to which a company wants to focus, and have in its portfolio, is driven by overall strategic considerations. This can relate for example to what kind of raw materials the company has an access, or what kind of application expertise or customer industry knowledge the company has. The planned portfolio of businesses must fit to the strengths and strategic orientation of the company. It is good also to remember that business portfolios are not static, but they should be actively managed. After the business portfolio is planned, the business models should be decided. Although the different business models and archetypes overlap, the main focus or priority of business model should be clear. Main theme of business model can be for example cost leadership, understanding customers applications, chemicals lifecycle management, or so forth. After the business model is designed, it needs to be also thoroughly implemented to it have the desired steering impact to the organization. (Bock, 2017) On figure 9 is presented strategic planning cycle and the impacting incentives & forces when designing business models.

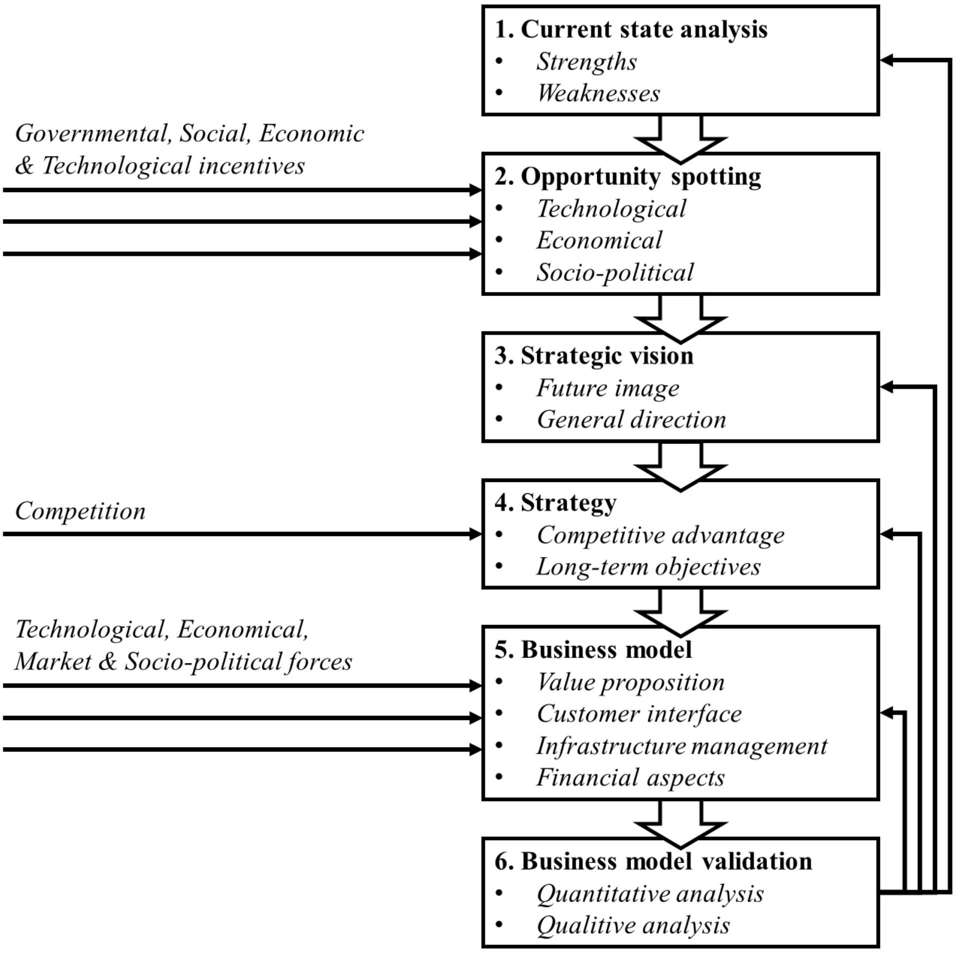


Figure 9. Strategic approach in designing business models (Machani et al. 2014)

12 SUSTAINABLE BUSINESS MODEL ARCHETYPES

It can be argued that traditional “the more you sell, the more you earn” business models are intensifying unnecessary consumption and generation of waste. In chemical markets this may lead to inefficient use of chemicals. Innovative business models are needed to contribute to waste and chemical consumption reduction, and to minimize risks of chemicals. (Schwager et al. 2016) Sustainable and circular business models can be seen as subcategories of business models. In circular business models is defined the rationale how an organization creates, delivers, and captures value within closed material loops. Closed material loops do not need to happen within domain of one actor. Beyond the single actor, the circular business model can happen in a network of independent actors. It is common that circular business models are networked and that them to be successful collaboration, communication, and coordination is needed between the different stakeholders. The challenge in these networked business ecosystems is to find and keep the “win-win-win” balance between the different independent actors. Respectively the sustainable business models take into consideration the broader view, the benefits from societal and environmental perspectives, beyond focusing only to economic value creation. (Antikainen & Valokari, 2016) In their work Bocken et al. (2013) differentiate eight different categories of sustainable business model archetypes, describing the underlying mechanisms and solutions that contribute towards sustainability. The sustainable business model archetypes according to Bocken et al. (2013) are:

1. *“Maximize material and energy efficiency*
2. *Create value from waste*
3. *Substitute with renewables and natural processes*
4. *Deliver functionality rather than ownership*
5. *Adopt a stewardship role*
6. *Encourage sufficiency*
7. *Repurpose the business for society/environment*
8. *Develop scale-up solutions.”*

“Maximize material and energy efficiency” archetype aims for maximizing material productivity and energy efficiency and to lower the resource consumption by reducing the volumes of resource flows. Actions in this archetype can mean e.g. lean production approaches and waste reduction. (Pal, 2017)

“The concept of creating value from waste” is focusing to restoration, designing and optimizing products, components and materials for closed material loops, disassembly and reuse. The used materials are reused either as new raw materials, products or components. This can mean also e.g. refurbishment and recycling. (Pal, 2017)

In “substitute with renewables and natural processes” archetype focus is on replacing fossil feedstock energy and resource systems with renewable materials. This is increasingly important due to resource scarcity of depleting fossil resources, and simultaneously happening global population and wealth growth. (Pal, 2017)

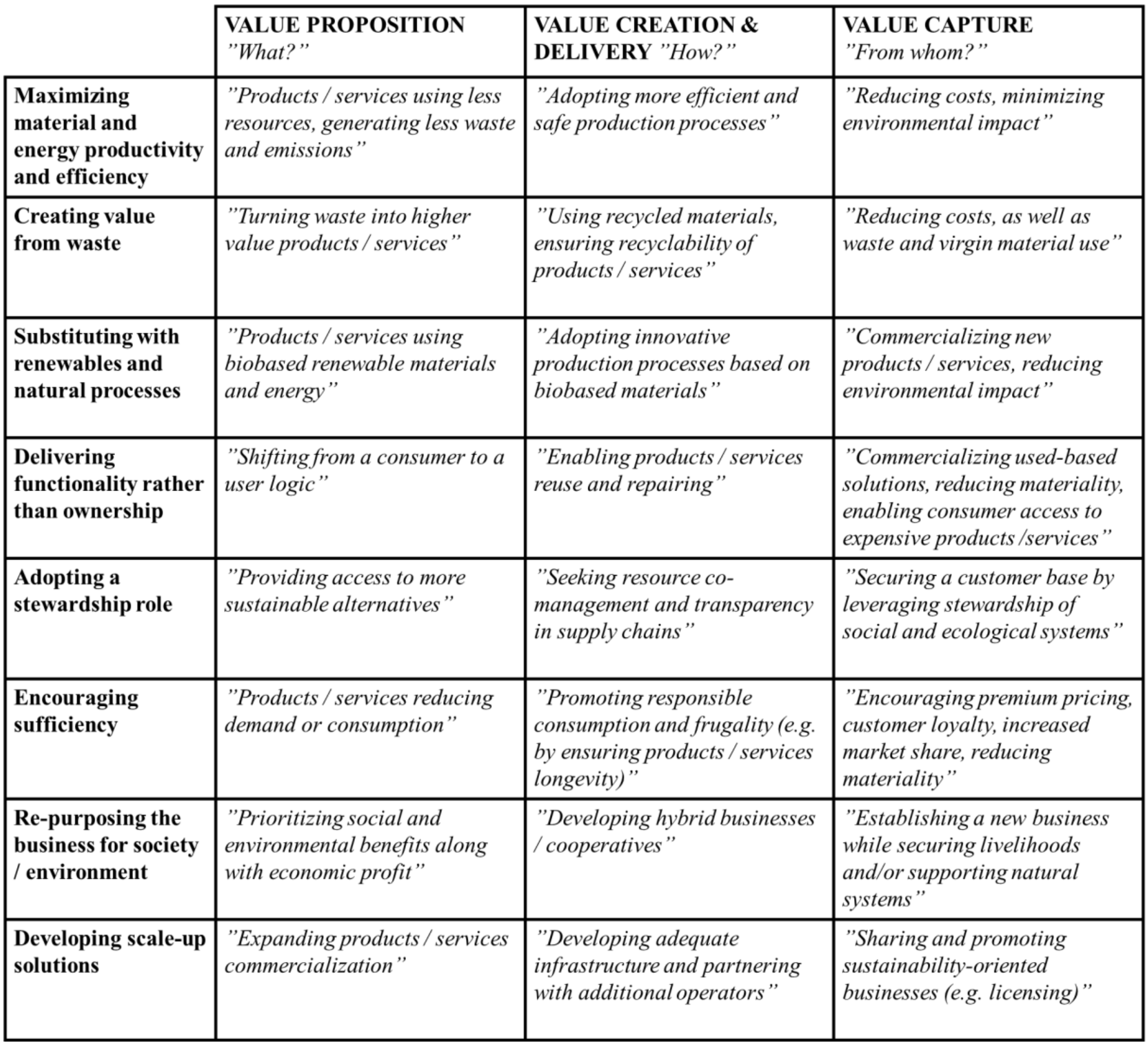
“Deliver functionality rather than ownership” archetype focuses on product-service systems and creating services, where functionality and access to resources are valued over the ownership of products or goods. Basically, the service providers provide performance or functionality against a fee, instead of physical goods or products. The aim and common benefit of creating services is increasing active usage and sharing capital costs of an asset. (Pal, 2017)

In “adopt a stewardship role” archetype company takes a role to ensure positive impact to its stakeholders, society and to environment. The benefit for company from acting in this role is typically price premium paid by consumers. Actions that company may take are e.g. fair wages, community development, and environmental protection. Third-party certification schemes and ecolabels are often linked to the stewardship archetype actions. (Pal, 2017)

“Encouraging sufficiency” archetype focuses to reduce the rate and volume of consumption. Examples from actions that companies can take are making products last longer, removal of built-in obsolescence features of the products, focusing on satisfying customer needs over promoting sales, and so forth. (Pal, 2017)

In “repurpose the business for society/environment” archetype business integrates itself with varied stakeholders through participatory approach. Actions can relate for example to collaboration with nonprofit organizations or with the local community. (Pal, 2017)

In “develop scale-up solutions” archetype focus is on new collaborative models that are beyond the traditional business scale-up thinking. Examples from this archetype are e.g. crowdsourcing/funding, open innovation platforms, online marketplaces connecting multiple stakeholders, collaborative networks and co-creation. The core idea is the potential for rapid scaling up and sustainability via local production and/or sharing economy. (Pal, 2017) As a summary the different mentioned business model archetypes and their typical business models are presented in figures 10.



