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Master's Thesis

Bioprospecting: Forest bioeconomy and bioproducts

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Abbreviations

PFI: Paper and Fiber Research Institute (PFI)

NIBO : The Norwegian Institute of Bioeconomy Research)

CMF: Continuous Motion Filling

LPMOs: Lytic polysaccharide monooxygenases

IEA: International Energy Agency

GDP: Gross Domestic products

CNC: Cellulose Nanocrystals

IEA: International Energy Agency

GDP: Gross Domestic Products

HCl: Hydrochloric acid

CEPA: chloroethylphosphonic acid

PDME: pinosylvin dimethyl ether

PMME: Pinosylvin monomethyl ether

PLA: Polylactic acid

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Abstract

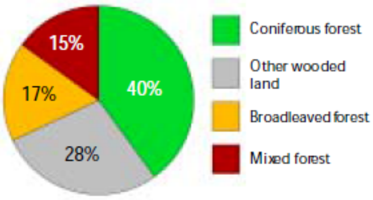
Extraction of the valuable bioproducts from forest resources is crucial inorder to reduce carbon emission, creating sustainable environment and contributions in national economy. Norway consists of a large area of boreal forest resources and biomass which has a very potential sources for providing bio based products. This approachs for searching, identifying of commercially valuable products from natural resources is termed as bioprospecting. Biorefineries are the platforms that manufacture bioproducts involving different stage/ process such as raw materials processing, technical process or methods for production of chemicals, and extraction/ recovery process for desired products. Apart from using biorefineries as the platform for value creation, appropriate strategies, plans and policies are also required to achieve the goal. The study has reviewed the possibilities of valuable products from Norwegian tree species eg. Scots pine, Norway spruce and Birch with the inclusion of case studies in Norway, Finland and Sweden. Furthermore, this study discuss and suggest the strategies to create the value from forest resources, figured out challenges related to Norwegian forest industry, and some recommendations to increase the value from Norwegian forest. While concluding this paper, the study was concluded with the focus on approaches like collaboration across related sectors, sustainable utilization of renewable forest resources along with its productions and extractions.

Keyword: Biorefineries, forest bioproducts, Scots pine, Norway spruce, Birch, strategies

1. Introduction

Bioprospecting is the investigation of biological resources for commercially profitable compounds, substances or genetic materials. Bioprospecting defines as the examination of nature for economically valuable genetic and biochemical resources (Arico & Salpin, 2006) "Biorefinery is the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, and chemicals) and energy (fuels, power, and heat)(IEA Bioenergy, 2014). A different concept of biorefinery had been subjected to emerge dating back from the turn of the century 50 during the last decade. Despite, providing food, feed, and energy, biomass has been contributed to the extraction of valuable products such as medicinal drugs, flavors, and fragrances. But the large-scale industrial conversion of biomass to chemicals and materials had been started only during the second half of the 19th century(Gallezot, 2012). The production of cellulose esters (nitrate and acetate) and oxidized linseed oil (linoleum) was started during this period. During the last ten years, the concerns for biomass conversion to chemicals has been arising greatly within industrial companies and Academia with the support of international and national agencies. Chemical manufacturers worldwide became interested in renewable feedstock for producing bulk and specialty chemicals, while start-up and SME companies developed innovative processes to produce chemicals and materials in niche markets. Interest in the biomass-to-chemical value chain raised as the chemical industry accelerated the development of sustainable manufacturing processes (Gallezot, 2012).

Among variety of natural resources, Norway is abundant in forest resources. According to statistics, forest and other wooded land cover 39 per cent of the land area in Norway. Over the last 50 years, the annual volume of timber harvested has varied between 7 and 11 million m3, with a downward trend the last ten years. Forest resources are contributing to national economy in Norway. These sectors contribute about 1.1 per cent of GDP, 1.6 per cent of the employment and 8.6 per cent of the export value not including oil and gas. Approximately 88 per cent of the forest area is in private ownership, which is divided among more than 120 000 properties(Norwegian Ministry of Agriculture and Food, 2007). Out of total forest area in Norway, most of the area has been occupied by the coniferous forest which are followed by wood landed forest, broadleaved forest and mixed forest subsequently.



	Area, km²
Forested area & other wooded land	120.000
Forested area	87.000
Coniferous forest	49.000
Broadleaved forest	20.000
Mixed forest	18.000
Other wooded land	33.000

Source: NIJOS

Fig1. Showing the forested area of Norway(Norwegian Ministry of Agriculture and Food, 2007)

According to statistics of Norway, among different tree species Norway spruce accounts for higher percentage (47%) of total species whereas scots pine occupies 32% of total forest resource and broadened leaves tree species accounts rest other percentage of forest mass.

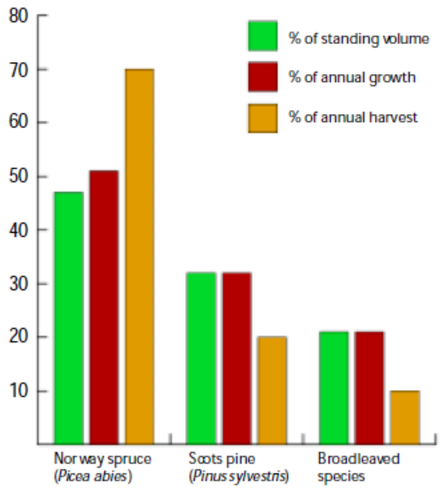


Fig 2. Distribution of Norwegian tree species along with statistics of annual growth, volume and harvest (Norwegian Ministry of Agriculture and Food, 2007)

Conifers like Norway spruce, Scots pine consists of various extractives and biochemicals which are produced as metabolic biproducts through different biocatalytic pathways, but it has been found that Birch species produce lesser variety of chemical compounds in comparison to conifers. However, the extractives obtained from tree species depends upon the concentration and variation in spatial distribution of extractives. To the prospects of the chemical constituent's extraction, Scots pine contributes to a greater number of extractives in comparison to Norway spruce. The proportion of extractives in different parts like stem wood, branch wood, stump, root wood, and foliage are higher in Scots pine in contrast to spruce except for bark(high in spruce)(Routa, Anttila, & Asikainen, 2017).

The genus Pinus is widely distributed on Earth, occurring from sea level up to more than 10,000 feet occupying boreal, temperate, and tropical regions although it is originated from Northern hemisphere. Due to its distinct properties like ability to successfully explore inhospitable habitats (such as semiarid and subal-pine/subartic regions) and its low technical requirements for planting, Pinus is considered as the one of the most appropriate woody species for cultivating and recovering of abandoned and degraded agricultural lands, as well as non-agricultural or marginal areas. Pine, in the form of logging residue can be collected as either green residues or brown residues. Green residues constitute of higher moisture content with needles whereas brown residue constitute of low moisture content with half of needles and small amount of thin branches that remain at logging site (Oasmaa, Kuoppala, & Solantausta, 2003).

Apart from the benefits of using pine trees in a commercial market as wood products, the species of Pinus has been employed for a wide range of products that are useful in industrial applications. Anciently, the species of pine have been used for the production of resins, but its utilisation is very essential for lumber and pulp. Large number of compounds including secondary, complex and organic compounds can be also synthesised by the species of pine in addition to cellulose. These compounds are the essential components located on the different anatomical structure of plant such as foliage, bark, needles and bole and therefore used by tree for physiological process like growth, reproduction and defence mechanism. Essential oils, resins(rosin, fatty acids and fatty acid esters), and terpenes are the examples of compounds that can be extracted from slash and milling waste (Kelkar, Geils, Becker, Overby, & Neary, 2006a). Pine species are able to synthesis a component terpenoid resin which is one of the defence mechanisms of these trees. This defence mechanism is targeted specially against bark beetle and the fungi. Furthermore, pine resin biomass composed of a monoterpene and sesquiterpene-rich turpentine and diterpenoid-rich rosin fraction which have numerous applications in industrial application as nonwood forest products (Rodrigues-Corrêa, de Lima, & Fett-Neto, 2012).

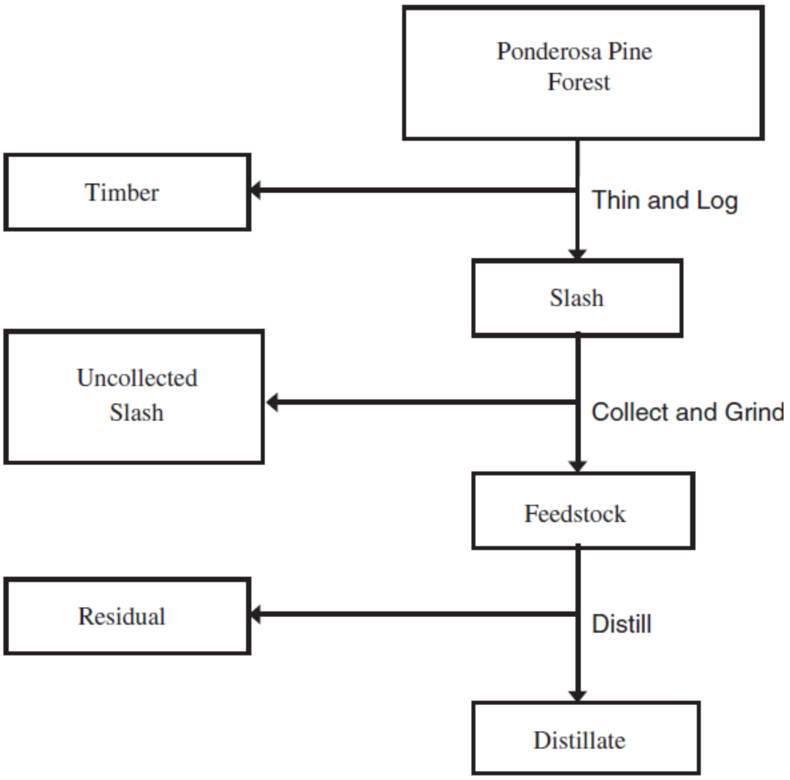


Figure 3. Schematic diagram for recovering essential oils by distillation from pine trees (Kelkar et al., 2006a)

Chemicals that are produced from species of pine are upgraded into many diverse products such as adhesives, inks, rubber, paints, coatings, surfactants, oilfield chemicals, paper size, and fuel. Depending upon the different anatomical parts of pine trees, different quantity of chemicals of chemical are extracted from different anatomical areas of plant. A large variety of chemical constituents can be extracted from different parts of plants but its yield depend upon the type of plant species used for extraction methods as well as the site of extractions. Chemical constituents like cellulose, lignin, arabinose, galactose, xylane etc can be tapped out from stemwood, bark and needles of tree (Oasmaa et al., 2003). Large quantity of hemicelluloses from residues generated by kraft pulping processes have been investigated from loblolly pine (Yoon & van Heiningen, 2010). During recent years, the use of biomass as dominant resources for biorefineries is considered as of great importance. However, transformations of raw material platform to bio will not be quick and simple. Several scientific disciplines such as agriculture, forestry, biology, biotechnology, chemistry, chemical engineering, environmental sciences, are required for the process. Besides these, other factors like industrialists, strong economic and political impulse, etc. are also required for the transformations (Gallezot, 2012).

pine	stem wood	needles	bark
extractives	3	12.6	4.5
lignin	28.1	28.4	29.2
carbohydrates	67.9	54	62.4
cellulose	40.8	29.1	36.2
glucomannane	15.4	11.8	5.2
galactose	1.1	3.7	4.2
arabinose	0.8	3.4	9.2
xylane	7.7	3.9	5.5
uronic acid	2.1	2.1	2.1
unknown	1	5	4

Table 1: Chemical composition of pine in percentage (Oasmaa et al., 2003)

Wide range of useful products including not only wood and cellulose but also nonwood products used by the chemical, food, and pharmaceutical industries, as well as for biorefineries have been produced by utilizing pine species. Various industrial applications of the chemicals or products obtained from pine forest are presented below:

- Different products from pine forest are used as biofuel that may be possible to replace non-renewable petroleum fuels
- Application in paint and coatings industry where pine chemicals are used in alkyd paints and as curing additives.
- Used as an adhesive and sealants in tape, bookbinding, non-wovens, electronics, and construction adhesive tackifiers and can-end sealants in bandage and other medical devices.
- pine chemicals are used in a variety of chemical additives, including fuel; metalworking; lubricants and other additives; PVC stabilizers and plasticizers; flavor and fragrances; paper sizes; food additives; cosmetic additives; seed coatings; and other specialties.
- Pine chemicals are used in construction, paper, cleaning products, printing and publishing and a variety of other industrial activity.

2. Aim of the study

The aim of the study is to suggest the strategy and plan to produce the valuable bioproducts from forest biomass which can serve as platforms in biobased industry. The study is mainly focused on mapping of wide range of products which can be obtained from forest resources or forest biomass through biorefineries in Norway. The general aim of the study is to insight about the possibilities of biochemicals, biomaterials and bioenergy obtained from Norwegian forest biomass.

The specific objectives are:

1. To identify the possibilities of high value-added bioproducts obtained from Norwegian forest eg. Scots pine, Norway spruce, Birch, etc.
2. To analyze the outcomes and lessons learned from selected research articles on forest bioproducts
3. To find out the strategy for commercialization of isolated products in market.
4. To insight the significance of forest resources and bioproducts into bioeconomy.

Limitations

- Only the trees from the forest are included.
- Other forest plants are not included in the study

3. Literature Review

Forests are considered as shelter and constitute approximately 50% of the species of organisms on the earth, consist of potentially useful foods, medicines, and useful chemicals. The tropical forests contain the cures for cancer and all the other diseases of mankind(Brockelman, 1997). A rich tropical forest does have thousands of species of plants and hundreds of thousands of insects and other small animals. These organisms can produce great diversity of chemicals. However, few organisms have been screened for useful chemicals (Brockelman, 1997). Practically, the primary sources for forest biomass and bioproducts consists of four main sources, wild stocks from timber productive forest, wild stocks from non-timber productive forest and lands, managed stocks from intensively managed forest and domesticated stocks from agroforestry ecosystem (Wetzel, S., Duchesne, L.C., Laporte, 2006).
Wood biomass consists of mainly chemical constituents like hemicellulose and lignin. Besides of providing these chemical constituents, it also consists of wide variety of low molecular mass compounds known as extractives. Therefore, interests in studying the individual component has been increasing in order to achieve the objectives of enhance effectiveness in feedstock utilization through product diversification and improved recovery (Routa, Anttila, et al., 2017). These extractives form the platform and functionalities for different types of industries including pharmaceutical, cosmetic, beverages, wood adhesive etc (Roitto et al. 2016).

3.1. Norwegian forest sector

The forest stock in Norway has been significantly increasing during recent year. The growth of forest stock has been occurred such a way that its volume has grown around 25% during the last decade. According to the calculations for the inventory cycle 2012-2016, the total stock in Norwegian forests is now 952 million cubic meters. The annual increment in total was 25.8 million cubic meters. In productive forest, the annual increment amounted to 23.8 million cubic meters; of which 18.5 million cubic meters are in conifer forest (Statistics Norway, 2017)

Approximately, the forest area occupies 37% of total land in Norway. Out of total 127544 forest property, 6.9 million decare of area is covered by productive forest area. The area of forest is growing particularly towards the north to higher altitude. Based on county of Norway, county Nordland accounts for covering highest area of productive forest area which is followed by Oppland and Hedmark respectively.

