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FOR/Maine

Global Market Analysis and Benchmarking Study

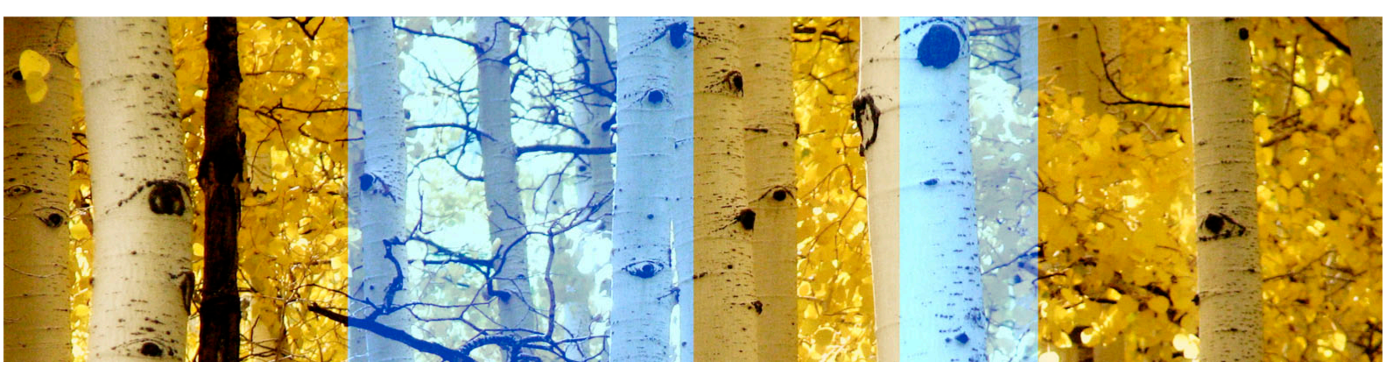
Phase 1: Global Market Analysis

Final Report

Washington & Auckland

July 13, 2018

A18 11451



This report was prepared by Indufor North America LLC using Federal funds under award number 01 69 14749 from the Economic Development Agency of the United States Department of Commerce. The statements, findings, conclusions and recommendations are those of the author(s) and do not necessarily reflect the views of the Economic Development Agency or the United States Department of Commerce.

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PREFACE

This report was prepared at the request of FOR/Maine and the Maine Forest Products Council (the Client) by Indufor North America LLC. The intended user of this report is the Client. No other third party shall have any right to use or rely upon the report for any purpose.

The Phase 1 project involved the initial selection of the 21 products which could potentially be produced in Maine, taking into consideration the resource availability, Maine's infrastructure, established industries and supporting industries, training and academic facilities. Once selected a detailed market analysis was carried out on the 21 selected products.

This report may only be used for the purpose for which it was prepared, and its use is restricted to consideration of its entire contents. The conclusions presented are subject to the assumptions and limiting conditions noted within.

Indufor Asia Pacific Ltd

Marcel Vroege
Senior Partner

Indufor North America LLC

Jeffrey Hatcher
Managing Director

Contact:

Indufor North America LLC
1875 Connecticut Avenue Northwest
10th Floor
Washington, DC 20009
USA

www.induforgroup.com

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1. INTRODUCTION

FOR/Maine has been awarded a federal grant from the U.S. Economic Development Administration for developing a shared long-term vision for the forest sector by identifying the key opportunities, challenges and obstacles in both domestic and foreign markets. The Global Market Analysis and Benchmarking is a critical component for this project. There are two phases in this component:

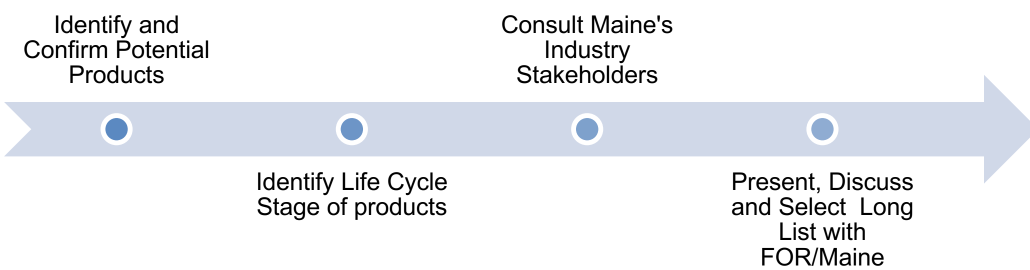
- Phase 1 – Market Study, to identify potential markets that best match Maine's forest and other resources with a focus on the utilization of softwood fibre and biomass quality chips.
- Phase 2 – Competitive Benchmarking/SWOT Analysis, to identify Maine's competitive advantages/disadvantages in the most promising markets and then benchmarking against regions that currently dominate the markets.

The following report is the Phase 1 report.

The initial step in the research has been the selection of twenty products for which the markets have been evaluated.

The selection of the twenty products has followed the following approach, as described in Figure 1-1 below.

Figure 1-1: Long List Development Approach



The approach to developing the long list has been carried out in four steps:

1. Identify and confirm suitability for Maine on all current and known softwood based industrial products. Suitability will be evaluated based on fibre (both log, forest and processing residues) availability over time, species and fit with the current industry and broader state of Maine infrastructure. (transport, energy, labour, etc.)
2. Identify the life cycle stage for each of the products.
3. Interview or have workshops with stakeholders of the Maine forest industry to identify industry desires and preferences for a long list of products.
4. Present, discuss and select the developed long list with FOR/Maine Committee.

Following the selection of the twenty products detailed market research has been conducted on each of the selected products (Appendix I).