	VALUE PROPOSITION *”What?”*	**VALUE CREATION & DELIVERY** *”How?”*	**VALUE CAPTURE** *”From whom?”*
Maximizing material and energy productivity and efficiency	*”Products / services using less resources, generating less waste and emissions”*	*”Adopting more efficient and safe production processes”*	*”Reducing costs, minimizing environmental impact”*
Creating value from waste	*”Turning waste into higher value products / services”*	*”Using recycled materials, ensuring recyclability of products / services”*	*”Reducing costs, as well as waste and virgin material use”*
Substituting with renewables and natural processes	*”Products / services using biobased renewable materials and energy”*	*”Adopting innovative production processes based on biobased materials”*	*”Commercializing new products / services, reducing environmental impact”*
Delivering functionality rather than ownership	*”Shifting from a consumer to a user logic”*	*”Enabling products / services reuse and repairing”*	*”Commercializing used-based solutions, reducing materiality, enabling consumer access to expensive products /services”*
Adopting a stewardship role	*”Providing access to more sustainable alternatives”*	*”Seeking resource co-management and transparency in supply chains”*	*”Securing a customer base by leveraging stewardship of social and ecological systems”*
Encouraging sufficiency	*”Products / services reducing demand or consumption”*	*”Promoting responsible consumption and frugality (e.g. by ensuring products / services longevity)”*	*”Encouraging premium pricing, customer loyalty, increased market share, reducing materiality”*
Re-purposing the business for society / environment	*”Prioritizing social and environmental benefits along with economic profit”*	*”Developing hybrid businesses / cooperatives”*	*”Establishing a new business while securing livelihoods and/or supporting natural systems”*
Developing scale-up solutions	*”Expanding products / services commercialization”*	*”Developing adequate infrastructure and partnering with additional operators”*	*”Sharing and promoting sustainability-oriented businesses (e.g. licensing)”*

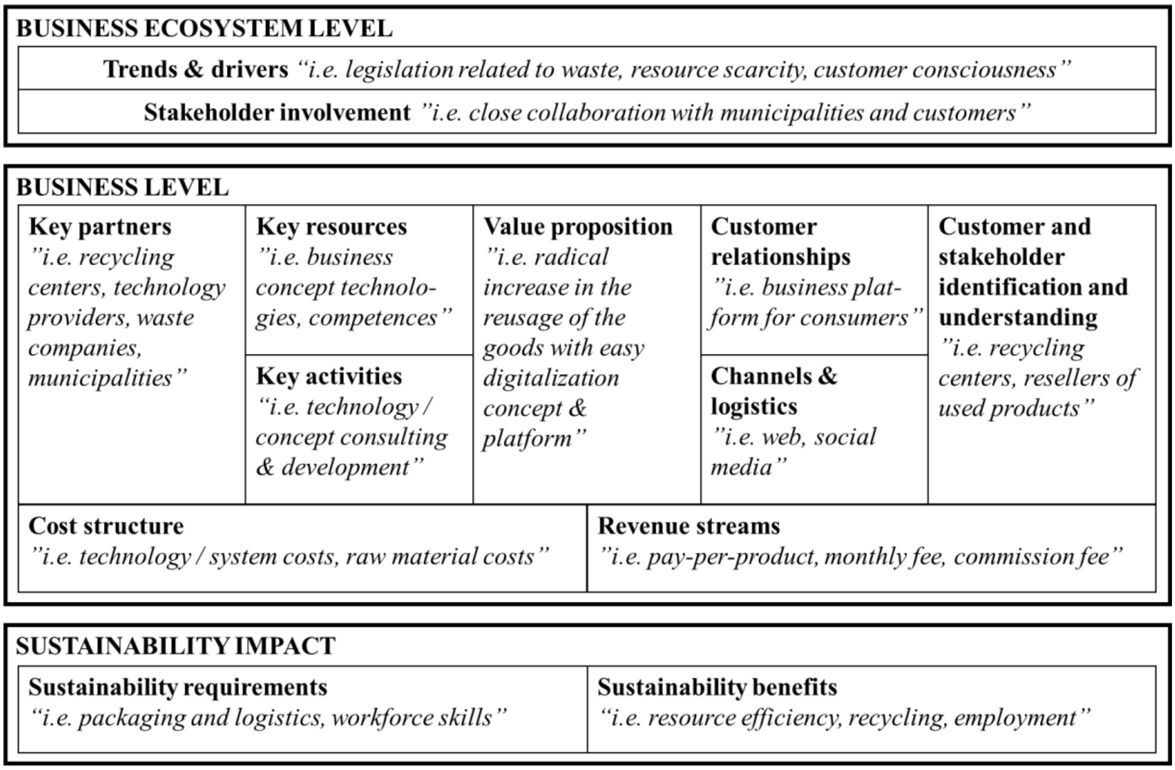
Figure 10. The sustainable business model archetypes (D'Amato et al. 2018)

13 BUSINESS MODEL CANVAS TOOL

The most well-known tool for describing business models is the business model canvas. It is a generic and easy-to-use tool, which has been applied in many different industries. Anyhow as the business ecosystem is changing and circular economy innovations are expected multilevel more holistic analysis are needed beyond the traditional business level focused models. (Antikainen & Valokari, 2016)

In their work Antikainen & Valokari (2016) propose that sustainable circular business models should integrate the global trends and drivers (macro level), the ecosystems and co-creation (meso level), and the companies, customers and consumers (micro level). Example from the integration is new legislation, which might have impacts to all business model levels. According to Antikainen & Valokari (2016) traditional business modelling tools and methods lack at least some of the identified and needed elements for innovating business models in a circular economy. In their work Antikainen & Valokari (2016) present enlarged version from business model canvas, that takes into consideration also these business ecosystem level and sustainability impacts. This is presented in figure 11. In their work Antikainen & Valokari (2016) identify the following important aspects for sustainable circular business model innovation:

- *"recognizing trends and drivers at the ecosystem level*
- *understanding value to partners and stakeholders within a business*
- *and evaluating the impact of sustainability and circularity".*



BUSINESS ECOSYSTEM LEVEL

Trends & drivers *“i.e. legislation related to waste, resource scarcity, customer consciousness”*

Stakeholder involvement *”i.e. close collaboration with municipalities and customers”*

BUSINESS LEVEL

Key partners *”i.e. recycling centers, technology providers, waste companies, municipalities”*

Key resources *”i.e. business concept technologies, competences”*

Key activities *“i.e. technology / concept consulting & development”*

Value proposition *”i.e. radical increase in the reusage of the goods with easy digitalization concept & platform”*

Customer relationships *”i.e. business platform for consumers”*

Channels & logistics *”i.e. web, social media”*

Customer and stakeholder identification and understanding *”i.e. recycling centers, resellers of used products”*

Cost structure *”i.e. technology / system costs, raw material costs”*

Revenue streams *”i.e. pay-per-product, monthly fee, commission fee”*

SUSTAINABILITY IMPACT

Sustainability requirements *“i.e. packaging and logistics, workforce skills”*

Sustainability benefits *“i.e. resource efficiency, recycling, employment”*

Figure 11. Enlarged business model canvas including business ecosystem level and sustainability impacts (Antikainen & Valokari, 2016)

Furthermore, when assessing opportunities and commercialization development potential of bioproducts or biobased technologies, they can be analyzed from these four different aspects according to Spekreijse et al. (2019):

1. *“Innovation and technological readiness (covering technological maturity, skills needed, uniqueness of the product, etc.)*
2. *Economic and market potential (covering market size, customer base, capital needed, market pull and push, etc.)*
3. *Social and environmental impacts (covering environmental impact, health hazards and benefits, employment, etc.)*
4. *Legal and regulatory factors (covering legal framework, restrictions on the use of substances, availability of grants, loans, guarantees and other funding opportunities, etc.)”*

Changes in economic, technological, political, social and market forces impact business models continuously. When planning business models, the different potential future scenarios should be assessed, and the business models should be updated regularly to keep up with the business environment changes. This is presented as time horizon picture on figure 12.

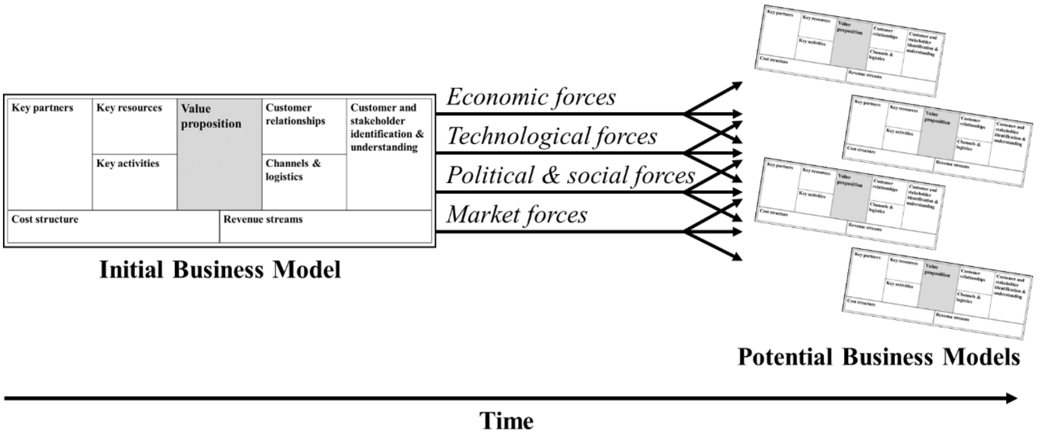


Figure 12. Scenarios development for business models (Machani et al. 2014)

14 SUSTAINABLE BUSINESS MODEL INNOVATIONS

Sustainable business models create positive, or significantly reduced negative, impacts for the environment and society throughout the way organization and its value network create, deliver, and capture value. Sustainable business models go beyond delivering only economic value, they include also environmental and social values of broad range of stakeholders. (Pal, 2017) Taking into account economic, environmental and social dimensions, when assessing sustainability or performance of companies is often called in the literature as Triple Bottom Line (TBL) approach. The sustainable business model innovations according to Bocken & Geradts (2019) can be defined as "*innovation to create significant positive impacts, and significantly reduced negative impacts for the environment and society, through changes in the way the organization and its value-network create, deliver and capture value or change their value propositions*". Knowledge about the key design elements (i.e. product, process, value network, relation, consumption pattern) enable companies strategically to develop sustainable business models and sustainable business model innovations (Pal, 2017).

When looking sustainable business model innovations from organizational perspective, Bocken & Geradts (2019) identify barriers and drivers related to them in three levels; institutional, strategic, and operational. The barriers and drivers for sustainable business model innovations are presented in figure 13. According to Bocken & Geradts (2019) there can be observed cascading impacts between the three mentioned levels. Focusing on shareholder value leads to short-termism and avoiding uncertainty. Which then again value operational excellence and existing processes over transformations on business models. (Bocken & Geradts, 2019)

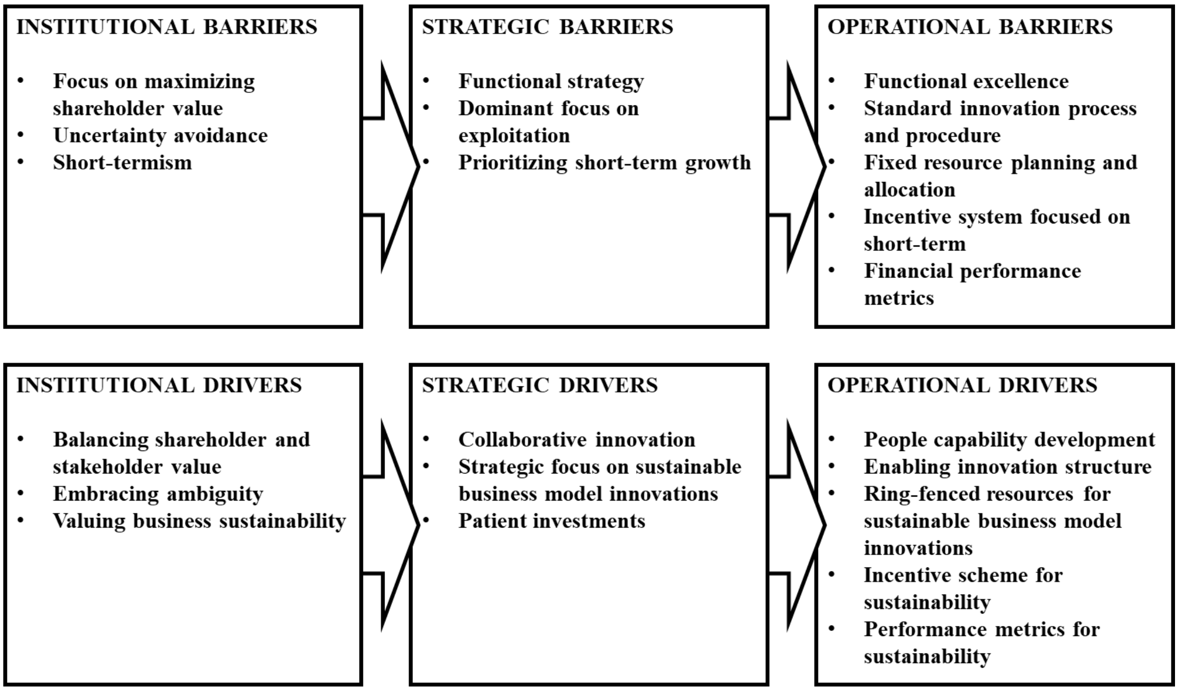


Figure 13. Barriers and drivers of sustainable business model innovation (Bocken & Geradts, 2019)