During these recent years, Norway has contributing in its national economy from selling its wood products. The statistics showed that 8% of timber price has been increased from 2016 to 2017. Sawlogs, pulpwood and sam´s works of Gran (Norway spruce) constitute the greater amount of price change during these years which is followed by the timber wood of pine trees(Norway Statistics, 2018)

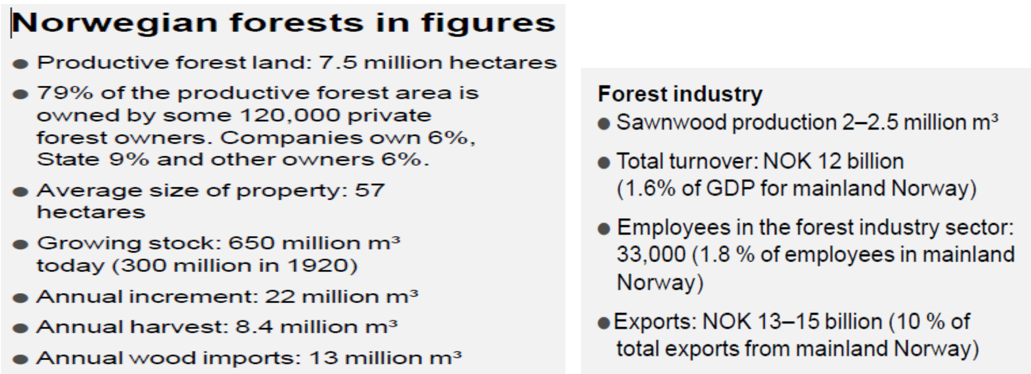


Fig 4. Statistical data of Norwegian forest sector (Nordic Forest Research Cooperation Committee, 2003)

3.2. Distribution of Norwegian trees species

There are various varities of plants available in Norwegian forests such as spruce, pine, yew birch, scots elm, oak, hazel, and holly. Among these tree species, the dominant species are: Norway spruce, scots pine and birch. 47% of total Norwegian forest constitute Norway spruce whereas Scots pine (33 per cent) and birch (18 per cent)(Statsministerens kontor, 2007)

3.2.1. Norway Spruce

Norway spruce (*Picea abies* L. Karst) belongs to the pine family (Pinaceae) and the genus Picea, which diverged from its sister clade 180 million years ago(Lockwood et al., 2013). The genus consists of about 34 species (Farjon, 2001). The eastern part of southern Norway and mid Norway from Sør-Trøndelag to Rana is found to be areas for distribution of Norway spruce. In addition, there are numerous smaller occurrences in western Norway, as well as a few populations in northern Norway (eastern Finnmark), close to the Russian border (Elven 1994). Beyond the natural distribution, Norway spruce has been planted in the lowlands up to Finnmark, the northernmost county in Norway (Aarrestad, Myking, Stabbetorp, & Tollefsrud, 2014).

Scots pine is presently distributed in most parts of the region, even though the pinewoods are rather scattered along the coastline and on the islands. Scots pine is found throughout West Norway from sea level to 1100 m elevation, on the highest mountain plains only as saplings. In the southern, coastal mountains the upper timberline of Scots pine is ~400 m, and it decreases to ~300 m in the northernmost districts(Oyen et al., 2006)

Birch (Betula pubescence) is distributed widely throughout Norway and this species dominate the Norwegian forest towards northern and upwards. In addition to these, another species of birch commonly known as silver birch (Betula pendula Roth) is common in the low lands of southern Norway whereas dwarf birch (Betula nana L) is common in the low alpine belt (Karlsen et al., 2009)

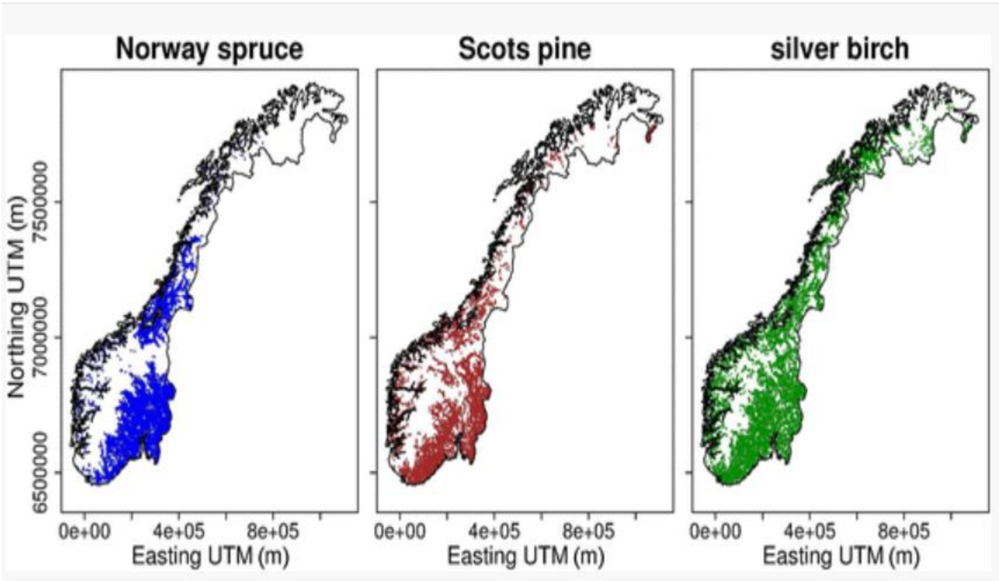


Fig 5. Regional ranges of Norway spruce, Scots pine and silver birch in the Norwegian National Forest Inventory (Schmidt, Breidenbach, & Astrup, 2018)

3.2.2. Norwegian Scots Pine

Scots pine (*Pinus sylvestris*), is also known as Scotch pine, Scots fir, Irish Giuis, common pine or red fir, is a tree belonging to the pine (Pinaceae) family. It is among the most widely distributed conifer species with a natural range from Western Europe (Scotland) to Eastern Siberia, south to the Caucasus Mountains and as far north to the Scandinavian Peninsula in the Arctic Circle. A mature tree is large, growing up to 35 m in height and 1 m in diameter. They often have a crooked trunk with sparse branching and an irregularlyshaped crown. The morphological characteristics of scots pine consists of leaves, flower, fruit, seed and root. The leaves of scots pine are needles and are slightly twisted, 2.5-5 cm in length, 1-2 mm wide and bunched in groups of two with a grey 5-10 mm basal sheath. Scots pine is an evergreen coniferous tree that can live for 80 years or longer under ideal growing conditions. Mostly common habitat for Scots pine include open pine forests and woodlands, rocky hills, eskers, bogs and swamps. Scots pine can tolerate a wide variety of soil types, however, it grows best on light, well-drained and sandy soils. Although the tree species can grows on permanent frozen areas, Sco.ts pine may also survive high temperatures, as it grows in the Mediterranean region of Europe(Marinich & Powell, 2017)

Wood biomass can be divided into soft wood and hard wood**.** Softwoods are gymnosper and originate from coniferous trees, including pines, spruces, and firs. Hardwoods are angiosperms and originate from deciduous trees, including oaks, maples, and birches(Woodford, 2015) . Forest wood consists of high content of cellulose, hemicellulose and lignin. The forest wood biomass that are found in the form of wastes like wood chips, branches, and sawdusts have also been used as bioethanol feedstocks. Biorefineries that are producing value added produts by utlilzing biomass undergoes a series of producion process depending upon the type of feedstock used In general, the biochemical conversion process of woody biomass to biofuels consist of four stages: pretreatment, hydrolysis, fermentation, and distillation. Unlike nonwood biomass, wood residue from forest require pretreatment and sachharification of woody biomass(Achinas & Euverink, 2016).

3.2.3. Bioproducts from Scots pine

Biomass consists of mainly chemical constituents like hemicellulose and lignin. Besides of providing these chemical constituents, it also consists of wide variety of low molecular mass compounds known as extractives. Therefore, interests in studying the individual component has been increasing in order to achieve the objectives of enhance effectiveness in feedstock utilization through product diversification and improved recovery (Routa, Brännström, et al., 2017). These extractives form the platform and functionalities for different types of industries including pharmaceutical, cosmetic, beverages, wood adhesive etc. (Roitto et al. 2016). Different types of extractives and chemicals can be obtained from scot pine which are then also further utilized by wide range of manufacturing industries to produce valuable commercial bioproducts in the market.

3.2.3.1 Essential oils

Essential oils are aromatic oily liquids obtained from plant material. The morphological part of plant materials that are used for obtaining essential oils include flowers, buds, seeds, leaves, twigs, bark, woods, fruits and roots (Collier, Short, & Dorgan, 2004). Several species of pinus are found for producing essential oils. Using steam distillation process, fresh twigs and needles of pinus are used for extraction of essential oils. In Norway, the extraction of essential oil which is known as pine oil are mainly carried from *Pinus sylvestris*. The distinguishing features of pine oil are: the oil is almost colorless, mobile and has a strong turpentine-like balsamic odor. Furthermore, there is no odor left on a blotter after 24 hours and due to its dry out characteristics this oil has been gaining a interest. It is used primarily in room fresheners, disinfectants, soaps, detergents and vaporizer liquids. Essential oils have multiple applications or uses depending upon the requirements. It can be used either as cleaning purpose like use for manufacturing detergents, soaps or as fragrance purpose like room fresheners, vaporizing liquids (Ciesla, 2001). Although essential oils have different end use in terms of cosmetic, food or pharmaceutical, the different quality requirements of the ingredients are also considered as crucial. For instances, in the cosmetic industry essential oils have to conform in terms of odor and flavor, physical properties, chemical composition, purity, absence of adulteration (Collier et al., 2004)

Essential oils constitute of different aromatic compounds. These compounds include α-pinene, β pinene. 3- careen, cardinol, terpinol etc. Among these compounds, pinenes are the most predominant compounds found in essential oils of pine. However, each component of essential oils has individual use and its applications(Kelkar, Geils, Becker, Overby, & Neary, 2006b).

Compound	Percentage	Usage
β-Pinene	45.7	Pharmaceutical
α-Pinene	10.2	Fragrance
3-Carene	8.4	Manufacture of menthol
Estragole (= methyl chavicol)	8.0	
α-Cadinol	2.7	
Limonene + β-Phellandren	2.4	
τ-Cadinol + τ-Muurolol	2.0	
Myrcene	1.4	Insect attractant
α-Terpineol	1.4	Perfume and household products
Terpinolene	0.8	Flavoring food and enhancing fragrance
γ-Cadinene	0.9	
Methyl eugenol	0.6	Pesticide and insect attractant
(ζ)-*trans*-α-bergamot	0.6	
Veridiflorol	0.6	
Camphene	0.5	Manufacture of synthetic camphor
cis-Ocimene	0.5	
Spathulenol	0.5	
α-Muurolene	0.5	
Santene	0.2	

Table 2. Components of essential oils recovered from pine needles(Kelkar et al., 2006b)

3.2.3.2. Oleoresin

Pine oleoresin may be one of the oldest natural products used in large scale by humans. During previous years, it had been used for the purpose like lightening, to seal, and preserve wooden ships (da Silva Rodrigues-Corrêa, de Lima, & Fett-Neto, 2013). Pine oleoresin is a complex mixture of volatile and non- volatile terpenes. Pine resin biomass is essentially composed of a monoterpene and sesquiterpene-rich turpentine and diterpenoid-rich rosin fraction, both finding numerous industrial applications as non-wood forest products (Rodrigues-Corrêa et al., 2012). Terpenes are secondary products that are derived from 5C carbon compound called IPP (isopentenyl pyrophosphate). Among the secondary metabolites, terpenes represent a large group consisting more than 40,000 different metabolites(Rodrigues-Corrêa et al., 2012). The biosynthesis of terpenes occurs in the in the cambium zone and associated vascular tissues through isoprenoid unit. The metabolic cascade for the synthesis involves classic mevalonic acid pathway (in the cytosol) from acetyl-CoA or through the plastid or MEP (2-C-Methyl-D-erythritol 4-phosphate) pathway (Bohlmann & Keeling, 2008). Pine oleoresin formation indicates defense mechanism of these trees against conifers particularly against bark beetle and the associated fungi of plant species (Franciele Antônia Neis et al., 2018). However, in many species of pines, the formation of oleoresin may occur as a constitutive pattern of growth and development (primary or preformed resin)(da Silva Rodrigues-Corrêa et al., 2013). Apart from environmental and genetic influences, the biosynthesis of oleoresin may be modulated physiologically by means of mechanical wounding and use for chemical stimuli for enhancing its synthesis. Commercially, pine oleoresin is tapped from living trees by means of a repeated wounding process (bark streaking method) or bark chipping (Tümen & Reunanen, 2010) which removes the bark and tissues beneath it, followed or not by a chemical stimulant application(Rodrigues-Corrêa et al., 2012). In contrast, some conifers also exude resin spontaneously from branches and cones. The amount of resin production also depends on the several genera of conifers. Some species can produce a large amount of resin which are then harvested and put to a wide variety of uses contributing one of the most important non-wood products from conifers (Ciesla, 2001)

The fully-grown trunk of pine trees consist of different cell layers like bark, phloem, xylem and vascular cambium. The resin ducts are distributed through the tissue. Therefore, the commercial method of oleoresin tapping technique involves removing the bark and further tissue beneath it at variable depth enabling the oleoresin extraction through the resin duct distributed throughout the cell layer. Different method of bark streaking methods like vertical bark streak(10 cm deep wide and deep enough to reach secondary xylem), V-shaped streaks (2–3 mm wide are cut in variable intervals every 24 h, 3 or 7 days in upward direction) etc are used during these days for oleoresin tapping procedure (Rodrigues-Corrêa et al., 2012).

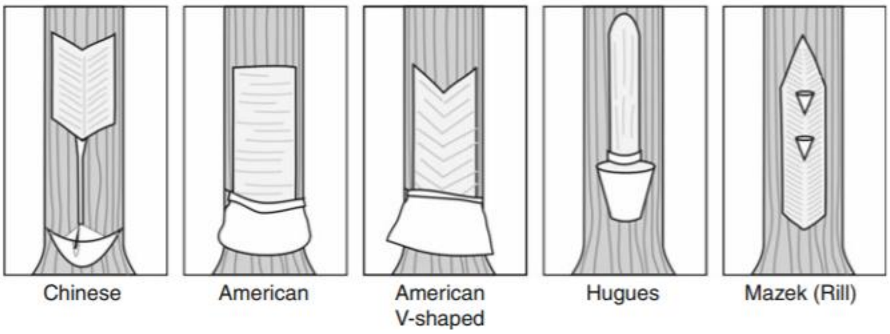


Fig 7. Method of resin tapping (Rodrigues-Corrêa et al., 2012)

Apart from obtaining oleoresin from mechanical wounding method, another principle known as chemical stimulant treatments are also been utilized for centuries to obtain oleoresin. For instances, in the Rill method of chemical stimulant treatment , a spray solution composed of an equal proportion mixture of hydrochloric (HCl) and sulfuric (H2SO4) acids is applied on the exposed "face" to improve resin yield whereas the American method involves a chemical stimulating paste containing sulfuric acid (20%) and CEPA (2-chloroethylphosphonic acid)

(3.5–4.0%) in its formulation is placed on the sapwood or cambium surfaces(da Silva Rodrigues, Apel, Henriques, & Fett-Neto, 2011)(Rodrigues & Fett-Neto, 2009).

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Fig 7. Bark streak method for tapping oleoresin from pine tree. Periodic streaking of bark wounding of time which was then followed by stimulant application. Plastic bags are belted around the trunk to collect the exuded oleoresin (Rodrigues-Corrêa et al., 2012)

3.2.3.3 Turpentine

Turpentine consists of organic compound, basically a various series of volatile compounds known as terpenes. The physical properties of turpentine is a clear liquid which have a pungent odour and bitter taste. The volatile fraction of turpentine, termed as terpenes is simple and can be found mainly as two forms in pines i.e. alpha pinene and beta pinene. However, the chemical composition of turpentine may differ significantly on the type and species of pinus used for its harvesting (Ciesla, 2001). Therefore, it can be found that different species of pine which are distributed in different geographical areas attribute to alteration in terpene composition. For instances, North American pine, *P. contorta*, contains phellandrene, a terpene contained in plants of the parsley family and has a grassy fragrance, Mediterranean species, *P. pinea*, and some North American species contain limonene and P. ponderosa resin contains a sweet smelling terpene, known as 3-carene (Ciesla, 2001).