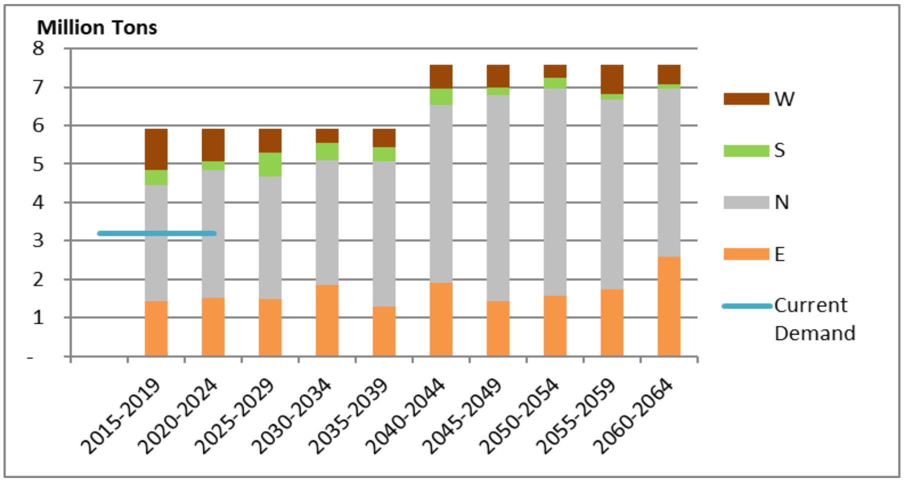
The results from the market study will identify which products will be taken forward into a for a detailed benchmarking evaluation.

2. RESOURCE AVAILABILITY

The resource study commissioned by FOR/Maine has been finalised and Indufor was provided with the initial outcomes on future potential harvest levels by species in Maine. For the next stage of the analysis, it will be critical that there is a sound understanding as to the grades of logs (pulp, small saw, large saw, peeler) that will be available to any new industry.

This analysis indicates that there is a significant opportunity for increased utilisation of softwoods in the State of Maine. By far the most significant opportunity can be identified for utilisation of the Spruce/Fir resource (S/F). Analysis indicates that S/F availability is more than 2.7 million tons/a with further increases possible in the future (Figure 2-1).

Figure 2-1: Maine – Spruce/Fir Future Sustainable Harvest and Current Demand

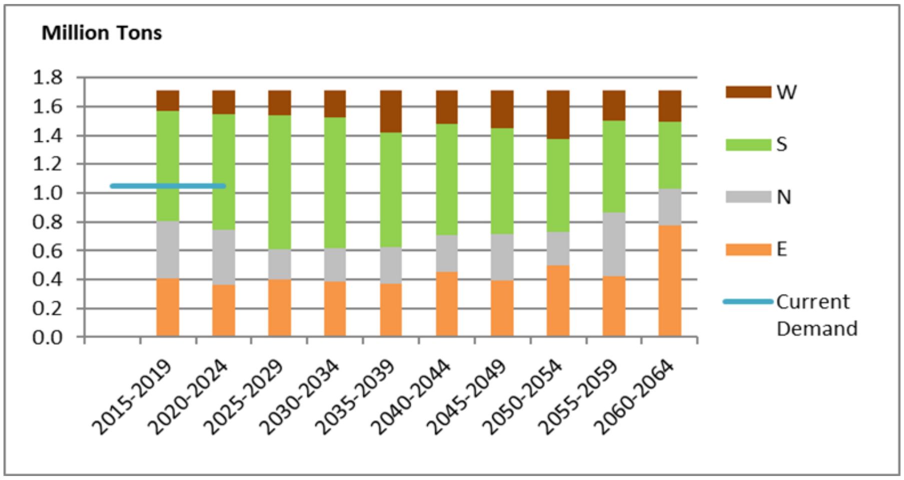


Source: Sewall Resource Evaluation, 2018

The majority of the S/F supply is concentrated in Northern and Eastern Maine, with only small amounts coming from the Western and Southern areas of the state.

Pine is the 2nd most abundant species of softwood available within Maine. The total sustainable harvest of pine is some 1.7 million tons, while current demand is some 1.05 million tons, indicating that some 0.6 million tons would be available for new or expanding industries (Figure 2-2).

Figure 2-2: Maine – Pine Future Sustainable Harvest and Current Demand



Source: Sewall Resource Evaluation, 2018

Pine supply is concentrated in Southern and Eastern Maine, with only small volumes available in Western and Northern Maine.

Other softwoods, mainly made up of Hemlock also show considerable potential to be used more intensively. Current demand is some 700 000 tons/a, and currently announced expansions would see this increase to some 1.1 million tons (Figure 2-3).

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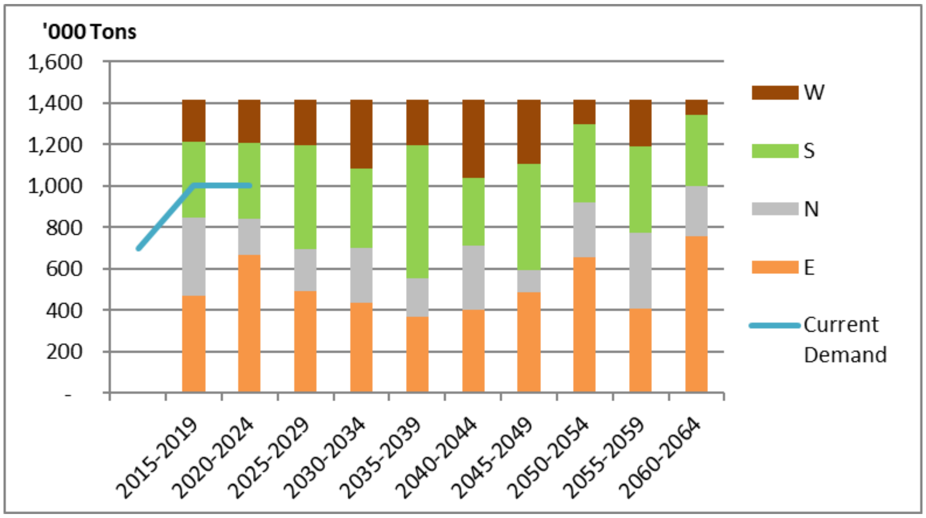
Figure 2-3: Maine – Other Softwoods Sustainable Harvest and Current Demand



Source: Sewall Resource Evaluation, 2018

Other softwood availability is concentrated in Eastern Maine, with increasing availability expected in Southern Maine over time.