15 BUSINESS MODELS IN CHEMICAL INDUSTRY

Simplified linear production chain of the business of chemistry, from raw material inputs to valued outputs, is presented in figure 14. In reality individual companies anyhow can be simultaneously suppliers, customers, and competitors. Often chemical manufacturers produce a wide variety of chemicals ranging from commodity industrial chemicals to specialty chemicals. (American Chemistry Council, 2019) Chemicals are sold into multiple of industries and use cases, so the degree of additional support and services offered with the chemicals varies also a lot. Often customers of basic chemicals are price-oriented buyers, whereas customers buying chemicals for a specific application value also the performance and the services related to the chemical. (Bock, 2017) In principle, three basic business models can be distinguished in the chemical industry according to Bock (2017):

- *"Basic chemicals, produced in big volumes. For this category of products, so-called commodities, scale effects as well as technological and cost leadership are decisive factors. Cost-competitive access to resources as raw materials and energy is key but can be compensated for by smart logistics and highly integrated production and infrastructure.*
- *Application-oriented solutions, products offering specific features for defined customer industries and complemented with services. Key success factors here are proximity to customers, understanding of their markets as well as regulatory requirements, and innovation power.*
- *Product innovation-driven specialties. The ability to develop new active ingredients or new chemical entities, formulation know-how, as well as life cycle management including regulatory expertise are critical success factors."*

Respectively, according to American Chemistry Council (2019) chemical industry can be classified into four segments: *basic chemicals, specialty chemicals, agricultural chemicals, and consumer products*. All of these have their own structure, growth dynamics, markets, developments, and issues. Although agricultural chemicals could be categorized to basic and specialty chemicals, they have one distinctive feature according to American Chemistry Council (2019), the strong demand patterns that are driven directly by one single end customer group, the farming. Based on the literature research done, in this thesis the different business models in chemical industry are split to four categories:

- Basic chemicals
- Specialty chemicals (including the application-oriented solutions and product innovation-driven specialties)
- Consumer products
- Product service systems

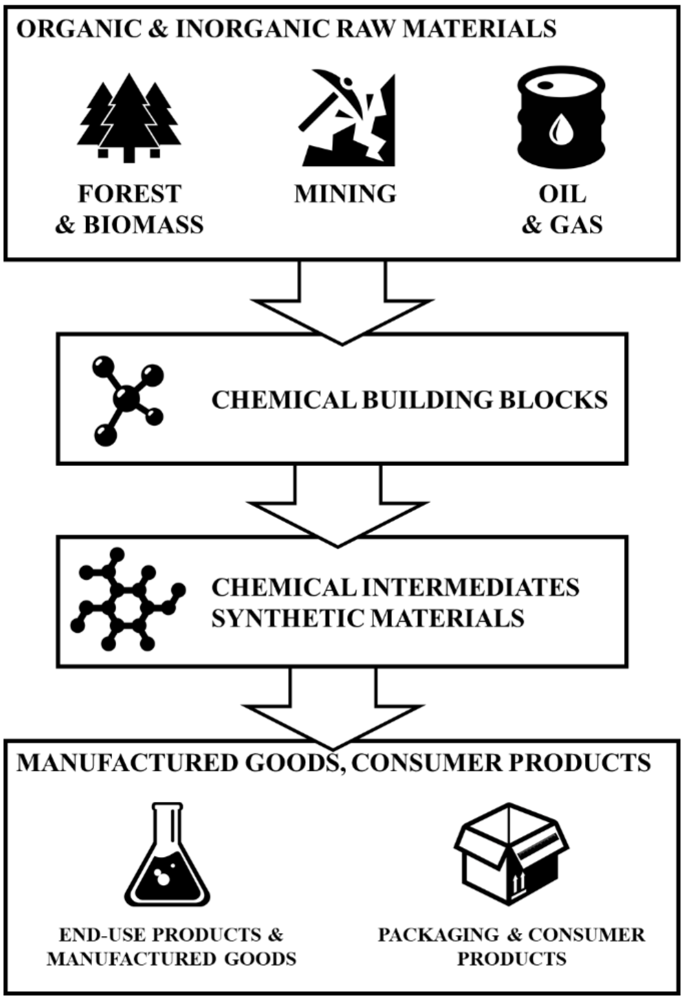


Figure 14. Simplified chemical chain from raw materials to outputs (American Chemistry Council, 2019)

15.1 Basic chemicals

Producing basic chemicals (also known as commodity chemicals) typically requires high capital investments. The planning and construction of new plants require often lead times of several years. The labor intensity is often low in basic chemicals production, due to automation and economies of scale. Sales & marketing and technical services of basic chemicals are often lean, as typically the performance features of these are well known and defined. The sales process of basic chemicals is often based on e-commerce platforms. When looking cost structure of operations, the raw material costs make up the major share of costs in basic chemicals. (Bock, 2017) According to American Chemistry Council (2019) cost for feedstock and materials in basic chemical segment can amount more than 65% of total costs.

The chemical composition of basic chemicals is homogenous in nature, there is no product differentiation. Basic chemicals are used typically on other manufactured products or used in their processing. Examples from basic chemicals are e.g. bulk petrochemicals, chemical intermediates, plastic resins, manufactured fibers, dyes, pigments, and so forth. (American Chemistry Council, 2019) Basic chemicals are easily exchangeable with competitors' products and they are used in many industries, which have stabilizing impact to their market price. (Bock, 2017)

Basic chemicals are mature business, and their selling prices highly correlate with capacity utilization levels and raw material costs. Basic chemicals typically have low profit margins. (American Chemistry Council, 2019) The differentiation between basic chemicals producers often happens only in terms of cost competitiveness, which is derived from access to cost-competitive raw materials and from production technology used. Products selling pricing in basic chemicals is often done based on customer segmentation and on the actual supply vs. demand situation. R&D intensity is often low on basic chemicals business, instead focus is on continuous process improvements to improve the cost competitiveness. (Bock, 2017)

The basic chemicals production factories are typically large in size and have high energy requirements. Therefore, basic chemicals production is often capital intensive. Basic chemical production has high entry barrier due to the capital requirements, environmental liabilities related to chemicals mass production, and due to access to raw material factors. From technology perspective requirements are moderate in basic chemicals production. In basic chemicals, the process technology is more important than product technology. The basic chemical producers typically have low-cost strategies throughout economies of scale and process technology related competitive advantages like patents. (American Chemistry Council, 2019)

15.2 Specialty chemicals

Specialty chemicals are also known as performance chemicals in some literature. In this segment first specialty chemicals are discussed as general group and after that is focused to two specific categories under to specialty chemicals, which are application-oriented solutions and product innovation-driven specialties.

Specialty chemicals are used for specific purposes and often they are technologically advanced products compared to basic chemicals. Typically, the specialty chemicals are produced in lower volumes compared to basic chemicals. Specialty chemicals are sold for what they do, rather than what they contain. Specialty chemicals make possible for customers to reduce their overall costs, enhance product performance or optimize manufacturing processes. Examples from specialty chemicals are catalysts, plastic additives, water management chemicals, and so forth. Specialty chemicals are used in many industries, and specialty chemicals have typically large customer-service or technical-service component included that the basic chemicals typically do not have. (American Chemistry Council, 2019)

Compared to basic chemicals, on the specialty chemicals focus is more on the markets. Raw materials for specialty chemicals production are often intermediates or basic chemicals. On the specialty chemicals segment the market availability & demand pressures impact less to the selling price than in basic chemicals. This due that their market prices are more reflecting value-in-use than production costs. (American Chemistry Council, 2019)

Typically, specialty chemicals are essential for end customers productivity and to their products costs. Specialty chemicals usually represent a small portion of customers total costs. As the specialty chemicals are application, or use case specific, there is switching cost barrier occurring to customers, if they desire changing their supplier. Generally, the specialties have higher profit margins and returns on equity than basic chemicals. (American Chemistry Council, 2019)

Specialty chemicals markets have high entry barrier compared to basic chemicals, as the value-add to end customers is more difficult to be duplicated. Furthermore, often producers are protected from competition with patents. In the specialty chemical markets strong customer relationships are important, which means that specialty chemical producers typically have strong technical service, marketing, and distribution competences. Furthermore, also the R&D spend of specialty chemicals producers is often high, as product innovations drive the growth of specialty chemicals producers. In the specialty chemicals business, the economies of scale are not so prevalent as in basic chemicals, so the plant / production size does not play so crucial role as in basic chemicals. Although consolidation and globalization are happening also among specialty chemicals producers, the specialty chemical markets and producers are more fragmented than in basic chemicals. E-commerce also impacts specialty chemicals markets, as it allows also the smaller producers to reach vast number of potential customers efficiently. (American Chemistry Council, 2019)

In application-oriented solutions the chemical products are designed to improve customers products or enable a specific application. The knowledge from how customer uses the chemical and knowledge from customers production processes, are crucial for success for application-oriented solutions. The value of product in this case is determined by the performance of the final end application. In this segment of chemical industry, it is more about selling specific application know-how and services than selling just raw materials. Projects with customers are common, and customer intimacy is high in the application-oriented solutions. The differentiation between competitors in this segment happen via application know-how and additional services over the traditional product offering. (Bock, 2017)

The product innovation driven specialties are characterized by high level of R&D and profound knowledge about chemical synthesis. These chemicals are usually new active ingredients, which are typically protected with patents. Regulatory expertise is a critical success factor in this segment of chemical markets. (Bock, 2017)

15.3 Consumer products

The customers of consumer products are typically households. Differently to basic and specialty chemicals, the consumer products are packaged to retail packages. Examples from this category are detergents, shampoos, cosmetics, skin and personal care products. The consumer products are often simple in terms of chemistry. They can be produced in batch-type operations or in large dedicated plants. The raw materials of consumer products are typically basic chemicals. (American Chemistry Council, 2019)

Brand image and point-of-sale impact are often the key factors in this segment. Branding may provide competitive edge to reach higher profit margins. Cost-efficient supply chain and packaging operations are important for profitability on this category. Distribution channel management is in very critical role to obtain shelf space in retail markets. The advertising costs are usually high in this category and e-commerce also plays role how companies market their products. The differentiation between competitors happens typically on branding in this category. (American Chemistry Council, 2019)

15.4 Product service systems

In the product service systems product is not sold, but it is offered as a service. According to Werning & Spinler (2019) there are three sub-categories of product service systems (PSS):

1. *“Product-oriented PSS often refer to leasing arrangements, including after-sales services (e.g. car leasing).*
2. *Use-oriented PSS refer to model, where payment is made only for the active usage of the asset (e.g. pay-per page in printing including inks and machines).*
3. *Result-oriented PSS refer to the solution of a problem, which is independent from the use of specific products (e.g. pest control instead of pesticides to guarantee a certain harvest yield)”.*

Similarly, to the above cases, with cost-per-unit invoicing concept is meant model where customer pays from the end result, not from the materials used to reach the result. Example from this is when car manufacturer pays from each perfectly coated car body, not from the amount of paint. (Bock, 2017) In this case the automobile manufacturer has coating requirements, that it purchases from coating operator, instead of purchasing paint. In this model the coating operator and the paint producer are integrated to the manufacturing processes of automobile manufacturer. (American Chemistry Council, 2019)

Another term used in the context of product service systems is chemical leasing. The main focus on chemical leasing is on service delivered, not on volume sold chemicals. Typically, chemical leasing contracts are based on functionality and measured in units like “number of pieces cleaned" or "amount of area coated". In this model the focus of chemical producer is shifted towards the function and benefits of a chemical, and away from the volume-based turnover. When chemical producer sells functionality as service, the chemical consumption becomes a cost factor to the chemical producer. Business incentives are aligned in chemical leasing between seller and buyer, this enables optimizing chemicals used, which leads to decrease in costs and minimizing the negative environmental impacts of chemicals. (Schwager et al. 2016) A practical example how model focusing on performance may work is following: the chemical producer delivers chemicals to customer, recovers chemicals after usage, reprocesses the recovered chemicals, and resupplies them to customer. This kind of business models are established for example in the catalyst business. (Bock, 2017) Similar examples can be found from electronics industry. In chemical leasing the chemical producers are freeing their customers from management of used chemicals. The producers typically also take a role of consultant helping their customers, solving problems, providing best practices and so forth. These actions are targeting to reduce waste and to mutual cost savings. (American Chemistry Council, 2019)

16 SUMMARY OF THE KEY ECONOMIC FACTORS OF BIOREFINERIES

There can be identified following essential factors impacting the performance of biorefineries, the cost and availability of biomass feedstock, the conversion/production efficiency, the scale of process, and the value of final products. Secured access to low cost feedstock is crucial for biorefineries. Biomass feedstock is typically low in density and high in moisture content, so it needs to be available locally. Biorefineries with imported feedstock often cannot be competitive. In the biomass feedstock there are some complex chemical structures present. Some of the structures present in the biomass raw material are in a form that enables their use after separation only with minor structural adjustments. In order to bioproducts to be successful in markets, they need to be capable to compete with fossil-based competitors. When chemically complex bioproducts produced from biomass sources, cannot be synthesized easily from fossil feedstock, then these high value bioproducts have competitive advantage. The conversion of biomass to bioproducts should happen through cascading approach, high value bioproducts should be produced first. The full potential of biomass should be valorized coupled with bioenergy production from the remaining waste stream. Moreover, producing multiple bioproducts protects company from market fluctuation risk, which is dangerous for single product biorefineries. (Budzianowski, 2016)

Anyhow, biorefineries can produce world-class high-quality products but still not make profit, if markets are not in place with reasonable selling price. Biochemicals need to be produced with reasonable costs, but they also need to have markets. When assessing commercialization potential of new bioproducts, the current and future market needs are very critical. The items impacting markets of bioproducts are for example competition from fossil-based products, supply and demand, product performance in end application and so forth. (Budzianowski, 2016) On biobased products, it is also important to understand, whether the customer is willing to pay “green premium” from the biobased product. Especially on cosmetics and on personal care products, there is typically a market benefit when product is biobased and natural. (Spekreijse et al. 2019; Bock, 2017) According to Budzianowski (2016) it can be summarized that “*promising bioproducts address market niches, are obtained at a reasonable cost and due to complex specific chemical structures avoid competition with fossil fuel derived products*.”