3.2.3.4. Stillbenes

As a process of biological metabolic pathways, species of pine produces different metabolites. Stillbenes are the one of the secondary metabolites produced in a cascade of metabolic pathway that occurs in plant**.** The compound stilbenes are produced from phenylpropanoid pathway and are derivatives of 1, 2 – diphenylethene, that possess a conjugated double bond system. e.g. Pinosylvin, Pinosylvin monomethyl ether (PMME), and pinosylvin dimethyl ether (PDME) are the examples of stilbenes and their occurrence on scots pine varies on morphology of plant species. The studies conducted on occurrence of stilbenes on the wood shows that it is found basically on heartwood and knots of Scots pine. Stillbenes are generated on plant species as a result of plant defence mechanism against microbial infections. Many studies and research carried on the applications of stilbenes on antimicrobial effect and its contribution on human health. A study carried out by (Välimaa et al., 2007) conduct a test performing antibacterial effects of stilbenes on several food-associated bacteria and concluded with the findings that pure pinosylvin and pinosylvin monomethyl ether have the most consistent antimicrobial and cytotoxic activities.]. Also another study carried out (Lindberg, Willför, & Holmbom, 2004) concluded with the results that pure pinosylvin, pinosylvin monomethyl ether, and dihydro-pinosylvin monomethyl ether are main compounds against paper mill bacteria . Furthermore, it was founded that pure pinosylvin is effective against selected microbials, i.e. *Candida albicans* and *Saccharomyces cerevisiae* with its potent growth inhibitory activity (Lee et al., 2005)

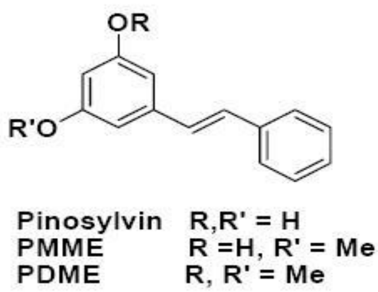

Fig 8. Molecule structure of Pinosylvin, PMME and PDME (Hovelstad, Leirset, Oyaas, & Fiksdahl, 2006)

3.2.3.5 Rosin

Rosin is the involatile residue that remains after the distillation of turpentine. It is considered as the one of the major product obtained from pine resin. Based on physical characteristics of compound, Rosin is a brittle, transparent, glassy solid insoluble in water but soluble in a number of organic solvents (Ciesla, 2001). The quality of rosin obtained depends on the physiochemical properties of the pine species used for the extraction. Mostly the application of rosin can be found in chemically modified form rather than its natural raw form. Rosin is primarily consist of mixture of abietic - and pimaric- type acid with smaller amounts of neutral compound (Coppen & Hone, 1995). Due to presence of this intrinsic acidity properties along with chemical properties, rosins are converted into derivatives products which have wide range of applications. For example, salts, esters and maleic anhydride adducts, and hy-drogenated, disproportionated and polymerized rosins are the derivatives of rosins and their significant use include the manufacture of adhesives, paper sizing agents, printing inks, solders and fluxes, various surface coatings, insulating materials for the electronics industry, synthetic rubber, chewing gums and soaps and detergent (Coppen & Hone, 1995). A study was carried out in order to examine the antimicrobial properties of rosin demonstrates that rosins produced from natural conifers have antimicrobicidal effects against human pathogens. The study was concluded with the findings that purified rosin from the trunk of Norway spruce (*Picea abies*) is antibacterial against the gram-positive bacteria e (S. aureus, MRSA, B. subtilis) and gram-negative bacteria (E. coli, P. aeruginosa) but also against yeasts, like *C. albicans* (Sipponen & Laitinen, 2011)

3.3. Biomaterials production using pine and other wood biomass

3.3.1 Bioplastic/ Biopolymers

Bioplastics are products that hold major attention as a sustainable renewable bioproducts replacing non-renewable fossil based plastic products. Depending upon the types of biomass resources used, different types and generation of bioplastic have been produced. Examples are Biopolyethylen, BioPE (from sugarcane), Polylactic acid, PLA (corn) and 2nd generation BioPE(waste fats and oils). , Bioplastics can be categorised in two groups; dedicated polymers with a new chemical structure (e.g. PLA) and drop-ins (e.g. BioPE) and production of bioplastics utilize both Both chemical and biotechnological production routes (IFBB report, 2016). Recent studies on bioplastic have been shown that bioplastic may be derived from non-agricultural residues like lignocellulosics from wood, agricultural residue and component from bark, however it has been found that the production process required for obtaining bioplastic from wood lignocellulosics is more demanding in comparision to production using agricultural residues. The conversion of lignocellulocis from wood component required fractionation into 3 major components into cellulose, hemicellulose and lignin. Furthermore, it is essential to convert biopolymer into monomer inorder to synthesise bioplastic through polymerisation(e.g. polyolefins, PLA, PHA)(Brodin, Vallejos, Opedal, Area, & Chinga-Carrasco, 2017).

Treatment of biomass for bioplastic production

Lignocellulose biomass is complex and consists of heterogenous structure and composition. Therefore, biorefineries involve different technology to produce bioplastic. Generally, the technology uses for the process include processes for the extraction and conversion of different products, the separation and purification of the intermediate’s compounds and the end-products streams, and their full integration in the overall process. The technological for conversion of lignocellulose biomass into bioplastic consists of following methods and process (Brodin et al., 2017).

A. Fractionation of forest biomass
    1. Mechanical treatment (eg. hammer, blade and roller mills)
    2. Radiation (eg. gamma radiation, ultrasound)
    3. Physiochemical (eg. steam explosion)
    4. Chemical treatment(using dilute acid, alkaline, autohydrolysis, ozone etc)
B. Separation and purification of components from different streams

    Separation and purification can involve (i) equilibrium-based processes, (ii) affinity-Journal based separation, (iii) membrane separation, (iv) solid-liquid separation, and (v) reaction-separation systems
C. Bioplastic

    1.Wood-based platform molecules like succinic acid, 2,5-furandicarboxylic acid (FDCA), 5-hydroxymethyl furfural (HMF), ethylene, levulinic acid, adipic acid and sorbitol

    2.Wood-based polysaccharides as bioplastics eg. cellulose

    3.Lignin-based routes

4.Forest-based components for the production of epoxy bioplastics- including lignin, vanillin (derived from lignin), suberins (derived from bark) and levulinic acid (derived from cellulosic biomass)

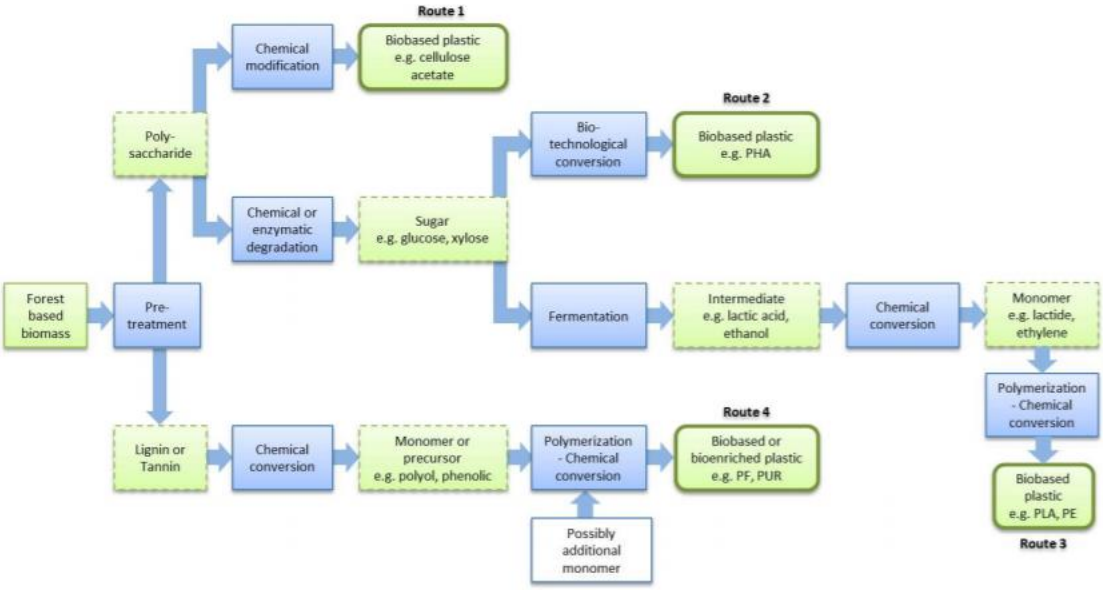

Fig 8. Production routes for forest based bioplastic(Brodin et al., 2017)

A study was carried out on the industrial applications of pine trees for the production of bioplastic. The study showed that two pinene-derived monomers, α-methyl-p-methylstyrene and myrcene, can be incorporated into ABA tri-block copolymers (PAMMSb-PMYR-b-PAMMS) that results in the production of biorenewable thermoplastic elastomers. The thermoplastic elastomers have distinct characteristics properties, including tensile strengths of up to 10 MPa, impressive low energy loss recovery attributes and elongation up to 1300%. Furthermore, elastomers in contrast with conventional petroleum derived products, it executes better performance at higher temperature. Also it has been found from the study that production of green plasticstyrene from fungus *Penicillium expansum* cultivated on forest waste biomass such as leaves, wood, soft bark and mature bark of pine species in the presence of yeast extract broth can be achieved from renewable forest waste biomass, including that from pines (Franciele A. Neis, de Costa, de Araújo, Fett, & Fett-Neto, 2019)

3.3.2. Nanomaterial

The production of nanofibrilled cellulose from woody biomass has gained lot of attractions and concerns during recent years resulting enormous studies on these areas. The characteristics, including biodegradability, renewability, carbonstoring capacity, biocompatibility, reduced toxicity, and low cost, finding several industrial applications and contributing to bioeconomy creates an impetus for conducting research on biobased nanomaterial (Franciele A. Neis et al., 2019). Wood is composed of several components but cellulose, hemicellulose and lignin are the main constituents of wood. 40% of wood components constitute of cellulose which other components constitute rest of it. Cellulose, homo-polymer derived from glucose forms the main skeleton of wood. It is usually in the shape of micro-scale fiber with a length of 1–4 mm and a diameter of 5–50 μm depending on the wood species. Morphological symmetry of plant reveals that the cellulose nano-components are embedded in a matrix of lignin and hemicellulose. This matrix is placed in a nano-gap located along adjacent cellulose nano-components which are mainly located between laterally adjacent nanofibrils (Yousefi, Azari, & Khazaeian, 2018).

3.3.3 Cellulose Nanomaterials (CN)

Cellulose nanomaterials (CN) have been used in wide variety of applications including reinforcement phases in polymer composites, protective coatings, barrier/filter membrane systems, antimicrobial films, network structures for tissue engineering, and substrates for flexible electronics Two general classes of CNs that can be extracted from plants, are cellulose nanocrystals (CNC, 3–10 nm wide by 50–500 nm in length, Fig. 1a) and cellulose nanofibers (CNF, 4–20 nm wide by . 1 mm in length(Zhou et al., 2013). Different methods can be applied to produce nanofiber cellulose from wood biomass. A study conducted by (Xiao, Gao, Lu, Li, & Sun, 2015) demonastrates the extractions of cellulose from pine needles which is then turn into CNF suspensions by combining acid-pretreatment with high-intensity ultrasonic treatment.

Similarly, another study on isolation of nanomaterial from wood biomass was carried out by using mechanical method without using chemical treatment. The study was carried out on Paulonia wood in which nanofiber was extracted by using disk grinding which concluded with the finding that this process is an environmentally friendly approach with a high conversion ratio of wood from micro to nano-scale.

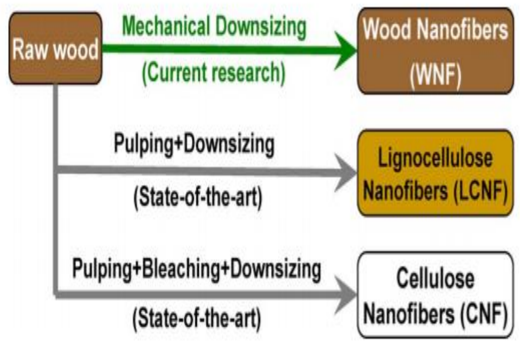

Fig 9. The production routes of nanostructures from raw wood microparticles without using any chemicals

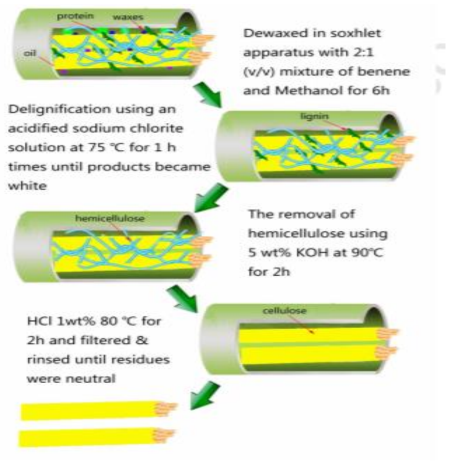

Fig 10. The isolation of cellulose fibre through chemical treatment

3.3.4 Silicon Nanoparticle

Silicon nanoparticle is also one of significant biomaterial and considered as industrial assets. It has a wide range of applications in industrial and agricultural field. NPs can be used as additive to polymers such as plastics and rubber, filler for reinforcing structural materials, support for catalysts, low toxicity drug delivery platforms, and controlled release of agricultural adjuvants (nutrients and biocides). Silica nanoparticles that are produced through conventional method are expensive and utilise non-renewable precursors, but it attracts major attractions towards industrial and agricultural applications. To solve these problems and sustainable use of nanomaterial, silica obtained from the plant sources known as biogenic silica could be best alternatives (Franciele A. Neis et al., 2019). Research was conducted on pine cones and needles to produce biogenic silica. The study describes the synthesis of nanosilica particles through thermal decomposition of pine cones and needles, acid treatment process followed by calcination at 60 degree for 3 hours (Assefi, Davar, & Hadadzadeh, 2015)

3.3.5. Silver nanoparticles

Silver nanoparticle is considered as microbiocidal agents and effective against four types of gram positive bacterial. AgNPs are therefore, increasingly used in medical applications as dressings for wounds, coatings for medical devices, in textile industry(AgNPs impregnated into fabrics) and food and pharmaceutical industry. (Velmurugan et al., 2015) showed an efficient way for the biosynthesis of AgNPs from an aqueous silver nitrate solution using young cone extract of *P. densiflora*. It has been proposed from the study that phytochemicals present in the cone extract could play a key role in the conversion of the ionic form of silver to the metallic nano-form.

3.4 Biofuels and bioenergy

The emission of enormous amount of carbon from fossil fuel creates a great concern towards reducing carbon level in the atmosphere. This can be achieved through action to decarbonize the transport sector that consumes one third of the final energy creating alternative renewable source through the use of biofuel. Biofuel obtained from biomass is only practical available renewable sources for aviation, marine and heavy-duty vehicles. It has been found that biofuel can also be produced from non-lignocellulose biomass but the use of wood biomass for biofuel production is also increasing nowadays (Kallio, Chudy, & Solberg, 2018). Based on the source of biomass feedstock has been used, biofuels are also classified into different generations. These are i. first-generation biofuels (produced from food crops like corn, sugarcane, rapeseed, etc.) and are involved in the production of bioethanol or biobutanol by the fermentation of sugars and in biodiesel production through transesterification of oil crops ii. Second generation biofuels are produced from nonfood crops like lignocellulosic biomass and iii. third-generation biofuels include bioethanol from microalgae and seaweeds, biodiesel from microalgae, and biohydrogen from microalgae and other microorganisms.