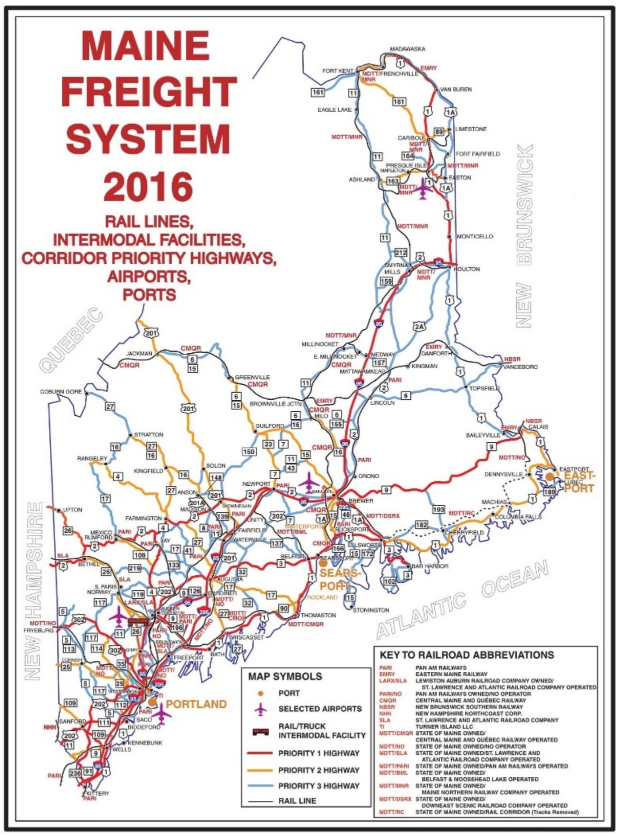
This availability analysis shows that significant and sustainable volumes of softwood are available within the state of Maine. The available amount is sufficient for practically all softwood processing options to be considered, with the only possible exception of a new softwood Kraft mill. A new, greenfield softwood Kraft mill would require wood volumes more than 5 million tons/a, which exceeds the availability of softwood fibre in Maine.

3. STATE OF MAINE'S INFRASTRUCTURE

The various product options have requirements regarding available infrastructure and competitiveness of this infrastructure.

The State of Maine has established road and freight rail infrastructure in place (Map 3-1), as well as several seaports. The industry has over the years identified issues which hinder the overall industries competitiveness. These include turnpike fees, rail services availability and inter-state connections, the ability to have regional container handling capability and access to line spurs. Additionally, quality and access to forest roads can place a significant burden on overall logistic costs—as construction and maintenance costs for the 10–15,000 miles of forest roads are not covered by the state government. If Maine were to address the significant challenges in rail, freight, road and shipping networks, Maine could become a strong competitor in major US and international markets.

Map 3-1: State of Maine Freight System



Services such as power, phone, internet and mobile coverage are all available throughout the state of Maine. Power costs in Maine have traditionally been relatively high compared to neighbouring states, but this difference has been declining in recent years.

Overall, the state of Maine's infrastructure, although not perfect, does not present a hurdle which would otherwise prevent the development and growth of existing or new forest industries.

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4. PRODUCT FIT WITHIN THE MAINE FOREST INDUSTRY CLUSTER

The Maine forest industry cluster includes a range of processors, including pulp and paper, nanocellulose, wood-based panels, engineered beams, sawmilling, pellet manufacture and energy production.

Significant closures that have occurred over the past years have seen a number of paper mills close, as these mills markets (newsprint and magazine papers) have seen a decline. The closure of those mills has resulted in a reduced outlet for residues for the sawmilling industry.

Also, the University of Maine has been actively involved in leading-edge developments in developing a bio-based economy through the Forest Bioproducts Research Institute. FBRI's research areas include science, inquiry, and product development from the forest floor to the factory floor. The institute is working on a numerous projects, including one focused on advanced wood to jet fuel technology (sponsored by the Defence Logistics Agency), various studies in relation to the manufacture and use of nanocellulose, as well as various confidential and private research studies.

Industries that would provide a "fit" within Maine's forest industry cluster have the following attributes':

- Increase resource utilisation of the available softwood resource in Maine and/or
- Provide a market for residues produced by the current industry and
- Provide long-term sustainable high-value employment opportunities and
- Provide a real, long-term, lasting value-add to the state of Maine and
- Can produce products that are profitable for local or global markets.

Indufor has evaluated at a high level, the possible resource fit and selection of products for the detailed market study – considering the impact on employment and value-add provided by the products.

The market study has identified products with a positive market outlook. The final benchmarking of selected products will provide analysis that determines which products are best suited for Maine's economy.

5. HUMAN RESOURCES

The State of Maine has seen a decline in direct and indirect employment by the forest industry. There is a global trend within the forest industry that has witnessed a continued increase in mechanisation. This is partly driven by the requirement to improve production efficiencies, but also due to the significant need to improve overall safety.

This increasing mechanisation in all aspects of forestry and the forest industry has resulted in a change in the skills required of employees. Increasingly, manual jobs are replaced by operator style activities, which in turn requires an increasingly sophisticated engineering support service.

Attracting new industries will be vital to maintaining future employment within the Maine forest industry cluster, and the requirements for employee's skills and educational level will continue to increase enhancing the employment value.

Training and education providers include the University of Maine, operating from Orono and Fort Kent in Maine, The Sustainable Forestry Initiative in Maine (SFI) who focus on management and logging and Northern Maine community college.