17 INTRODUCTION OF THE CASE STUDY

In the case example of this thesis is covered a potential use case for birch bark based biochemicals in textile industry. First the chemicals used in textile industry are studied. After that chemical composition of birch bark is discussed. Extraction of biochemicals from outer birch bark and the water repellent properties of these chemicals are also covered. Finally, potential new betulin and suberin material flows in industrial wood usage are briefly described and business case framework is presented and discussed. As part of the case example an Excel-based tool is created to analyze economic feasibility of the proposed use case.

18 CHEMICALS ON TEXTILE INDUSTY

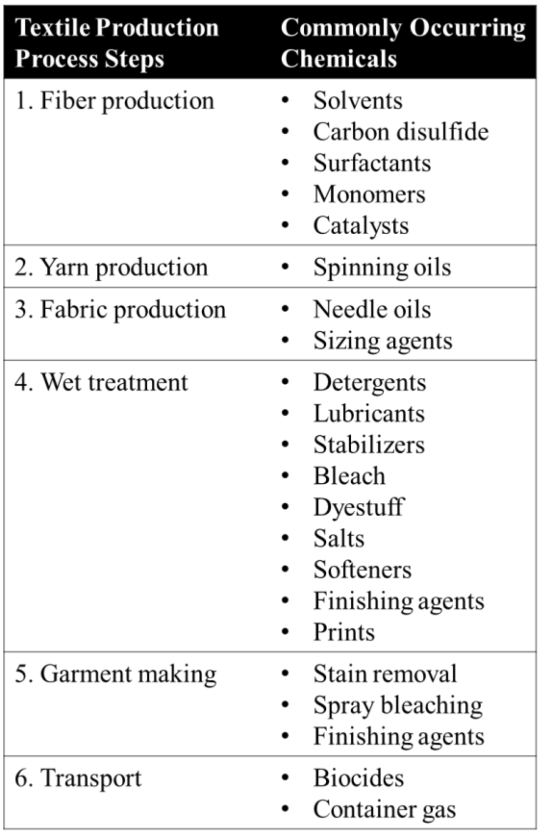
Textile and clothing industry is one of the most polluting industries. The industry has many environmentally unfriendly production practices, high amount of chemicals used in production, and high volumes of emissions and effluents from the production. Additionally, there is lack of good recycling practices for end-of-life textiles. The production of textiles and clothing is largely concentrated to low cost countries with low regulations, health & safety standards and unfair labor wages. (Pal, 2017) Examples from commonly used chemicals in the textile production are represented on table 3.

On the positive side, according to Jönsson et al. (2018) currently legal and voluntary restrictions of chemicals content in textile industry products are developing. There are initiatives in the textile industry promoting use of more environmentally friendly materials. These initiatives can focus for example to innovations optimizing existing technologies or approaches of closed loop systems, green chemistry or recycling. For example, alternative raw materials are being explored to replace materials having slow regenerative or long replacement cycle. (Pal, 2017)

When greening the manufacturing processes, textile industry supply chain should consider the following actions according to Pal (2017):

- *“Zero discharge of all hazardous chemicals*
- *Prevention and precautionary actions toward the elimination of hazardous chemicals at source through substitution with sustainable alternatives or with product redesign*
- *Full transparency by brands to their supply chains and public disclosure of information about hazardous chemicals used and discharged”.*

Table 3. Commonly used chemicals in the textile production (Jönsson et al. 2018)



Textile Production Process Steps	Commonly Occurring Chemicals
1. Fiber production	• Solvents • Carbon disulfide • Surfactants • Monomers • Catalysts
2. Yarn production	• Spinning oils
3. Fabric production	• Needle oils • Sizing agents
4. Wet treatment	• Detergents • Lubricants • Stabilizers • Bleach • Dyestuff • Salts • Softeners • Finishing agents • Prints
5. Garment making	• Stain removal • Spray bleaching • Finishing agents
6. Transport	• Biocides • Container gas

According to Jönsson et al. (2018) the chemicals used in textile industry can be divided into two groups based on their functional properties:

- *“Effect chemicals. These provide function to the final textile product (softeners, plasticizers etc.). The functions are usually selected by the product designer and/or the procurer. Sometimes this group of chemicals is addressed as “functional chemicals”, hence giving function to the final product.*
- *Processing chemicals. These are used in the processing of textiles in the production (antifoaming agents, catalysts etc.). The functions are selected by the process engineer or sometimes specified by the chemical company to achieve compatibility with chemicals added to provide final effect.”*

The processing chemicals are used in the manufacturing processes, but they are not embedded to end product. Some examples from processing chemicals are solvents, surfactants, curative agents, defoaming agents, and so forth. The processing chemicals may cause environmental and health issues, if remainders of them stay in final products. (Jönsson et al. 2018)

The effect chemicals give the textile product a desired function. Typical examples are colorants, flame retardants, biocides, and water repellents. From chemical requirements perspective, the effect chemicals need to have good solubility and affinity to textile fibers. Also, the ageing durability is a factor to be considered, sufficient functional properties stability is required over the time textile is in active use. Sometimes the functional chemicals have can have toxic properties. As these chemicals are embedded to final product, they can possibly make the disposal and recycling of the textile more challenging. (Jönsson et al. 2018) When considering replacing an effect chemical in textiles with a biobased alternative, the properties that need to be fulfilled according to Jönsson et al. (2018) are:

- *"Functional properties*
    - *Provide the same function as was provided by the original effect chemical*
    - *Not alter electrical properties*
- *Mechanical properties*
    - *Not significantly alter the mechanical properties of the textile material*
    - *Be easy to incorporate into the host textile material*
    - *Be compatible with the host textile material*
    - *Be easy to extract/remove for recyclability of the textile material*
- *Physical properties*
    - *Be colorless or at least non-discoloring (not applicable for dyestuffs and pigments)*
    - *Have good light stability*
    - *Be resistant towards ageing and hydrolysis*
    - *Not cause corrosion*
- *Health and environmental properties*
    - *Not have harmful health effects*
    - *Not have harmful environmental properties*
- *Commercial viability*
    - *Be commercially available and cost-effective."*

19 BIRCH BARK

Birch bark has interesting properties as a material. It is low in density, it has low thermal conductivity and good fire resistance, and it contains high amount of extractives. The possible products that could potentially be produced from different barks in general are presented in figure 15.

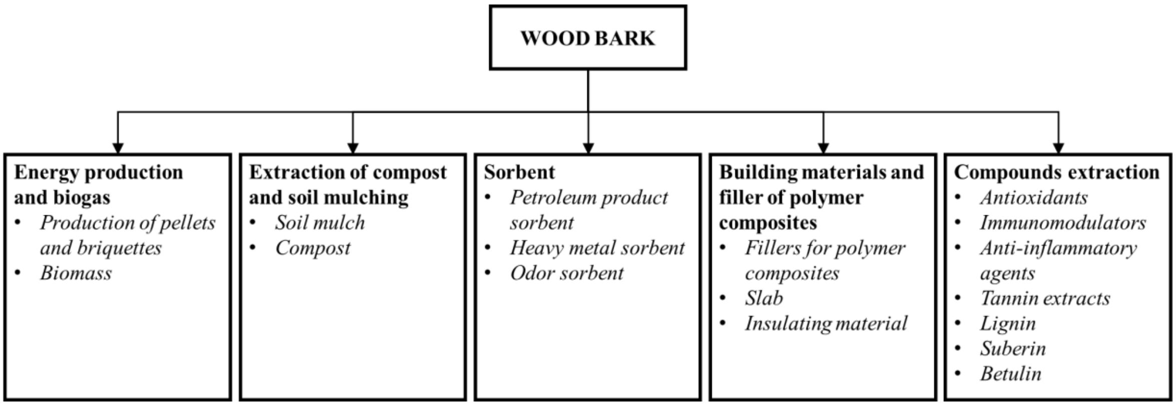


Figure 15. Opportunities of wood bark (Jansone et al. 2017)

Currently large amounts of bark side streams are produced in forest industry, where it is mainly used to produce heat and power. It is proposed that the valuable components of bark should be extracted before its combustion to energy. This would provide better utilization of bark. (Routa et al. 2017) Bark represents typically ~10-15 % from the weight of tree stems. Bark is consisting two parts: inner bark and outer bark. These two parts have different chemical compositions, and the proportions of inner and outer bark in trees varies between species, according to age of tree, and also position in the tree. (Routa et al. 2017; Pazhe et al. 2012) The birch bark thickness is strongly related to stem diameter (Miranda et al. 2012). The inner bark is consisting living cells and its having function in transporting liquids and nutrients. The outer bark is consisting periderm and it is protecting the three against pathogens. (Karnaouri et al. 2016) Outer bark is about ~2-4 % from birch logs mass. In general, the density of birch bark is around ~260-270 kg/m^3 when logs are having moisture content ~35-40 % in weight. After separation and processing, the dry birch bark is having even much lower density. Therefore, it is proposed in the literature, that if birch bark is transported long distances between processing plants, pelletization of it should be considered. (Pazhe et al. 2012)

The birch bark has promising chemical composition for biorefinery concept and it could be used as raw material to produce biochemicals (Jansone et al. 2017). The birch bark is potential source for different organic chemicals, like different triterpenoids such as lupeol and betulin (Krasutsky et al. 2012). Bark is considered as potential raw material for production of high value bioproducts, due to its extractives content. The possible value-add products could be either platform or specialty chemicals. (Routa et al. 2017) As bark is often burned to energy, the cost of using birch bark for new applications will correlate with loss of heat and energy received from burning. Birch bark based bioproducts are yet anyhow poorly developed, and to produce high value bioproducts from birch bark would require more investments. The risks with investments associated to the new applications for birch bark are related to adoption of new technologies and scaling-up the processes to industrial scale. (Li et al. 2015; Jansone et al. 2017)

19.1 Composition of outer birch bark

Bark is chemically and morphologically very heterogenous substance, its properties vary considerably between species. The composition of outer birch bark is mainly non-soluble polyester suberin (~40-50 %) and triterpene extractives (~30-40 %). The rest of outer bark being polysaccharides, lignin and minerals. Looking from this perspective, the chemistry of outer birch bark can be subdivided to the chemistry of extractives and to the chemistry of suberin polymer. (Karnaouri et al. 2016; Korpinen et al. 2019; Routa et al. 2017; Pazhe et al. 2012) As a comparison, the inner bark has very high phenolics contents (Routa et al. 2017), but the suberin content in inner bark is much less. According to Korpinen et al. (2019) birch bark containing both inner and outer bark fractions has only around ~6 % of suberin.