3.4.1 Bioethanol

Bioethanol is a promising biofuel that are produced from ligno-celloulse biomass contributing lower carbon emission. The production of bioethanol from lignocellulose added more advantage in spite of reducing greenhouse effect and limit global warming. Because of the production of bioethanol from lignocellulose, it minimizes the use of food resources for biofuel production thus reducing the food scarcity. Properties of bioethanol include high octane number (108), low boiling point, higher heat of vaporization, and comparable energy content which added benefits for its application. Bioethanol production from lignocellulosic biomass involves three major unit operations: pretreatment, enzymatic saccharification, and fermentation. A lot of study has been carried out for bioethanol production, although there are some limitations for establishing bioethanol plant. The limitations are high processing cost that includes cost of feedstock, cost of enzymes, detoxification cost, and ethanol recovery cost, which makes the process economically unviable (Sindhu et al., 2019)

3.4.2. Biomethanol

Biomethanol is another alternative energy source. Biomethanol can be produced by two process either by i. pyrolysis or ii. by gasification process. But the yield of biomethanol through gasification process is higher than production yield through pyrolysis process (Sindhu et al., 2019). (Hasegawa, Yokoyama, & Imou, 2010) carried out the comparison of two conversion technology i.e. methanol synthesis and bioethanol synthesis. The study was concluded with the findings that the biomethanol process was preferable in terms of thermal efficiency, CO2 emission and environmental burden. The study also shed light on the future perspectives of biomethanol as it has a greater potential for gasoline substitution and CO2 mitigation.

3.4.3 Biobutanol

The fermentation of lignocellulose biomass leads to the production of biobutanol which acts as a promising renewable biofuel. Bioethanol is considered as superior biofuel compared to other biofuel like bioethanol, biohydrogen, biomethanol etc. The character tics inherited with biobutanol is that it has high-energy input, low volatility, is less corrosive, and can be used in current distribution pipelines and car engines without modification. Furthermore, biobutanol not onlype contribute its applications on renewable energy source but it has its great uses as a solvent in industries such as for plasticizers, perfumes or artificial flavorings, and chemical intermediates and additives for various manufacturing ingredients. Wood is mainly composed of cellulose, hemicellulose and lignin. Structurally, the individual cellulose molecules in plant are linked together to form elementary microfibrils and are aggregated by intermolecular hydrogen bonding into larger subunits called fibrils. Biobutanol can be produced by fermentation process that uses fermentatively microorganisms usually *Clostridium* spp. The fermentation process is known as acetone-butanol-ethanol (ABE) fermentation that involves biphasic fermentation stages which are i. acidogenesis (acid production stage), and ii. solventogenesis (solvent production stage). During this process the microorganism produces solvents (acetone, butanol, and ethanol), acids (acetic and butyric), and gases (hydrogen and carbon dioxide) as its byproducts. Although large number of studies has been carried out for the biobutanol production from wood or lignocellulose biomass, but it has been found difficult and challenging for the conversion of lignocellulose biomass into fermentable sugars. The reason behind this is, the access of cellulase enzymes to cellulose becomes difficult due to the presence of lignin and hemicellulose, thus reducing the efficiency of the hydrolysis process.

Therefore, the single or multiple step pretreatment process such as physical, biological and chemical process can be applied in order to remove the lignin and/or alter the compositional structure and/or reduce the particle size for efficient enzymatic degradation for getting valuable product (Ibrahim, Kim, & Abd-Aziz, 2018)

3.4.4. Biodiesel

Biodiesel is another alternative renewable source of energy. Biodiesel is fatty acid methyl ester. The chemical composition of biodiesel reveals that it is produced by transesterification reaction of triglycerides with methanol in the presence alkali as a catalyst. Research have shown that biodiesel is primarily produced from vegetable oil. To overcome, the limited availability for food sources as a feedstock for producing biofuel, it is required to use alternative feedstock for biofuel production. Studies have been conducting on the use of wood oil and tall oil for biodiesel production. In a study, spruce wood sample has been utilized to produce biodiesel through tall oil and oleoresin. The production was achieved using process methylation of resin acid and esterification of tall oil (Demirbas, 2011)

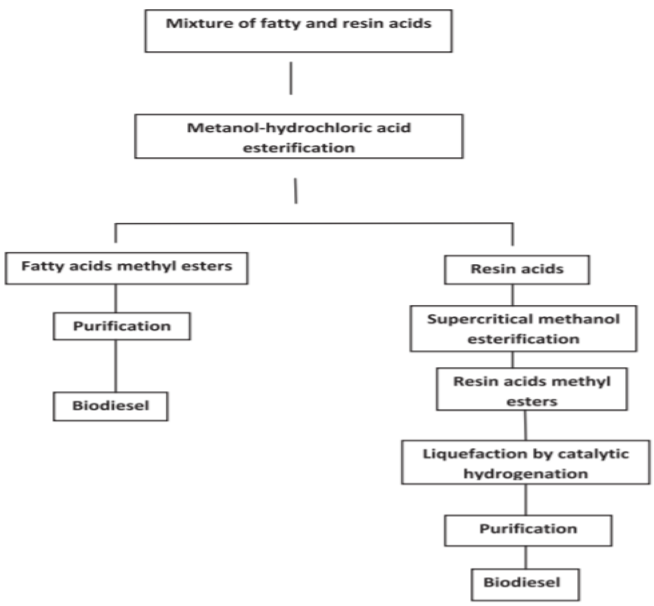

Fig 11. Biodiesel production through two step liquefaction resin acid of tall oil (Demirbas, 2011)

3.4.5 Green batteries

Different types of electronic devices like cell phones, laptops , cameras that we are using nowadays required chemical energy storage. Lithidium -ion batteries are widely used as a source of chemical storage for these devices due to their design flexibility, high voltage output, high energy density, high specific energy, and long cycle life. The necessity of these recent days as well the limited nonrenewable and finite sources. Therefore, the replacement of inorganic electrodes by organic electrodes creates sustainable and ecofriendly environment through recycling. Various kinds of organic electrode materials have been exploited. These include dilithium trans–trans benzenediacrylate (BDALi2), an organic material for lithium-ion batteries and terephthalaldehyde(Franciele A. Neis et al., 2019). Terephthalaldehyde (prepared through the reduction of terephthalic acid, which can be produced from limonene, α or β-pinene present in pine resin) whereas BDALi2 can be produced from natural compounds being synthesized through condensation of malonic acid (organic acid found in fermented fruit, fruit vinegars, and alfalfa (Medicago sativa L.)(Renault, Brandell, & Edström, 2014). Pine resin consist of limonene which can be converted into terepthlalic acid via p- cymene. This synthetic routes uses a chemical catalytic pathway for the formation of desired product(Colonna et al., 2011).

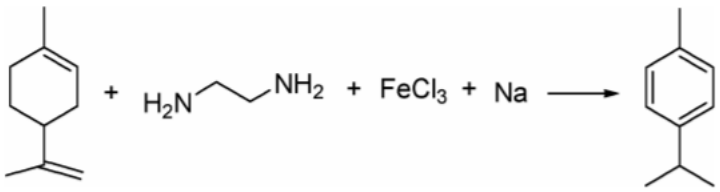

Fig 12. Preparation p-cymene from limonene

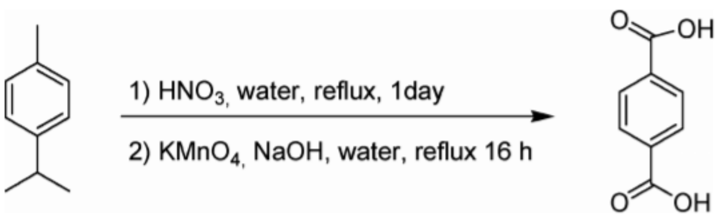

Fig13. Oxidation of p-cymene to terephthalic acid

Furthermore, the most important concern in order to achieve ecofriendly and sustainable environment is recycling of lithium and other batteries after its use. The process can be achieved by separation of all the components of batteries and soluble in H2O but in some batteries like BDALi2 decomposition products are formed during closed circuit and it is recommended to destroy the battery thermally yielding a pure powder of Li2CO3, a starting material for new synthesis(Renault et al., 2014)

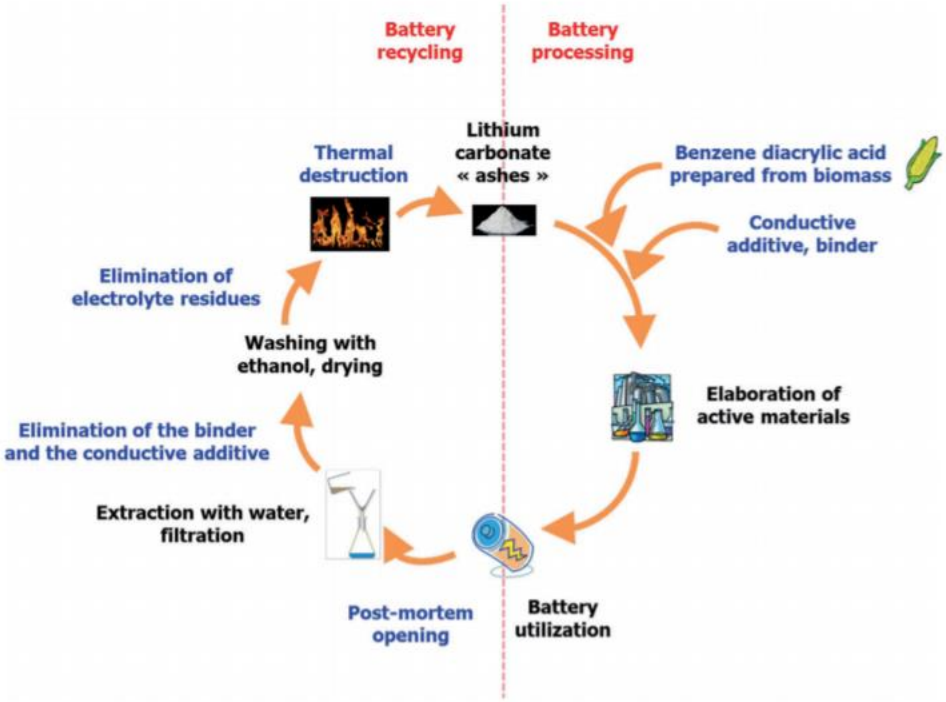

Fig 14. lithium recycling process of batteries made of organic electrode materials obtained from renewables(Renault et al., 2014)

3.4.6. Organic solar cells

Solar energy is potentially the largest source of renewable energy at our disposal. Many studies have been conducted on photovoltaic technologies that uses nonrenewable resources for the solar energy. However, significant advances are required to make photovoltaic technologies from renewable and sustainable resources in order to achieve economically viable, environmentally friendly, and consequently scalable technology. During recent years, organic solar cells are an attractive technology because of their potential for low-cost fabrication, light weight, and good mechanical flexibility in contrast to organic solar cells like Polyethylene terephthalate (PET), polyethylene naphthalate (PEN), or polyethersulfone (PES) derived from petroleum derived substrates. Using wood as a substrate for solar cell energy technology create a great attraction towards research in this areas due to low cost of wood and sustainable resources. Cellulose nanomaterials (CN) are cellulose-based nanoparticles because they have good mechanical properties, high aspect ratio, low density, low thermal expansion, surfaces that can be readily chemically functionalized, low toxicity and also are able to be produced in industrial quantities (Zhou et al., 2013). These organic solar cells are constructed in such a way that solar cells are fabricated with Ag/polymer surface modification as the bottom electrode and MoO_3/Ag as the top electrode without the need of aqueous solution. Also the important consideration is about recycling of solar cells that the polymer solar cells fabricated on CNC substrates are found to be easily recycled at room temperature by simply immersing them in water, where the CNC substrate is redispersed (Zhou et al., 2013).

A study carried out on photovoltaics(energy that convert solar energy into direct current electricity through semiconducting materials) shows that transparent wood can be used as solar cells for generating electricity in contrast to crystalline silicon solar cells and thin film solar cells which are based on high-purity, single-crystalline semiconductors and therefore rely on high-temperature manufacturing processes. However, there is limitation for application of wood-based materials in photovoltaics is that wood is not transparent. The low optical transmittance of wood is the light scattering at the interfaces between the cell wall tissue and the empty pore space ("lumen") in wood cells (e.g., cells such as tracheids, wood fibers, and vessels) contributes to the reason for low transparent of wood substrates. But, recently efforts have been developed to combine optical transparency with mechanical performance for light-transmitting, energy-efficient building applications (Li et al., 2019)

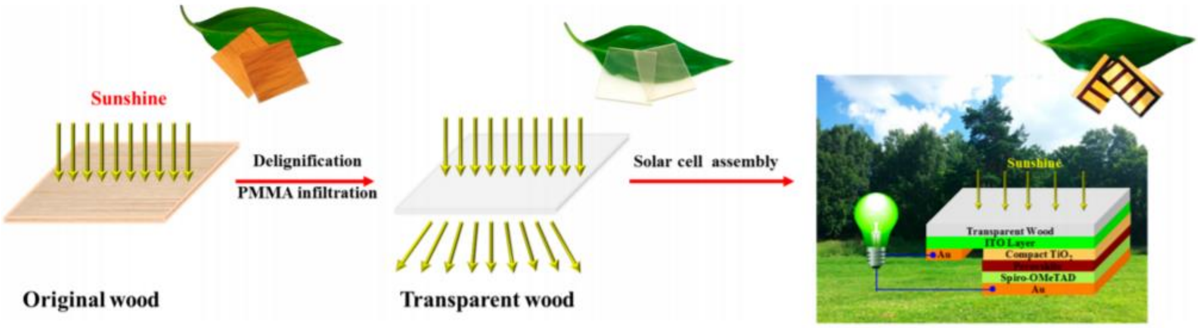

Fig 15. Schematic sketch showing the process of transparent wood preparation and assembling of a solar cell on the transparent wood substrate(Li et al., 2019)

3.5 Other value added products from forest biomass

3.5.1 Thermal insulating material from conifer needles

The use of environmental friendly natural materials has been increasing nowadays especially in construction works. Heat insulating materials, that are made from organic raw materials has gained a center of attractions towards natural fiber. Examples include hemp wool, coconut fiber, flax cotton etc. The increased popularity towards these types of natural fiber is due to the material' low mass density and the structure of its cells, which is why the material has very good sound and heat insulation properties. A study was carried and published that needles and thin branches of conifers can be used as heat insulating material with its renewable property. A study was conducted to produce heat insulating material from needles of pines, spruce and to evaluate the heat conducting coffecient of this material and factor influences it. Heat conducting material was produced by mining needles and tested with three factors: strength of pressing, heating temperature of raw material and drying temperature of pressed material. The study was concluded with the findings that the heat insulation milled pine and fir-tree needle mass material has a low average heat conductivity coefficient which proves that it may be used as a heat insulation material and is competitive with the existing forest resource heat insulation materials (Muizniece, Blumberga, & Ansone, 2015)

3.5.2 Bird and animal feed from conifer needle

Pine needles are used as food and dietary supplements inorder to improve the poutry health and production. Pine needle powder is a natural food additive that can improve poulty meat quality without reducting meat production and feed conversion rate. The production process of PNP includes stripping of pine needles from the stems and then cut into pieces, thinly spread on a mat and air-dried at room temperature (15–25°C). The air-dried pine needles were then ground to powder and sieved through a 1.0-mm sieve. The PNP produced through this method acts as supplements on broiler diet aids advantage as antioxidants and immunological status without negative impacts on growth performance(Guo, Cheng, Mamun, Xiong, & Yang, 2018)

3.5.3 Ioncell- F textile

Ioncell is a process used for producing cellulose based textiles. Raw materials derived from the forest resources are used in the production of Ioncell fabrics and considered as an important bioproducts in terms of ecological, sustainability and economic interest. Unlike other wood derived fiber cellulose and viscose, Ioncell is an ecological alternative that donot use toxic chemicals. There are three stages in creating Ioncell fibres: cellulose dissolution, fibre spinning, and recycling of the ionic liquid followed by carding and yarn spinning, in the same way as other textile fibres. Ioncell fibres are strong and durable, and can be used for high-quality clothing, interior textiles and even some technical textiles in the future. The pilot plant for producing Ioncell has been established in Finland utlise hardwood birch as a rawmaterial feedstock(Aalto University, 2018).