The availability of both a workforce with a long history of working within the forest industry and a wide range of training and education providers should ensure that any expanding or new sectors should have access to well trained and highly skilled people.

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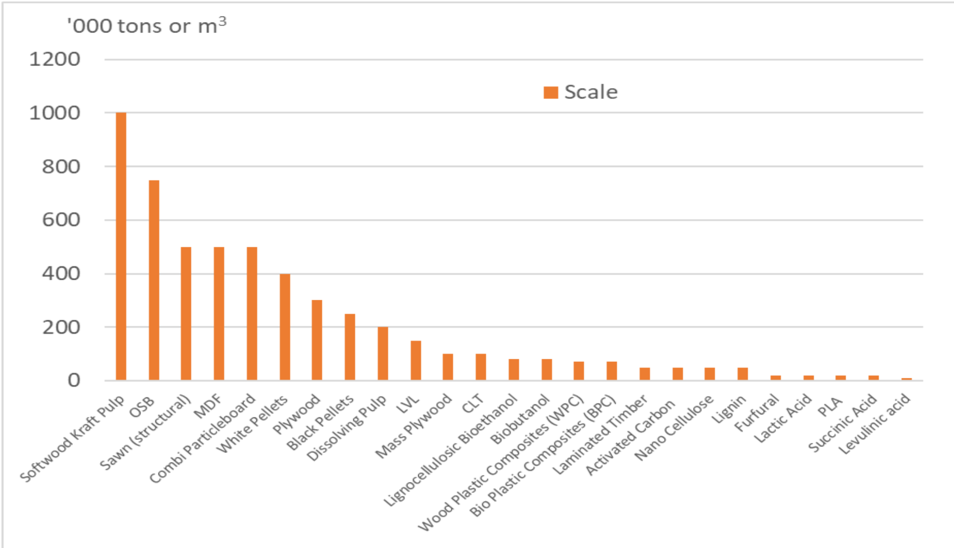
6. PRODUCTS COMPARISONS

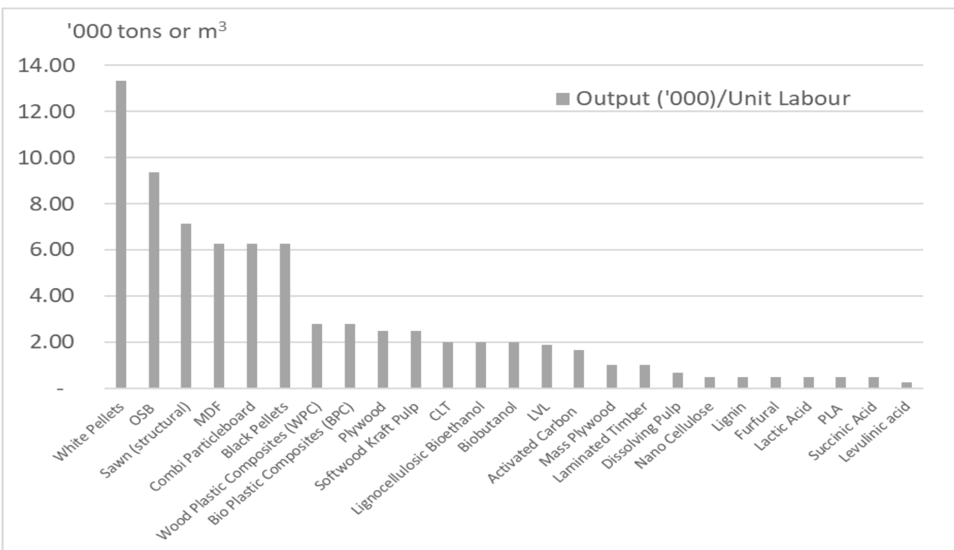
To select the most attractive products for further analysis, a range of comparisons can be used. i.e. if the objective is dominated by seeing significantly higher resource utilisation, large-scale processing options such as Kraft pulp, OSB, structural sawmilling and other wood-based panels options would be attractive (Figure 6-1).

Figure 6-1: Indicative Scale of Processing Options



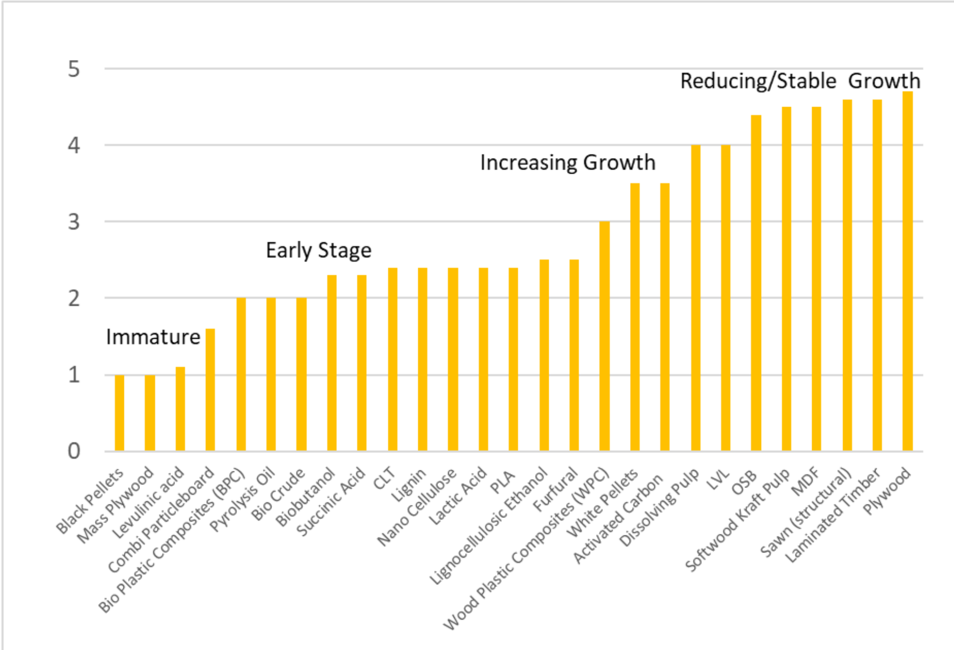
However, if employment is taken into account, options with a relatively low production per employee would be more attractive (Figure 6-2).