19.2 Triterpene extractives

Triterpene extractives are low molecular mass non-structural compounds that are present in wood and can be extracted with polar and non-polar solvents. Extractives are protecting the tree from pathogens and from other biotic attacks. (Routa et al. 2017) Triterpenes are biologically active substances, which can be enhanced with synthetic modifications (Pazhe et al. 2012). Most of the triterpenes are secondary metabolites, and many of them have pentacyclic structure (Krasutsky et al. 2012; Routa et al. 2017). From the outer birch bark extractives around ~78 % is betulin, ~8 % lupeol, ~4 % betulinic acid, and rest is smaller amounts of other triterpenes (Huang, 2019). The birch bark contains ~2-6 times more extractives than stem wood does (Routa et al. 2017).

Many cosmetic products contain birch bark extracts or betulin (Routa et al. 2017). Anyhow according to Budzianowski (2016) the extractives found in barks are currently underexploited due to lack of efficient extraction and separation methods. Betulin has low surface energy, and it could be considered that betulin would be used for hydrophobization instead of being simply burned as waste for energy (Huang et al. 2018). As betulin has shown signs of bioactive properties (i.e. anticancer, anti-HIV, antifungal and antibacterial properties), it has been also studied as precursor for medical and pharmaceutical applications (Huang, 2019; Karnaouri et al. 2016; Fridén et al. 2015).

19.3 Suberin

Suberin is found in nature mainly from birch and cork oak bark. Only these two wood species produce it in large enough amounts that could be for industrial purposes. (Routa et al. 2017) Suberin is a complex polymer and inside the birch bark suberin is in complex macromolecular network format that is insoluble to solvents (Korpinen et al. 2019; Krasutsky et al. 2012). Suberin contains many different fatty acids which are not abundant elsewhere in nature (Pazhe et al. 2012). Chemically suberin is a biopolyester, a cross-linked co-polymer having polyaliphatic and polyaromatic domains made mainly from esterified long- and mid-chain hydroxy/epoxy fatty acids and fatty diacids. It is unique component to bark and it is not present in the wood stem itself. (Routa et al. 2017)

The most interesting components of suberin, that are not abundant elsewhere in nature, are ω-hydroxyfatty acids, α, ω-dicarboxylic acids and homologous mid-chain dihydroxy/epoxy derivatives. Suberin could be used as building block for variety of materials. Especially it has been proposed that it could be used in cosmetics industry. Derivates of suberin could be used for example in skin- and hair care products, washing materials and shampoos. Suberin might also be potentially used in some pharmaceutical applications and on biodegradable plastics polyesters. Furthermore, the suberinic fatty acids are potential building blocks for biopolymers and coating materials. (Routa et al. 2017)

20 EXTRACTION OF BETULIN

The different extraction methods have different features compared to each other. From economic perspective, the most interesting differences to compare are yield / recovery rate, purity, energy and solvent consumption, and industrial scale feasibility. (Fridén et al. 2015) Related to extracting betulin from birch bark there has been done academic studies from the possible technological option. Examples from the studied options are pressurized liquid extraction (PLE), supercritical fluid extraction (SFE), microwave assisted extraction (MAE), classical reflux boiling (RB) and leaching. Pressurized liquid extraction and microwave assisted extraction methods require specialized equipment, but they could possibly provide better extraction results compared to classical reflux boiling. Supercritical fluid extraction compared to other options could possibly provide more selective extraction results. Betulin can also be extracted with leaching method by using organic solvents, like for example ethanol or heptane. There has been also studies to use green solvents, like pine monoterpenes or limonene, to extract betulin. (Fridén et al. 2015; Huang et al. 2019)

Fridén et al. (2015) compared in their work classical reflux boiling and pressurized liquid extraction. Following differences can be summarized from their study. Classical reflux boiling produced better purity, while pressurized liquid extraction produced better yield. Solvent consumption per final product was higher in pressurized liquid extraction compared to classical reflux boiling. Anyhow, when planning industrial scale processes the solvent consumption should be kept as low as possible. This is due to the fact, that solvent recycling is very energy demanding step in the production process. Therefore, also the pre-treatment processes of bark are to be assessed (i.e. boiling with water) before extraction process steps to remove / mitigate contaminations to process and solvent. (Fridén et al. 2015)

The intended end use of the final product impacts the required purity level. This need to be considered also when planning processes, for example medical products are more regulated and have stronger requirements compared to other end uses. Furthermore, when planning industrial feasibility, the aspects like energy source for solvent recovery in production scale and required financial investments, are to be also considered. (Fridén et al. 2015)

Related to extractives produced, it is important to acknowledge that many of them are volatile or chemically unstable. This means that the extractives content (and also their chemical composition) in birch bark will change after felling during storage. When planning valorization of extractives from birch bark, this phenomenon needs to be taken into account when planning the raw material supply processes. Furthermore, also wood handling processes affect to extractives content, so they need to be also considered. The amount of extractives changes significantly already in few weeks, so the freshness of the feedstock is factor, that needs to be assessed, when planning industrial scale processes for birch bark extractives. In figure 16 is presented the change of extractives amount on birch bark over storing time. When adding extractives valorization step in existing biorefineries processes, it puts pressure to accelerated wood supply processes, to avoid losses of extractives. (Routa et al. 2017)

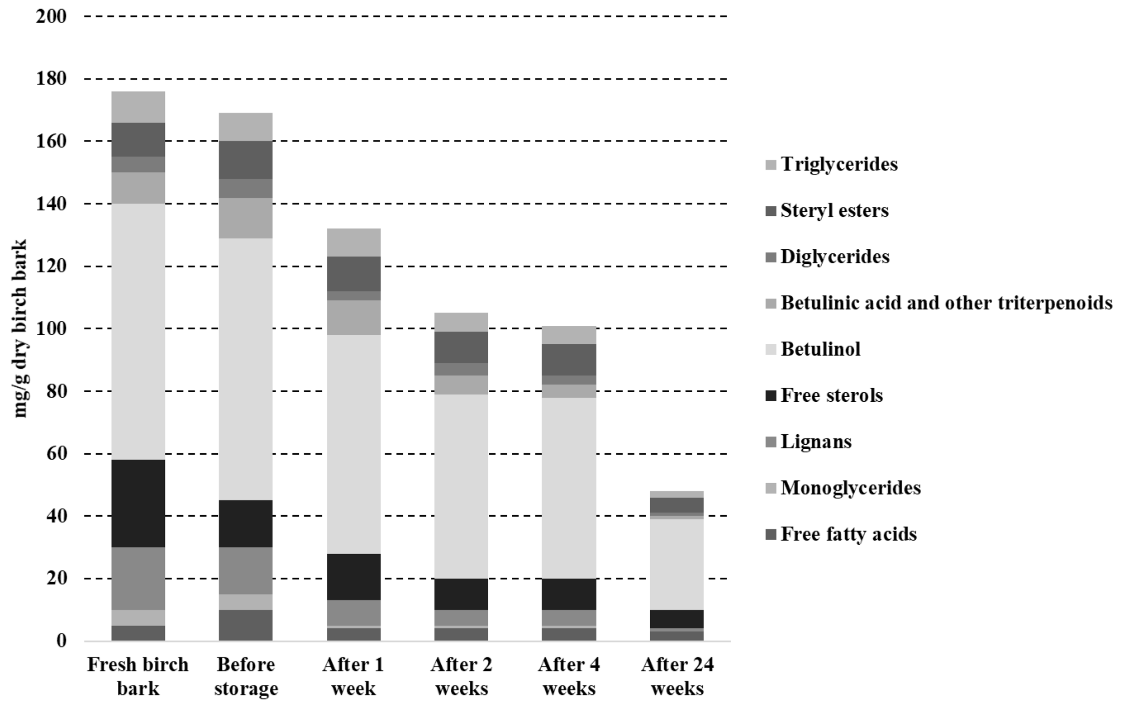


Figure 16. Change of extractives yield from birch bark over storing time (Lappi et al. 2014)

21 WATER REPELLENT PROPERTIES OF BETULIN AND SUBERIN

To reach hydrophobicity on different surfaces a combination of both high roughness and low surface tension is needed on them. Currently paraffin waxes and fluorinated silanes are used on cotton textiles to achieve hydrophobicity. Problems of these chemicals are that they are not biodegradable, and they cause environmental pollution on the production process. Furthermore, paraffin waxes introduce issues like of lack of air permeation and low comfort on textile itself. (Huang, 2019) Properties of textiles processed with fluorinated silanes are better, but the problems of fluorinated silanes are that they are expensive and contaminated wastewater is generated during the treatment process (Huang et al. 2018).

Huang (2019) proposes, that betulin could possibly be used to achieve hydrophobicity on cotton textiles with less environmental impacts. According to work of Huang (2019) textiles impregnated with solution of betulin-based copolymer reached water contact angle of 151°, indicating superhydrophobicity, and that the betulin-grafted textiles showed static water contact angle of 136°. Betulin furthermore has also good antibacterial properties, it is proposed that it could be used as green alternative to achieve hydrophobicity on textiles. These textiles could also be potentially used on applications where antibacterial properties are also needed, like medical mattresses and bandages. (Huang, 2019)

Also, usage of suberin for water repellency applications has been proposed in literature. According to Li et al. (2015) suberin is a natural hydrophobic material, which could be for example used to improve the water repellency of cellulose surfaces. According to their research cellulose sheets became considerably more hydrophobic after modification with suberin. Beside the textiles, also packaging solutions often need property of water repellency. As untreated paperboard disintegrates if it becomes wet, currently polyethylene is used to laminate paperboard when water resistance is needed. Suberin fatty acids could be utilized to create excellent water repellent properties to fibrous materials. The disadvantages from using suberin fatty acids is that they may change color / brightness of the product, and that they may impact to tear strength also. However, the color change is not issue in all application, like for example in brown packaging materials. Another advantage beside water repellent properties is that suberin fatty acid treatment may also improve tensile strength of fibrous packaging materials. (Korpinen et al. 2019)

22 BUSINESS CASE FRAMEWORK AND DISCUSSION

Business case framework was created to assess business potential of selected use case: “birch bark based biochemicals in textile industry”. Highly simplified flow diagram from production of birch bark based chemicals is presented on figure 17. On figure 18 is presented illustrative examples from possible alternative options related to value chain downstream integration depth on chemicals production. The analysis of this study was limited to chemical building blocks production, and in the study chemical industry is seen as the main customer. Finally, the mind map from the created business case framework is presented on figure 19. The framework was modelled to Excel-based tool from the perspective of economic feasibility of the proposed use case. The main measure in the model was selected to be return on capital employed. In the framework created can be identified different entities impacting economic feasibility, which are raw material, technology, sales, and cost related items.

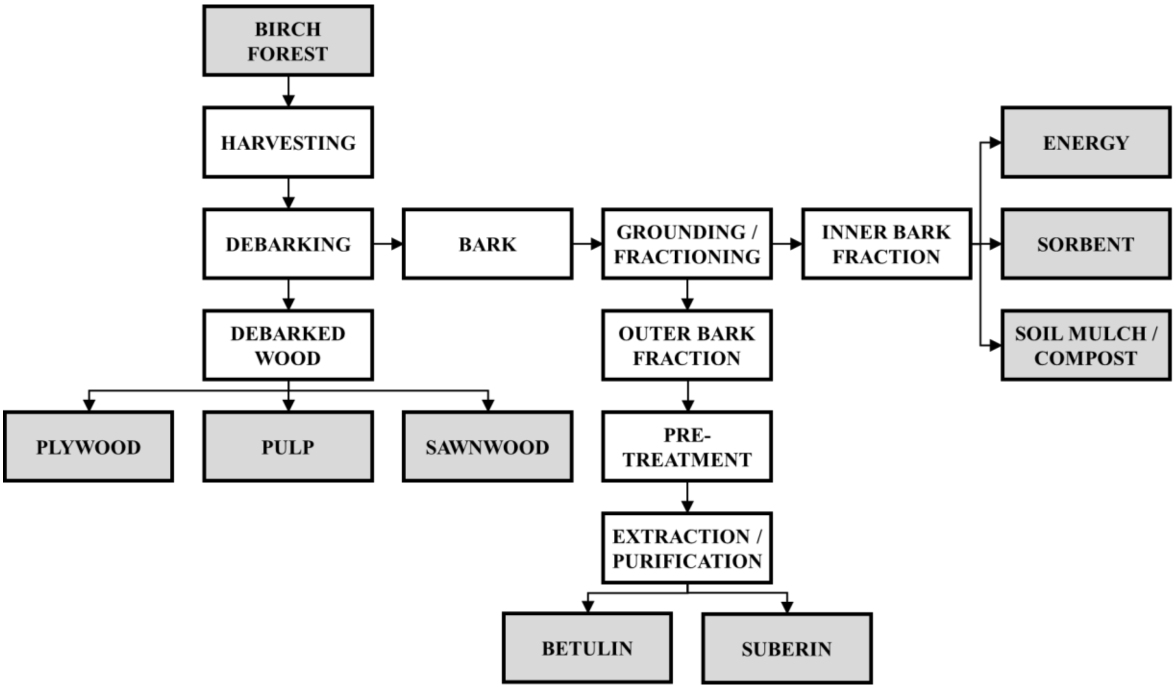


Figure 17. Simplified flow diagram of potential new betulin and suberin material flows from birch bark in biorefineries