Table 3: summarization of the products that can obtained from Norwegian tree species with its applications(Routa, Anttila, et al., 2017)

Products	Tree species				Applications
	Norway Spruce	Scots Pine	White Birch	Silver Birch	
A. Extractives					
1. Phenolic extractives					
a. Stilbenes	picetannol (bark), astrigin(needles,bark), piceid etc.	Picetannol, Pinosylvin etc.			Therapeutic applications as antimicrobial, anticancer, antioxidants etc
b. Flavonoids	Quercetin (needles), glycosides of myricetin, catechin	Quercetin, pinocembrin, catechin etc.	Acacetin, Glycosides of myricetin (leaves), Catechin	Apigenin (leaves), Acacetin, Catechin (leaves. stemwood Bark	Reduced risk of coronary heart disease, allergenic, antiaflatoxin, antiallergic, anti-histaminic, antimalarial, antimutagenic

c. Tannins	Tannic acids (needles)	Gallic acid, epigallocate-chin			Therapeutic applications as antibacterial, antiviral, antifungal, anti-inflammatory
c. lignan	Mataresinol, pinoresinol, alpha-conidendrin, lignan A	Mataresinol. Pinoresinol (bark)			Acts as anti-leumic, chemopreventive effects, and antioxidants.
2. Terpenes and terpenoids	Dihydroabeitic acid,sitosterol, Alpha- pinene	Dihydroabeitc Acid, sisterol, alpha-pinene, beta-carotene (needles)	Betulinol (bark), betulinic acid, sitosterol	Betulinol (bark), betulinic acid, sitosterol	Therapeutic applications as it decreases the amount of cholesterol pro-duced by the live, anti-HIV, antimalarial, anti-inflammatory,antibacterial, anti-oxidant, anti-viral.
3. Fat, wax and their components	Monoglycerides, Diglycerides, triglycerides, pinolenic, taxoleic, and sciadonic acids	Monoglycerides, Diglycerides, triglycerides, pinolenic, taxoleic, and sciadonic acids	Monoglycerides, Diglycerides, triglycerides, pinolenic, taxoleic, and sciadonic acids	pinolenic, taxoleic, and sciadonic acids	reduce carcinogenesis, atherosclero-sis, insulin resistance and body fat mass
4. Suberin and its components			Suberin(bark)	Suberin(bark)	synthesis of new biopolymers, as well as novel coating materials
B. Fermentable sugars	Cellulose, hemicellulose and lignin				Used as a substrate for wide variety of chemicals, biomaterials etc in industrial applications
C. Paper and pulp products	Fibers, Paper and pulp				Wide variety of industrial applications, construction materials
D. Biofuel	biethanol, biomethanol, biobutanol				Used as source of fuel from renewable sources.

3.6 Forest biomass and bioeconomy

Abundant forest resources and biomasss are essentials factors and play a vital role in national bioeconomy. Forest acts as source of material (wood and non-wood), bioenergy and a wealth of other regulating and cultural ecosystem services but sustainable development practice of forest resources are required during its consumption and for successful bioeconomy. The things that should be keep in mind for sustainable use of forest resources should address the following question: What are the potential capacity of forest resources to contribute sustainability? What are the sustainable production processes, products and services for sustainable production? How are non-wood goods and ecosystem services managed andvalued? Where and how are forests and biodiversity protected?(Bernhard Wolfslehner, Stefanie Linser & Annemarie Bastrup-Birk, 2016)

According to EU Bioeconomy Strategy, the bioeconomy is a more innovative and low-emissions economy, reconciling demands for sustainable agriculture and fisheries, foodsecurity, and the sustainable use of renewable biological resources for industrial purposes, while ensuring biodiversity and environmental protection. A report prepared on forest bioeconomy focuses on the dimensions on forest bioeconomy which can be assessed by existing sustainable forest management indicators and proposed strategy for the bioeconomy. The study initially pointed out 203 potential indicators for accessing bioeconomy which are further categorized into few groups. Analysis of the study on indicators revealed that majority of indicators are output and outcome indicators focusing on products, goods and services or on more general results whereas few input, activity and process indicators were also found. The study report findings focus on a consistent, coherent and systematic indicator set that demonstrates and assesses the contribution and performance of the forest-based sector in a bioeconomy (Bernhard Wolfslehner, Stefanie Linser & Annemarie Bastrup-Birk, 2016)

Table 4. Key indicators of forest bioeconomy(Bernhard Wolfslehner, Stefanie Linser & Annemarie Bastrup-Birk, 2016)

Resource use
Resource productivity
Resource and materials efficiency
Water footprint
Natural resources index
Share of renewable energy in gross final energy consumption
Indirect land use/embodied land for agriculture and forestry products
Red List Index of threatened species
Carbon footprint of the forest and harvested wood chain (carbon stock changes)
Greenhouse gas balance (emissions and sequestration)
Employment in forest-based bioeconomy sectors, and contribution to regional employment
Eco-innovation index

4. Methodology

4.1 Data collection method

The study has used secondary method of data collection. There are two basic methods of data collection. The first is collection from primary resources which includes data collection for the purpose of research through interview, personal visits to participants, distributions of questionnaire to participants, telephonic conversations or tape recordings.

The second is collection of data from secondary sources. Secondary sources of data consist of review of existed research carried out on particular subjects. The secondary sources studies encompass thorough study of published study that precedes the current study and findings similarities and dissimilarities between preceding and current studies.

4.2 Data collection tool

The literature related to forest bioprospecting process was identified by searching bioscience journal database. Different databases like PubMed, Elsveir link, Google scholar, were searched by developing a search-string, by connecting keywords AND, OR and NOT. The information about the products from bioprospecting process was taken from the webpage of the concern company.

4.3 Research Approach

A quantitative research approach based on the literature review has been used in the study. The data gathered was studied to discover answers to research questions listed in this study. The study deals to figure out possible innovative products that can obtained from forest biomass in different regions through biorefineries. The study also focuses on to insight strategies required to achieve value added bioproducts and its market penetration as well as commercialization. Similarly, inference about forest bioproducts business strategy, its contribution in bioeconomy and benefits and challenges learned from various projects is drawn to recommend forest biorefineries in Norway.

In this study, the case from different regions related to forest bioprospecting were studied. The cases were investigated for mapping what can be done in forest sector and to draw inferences about pros and cons for forest biorefineries in Norway.

5. Case studies

5.1 Forest biorefineries in Finland

During recent years, large number of research project have been developed in order to contribute directly and indirectly into biorefineries areas in Finland. The research and cluster involved for contributing into biorefinery activities and development consists of research and universities, as well as industry company and consultants. Several research projects and companies in Finland are supported by some important funders like TEKES – Finnish Funding Agency for Technology and Innovation (main public funding funding for research development and innovations), The Academy of Finland (funding for scientific research of the highest quality). Other important funding agencies are The Centres for Economic Development, Transport and the Environment (ELY)

5.1.1 UPM Biorefineries

UPM's Lappeenranta Biorefinery is the first commercial scale biorefinery plant which are established to produce wood based renewable diesel and naphtha. Furthermore, the coordination of UPM with FibreEtOH project has been done which aims to demonstrate ethanol production based on paper fibre on a commercial scale. The setting of UPM Lappeenrantta plant is organised in a vicinity area with UPM kakaus mill so that its collaboration facilitates the supply of raw materials. Crude tall oil which are extracted as a residue during wood fibre separation process for pulp production. Crude tall oil is the feedstock used by UPM's Lappeenranta Biorefinery for biofuel production. By using residue products as feedstock for biofuel production, it demonstrates less effect on raw materials availability as it consumes less wood, low risk of displacing current biomass production or diverting feedstocks away from other uses. The general technical process carried out by UPM Lappenranta biorefinery from biomass to product recovery includes feedstock(crude tall oil), pre-treatment, hydrotreatment, fractionation and product (either renewable diesel or renewable diesel) (UPM Biofuels, 2019). UPM biofuel is focused on market and customer driven business with scalable and profitable production. UPM biofuel implement strategy that provides dependable, high quality products for road and sea transport, and working with their customers to deliver sustainable growth.

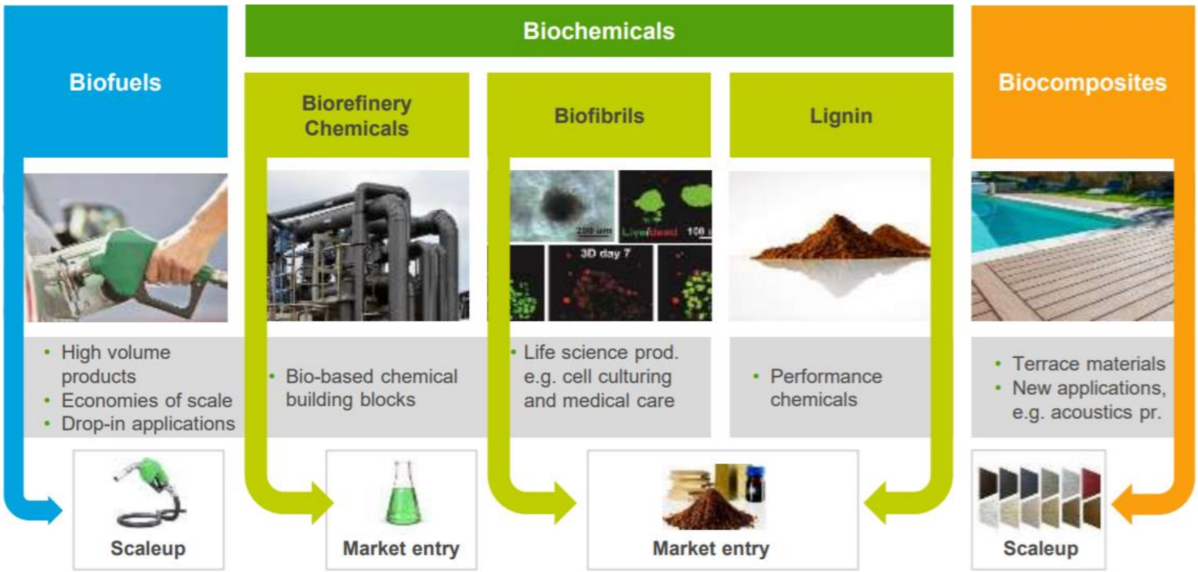

Fig 16. New business opportunities for UPM (UPM Biofuels, 2019)

Fig 17. UPM biodiesel and napthol (UPM Biofuels, 2019)

5.2 Biorefineries in Sweden

5.2.1. SEKAB company

SEKAB is a Swedish company lies in the midst of northern forest of Sweden. Although the company has its history for producing ethanol started over hundred years ago but recent trends for developing innovative products from green biomass creates an impetus for manufacturing next generations of sustainable bioethanol and innovative solutions in green chemistry. The organisational network of SEKAB consists of several cooperation partners. BioFuel Region, EuropaBio, F3 Företagsutbildarna, KOMTEK, Processum, Scania, Svebio, Taurus Energy, UNICA, Collaboration 2gen ethanol are cooperation partners of SEKAB.

Based on the production prospectives, the company uses its unique technology cellulosic ethanol production. SEKAB Technology works with development of ethanol production from cellulose, including pre-treatment, hydrolysis, fermentation and distillation (SEKAB 2012). Biogas and lignin are by-products from the ethanol production. The business strategy of company comprises 1. filling number of patents that covers all the process from pre-treatment of raw material to downstream processing and system optimization. The application of CelluAPP® enables possible to refine almost all forms of biomass into eco-friendly, high-quality and profitable chemical products, biogas and lignin 2. Extensively collaboration with research institutes, universities, government agencies, vehicle manufacturers and other companies within the forestry and chemical industries aiming to build extensive network in the forestry and processing industries.3. sustainable utilisation of biomass with profit maximisation (SEKAB, 2019).

5.2.2 Domsjö Fabiker biorefineries

Domsjö Fabriker is a part of leading multinational company the Aditya Birla Group, which is the world's largest producer of viscose fibres. Domsjö Fabriker AB aims at producing sustainable products from renewable wood resources. Cellulose, lignin and bioethanol are the main products achieved by refineries exploiting Swedish forest resources. Raw materials used for product manufacturing process includes timber from conifers trees like pine, spruce. Depending upon the type and nature of raw material, wide range of raw materials such as saw dust, hard wood, fuel wood, wood chips are being used by the refinery plant. The applications sectors of the cellulose include medicine, tablets and food and other products while viscose is used in textile industry. The biorefinery plant adopted a technical biomass conversion which consist of multiple steps. The process starts with the use of debark chipped wood and fed together with the cooking chemicals into the digesters. The bark is burned and recovers energy in the form of steam. After cooking the cellulose is washed, followed by bleaching with hydrogen peroxide in the closed-loop bleaching unit. The bleached cellulose is then dried and delivered in bales. The recovered bleached cellulose exihibits highest brightness. Therefore, Domsjö Fabriker was the first mill in the world beaching to the highest brightness completely without chlorine. Besides producing value added products, Domsjö Fiber exhibit's successful co-operation between biofuel consumers and pulpwood consumers which could be the great approaches for maintaining sustainable value chain (DOMSJÖ FIBER AB, n.d.)

5.3 Forest biorefinery in Norway

For the purpose for maximum utilisation of forest resources and its contributions in bioeconomy through extraction of value-added products, various research institutions in Norway are involved in the field of biorefinery. The main research organizations involved include the Paper and Fiber Research Institute (PFI), the Norwegian University of Life Sciences, SINTEF Materials and Chemistry and the Norwegian University of Science and Technology. Furthermore, forest biorefineries projects in Norway are also funded and supported at a national level. Research council of Norway is a national body responsible for conducting activities on these areas while other regional body like the Nordic Energy Research has also involved in funding of biorefinery projects at a regional level.

5.3.1. Borregaard biorefinery

Borregaard is a Norwegian company, established in 1889 in the southeastern town of Sarpsborg in Østfold county. It is the oldest biorefineries in Norway where its traditional products were paper and pulp. Borregaard is a biggest company with 1,200 employees, eight production sites and sales offices in 17 countries throughout Europe, the USA, Asia and Africa. (Borregaard. 2012). The production of environmental friendly products in the areas like biochemicals, biomaterials, bioethanol makes the biorefineries as the world's most cutting-edge, sustainable biorefineries. Sustainable raw materials from forest resources are used by Borregaard to produce sustainable products replacing fossil-based products (Borregard 2012). Borregaard produces lignin, specialty cellulose, vanillin and bioethanol for a variety of applications, including agriculture and fisheries, construction industry, pharmaceuticals and cosmetics, foodstuffs, batteries and biofuels. The structural organisation of Borregaard is divided into four business areas depending upon types of products.