Figure 6-2: Indicative Output/Employment Unit (Direct)



Regarding the products life cycle, we can evaluate various products to understand where they are in their product development. Products that are immature require substantial R&D to understand their future in terms of industrial process, manufacturing costs and market acceptance. Products which are mature often operate in highly competitive markets and require a cost-effective manufacturing position, as well as well-developed distribution chains.

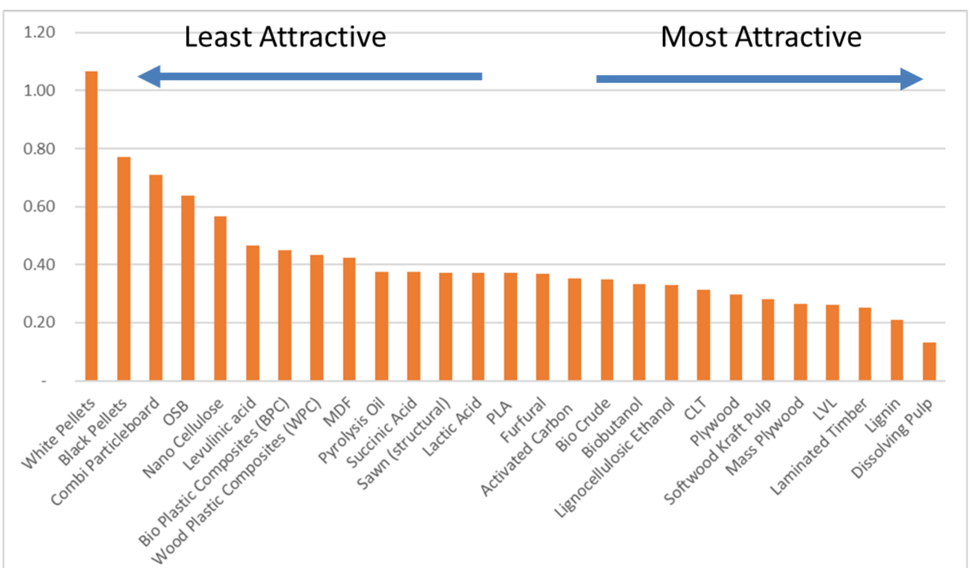
Figure 6-3: Indicative Life Cycle Stage of Products



Indufor suggests that product selection for the long list would take a balanced approach, including products at various stages of their life cycle.

Combining and weighing the above products attributes can provide us with a ranking of products for selection (Figure 6-4). It should be noted, however, that among the list of products, a considerable number are new products. Many of the new products are only manufactured at pilot-scale, and so large-scale production is likely to see a significant increase in scale. Also, several products typically require their raw materials from other forest products industries within the cluster, using by-products and/or residues as their raw material. Worth noting, is the importance a dissolving pulp mill has as both a key producer of not only dissolving pulp, but also a range of other products used in the manufacture of various biochemicals and fuels.

Figure 6-4: Attractiveness Ranking of Processing Options for Maine



The above ranking was achieved by providing a relatively balanced weighting on all attributes. However, if these changes the rankings will change as well.

Of note is the relatively low ranking of OSB. This is caused by the relatively low labour intensity in a modern wood-based panel plant, combined with a relatively low value-add, as commodity

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OSB is a relatively low-value product. In contrast, dissolving pulp is very attractive, due to both, it's scale and high value-add of the product.

7. FINAL PRODUCT SELECTION OF PRODUCTS FOR DETAILED MARKET RESEARCH

Taking the above into account, and after discussing with the steering group, the following twenty-one products have been selected to bring into the more detailed market research analysis (short descriptions of the products are found in Appendix 2).

1 Sawn (structural)
2 LVL
3 OSB
4 MDF
5 White Pellets
6 Wood Plastic Composites (WPC)
7 Bio Plastic Composites (BPC)
8 BioChar
9 Activated Carbon
10 Dissolving Pulp
11 Nanocellulose
12 PLA
13 Lactic Acid
14 Succinic Acid
15 Furfurals including HMF and FDCA
16 Levulinic acid
17 Lignin
18 Bio Crude / Pyrolysis Oil
19 Lignocellulosic Ethanol
20 Lignocellulosic Biobutanol – including Jet Fuel
21 Xylitol

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8. MARKET RESEARCH OUTCOMES

Detailed reports of the market research carried out on the selected products is presented in Appendix I. The market research has identified a significant number of products with attractive market opportunities in either local and or global markets.

Table 8-1 presents some of the key findings from the market analyses, including market size, drivers of growth, current prices, growth rates, main players, and current and potential end uses.

8.1 Market Attractiveness Scoring of Selected Products

Based on the market research findings, Indufor has scored the various products on the following characteristics using a 1 to 10 score, with 1 being the least favourite for a product, and 10 being the most attractive.

1. Markets (including US and global markets and anticipated market growth)
2. Competition
3. Barriers to Entry
4. Product Opportunities
5. Product Constraints

The score is relative to the products and their markets. At this first stage of the comparison, the various attributes have not been given a weighting.

Figure 8-1 shows the score by attribute for the selected products, ranked from left to right according to their total score.