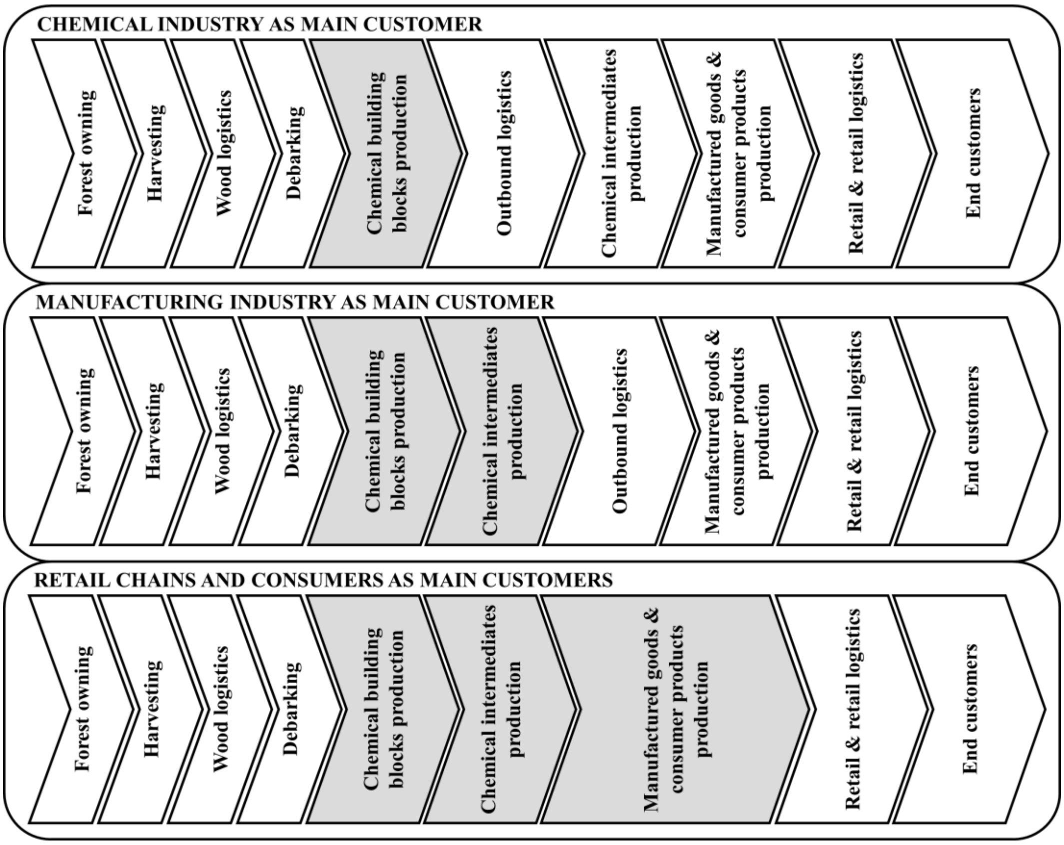


Figure 18. Illustrative example from possible alternative options of value chain downstream integration depth on chemicals production

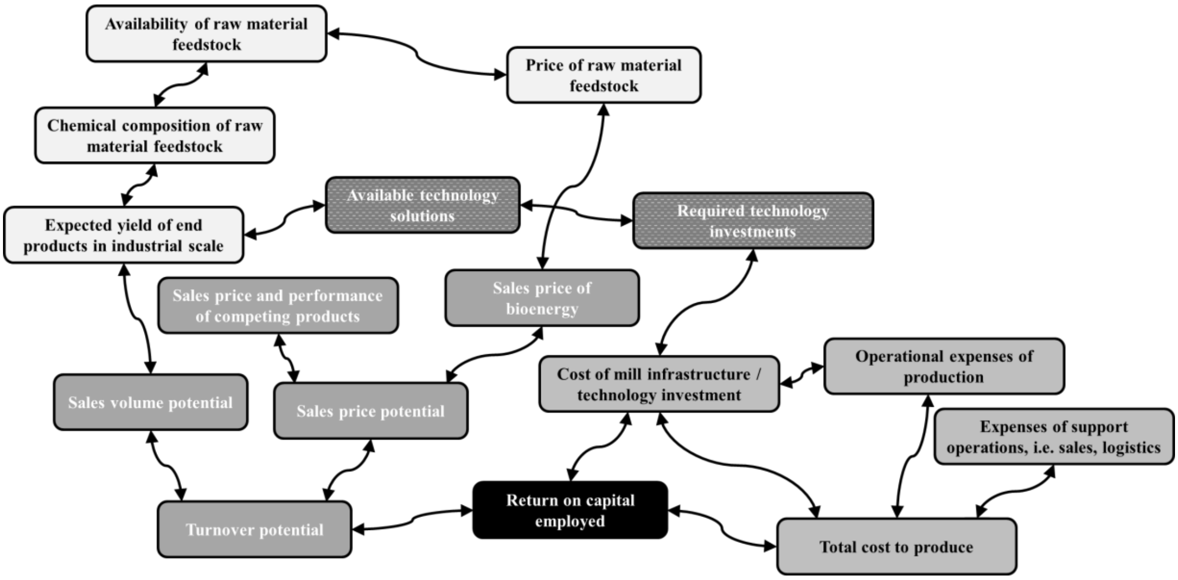


Figure 19. Mind map of the business case framework created

Raw material availability and price are key factors for economic performance of biorefineries. In the selected case secured availability to birch bark is assumed. This is due to it being a side stream in company and being currently mainly burned as energy. Price of energy has direct linkage to economic feasibility of utilizing birch bark to biochemicals production in the selected case, due to bark being used to biochemicals production instead of energy use. Furthermore, the production of biochemicals will require energy and less bioenergy is possible to be sold outside the biorefinery. As the storage time of birch bark impacts its chemical composition, this will also impact to potential yield of production, and possible sales amounts of end products. In the model is not included raw materials supply chain optimizations to receive more fresh birch bark for biochemicals production. This is due to other large volume products that company is producing from the stem wood. The possible optimization would require taking into account whole production schema and working capital considerations also.

The total turnover potential of biochemicals production is dependent from possible production volumes and from potential sales prices. When assessing potential sales prices, it is possible to asses it from different perspectives. One view is production costs and the decreased bioenergy sales when outer bark is not anymore burned as energy. Product sales price should be high enough to be economically feasible to convert already existing bioenergy sales to biochemical sales. Another view is competing existing products. For end customers in textile industry there needs to be business case to switch to usage of new bark-based chemicals. From the end customer perspective, the combination of “functional performance and total production costs with new chemicals” compared to competing alternatives needs to be appealing. Otherwise there is no market buy-in in large scale.

Available technology solutions will impact also economic feasibility. The selected production technology will impact expected yield and purity of end product, which will further impact to potential sales prices. The chosen production technology will also impact required capital investments and operational costs of production, which both impact the total cost of production. The operational costs have a linkage to required energy needs, which is in this case further linked to price of bioenergy. The investment needs are also dependent from the existing infrastructure of a company. Commonly used terms in this context are greenfield and brownfield investments. With greenfield investment is meant building up new facilities and processes from ground up. Respectively, with brownfield investment is referred to an investment that utilizes or re-purposes existing facilities/infrastructure.

Return on capital employed is used as the main economic measure in the model. This is derived from total costs of production, turnover potential, and from required capital investments. When assessing all of these above mentioned dimensions, the time perspective needs to be considered carefully. The proposed use case is new technologically, and continuous developments will impact production costs. The sales prices of biochemicals need to be also considered over time. This should be done from perspective of the market maturity changes over time also. On figure 20 the typical product life cycle phases and the phases on market development are presented.

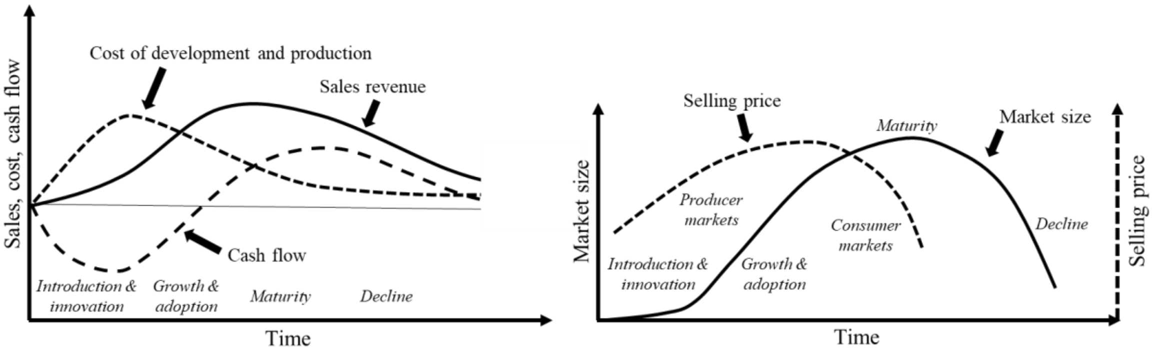


Figure 20. The product life cycle phases and the phases on market development (modified from Budzianowski, 2016)

Durable oil and water repellents are important in many textile applications like in outerwear garments and personal protective equipment (PPE). As an example, the annual market size of outwear garments in EU was around ~10 billion EUR in 2012. And estimate for worldwide PPE markets was around ~9 billion EUR in 2014. (European Commission, 2016) While having large market volumes, the textile industry also has significant environmental issues.

The sustainability issues in textile processing can be categorized into three major areas according to Arputharaj et al. (2016), which are

- *"Usage of water*
- *Energy consumption and carbon footprints*
- *Pollution load and waste generation".*

Furthermore, the sustainability categorization in textile industry can also be extended to cover health hazards and concerns.

The textile wet processing is one of the most water-consuming industries. It has been estimated that total of 50-200 liters of water is required to convert one kilogram of raw textile to finished product. The end product does not contain any water, so all the used water is processing water. The effluents from textile industry are typically contaminated with dyes and chemicals. Reusing the water in processes would mean tedious and complex effluent treatments. The energy usage is also one key factor in textile processing. Many of the wet processing techniques require heating, and some chemicals for example have defined operating temperature ranges. This means that choosing the processing chemical impacts to the energy consumption of the process, not just only to needed water usage amounts and environmental pollution impact. (Arputharaj et al. 2016)

Related to pollution impact, fluoropolymer-based water and stain repellents like perfluorooctane sulphonates (PFOS) and perfluorooctanoic acid (PFOA) pose significant health concerns. These chemicals are very stable, and they create ecological threat as they do not easily degrade. These chemicals may build up in the food chain and remain there relatively long time. Studies have shown that half-life of fluoropolymer-based chemicals in the human body is around ~4,5 years. (European Commission, 2016) Although both in academic literature, and in governmental reports, alternatives for currently used water repellents have been studied, finding reliable commercial information about textile water repellents from public sources is problematic. In general, the economic information available publicly about water repellent chemicals is scarce. For example, van der Putte et al. (2010) studied alternatives for PFOA, but concluded in their work that it was not possible to perform reliable economic analysis based on information available on open markets. The companies producing alternative options for PFOA consider their prices as confidential business information, and are not willing to release information, they are kept as trade secrets.