A. Borregard chem cell

   Although Borregaard has producing pulp from 100 years ago and speciality cellulose since 1921, nowadays Borregaard refinery plant in sapsborg , Norway provides a broad range of high-quality, tailor-made specialty cellulose qualities where the focus is on parameters like viscosity, brightness, purity, density and reactivity. Borregaard chemcell has a wide range of products including ethanol and specialised range of broader cellulose products. Borregaard chemcell has established itself as a global leader for biobased chemicals.

B. Borregard LignoTech

Borregaard lignotech is primarily focusing on production of lignin and a leading supplier of products based on lignin. The application areas of Borregaard lignin products include dispersing agents in concrete and in for example textile dyes, pesticides, batteries, ceramic products, animal feeds and briquettes etc..

C. Borregaard Synthesis

Borregaard synthesis manufactures fine chemicals and it has targeted to meet the demands of pharmaceutical market. It serves targeted applications including advanced intermediates, x-ray contrast media intermediates, active pharmaceutical ingredients, and specialty excipients.

D. Borregaard Ingredients

Borregaard is manufacturing vanillin and ethylvanillin from spruce wood. Borregaard refinery is only one producing vannilin from wood. Vallin is flavouring agent and its application includes food industry where it is used in products like chocolate, bakery, dairy and sweets.

Although Borregaard has established its market through variety of products, the company is still focusing to deliver innovative sustainable products. Innovations is the company`s strategy for its value chain. Many approaches have been done to carry out innovation in the company. Some of the approaches of Borregaard for innovation processes are listed below

- By investing considerable resources in research and development (R&D) concentrating on organic and wood chemistry.
- Formulating a strategy for specialisation and increased value creation which is pursued through R&D actions
- extensive collaboration with customers, universities and research institutions in several countries and maintains close relationships with its customers to be able to provide innovative solutions for them

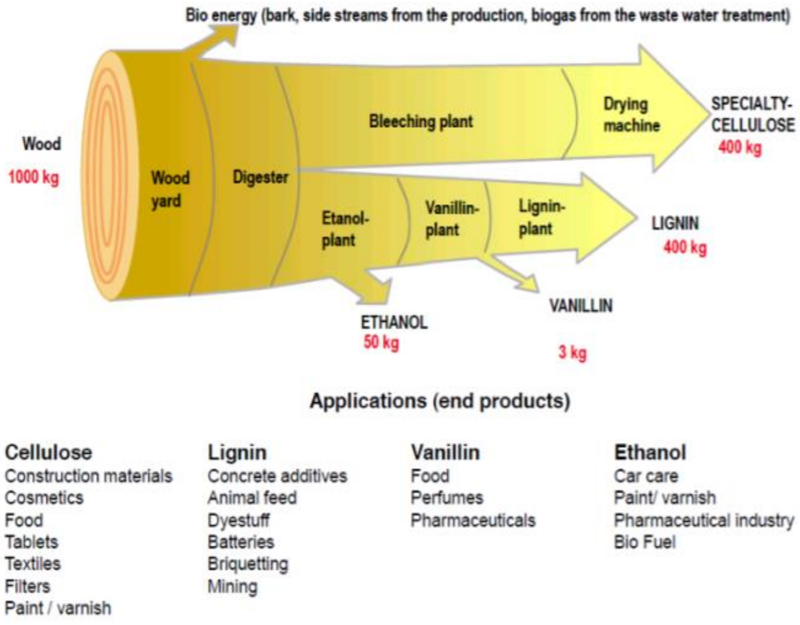

Fig 18. Borregaard product chart (European Biofuels Technology Platform, 2016)

5.3.2. BioMim - Advancing biomass technology project

The project is conducted under division of forest and forest resources. The project is driven by a research institute NIBO (The Norwegian Institute of Bioeconomy Research) which collects funding required for project from both national and international sources. Regarding BioMim project, the focus has been concentrated in the utilisation of biomass in order to meet growing energy demands, address climate change, and support forest economies. BiMim project has conducted until the period on January 2015 to December 2018 with total budget 27,3 mill NOK. For the successful completion of the projects, the project has done collaboration with other research partners Norwegian University of Life Sciences, University of Oslo, Paper and Fibre Research Institute, Borregaard, Kebony, Virginia Polytechnic Institute and State University (Virginia Tech). The targeted area of this project is Norwegian wood resources e.g. Spruce and scots pine. BioMim projects focus on extensive exploitation of lignocellulosic biomass as a feedstock for a variety of products is the key to develop a viable bio-economy. It is obvious that treatment of lignocellulose biomass is very difficult, challenging and high cost operated process. Therefore, the project address the new insights into how brown rot fungi degrade wood through unique fungal metabolism for plant cell wall degradation and these will be used to improve biorefining processes as well as wood protection

Different work aspects and proposed hypothesis like Raw materials - Pre-processing and characterization, Mimicking the CMF system, The role of LPMOs (and other redox enzymes), CMF-enzyme interactions, Wood protection has been clearly included and discussed under the project (NIBO, 2019).

5.3.3. Norwegian biorefinery research and development projects

a. Norwegian biorefinery laboratory (NorBio Lab)

It is a national infrastructure for biorefinery research. The vision of NorBio Lab is to provide fundamental for developing advanced biorefinery processes at top international level, tailor-made for Norwegian conditions. NorBioLab provides the tools to develop the processes to convert these resources. NorBioLab addresses four central biorefinery technology platforms as defined by IEA. These are

- C6 and C6/C5 sugar conversion Platform
- Biogas Platform
- Syngas Platform
- Pyrolysis Oil Platform

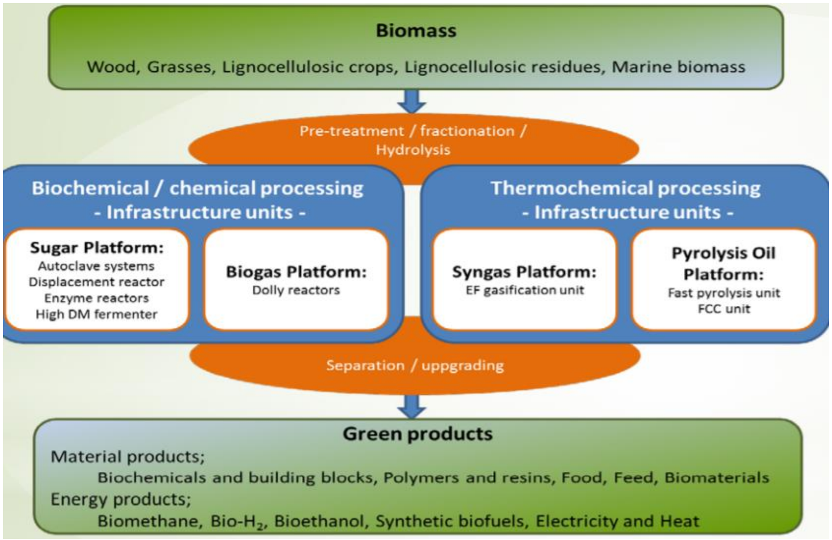

Fig 19. NorBio biomass conversion to sustainable green products via different routes

b. LignoRef project

The project “LignoRef” was conducted in Norway during the period from 2009-2012. The project has made collaboration of several R&D(research institute and universities etc.) and industrial partners(forest owners, biorefineries, energy producers etc.). The primary objective was to establish fundamental knowledge about central processes involved in the conversion of lignocellulosic biomass to second generation biofuels and value-added products. The central processes included biomass pre-treatment and separation, enzymatic hydrolysis, fermentation and thermochemical conversion of biomass and process by-products has been discussed and demonstrated by the project. The project has shown to gathered central national players in the biorefinery area in order to promote national progress in this field.

6. Findings and Discussions

The findings of the study has been derived after analysis of literature review through this study and from case studies. Valuable innovative products can be created by using forest resources through its efficient utilization however it is essential to formulate and implement efficient strategy to achieve the goal.

6.1 Biorefineries strategies for obtaining value added forest products

The forest products of Europe and North America has been gradually decreasing in some market segments like newspaper and paper in past decade. These segments of market have gained least interest and demand nowadays due to introduction of innovative forest bioproducts(Sophie D'Amours, Mustapha Ouhimmou, Jean-François Audy, 2016) Low-cost competitions from emerging competitors are the driving factors in which forest biorefineries should consider for revenue diversification and transformations of existing business model. Therefore, it is most crucial to have sound sustainable business models for already existed business products as well as for launching new products in competitive market. For biorefineries to become a reality, the industry needs information about new business models and cross-industry collaboration will likely be necessary, resulting in new networks and ways of integrating.

Many efforts are required for creating new structures that allow disruption of existing ones while facilitating the exploration of innovation structure. These efforts include:

A. Establish a separate R and D unit

The research and development (Rand D) system is required to enable the development of revolutionary products and technology. Rand D unit have its separate unit which have its own culture aimed at transforming various components of the wood, both as an alternative raw material in existing production processes and production brand new products. R and D has purpose of solving specific knowledge needs and its activities in forest biorefinery includes improvements in existing value chains or creating new unique value chain, improvements in forest production, improvements in operational methods and technology applications. However, many forest companies that do not have R and D unit mostly fails to achieve company goals. An alternative for separate R and D unit can be achieved for facilitating innovative creations include collaboration with research institutes and universities on relevant projects. The collaboration with research organizations and governmental programs facilitate research, development, and innovation, especially in small companies (Hansen, 2016)

B. Establish Cross-functional Teams

A group of innovative individuals are required for new value products. Innovative team members can be created within or outside the country to form mature organisation. Thus, networking of team members formulates broader set of ideas and facilitates the creation, adoption of product, process and business systems

C. Create a Subsidiary

Creating a closely held subsidiary company is another effort for innovative products development. For this approach an executive team with a sufficiently innovative culture is essential to envision the creation of a new company and its business model. The new company operates to explore and experiment with business models appropriate for new products and/or new markets.

D. Initiate Cross-company Collaboration

Because biorefineries require new knowledge, ideas, and business model, collaboration with highly different companies that have different products and expertise is the most fruitful. The results of such collaboration with enables to explore new concept, formulations and experiences. However, collaboration with contrasting company could be challenging. Cross company collaborations of forest biorefineries primarily envisioned how forest products can interact with other products via the Internet of Things.

E. Purchase Another Company

Purchasing of another company is another approach to access into the new ideas, product and market. Purchasing make the ease of barrier for market penetration and new products as well as match the competitors’ offerings

Forest product companies should focus on improving existing processes with the implementation of new technologies, optimizing access to new biomass demands, and systematically developing new product supply chain strategies. Although many forest companies use operational effectiveness to create operating cost advantage, but the achievements of operational effectiveness are supported by company strategic positioning efforts. Two approaches for strategic positioning has been used i.e. “inside-out” transformation and “outside-in” transformation. The former approach relates with the improvement of work and process in terms of cost competitive achievements whereas the later approach relates with core transformations of vision and mission of company (Chambost, McNutt, and Stuart 2009). Thus, diversification of product portfolio and business model transformation enables forest refineries targeting new customers from commodity-driven to specialty-driven markets, including proactivity, efficiency, responsiveness, and flexibility in the business model.

6.1.1 Phased Implementation of the Biorefinery

The phase approach of biorefinery can be recommend in order to mitigate the risk and incremental transformation of business model. Three phase approach of biorefinery has been termed to achieve short term or long-term goal of biorefinery implementation. Phase I of biorefinery implementation focuses on reducing risks related to the implementation of new processes and products in the shorter term and sets the path for a longer-term vision defined by the corporation. It typically involves to lower operating cost and selling of products in the market to generate early cash flow. Products like biofuel and bioenergy comes under phase I implementation of biorefinery. Phase II approach focuses to create improved margin of manufactured value added bioproducts, market development strategies of product. Phase III focus on maximization and improvement of supply chain, advance information system and manufacturing system that exploit product flexibility and new delivery mechanism (Chambost, McNutt, and Stuart 2009).

6.1.2 Strategic Interaction between Business and Technology Plans

The interaction between the product-market-business strategy and technology-process strategy, coupling process and product design methods are the most essential strategy to achieve successful biorefinery. Product design for the biorefinery is vital and various methods have been developed to produce promising biorefinery product through process design. Process design defines technically and economically feasible processes for the manufacture of products along with the assessment of technological, environmental, and economic risks at different production scales. Nowadays, many biorefineries and forest research laboratory have presented methodologies to identify promising bio-based products. These methodologies constitute assessment and review of preliminary economic and technical potential, a screening based on chemical functionality, the determination of technical barriers based on best practices, and the potential for each building block chemical to produce a range of derivatives. It has been clear that biorefineries producing forest based bioproducts should employ both market-driven and process-driven approaches within the strategy-building framework.

6.1.3 Market and competitive assessment of biorefinery strategies and isolated products

Market assessment is another important point to be considered where new product development success depends on its criteria. Market assessment process involves revaluation of strategy in order to ensure (1) functionality and fit on the market, (2) optimum pricing and distribution strategy, and (3) the ongoing recognition and mitigation of market risks and uncertainties. The market strategy for business model depend on two major activities, i.e. value creation through assessment of market potential and value retention through the maximization of competitive advantages associated the product or process strategy. The products obtained through biorefinery are characterized as replacement product (with similar chemical product as existing product), substitution (similar or enhanced functionality) or breakthrough products (new functionality compared to existing product). Therefore, based on the type of products the existing value chain should be assessed in order to evaluate positioning in the market, point to entry in value chain and potential for competitive advantages. Similarly, biorefinery product also required systematic assessment for product portfolio in terms market centric approach. The assessment for biorefinery products is done by activities like market assessment for individual products, assessment of value creation through development of product family of bioproducts, definition of company-specific supply chain for product sale and identification of partnership to mitigate risk and facilitate product positioning

Competitive Analysis

Besides creating value of biorefinery products, it is often essential to define potential of company to retain its product value in competitive position. Competitive analysis assessment is also most important activities of business performed to retain its product value in specific value chain and provides a framework for securing its profitability over time relative to the marketplace. Analyzing of competition can be done by identification of five forces 1. Direct competitors 2. New entrant 3. Power supplier 4. Power buyers 5. Substitute products. Direct competitor’s analysis gives an overview of market share potential targeting specific market segments and the intensity of competition is analyzed by number and size of competitors, market growth, type of product (value driven, or cost driven) etc.

The threat of new entrant has impact on the potential competitive position of company. The level of threat depends on the unique supply chain of existing company, production economies of scale, capital requirement. Cost reduction strategy is also an important strategy that creates barrier to entry on supply chain of existing position holder by newcomer.

Another factor as competitor analysis, is power of supply and buyer that basically focus impact on value chain dynamics created by change of supplier concentration on target market segments. Therefore, the transition or switching of one supplier to another supplier for a purpose of product standardization may lead to a strong pricing negotiation position.

substitute products are defined as the products that offer fulfilling partially or completely the same needs on the market. These products create threats to company position and the threats becomes even more high if substitute product offers an attractive price-performance, thus reducing profitability for company.

It has been clear that the competitive assessment leads to the identification of certain market and business risks associated with the biorefinery implementation.

Therefore, using this analysis forest biorefinery can assess unique product attributes, barrier to entry, unique value chain potential by using this analysis.

6.1.4 Practical approach for the evaluation of biorefinery strategies

After analysis and implementation of biorefinery strategies, it is critical to evaluate those strategy by forest companies. Generally, forest refineries build a product design in a structured way to evaluate overall biorefinery strategy process in conjunction with technology and their business and economic advantages. Three approach for evaluation are mainly used (1) benefit measurement techniques, (2) economic models, and (3) project portfolio optimization methods (Killen, Hunt, and Kleinschmidt 2007; Cooper 2001b). Benefit measurement technique relates to the early stage of design process and recognize the lack of accurate data. Economic models consider each project as an investment for which economic targets can be estimated. The third one approach relates with evaluation of project not as individually but as part of an overall project portfolio of the company.