Figure 8-1: Total Unweighted market Score

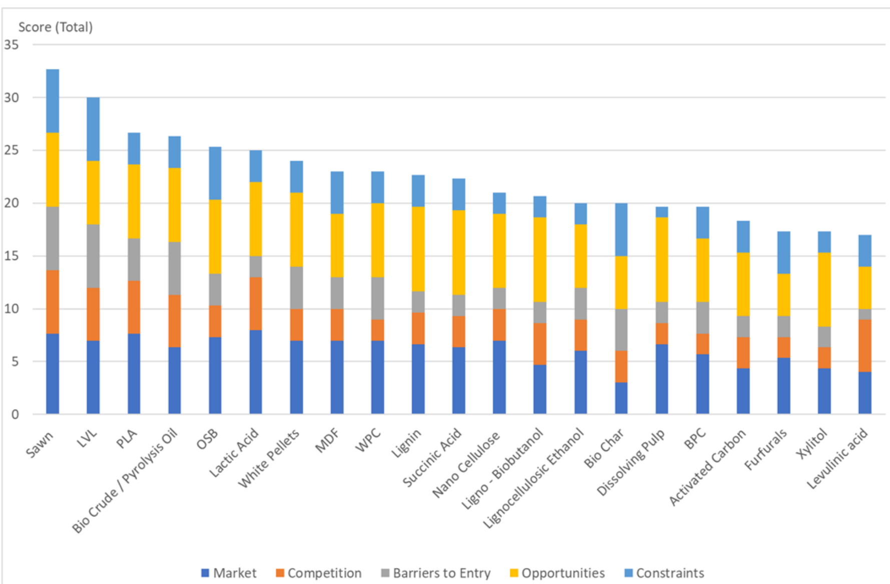

Table 8-1: Key Market Findings for Selected Products

Product	Market Size	Drivers	Price	Growth rate	Main Players	Current End Uses	Potential End Uses
Sawn	Global – 350 million m3; USA – 35 Billion BFT	Construction	500 USD/MBFT	4 to 5%/a	Weyerhaeuser Co., Georgia-Pacific, West Fraser*, Sierra Pacific, Interfor*, Canfor*	Construction	Construction, including mass timber (CLT)
LVL	Global – 4.3 million m3; USA – 2 million m3	Construction	600-630 USD/m3	4 to 5%/a	Global LVL Inc., Pacific Woodtech Corp, Roseburg, Louisiana-Pacific, Boise	Construction	Construction, including mass timber (CLT)
OSB	Global – 33 million m3; USA – 18 million m3	Construction	250 USD/m3	4 to 5%/a	Tolko Industries, Weyerhaeuser, Georgia Pacific, Louisiana Pacific, Norbord	Construction	Construction, including mass timber (CLT)
MDF	Global – 89 million t; USA – 5.1 million m3	Furniture & Construction	300 USD/m3	4 to 5%/a	Arauco North America, Kronespan, Del-Tin Fiber Georgia Pacific, Langboard,	Furniture, joinery, flooring	Outdoor end uses
WPC	Global – 4.3 million m3; USA – 2.0 million t	Construction Home improvement	3-6 USD/lft	12.3%/a	Trex TimberTech Azek, Fiberon LLC, Advanced Environment Recycling Technologies Tamko Building Products	Decking, moulding/trim	Car parts furniture,
BPC	Global – 2.1 million t; USA – 0.6 million t	International trade	1 to 1.8 USD/pound	5-7%/a	BASF, Braskem NatureWorks, Telles, Novamont, Meredian Holdings Group	Packaging, textiles, consumer goods	Car parts construction elements
Bio Char	USA market <5000 tons/a	Environmental	500 to 1000 USD/t	0 to 5%/a	Vermont Biochar, Cool Planet, Oregon Biochar Solutions, Biochar Supreme, Wakefield Biochar	Soil Enhancement	Carbon sequestration
Activated Carbon	Global – 2.0 million t; USA – 0.6 million t	Pollution control	1500 to 2000 USD/t	10-15%/a	Kuraray Suppliers Oxbow Coal SARL, HayCarb, Indo German Carbons Limited, Shinkwang Chem. Ind.	Gas and liquid purification	Same
White Pellets	Global – 39 million tons; USA – 3.2 million tons	Renewable energy demand	Export – USD140-150/t	8%/a	Enviva, Drax, Pinnacle Pellets, Georgia Biomass, Westervelt and Pacific Bioenergy Corp	Heat and Power	Same
Dissolving Pulp	Global -6.8 million t; USA – 0.4 million t	Textile demand, cigarette filter demand and food additives	900 to 1000 USD/t	4 to 5%/a	Sappi, Bracell, Lenzing, Rayonier, Aditya Birla Group	Textiles, cigarette filters and food additives	Cosmetic and pharmaceutical end uses.
Nano Cellulose	Mainly NFC is commercial; (1350 t/a). CNC & BC markets very small	Growing demand for packaging	10-1000 USD/kg	Very high AGR of 30% expected (2016-2021)	NFC: Paperlogic, Imerys, Borregaard, UMaine, American Process, Nippon Paper Crecia Co. Ltd	MFC & NFC mixtures: fillers & additives in packaging	NFC: Paper, paperboard, composites, coatings, paints
Lactic Acid	477 kt/a	PLA for food packaging, food and beverage	1215 USD/t	AGR of 6.4% expected (2015-2020)	Corbion & Cargill, Henan Jindan Lactic Acid Technology, Galactic and Anhui COFCO, Galactic	PLA production, flavour enhancer, preservative in food & beverage	3D printing filament
PLA	150 kt/a	Demand for bioplastics, environmental regs	2070 USD/t	AGR of 13.2% expected (2014-2022)	Nature Works, Corbion, Hebei and SUPLA New Materials	Food containers (foam trays, coffee capsules), shopping bags	Automotive industry, floor coverings, electronics
Succinic Acid	59 kt/a	Growing Demand for bioplastics	2000 USD/t	AGR of 6.5% expected (2016-2021)	BioAmber, Myriant, Reverdia, Succinity	Polyurethanes, resins, coatings, personal care	Precursor for BDO and PBS