Regardless of missing fully reliable information, anyhow some indicative key figures can be found from open data sources. European Chemicals Agency (2015) has estimated that textile industry in EU uses around ~1 000 tons/years PFOA-related substances, and that ~150-200 tons/year is used for the treatment of paper in Europe. It is good to acknowledge that outdoor garments are mainly produced in Asia, but unfortunately market and chemicals usage information from these products is not available. Anyhow, the European Chemicals Agency (2015) has estimated that the imported textiles to EU contain in magnitude of ~1 000-10 000 tons/year PFOA-related substances. The prices of PFOA-related substances are estimated to be around 20-80 EUR/kg according to European Chemicals Agency (2015). Related to chemicals usage amounts in end products, the amount of bound PFOA side-chain fluorinated polymers in textiles is estimated to be typically around ~0,5-1% from the weight of fibers. (European Chemicals Agency, 2015) Other examples from prices of textile water repellant chemicals can be found from work of Ferrero & Periolatto (2013). They estimate that price of 1H,1H,2H,2H-Fluorooctyltriethoxysilane (FOS) is 40 EUR/kg and Fluorolink® S10 is 80 EUR/kg. According to estimate of United Nations (2016) price of PFOS products used as mist suppressant for non-decorative hard metal plating is around 13-27 EUR/kg, and alternative chemicals are estimated to cost around 16 EUR/kg. It is good to understand that usage amounts needed to achieve required end result varies between different products and impacts cost efficiency. The usage amount of PFOS derivates in textiles is typically around ~2-3% from the fiber weight and around ~15% when used on carpets. (United Nations, 2016) Furthermore, it has been estimated that world-wide production of fluorotelomers is around ~11 000-14 000 tons/year, and that about 50% of the volume is used in textiles. The other two large use cases for the fluorotelomers are carpets and paper coatings. (Lassen et al. 2013)

Plant wax is broad term referring to the complex mixtures of hydrophobic compounds from herbaceous plants. Waxes are extensively used is in coatings due to their hydrophobic nature. Wax coatings are used for example in food packages, papers, textiles and so forth. Some edible waxes can also be used to coat fresh fruits and vegetables to improve shelf life. The total wax market globally was around ~4.5 million tons in year 2013, and the large petroleum wax producers where mainly located in Asia. Related to plant waxes, the average price of non-petroleum waxes imported to United States in year 2015 was 5,75 EUR/kg. Few examples from typical prices of waxes are: beeswax 7,66 EUR/kg, carnauba wax 7,15 EUR/kg and candelila wax 2,68 EUR/kg. Currently some of petroleum wax producers are shifting their production away from feedstock needed for wax manufacture. The possible supply reduction in petroleum waxes combined with predicted growth in demand may lead to increasing prices. Additionally, the movement towards greener consumer products may result to new opportunities for natural sustainable wax producers. (Attard et al. 2017)

When looking global superhydrophobic coatings market in general, not just textile water repellents, there is expected to be significant growth in future. Currently only small number of companies manufacture fluorine-free superhydrophobic products. Majority of global production is still fluorine-based, although as stated many environmental concerns are related to these products. Research has increased towards cost-effective coating materials, which would be made from natural polymers and silicon-based alternatives. Anyhow beside the cost aspect, durability and longevity against temperatures and corrosive compounds are hurdles that the new more environmentally sustainable alternatives need to also overcome. (Ghasemlou et al. 2019)

Related to the case "birch bark based biochemicals in textile industry" and Excel-tool created, Monte Carlo simulation method was selected for concept screening purposes. Monte Carlo simulation is commonly used stochastic optimization method. It is tool that can be used for example in insurance modelling, capital budgeting, risk management, and in strategic planning. The simulation method is based on artificially recreating a chance process and then running it several times. In essence, the Monte Carlo simulation method repeats process or situation large number of times with random samples linked to specified variables. When the modelling is setup properly, the input variable are independent random quantities which do not correlate with each other. The industry benchmark is that 10 000 iterations is often already enough to obtain reliable results. (Lan et al. 2019; Zaroni et al. 2019) The main objective of the Excel-tool was to summarize "order-of-magnitude"-model for studying the proposed case. The done research suggests that there would be realistic amounts of raw material available required by industrial scale production of suberin and triterpentine extractives. The possible end use market volumes are potentially also feasible from perspective of the selected case example. Anyhow, with uncertainties due to missing publicly available data, the analysis gives very wide range of possible ROCE% for the proposed case. This outcome links to economic, financial and path-dependency barriers discussed earlier in thesis, which cause challenges for new greener technologies and solutions. In the case example model chemical industry was assumed as main customer. Anyhow deepening towards the downstream value chain could potentially increase the economic potential. Although investment needs and uncertainties would be even higher, this approach would enable revenue also from product service systems and high value products. Entry barrier for competitors would be also higher, when chemical intermediates and product service systems for manufacturing industry would be the targeted products.

As a summary, further studies are needed beyond the scope of this thesis to limit the economic uncertainties involved to model created, as the potential ROCE% outcome range was rather widespread. More thorough studies are needed on market demand aspects of the birch bark based chemicals, and especially their prices when would be produced/sold in industrial scale with guaranteed/defined quality level. Further studies are also required and proposed on technical feasibility of bark based chemicals as water repellents in industrial scale. The laboratory-scale tests done on academic literature should be next validated in pilot-scale.

23 CONCLUSIONS

Currently global chemical sales are around ~3 350 billion EUR a year. China is the dominant country in chemical industry and covering over a third of the global sales. Megatrends like population growth, urbanization, global warming and digitalization will all impact chemical markets. It is expected that chemical production grows faster than global GDP in near future. Biorefineries are integrating biomass conversion processes to produce various bio-based products and bioenergy. Biorefineries are becoming more important as fossil oil and gas reserves are depleting, they are needed to mitigate the uprising resource scarcity. Furthermore, biorefineries and renewable raw material sources help on fight against global warming and environmental impacts by reducing fossil-carbon dioxide releasing. Biomass feedstock contains complex molecules compared to fossil feedstock. These ready chemical structures should be used as advantage in biorefineries and on bioproducts instead of taking them fully apart or using biomass only as energy source. The biomass feedstock contains large amounts of moisture and it is low in density. To optimize supply chains, biorefineries are more localized and smaller compared to oil refineries. Biobased chemicals can be either drop-in chemicals (chemically identical versions to fossil-based chemicals) or dedicated bioproducts (products that do not have identical fossil-based counterparts). Typical prices of bulk chemicals are around ~1-2 EUR/kg, while specialty chemicals and consumer products are often more expensive. Regulation impacts chemical prices (for example incentives for bioproducts and environmental laws). In some market segments end customers are also willing to pay premium from biobased green products.

Industrial sustainability has evolved from lean manufacturing (process efficiency view) to more broader concepts of green production (pollution reduction) and circular economy (closed material loops). To support these sustainability targets biomass feedstock should be used on cascading way. This means producing high value products first, before other secondary bioproducts, and only the last remainder of feedstock material should be burned for energy. Environmental regulation and policies are driving cleaner chemistry production forward. Furthermore, customer demand for more environmentally friendly products and technology development are supporting green chemistry. However, there are potential barriers for bioproducts to be successful on markets. The main obstacle for bioproducts is that they are often more expensive to produce than fossil-based alternatives. Similarly, from circular economy perspective different factors acting as drivers or barriers can be identified. The biggest barrier for circular economy development is the uncertainties related to long-term economic benefits, this hinders investments and promotes short-term benefits. For bio-based chemicals to be commercially successful they need to be economically competitive and their functional performance needs to match or exceed alternative fossil-based products. Furthermore, the bio-based chemicals need to also have sustainable life cycle impact.

Business models are used to represent how organization creates, delivers and captures value. Business models are important tools for companies to plan their revenue model and differentiation from competitors, both are important aspects in order to be economically competitive. Different sustainable or circular business models can be identified existing. The sustainable business models take into consideration also social and environmental perspectives in addition to the economic value. Challenge in these models often is finding and keeping the right win-win balance between the different independent network actors. Business model canvas is commonly used tool to describe business models. The business model canvas can also be used to describe sustainable or circular business models. It can be enlarged to encompass also business ecosystem level and sustainability impacts beyond the traditional business level view. In chemical industry different basic business models can be identified. In basic chemicals business cost-competitiveness is prominent feature, as volumes are high, margins small and products interchangeable. Respectively, specialty chemicals business is driven by product performance and features. Products are less interchangeable between producers as specialty chemicals are often application or use case specific. On product-service-systems the business models are based on services where customer is paying from the result, not from the chemical itself. The business model chosen by company needs to be aligned with its strategy and its strengths.

Sustainable business model innovations create positive (or reduce negative) impacts for environment and society beyond the economic value. Sustainability performance of companies is possible to assess with Triple Bottom Line approach taking into account economic, environmental and social dimensions. When considering economic performance of biorefineries against fossil-based competition, the key factors are secured access to low cost biomass feedstock, cost-efficiency of production, and value of the final product for end customer. Furthermore, when assessing the potential of biorefinery products, the maturity of targeted markets and selling price changes over time should also be considered. Although the competition on mature chemical markets may lower selling prices, companies should also consider the market dynamics from their end customers perspective. A possible supply risk can be experienced by end customers on new products/chemicals that have only one single manufacturer. This may even create entry barriers for the new products/chemicals.

In the case example chemicals from birch bark for textile industry were studied. Currently textile and clothing industry is one of the most polluting industries and it is concentrated to low cost countries with low environmental and social regulations. The chemicals used by textile industry can be divided to processing chemicals used in production process and to effect chemicals that provide function to the end product. Instead of burning bark as fuel, different possible value-add use cases for birch bark are proposed in academic literature. The birch bark is chemically interesting, and especially the outer bark layer is a potential source of biochemicals. Main chemical components of outer bark are various triterpene extractives (~30-40 %) like betulin and non-soluble polymerized suberin (~40-50 %). When assessing industrial scale feasibility of triterpenes extraction processes, the solvent consumption, energy usage, purity of end product, and the yield are critical elements for the economic feasibility. Many of triterpenes are volatile or chemically unstable, and this feature needs to be acknowledged, when planning the raw material supply chain. The amount of extractives on outer birch bark decreases significantly over storage time already in few weeks. As the birch bark has rather low density and the storage time impacts to the yield of extractives, the economic aspects of bark transportation need to be considered carefully. As a summary one could reason that, the valorization of extractives from birch bark is more economical to be done as onsite extension to existing production processes, compared to detached production facilities requiring separate collection and logistics of the bark.

It is proposed in literature that both betulin and suberin could potentially be used in textile industry as more environmentally friendly options instead of e.g. paraffin waxes and fluorinated silanes to achieve water repellent properties. Further studies are required in this area, but some initial studies have shown that with betulin-based copolymers is possible to achieve high hydrophobicity in the laboratory environments. The potential new betulin and suberin material flows in industrial wood usage were studied and Excel-based tool was created to analyze economic feasibility of the proposed use case. In the studied case the production volumes possible are limited by raw material availability, and the potential end use market size is also smaller compared to the common building block chemicals. The proper business model should be therefore planned from specialty chemicals and application oriented solution perspective for this initial proposed case. Although the operational excellence and economies-of-scale are important in the chemical industry, the focus should be more on delivering performance benefits and potential competitive advantage with green alternative to end customers of textile industry.

Related to selling prices of chemicals, often higher purity rate of a chemical increases the selling price received. Anyhow aiming for high purity rates may require larger investments, as additional separation/purification process steps often are required. From economical profitability perspective, the different process options need to be analyzed both from investments required and selling prices for certain purity rate perspective. It is additionally good to acknowledge that in some industries, like pharmaceuticals or food industry, end customers may want to carry out themselves the final purification step due to product liability reasons. Therefore, understanding the market dynamics is critical, in some cases selling price premium received from higher purity may be limited or marginal compared to required investments.

Further studies are required in the area economic feasibility, market demand, and prices of chemicals in industrial scale. The main outcome and value-add of this thesis was to collect broad overview to chemical markets, barriers and drivers of biochemicals, and to business models found in chemical industry. Additionally, an “order-of-magnitude”-model for concept screening purposes was created for birch bark based chemicals.