6.2 Bioeconomy and biomass value pyramid

Bioeconomy is broad area comprising a large value chain encompassing large possibilities for future development. The sectors like forestry, agriculture, fisheries, aquaculture and related industries are covered by the term bio-economy. The bioeconomy play a key role in maintaining and creating economic growth and jobs opportunities, while improving the economic and environmental sustainability of primary production. By implementing bioeconomy strategy, it can contribute in the development of rural areas by promoting biomass supply and demand actions with regional dimension, supporting the creation of supply chains for bio-based industries, and the establishment of a network of small-scale local biorefineries. Biorefineries are a key enabler of a circular bioeconomy, providing significant opportunities where biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass are achieved.

Biomass value pyramid

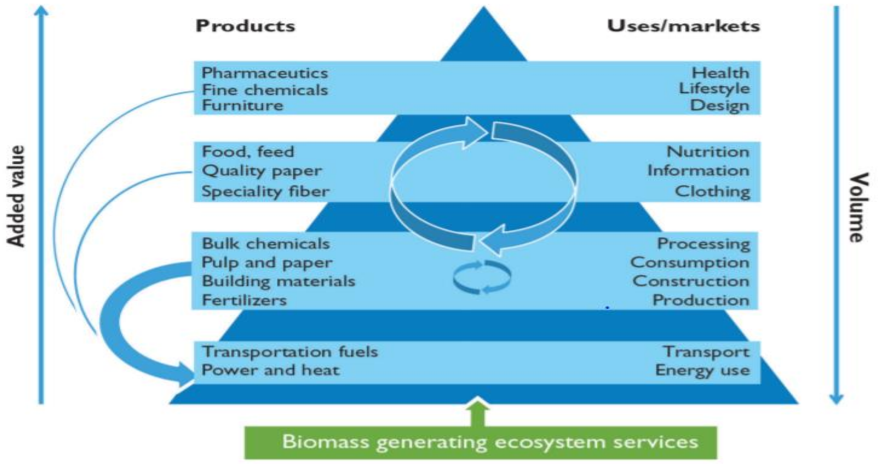

Fig 20: Biomass value pyramid for a circular bioeconomy (Antikainen, Lammi, Timo Rüppel, & Valkokari, 2017)

After conversion of biomass resources into product, there is important division between main products and byproducts. However, by-product sometimes could even be more valuable than the main product (or can be made more valuable through research and development). Many approaches have been done to conceptualize the use of resource in terms of value. A value model "The Biomass Value Pyramid" demonstrates how biomass can be optimally cascaded firstly into high-value, low-volume products. It shows cascades of products where products from pharmaceutical and fine chemicals market placed at first; secondly, into relatively high-value and high-volume products including food, feed, proteins, functional chemicals and bio-based materials; and lastly, into high-volume, low-value energy products such as fuels and electricity. This model clarifies that 'energy' is regarded the least valuable use, with successive increase in value with 'chemicals and materials', then 'nutrition', and 'healthcare and lifestyle' on top. From this it has been clear that to produce energy products from a certain biological material is the least valuable and should be the last "resort". Therefore, cascading approach to biomass, by converting biomass and residues into food or feed, value-added products and energy in an integrated system can be promoted by using biorefinery concepts.

On perspectives of biorefinery optimization, it has been also found that biorefinery process will produce a profitable combination of value-added products, while at the same time producing enough high-volume products. It has been found from the study that using the concept of integrated biorefinery approach, multiple products can be produced with their multiple uses in addition to the main products. The resulting end product produced through integrated biorefinery concept consists of promising products- dissolving pulp, furfural, carbon foam and battery anodes—have established markets, reducing the risk for the first commercial plant. From this point of view, we can assume that biorefinery that are used for biofuel production could generate the most profitable and commercially significance bioproducts from forest biomass as energy biorefinery operated as similar as integrated biorefinery concept with multiple co-products(Budzianowski, 2017).

6.3 SWOT Analysis for Norwegian forest biorefineries regarding valuable forest bioproducts

As the need of innovative and value added bioproducts are increasing, the use of different strategies for obtaining for those products are also been formulated and tested. Based on the research, the study has found that forest biorefineries are the platform that convert unutilised biomass into value added products. Depending on the type of bioproducts, biorefineries utilise different process, technology, design and system to yield desired products. Therefore, the selection of appropriate process or technology with maximum yield is essential for profitability and successful business model. SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis is an instrument of strategic planning which scans internal strengths and weaknesses of organizations and illuminates the opportunities and threats of the environment. Using SWOT, it creates a framework for deriving strategies for business organization by providing transparent initial overview and identifies problem areas.

Table 5. SWOT analysis for Norwegian biorefineries

	Success factors	Failure factors
Internal factors	Strength ▪ Abundant sources of raw materials in Norway for creating value added products through biomass conversion. ▪ Existing infrastructures that enables a production of wide range of bio-based products like chemicals.	Weakness ▪ Transportation for raw materials costs higher in Norway. Lack of transportation policy creates weakness for Norwegian biorefineries for generating value ▪ High operation costs for logging forest biomass.

	biomaterials, biofuels, food and feeding materials etc. ▪ Biorefineries consists of a group of teams which focuses on the technical and nontechnical aspects for the product design. Therefore, the presence of knowledge and expertise on the specific areas attributes the great strength to Norwegian biorefineries ▪ Support from governmental and research organisation like Innovation Norway, SINTEF, Research council of Norway for value creation and new green jobs. ▪ Collaboration between industries, research institutions and value chain in Norway adds strength to biorefineries for innovative bioproducts.	▪ Lack of interest and involvement from private forest owners in terms of raw materials utilisation. ▪ Low price of oil obtained from non-renewable source in comparison to sustainable sources ▪ Need more investment in new technology
External factors	Opportunities ▪ Norwegian Forest biorefineries can make contribution to sustainable development ▪ Strengthening the economic position of forest market and national economy. ▪ Production of green chemicals and bioenergy creates consumer preference towards environment sustainability ▪ Emerging global and local markets	Threats ▪ Competitors with the established product in the existing market ▪ Changing government policies ▪ Availability and contractibility of raw materials like climate, logistics, policies e.t.c. ▪ Topography and infrastructures of the site for setting refinery plant. ▪ Fast Implementation of other renewable energy sources to satisfy market demand instead of sustainable resources.

6.4 Market segments and market opportunities for Norwegian forest bioproducts

Understanding the market of forest and wood products needs analysis of global trends on the economy, demography, environment, consumption, technology and politics. Traditional markets of forest industry are newsprint while growth opportunities within areas such as wood mechanical products, fiber-based packaging and biofuels has been found recent years. However, it is crucial to develop comprehensive policy with measures and framework conditions which creates new market that meets the industry's potential. The market segments for forest bioproducts are categorized according to following basis:

On the basis of product. Utilizing biomass from forest enables to develop variety of bio-based products. These include either existing products from traditional method or products from innovative emerging products. Based on the product types, market segments for forest bioproducts are classified into following groups:

-Bioenergy -Biofuel

-starch-based products -Medical biomaterials

-cellulose based ethanol

On the basis of the end users/applications: On the basis of application/end users and consumption of bioproducts, markets for forest products are divided into following groups:

-Building Materials -pulp and paper

-Medical - Energy

- Chemical industry -Agriculture

- Others

Market opportunities for Norwegian forestry is determined by the properties of wood as a raw material for multiple applications and its global trends.

Construction

Construction sectors directs greenhouse gas emission. Therefore, Increased focus on building materials CO2 footprint is needed. In construction industry, the development of wood and wood fiber-based component with other components creates an opportunity for new markets for several industries in Norway. But it is recommended to focus towards increased investment in industrialization, standardization and digitization in planning and production of buildings.

Energy

Energy is another sector where market opportunities for forest bioproducts can be achieved. The transport sector accounts for the largest emissions of greenhouse gases in Norway by 33 per cent of total land-based emissions. Use of sustainable biofuels contribute to trigger greenhouse emission by replacing fossil-based fuel. The growth in the energy area be achieved through the production of liquid biofuel (such as fuel and bio oil) as well as solid biofuel (pellets and bio-coal)

Biochemistry and Refining

Nanocellulose is the derivatives of cellulose with its characteristics of broad availability, biodegradability, biocompatibility, and renewability, can be used as sustainable materials for biomedical and industrial applications such as packaging, hygiene, paper, films, membranes, tissue engineering, hydrogels, and aerogels. Within the fields of biomedicine, the fiber structure covers a scope including its applications such as vascular grafts, artificial skin, blood vessels, and implantable scaffolds. Furthermore, within an area of biorefining, the fiber material can as be used as material for reinforcement in composites and oxygen barrier or as a liquid adaptation of viscosity or emulsion regulation.

Other application areas:

- Packaging and hygiene products
- Viscose for textile production
- Agriculture area for soil improvers
- Proteins and fiber for fish feed, animal feed and human food
- Bio-based chemicals and bioplastic

6.5 Commercialization of forest bioproducts

Commercialisation of product after its manufacture through a process is most essential steps in any business model. After the manufacture of the product, it should reach to desire market fulfilling the demands of the customers. Although the production of bio-based chemicals and products are technically feasible, smaller number of products are commercialised. Two assessment criteria are required for commercialisation of bio-based products.

1. Market assessment (raw materials availability, product profitability, competitive nature of market etc.)
2. Technical assessment (commercial experiences, capital investment, accesses to technology, environmental consideration etc.)

To promote implementation of forest bioproducts commercialisation, it is required to understand production-to-consumption system or 'value chain'. 'supply chain', or 'market chain'. Forest bioproducts value chain can be divided into several sets of activities. Production, collection, processing, storage, transport, marketing and sale are the major activities of forest product value chain through value added bioproducts reach to their targeted customers. However, the relative importance of certain steps of value chain depends on the type of products. For example, value chain for some locally traded products are short and simple, with harvesters selling their products direct to consumers

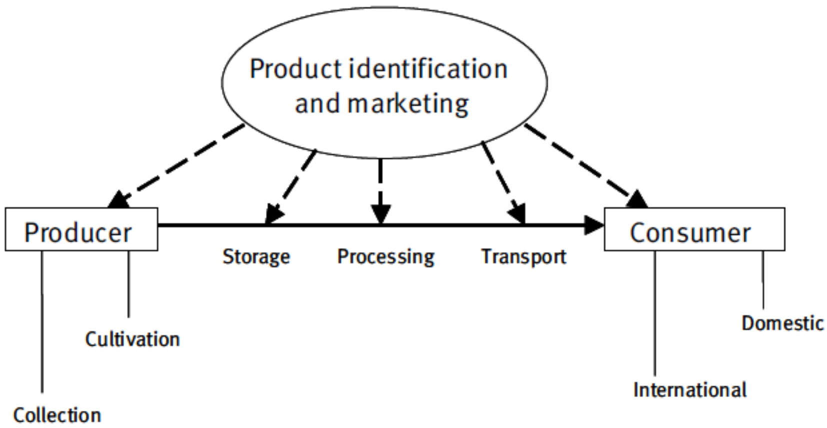

Fig 21. From production to consumer or value chain

Furthermore, there are some requirements if the product is targeted on international trade. Certain criteria and requirements such as quality standards, permits and taxes, safety regulations are required in case of export of products and condition such as storage, processing and transport may be required for importing inside country before selling it from retailer to final customers. Also, recognition of new products materials makes easier for the market establishment particular. So, innovative products take times for supply chain participants and downstream processor to adapt equipment and process. For instances, the bio-based chemicals such as ethylene, propylene can enter market easily because these chemicals has already found place in the existing market except considering few factors like price and environmental footprint.

Commercialization of forest bioproducts and processes can be strengthened by applying open innovative process. Open innovation process strategy consists of application of 3 innovation process:

(1) outside-in processes, e.g. customer and supplier integration, participation in innovation clusters, applying innovation across industries, buying intellectual property and investing in global knowledge creation.

(2) inside-out processes, e.g. licensing intellectual property (IP) and/or multiplying technology by transferring ideas to other companies, and commercializing ideas in different industries (cross-industry innovation)

(3) a coupled process including the outside-in process (to gain external knowledge) and the inside-out process (to bring ideas to market) (Gassman & Enkel, 2004)

Although commercialisation is most crucial steps in business, there are some challenges associated forest products markets that must be understand while promoting the bioproducts.

- Production is often dispersed and markets poorly developed
- Markets are diverse and faddish, but product development is long
- Small Products Volumes
- Use of appropriate technology
- High level of Barriers to enter into the market
- Certification requisition
- Intellectual property rights issues

6.6 **Possible sources and types of forest biomass for bio-based products**

The term biomass is defined as any organic matter such as dedicated energy crops and tree, agricultural food and feed crop residues, aquatic plants, wood and wood residues, animal wastes, and other materials which are available on a renewable basis|. Nowadays there has been arising questions regarding the replacement of fossil resources. So, biomass could be the best solutions for addressing those concerns by solving the problem of energy and raw materials for the chemical industry and others. Also, in a long -term basis sustainability cannot depend on finite resources and biomass as a renewable resource can correspond this concept. The following are the type of forest biomass that can be used to generate valuable products from forest resources:

1. Dedicated forest

   Apart from timber and furniture products, forest has been realised as the important resources in bioeconomy by creating valuable bio-based chemicals, biomaterials and bioenergy. Due to this reason, public interest towards forest industry are increasing gradually and therefore, plantation/ establishment of forest by public and private sector at a local or national level has been accompanied. Such forests which are established solely for its particular application purpose are termed as dedicated forest. Dedicated forests serve as sustainable source of feedstock for biorefinery enabling manufacturing of desired products. In Norway, various private and public owned forests are present which can contribute as raw materials for biorefinery and biobased industry.

2. Saw-milling and other wood manufacturing residue

   Large amount of saw dust can be obtained from sawmill while logging wood. Saw-mill residues are used for various purpose depend on local conditions, but bulk amount is found to be unused. Therefore, unused residue can be used to generate valuable products using biomass conversion process. Furthermore, other residues like wood chips, wood pellets, barks are harvested during logging of tress, wood processing industry and pulp industry acts as resources for forest biorefinery.

3. Logging residue

   Logging residues consist of branches, leaves, lops, tops, damaged, or unwanted stem wood. Such residues are generated after logging of trees and often left in the forests. This unused forest biomass creates an opportunity for creating products.

4. Residue from other industry

   Residue obtained from various industry can be used as feedstock for another products. Paper and pulp industry produce different intermediate products along with desired product during the process. So, these intermediate or residue are separated and can be used as raw material for generating other valuable products. For example, crude tall oil is extracted as residue during wood fibre processing in pulp industry can be used as raw materials for biofuel productions.