						and food products	production for bioplastics
Furfurals	Furfural 441 kt/a; Furfuryl alcohol: 391 kt/a	Demand by oil, gas, car industry (metal castings)	1300-1500 USD/t	Furfural: 4.3% AGR, furfuryl acohol: 2.5% AGR	Jinan Shengquan Group, Central Romana, Henan Hongye Chemicals, TransFuran Chemicals	Furfural: binders for metal castings; Furfuryl alcohol: solvent	Cosmetic and pharmaceutical end uses.
Levulinic acid	Very small market of about 3 kt/a due to technological challenges	Demand for derivatives e.g. GVL, ethyl levulinates, etc.	4000-5000 USD/t (China)	No growth	China: Jiangsu Yancheng China Flavor Chemicals, Hebei Langfang, etc. US & EU: Biofine	Solvents, pesticides, herbicides, polymer resins, cosmetics	Expected to remain being used for biofuel production
Lignin	Lignin: 50-70 Mt/a; Lignosulfonates: 1.3 Mt/a	Replacement of fossil-based counterparts e.g in resins	300-1000 USD/t (varies with purity & value)	Market is expected to grow as new applications will emerge	Borregaard, Tembec, Aditya Birla,Sappi, Nippon Paper, Ingevity, Stora Enso, Domtar, etc.	Phenolic resins, composites, binders, sorbents, fuel additives,	Replace fuel ethanol and fossil-based butanol
Bio Crude	Global < 50 kt/a	Renewable energy standards for heating fuels	300 USD/t	nil	Fortum, BTG-BTL, Ensyn	Heating Fuels	Transport fuels and as raw material for chemicals.
Lignocellulosic Ethanol	200 - 350 million litres in 2017	Demand for biofuels (e.g. EU's RED II)	1.7 USD/gal (corn-based, US, 2017)	AGR of 2.1% expected until 2022	Shangdong Longlive Biotechnology, Henan Tianguan Group, Dow DuPont, Synata Bio, Poet	2G ethanol is entirely used for biofuels production	Expected to remain being used for biofuel production
Lignocellulosic Biobutanol	Very small market of 1.3 kt/a due to high costs (Gevo only bio-isobutanol producer in 2016)	Demand for biofuels, demand for bio-alternatives	1150-1500 USD/t (Gevo's bio-isobutanol)	AGR of over 9% expected for the coming years	Bio-isobutanol: Gevo, Butamax Advanced Biofuels Bio-butanol: Green Biologics, Abengoa Bioenergy	Used as bio-alternative in limited applications	Replace fuel ethanol and fossil-based butanol
Xylitol	Global - 200,000 tons	Health concerns over sugar.	2USD/kg	15%/a	Danisco, Roquette, Futaste, Huakang, Shandong LuJian Biological, Shandong Longlive Bio	Food sweetener.	Food sweetener and possible other industrial uses.

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8.2 Weighting of Market Attributes

The next step is to assign a weighting to each of the attributes, i.e. how important in the selection process is this attribute. This can be done by product, or for all products. Indufor has assigned the following weightings to the various attributes:

Table 8-2: Weighting of Market Attributes

Attribute	Markets and Growth	Competition	Barriers to Entry	Opportunities	Constraints
Weight	7	5	2	6	6

The weighting applied at this stage of the evaluation is based on the following rationale;

Markets and Growth – Products with good global markets are typically well established and allows producers to market their products in export markets. A relatively stronger US market is regarded as being advantageous to a local producer, having better opportunities to market their products within their local market. Strong growth in a market creates opportunities for new suppliers. These combined factors are therefore given a score of 7.

Competition – Competition can both pose opportunities as well as threats to a new producer. Greater competition often means a more significant number of suppliers which indicates an active and thus attractive market. A market with no or limited competition is often not well developed or not very sufficiently attractive to attract new entrants. Hence, a relatively neutral weighting of 5.

Barriers to Entry – High barriers to entry into a market is beneficial to the existing producers. For a new producer, low barriers to entry are advantageous as it lowers the cost and effort required to enter a market. However, for an existing producer, the reverse is true. For this evaluation, Indufor has taken the viewpoint either can be the case for new products to be developed in Maine and hence has given it a relatively low weighting of 2.

Opportunities – Opportunities in the marketplace are essential to market new or additional volumes of products. This results in a weighting of 6.

Constraints – Similar to opportunities, these shape possibilities for growth and future markets. They have been assigned a weighting of 6.

This is an initial assignment of weights to the various attributes. Indufor anticipates that these will be discussed and are likely to change to incorporate the view of the various committee members.

8.3 Final Market Attractiveness Score

The final attractiveness score based on the market score and the weighting of the attributes provides for a ranking of the selected products (Figure 8-2). The most attractive market option for Maine identified through this process is sawn timber, followed by PLA, Lactic Acid, OSB and LVL.

Changing either the score or weightings is likely produce shifts in the rankings.

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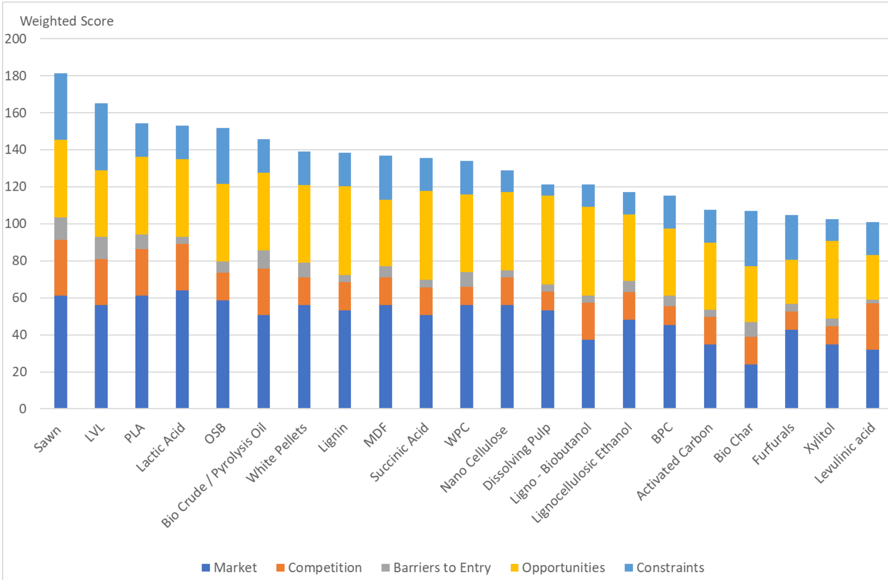
Figure 8-2: Weighted Total Score of Selected Products