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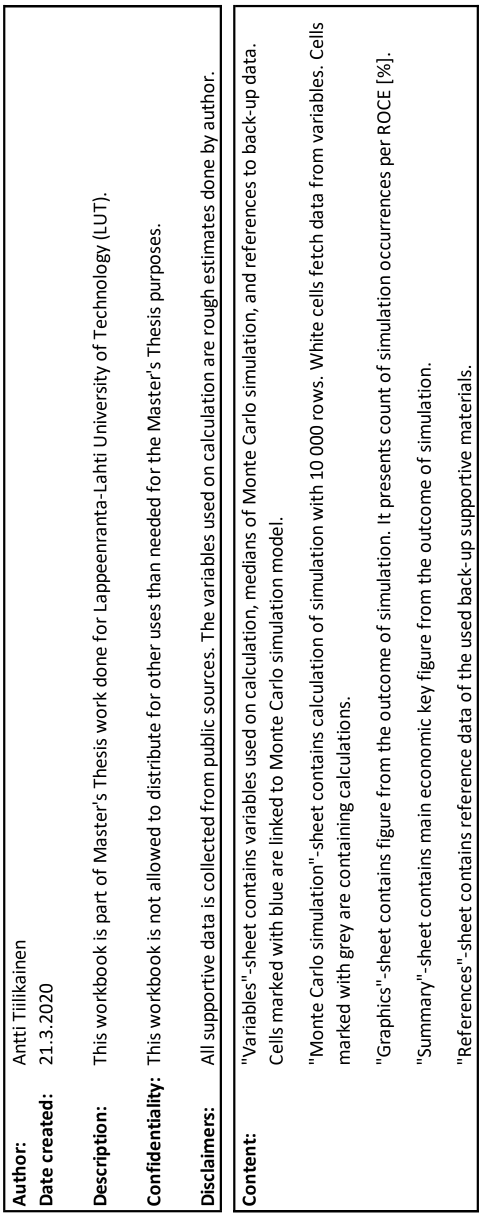
LIST OF APPENDICES

APPENDIX 1. Business case Excel tool

Sheets in Excel tool:

- Cover page
- Variables
- Monte Carlo simulation & summary [*not attached*]
- Graphics
- References

Cover page



Author:	Antti Tiilikainen
Date created:	21.3.2020
Description:	This workbook is part of Master's Thesis work done for Lappeenranta-Lahti University of Technology (LUT).
Confidentiality:	This workbook is not allowed to distribute for other uses than needed for the Master's Thesis purposes.
Disclaimers:	All supportive data is collected from public sources. The variables used on calculation are rough estimates done by author.
Content:	"Variables"-sheet contains variables used on calculation, medians of Monte Carlo simulation, and references to back-up data. Cells marked with blue are linked to Monte Carlo simulation model. "Monte Carlo simulation"-sheet contains calculation of simulation with 10 000 rows. White cells fetch data from variables. Cells marked with grey are containing calculations. "Graphics"-sheet contains figure from the outcome of simulation. It presents count of simulation occurrences per ROCE [%]. "Summary"-sheet contains main economic key figure from the outcome of simulation. "References"-sheet contains reference data of the used back-up supportive materials.

Variables

Raw material availability	**Min**	**Max**		**References for estimate:**
Annual birch wood availability [m3]	X	Y		[1-8]

Selected raw material usage range	**Min**	**Max**	**Median of simulation:**
Annual usage of a pulp mill [m3]	X	Y	Z

Production yield	**Min**	**Max**	**Median of simulation:**	**References for estimate:**
Amount of outer bark from birch wood [%]	X	Y	Z	[9-10]
Density of birch bark (moisture 35-40 wt.%) [kg/m3]	X	Y	Z	[10]
Amount of suberin in outer bark [%]	X	Y	Z	[10-13]
Amount of triterpenes in outer bark [%]	X	Y	Z	[10-13, 15]
Betulin content from triterpentine extractives [%]	X	Y	Z	[10, 14, 15]
Lupeol content from triterpentine extractives [%]	X	Y	Z	[10]
Triterpene extractive losses due to storage [%]	X	Y	Z	[14]
Yield in production scale from theoretical scale [%]	X	Y	Z	[16-17]

Production yield	**Median of simulation:**
Amount of outer birch bark (moisture 35-40 wt.%) [kg]	Z
Amount of dry outer bark [kg]	Z
Amount of suberin [kg]	Z
Amount of betulin [kg]	Z
Amount of lupeol [kg]	Z

Options in core equipment	**Small plant**	**Large plant**	**References for estimate:**
Bark unloading & storage [€]	X	Y	[18-20]
Bark crusher and screening [€]	X	Y	[18-20]
Boiling pre-treatment of bark [€]	X	Y	[18-20]
Bark drying machinery [€]	X	Y	[18-20]
Reactor vessel [€]	X	Y	[18-20]
Storage tanks [€]	X	Y	[18-20]
Pumps & compressors [€]	X	Y	[18-20]
Filtering equipment [€]	X	Y	[18-20]
Waste handling equipment [€]	X	Y	[18-20]
Total [€]	X	Y	

Purchased core equipment	**Min**	**Max**	**Median of simulation:**
Mid-to-large size equipment [€]	X	Y	Z

Uncertainties in purchased equipment prices	**Min**	**Max**	**Median of simulation:**	**References for estimate:**
Accuracy range [%]	X	Y	Z	[21-22]

Rationed investment cost components	**Min**	**Max**	**Median of simulation:**	**References for estimate:**
Equipment installation [+% to core equipment]	X	Y		[23-26]
Instrumentation & controls [+% to core equipment]	X	Y		[23-26]
Piping [+% to core equipment]	X	Y		[23-26]
Electrical systems [+% to core equipment]	X	Y		[23-26]
Buildings [+% to core equipment]	X	Y		[23-26]
Service facilities [+% to core equipment]	X	Y		[23-26]
Land & yard improvements [+% to core equipment]	X	Y		[23-26]
Engineering and supervision [+% to core equipment]	X	Y		[23-26]
Construction expenses [+% to core equipment]	X	Y		[23-26]
Overheads & contract fees [+% to core equipment]	X	Y		[23-26]
Contingencies [+% to core equipment]	X	Y		[23-26]
Total [+% to core equipment]	X	Y	Z	

Investment	**Median of simulation:**
Purchased equipment incl. uncertainties [€]	Z
Other investment components [€]	Z
Total investment [€]	Z

Options in operational personnel	**Small plant**	**Large plant**	**References for estimate:**
Operators [FTEs]	X	Y	[26-27]
Shift engineers/supervisors [FTEs]	X	Y	[26-27]
Plant managers [FTEs]	X	Y	[26-27]
Distribution & marketing [FTEs]	X	Y	[26-27]
Other personnel [FTEs]	X	Y	[26-27]
Total [FTEs]	X	Y	

Operational personnel	**Min**	**Max**
Mid-to-large size operations [FTEs]	X	Y

Operational costs, personnel	**Min**	**Max**	**References for estimate:**
Wages & salaries [€/year/FTE]	X	Y	[26-27]
Overhead, office, phone, protective gear [€/year/FTE]	X	Y	[26-27]
Personnel related costs [€]	X	Y	[26-27]

Operational costs, rationed to equipment	**Min**	**Max**	**Median of simulation:**	**References for estimate:**
Maintenance [% from capital of equipment]	X	Y		[26-27]
Taxes & insurances [% from capital of equipment]	X	Y		[26-27]
R&D [% from capital of equipment]	X	Y		[26-27]
Patent & royalty charges [% from capital of equipment]	X	Y		[26-27]
Total [% from capital of equipment]	X	Y	Z	

Operational costs, rationed to production	**Min**	**Max**	**Median of simulation:**	**References for estimate:**
Calorific value of moist birch bark [MJ/kg]	X	Y		[35]
Calorific value of moist birch bark [MWh/kg]	X	Y	Z	[36]
Energy price of raw material [€/MWh]	X	Y	Z	[28]
Energy needs to dry bark [MWh/m3]	X	Y	Z	[29-30]
Energy needs to process 1 kg of betulin [GJ]	X	Y	Z	[31-32]
Solvent needed per 1 kg of betulin [kg]	X	Y	Z	[32]
Solvent recovery rate [%]	X	Y	Z	[33]
Price of solvent [€/kg]	X	Y	Z	[34]

Operational costs	**Median of simulation:**
Personnel related costs [€]	Z
Operating cost rationed to investment [€]	Z
Raw material price [€]	Z
Energy needs to dry bark [€]	Z
Energy needs to process extractives [€]	Z
Solvent consumption [€]	Z
Total operational costs [€]	Z

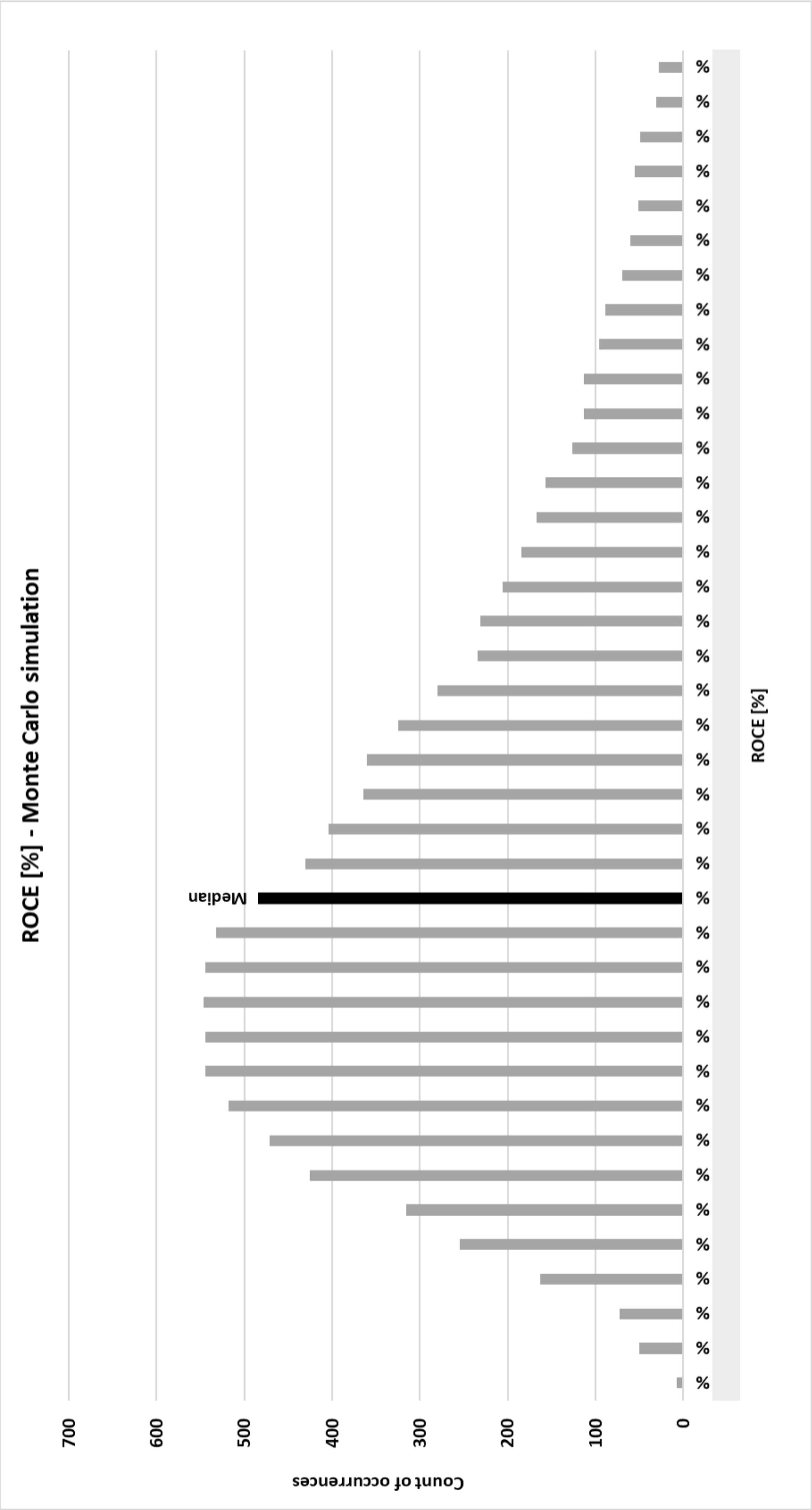
Key operational figures	**Median of simulation:**
Energy needs to dry bark [MWh]	Z
Energy needs to process extractives [MWh]	Z
Total energy needs [MWh]	Z
Solvent consumption [kg/year]	Z

Depreciations	**Annual**	**Median of simulation:**	**References for estimate:**
Plant & machinery depreciations [%/year], [€]	X	Z	[37-38]

Selling prices	**Min**	**Max**	**Median of simulation:**	**References for estimate:**
Suberin [€/kg]	X	Y	Z	[49-51]
Betulin [€/kg]	X	Y	Z	[39-44]
Lupeol [€/kg]	X	Y	Z	[45-48]

Key financial figures	**Median of simulation:**
Turnover from Suberin [€]	Z
Turnover from Betulin [€]	Z
Turnover from Lupeol [€]	Z
Turnover [€]	Z
Total operational costs [€]	Z
EBITDA [€]	Z
EBITDA [% from sales]	Z
Depreciations [€]	Z
EBIT [€]	Z
ROCE [%]	Z

<u>Graphics</u>


ROCE [%] - Monte Carlo simulation
Count of occurrences
0
100
200
300
400
500
600
700
Median
ROCE [%]
%

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