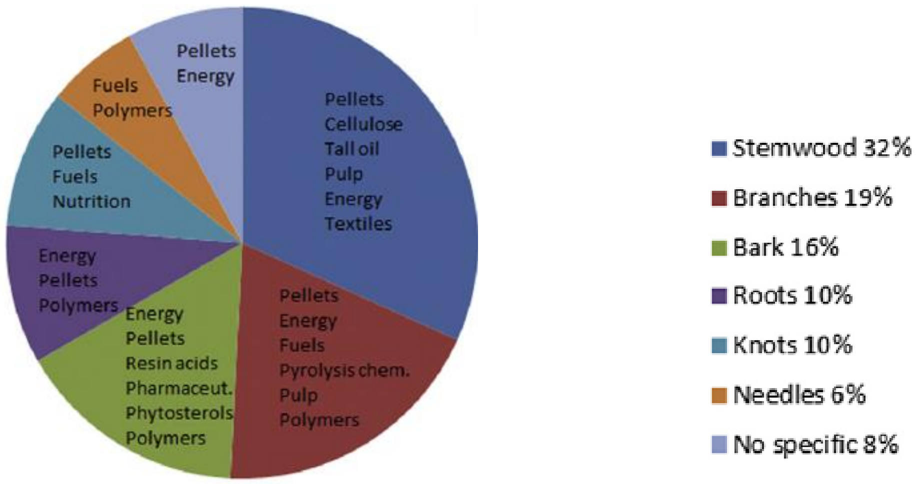

Fig 22. Preferences of tree part for needed for products (Backlund, Karlsson, Mattsson, & Bergsten, 2014)

6.7 Lessons learned from different case studies

Generating of valuable bioproducts requires a strategic transition from forest biomass to value added products. Biorefinery is the platform which serves as a conversion of feedstock to desired products using technology, process and methods. Depending upon the type of products, chemicals or extractives need to be isolated, different biorefineries applied different techniques. The success of the forest industry sector is based on increasing demand for forest-based products, availability of sustainable raw wood material, economic energy prices, advanced forest industry technologies, efficient production machinery, and the special status of the forest sector in the national economic policy. Different biorefineries in different areas adopt different strategies which has been figured out in this study.

From Finland biorefineries it has been found that finish forest industries has been contributed in bioeconomy by the support from research institutions and collaboration of government bodies. For this purposes, funders from some research projects and companies was found to be involved. Similarly, other important funding agencies like The Centres for Economic Development, Transport and the Environment (ELY) were also found to contribute for Finish forest industry. As UPM biofuel case studies from Finland, it has been learned that the collaboration between two biorefineries will be beneficial for raw materials optimisation and profit maximization. This kind of biorefineries setting (UPM Lappeenrantta plant is organised in a vicinity area with UPM kakaus mill) creates low risk for biomass availability as well as optimised cost for pretreatment for lignocellulose biomass. Therefore, the generation of sustainable biofuel along with its optimized biorefinery process will be of greater significance.

The study conducted on Swedish biorefinery SEKAB shows that it has approached products trends from traditional ethanol to sustainable bioethanol. The recent innovations on bioproducts creates an impetus to company for manufacturing next generations of sustainable bioethanol and innovative solutions in green chemistry. From the study it has been learned that the company adopt strategies like i. sustainable utilisation of biomass with profit maximisation ii. extensive collaboration across sectors, industries and disciplinary fields to build extensive network in the forestry and processing industries iii. filling number of patents for protections. Also, the studies on Domsjö Fabriker showed that it has emphasized, show approaches for maintaining sustainable value chain successful by co-operation between biofuel consumers and pulpwood consumers.

The study on Borregaard biorefiney in Norway shows that the company has figured out the strategy in order to develop innovative value added bioproducts. Innovations is the company`s strategy for its value chain. The approach that has been adopted by the company in order to achieve innovations includes i. investing considerable resources in research and development (R&D), ii. Formulating a strategy for specialisation and increased value creation, iii. extensive collaboration with customers, universities and research institutions in several countries and maintains close relationships with its customers. Furthermore, Borregaard has a wide variety of chemicals and it has collaborations with other chemical industries creating sustainable value chain.

Similarly, other research projects in Norway like BioMim - Advancing biomass technology project has focused on the utilization of raw materials. From this study, it has been found the extensive exploitation of raw materials for product manufacture will be more beneficial and profitable. Lignocellulose biomass processing is very difficult, challenging and high cost process. So, the study emphasised on the the use of biological process by using fungi as natural process can be more beneficial, profitable contributing optimization of biorefinery.

Also, another Norwegian project "LignoRef has focused its objectives about central processes included biomass pretreatment and separation, enzymatic hydrolysis, fermentation and thermochemical conversion of biomass and process by-products. It has been found that the use of the technical processes, methods from biomass treatment to production extraction is very significant in biorefineries. The choice of appropriate process enables the value creations in terms of concentration, amount and quality of extracted products.

6.8 Norwegian forest industry and its bioeconomy

The potential for value creation associated with the bioeconomy are considered to be significant in the global economy. So efficient use of renewable biological resources in an extensive manner is also considered as a key to a shift toward a low carbon economy. As explained by the European commission "The bioeconomy's cross-cutting nature offers a unique opportunity to comprehensively address inter-connected societal challenges such as food security, natural resource scarcity, fossil resource dependence and climate change, while achieving sustainable economic growth (European Commission, 2012) Being provided with an abundant supply of renewable forest resources as well as an industrial and knowledge base, Norway can create a great opportunity to exploit this potential. To this approach, the targeted and the coordinated efforts, better use of renewable biological resources can contribute to renewed growth and a green shift in the Norwegian economy (Norwegian Ministry of Agriculture and Food, 2007).

Although Norway has build an economy dependent on fossil, non-renewable resources through mining of sea oil, the realisation of green shift has been conceived and current policy makers see a national focus on the bioeconomy . The national strategy has been emphasized in order to increased value creation and employment, reduction in GHG emissions and more sustainable utilization of resources as its overall ambition for the future bioeconomy. The forest bioeconomy sector in Norway had a value added of 4.7 Billion (Lillian & Hilde, 2017). It has been focused and emphasised that the research and innovation will assist the bio-industries' ability in developing new knowledge and enhancing cooperation across major sectors like forest resources. Furthermore, it has been stressed that for a sustainable development of the bioeconomy, integrated policy schemes and activities based on engaging a broad range of stakeholders are required.(Lillian & Hilde, 2017)

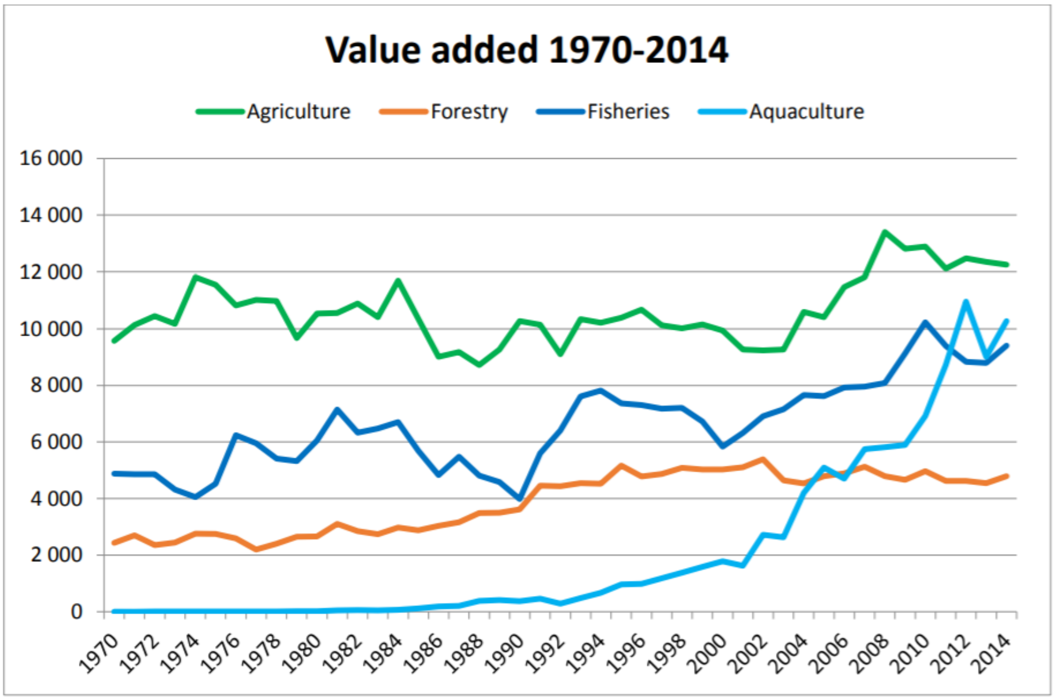

Fig 22: Comparision of value added in selected bioeconomy industries in Norway 1970-2015, in mill. 2005 NOK. Source: SSB (Lillian & Hilde, 2017)

6.9 Opportunities and challenges for forest biorefinery

The production of fuels, chemicals and materials from forest/wood biomass can create a great opportunity and solutions to achieve a sustainable future, especially in countries with extensive forest cover. Although the application of wood resources as a construction and as a source of fibres will remain unchanged or will remain more important in future e.g. for building environmentally friendly houses (CO2 sinks) but the production of unutilised lignocellulosic result in important contributions to the social and economic development. The realistic biomass potential of European forests in 2030 is estimated to be in the range of 623-895 million m^3 $year^{-1}$. This amounts to 58- 80% of the theoretical potential. In Norway, the potential of value creation from forest industry is large. Therefore, production of innovative forest bioproducts may signifies active and profitable forestry while competitive forest industry is of importance to settlement, employment and business development in large parts of the country. Similarly, to be profitable, the value of the new biorefinery products, or the net profits generated, must exceed the values and net profits provided by traditional wood-based industries. Besides this, profitability also depends on other factors how we use techniques/ process for biomass utilisation for prioritised and targeted products. To explore potential in Norwegian forest sector, it is required to implement Forestry policy that facilitate sustainable resource management, where harvesting does not exceed the regrowth rate, and take into account other essential functions of forests such as wildlife habitat, recreational arena for people, and as storage and sinks of carbon.

Challenges

There are some challenges faced by biorefinery industry. These challenges are associated with technical challenges, resources challenges, market challenges etc. In general, biorefinery may face difficulties in few circumstances related with i. knowledge (lack of knowledge of new industries stifles innovation and has created a dependency on extractive industries, masks potential new opportunities) ii. Product demand globally and competition affect local competitive capabilities iii. government policies and governance mechanisms for use of forest resources and new investment in these sectors iv. clusters and networks to create economies of scale v. lack of entrepreneurs. In Norwegian forest biorefinery industry, the following list are possible challenges faced by the company while producing bio-based products

- Costs related to logging of timber; transport are significance of forest income for forest owners. High operating costs like investment of capital for heavy operating equipment, its relocation as well as low income from forest creates a forest owner for lack of interest in employment in forest activities and economy. The framework conditions associated with tax and fees, vehicle rules and infrastructure are worse in Norway than in our neighboring countries which limits the ability to invest in restructuring and innovation in these sectors. Therefore, lack of investment on such sectors effects on raw materials to further reduced profitability and thus further red.
- Proper utilization wood residue: Lack of sales opportunity for raw materials like wood chips within Norway leads to export of biomass to other countries reducing earning.
- Operating conditions and topography of Norway: Operating conditions in Norway are more difficult in comparison to neighboring countries like Sweden and Finland. Topography of Norway and its forest infrastructure creates far access of roads and high transportation cost
- a growing competition between the sales organizations for timber in Norway has led to one competition for the timber that has helped keep timber prices and felling up.

Thus, high cost for raw materials for manufacturing bio-based products limits the profitability.

- Market challenges: Although bioenergy has obvious environmental benefits compared to fossil energy, the development of value chains for bioenergy in Norway therefore depends on market stimulation and facilitation. Production of biofuels has so far not had its commercial breakthrough.

6.10 Intellectual Property Rights (IPR) for forest bioproducts

As we have discussed with the potential of products obtained from forest biomass and the various strategy required for transitions from raw materials to finished products in a biorefinery concept. At the same time, it is also important for securing IPR for innovative bio-based products. Obtaining protection for innovative bio-based products or patenting technical process/methods is highly imperative. For instances, US patent publication in biofuel(lignocellulose technology) have increased about eightfold in this period between 2002-2015 and count about 130–150 per year currently, and could soon reach 200 annual filings (Toivanen & Novotny, 2017).

Biofuel as a most promising renewable sources for energy replacing fossil-based fuel. Various technology for the biofuel has been proposed and applied for the production process. During the last decade, business interest to develop a cost-efficient and technologically sound wood-based biorefinery concept has been increased. This interest has been materialized in research areas with scientific publications and patents applications. To secure return of business investment through development of technology/process, it is required to protection via exclusive IPR. The Canadian patent belongs to the technical field of bioenergy and claim for the preparation methods of biofuel. The invention aims to provide the preparing method of the biofuel, which is easy to ignite, complete in combustion and high in thermal efficiency. Apart from filing patents for technical methods for obtaining biofuel, another patent has been found which claims for invention of burner required for gasification process during gasification process. The subject of invention is a gasified biofuel burner, especially intended for wood pellets or other fine granulated ecological fuel. Similarly, several other patents like automation method for producing biofuel, new biofuel clumps, formulations of forest resources for biofuel production, integrated biorefinery plant for biofuel production etc. has been found for patent protections.

Searching of patents for forest bioproducts reveals that US company Fribria Cellulose SA filed patents for integrated process for biomass and production of biooil. The invention aims to provide an integrated process for the pre-treatment of biomass and its use as a feedstock in a process for the production of biochemicals and biofuels, from a biomass such as wood, forest residues, and residues from the sugar-alcohol and energy cane industry. Similarly, China patent claims its invention to produce biochemicals from forest resources. The invention discloses a preparation method of a novel bio-based emulsifying agent and application. The novel emulsifying agent is a grafting product of undecylenic acid and alkali lignin and is a novel bio-based emulsifying agent prepared from the alkali lignin and the undecylenic acid.

7. Conclusions and Recommendations

The study has explored the various approaches that can be used to create value from Norwegian forest industry. The study has reviewed various possibilities of valuable bioproducts with its production methodology using biorefineries as a platform, suggests the possible strategy for Norwegian forest industry, and pin out some of the challenges associated with Norwegian forest sector. The study shows that the strategy and approaches for the value creation from Norwegian forest industry includes i. collaboration across sectors, industries, and discipline areas ii. processing and use of renewable resources iii. Sustainable production and extractions of biological resources, iv. Markets for renewable biobased products. Furthermore, it has been concluded from the study that the strategy of achieving value creations from Norwegian forest is mainly based on the following pillars.

1. A sustainable forest resources
2. High forest production and increased timber harvesting for their applications in industries, sectors and disciplines areas
3. High degree of processing of forest resources and value creation in Norway with sustainable production process.
4. Continuous innovation and efficiency improvement in Norwegian forestry
5. A high level of expertise, a strong knowledge base in all and an active recruitment required for forest business

Since the availability of forest resource in Norway creates an great opportunity for biobased products apart from wood products and the proper utilisation of forest resource in Norway creates a significant contribution contributions in national economy however national plans and policies are also needed to formulate, implemented to achieve the goals.

Following points are recommended in order to create values from Norwegian forest industry:

1. Norway should strengthen the efforts to recognize the potential contributions of forest products and bioenergy from sustainably managed forests through the creation of an environment for fostering higher innovation, productivity and efficiency in implementing sustainable forest management and inclusive forest product value chains.

2. By initiating the public-private partnerships, there will be the advantages of knowledge transfer, best practices and sound technologies, for improving the performance of wood-based products to facilitate transition towards a bioeconomy.
3. Norway should promote positive perceptions in the society towards developing and using a wider range of green products, innovative forest-based products as contributors to bioeconomy. Economic incentives could be the approaches and should be implemented to promote green energy solutions must be implemented
4. Norwegian forestry becomes an exporter of raw materials . It must be avoided where forest biomass have potential for value creation that are in processing must be at their greatest possible degree in Norway.
5. Through changing in tax system, including taxing forest income as capital income creates interest to forest owners thus enabling the utilisation of forest resources.
6. Norway should give emphasis on the development of forest roads and other measures such as reduces operating costs in forestry.
7. It is recommended that Norwegian forest industry should create a cluster cooperation with others strong Norwegian industry, including the smelting industry, fishing industry, agriculture, oil and gas.
8. Public investment in infrastructure, development and streamlining of environments for research should be implemented. Efforts can be made to operationalize research results through demonstration projects, such as demo and pilot plant.
9. To encourage value creations from Norwegian forest sector, it should be required to develop / adapt technologies as suitable for profitable small-scale production.

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Appendix