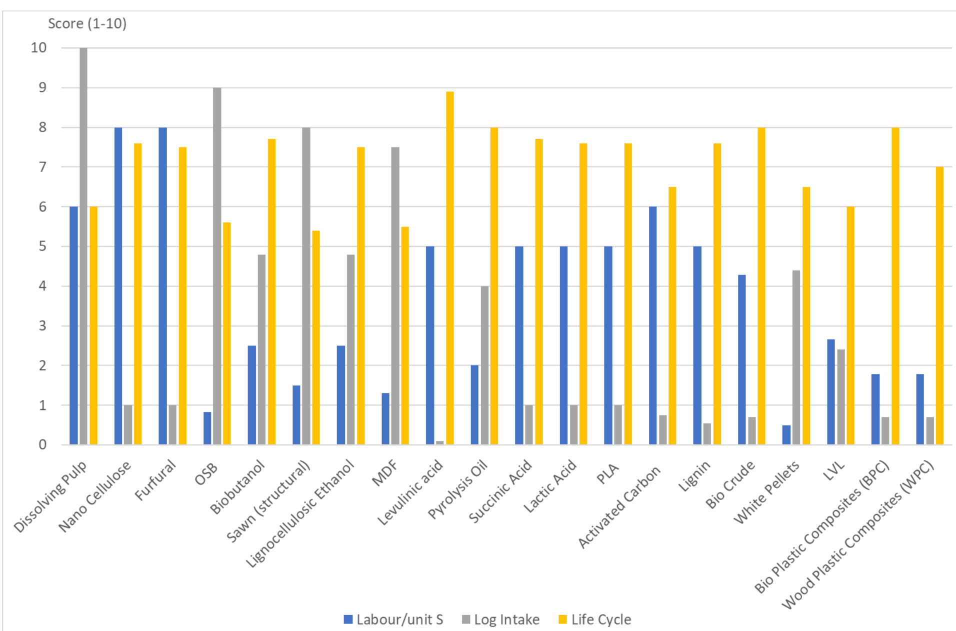
This above ranking does not consider the classification of the products regarding resource and industry fit, impact on job creation, the value-add for the State of Maine, and other potential attributes that require addressing before a final ranking and selection is possible.

8.4 Fit Within Maine

Various attributes that could be important for the State of Maine can be addressed similarly.

Just evaluating labour intensity, the scale of log intake and life cycle position of the selected products allows us to score the various selected products (Figure 8-3)Figure 8-2. Indufor has worked under the assumption that higher quantity log intake (scale) would be preferred by Maine, as would labour intensive, and early life cycle products. Prior to aggregating the weights of each product, their attractiveness scores have been listed below.

Figure 8-3: Attractiveness Scoring by Log Intake, Labour Intensity and Life Cycle



Aggregating the weights shows the relative importance of each specific attribute in the overall product scoring. In the following, Indufor has assumed that both scale and labour intensity take preference over life cycle position, and has weighted labour intensity as leading in importance

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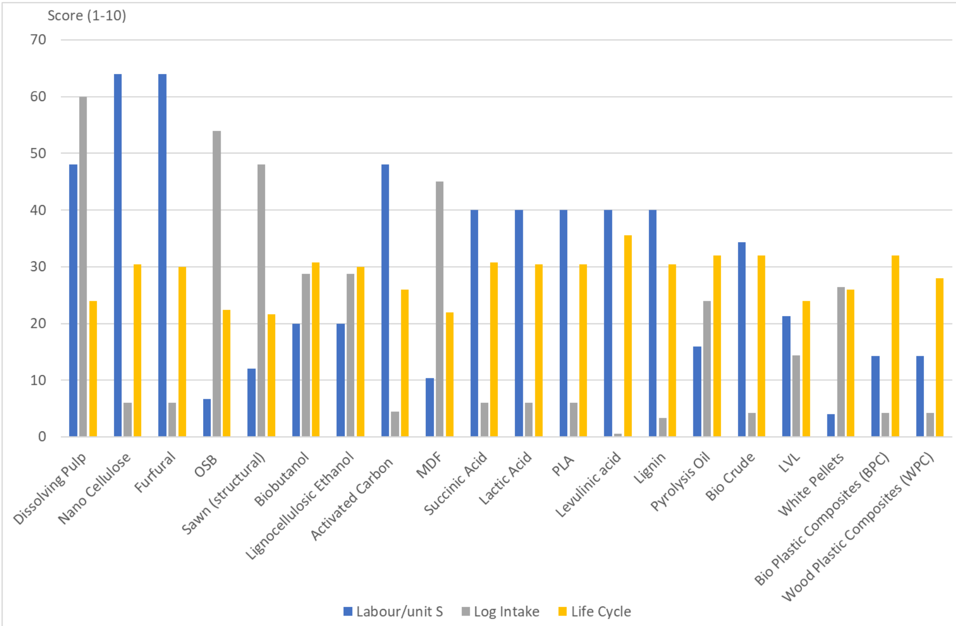
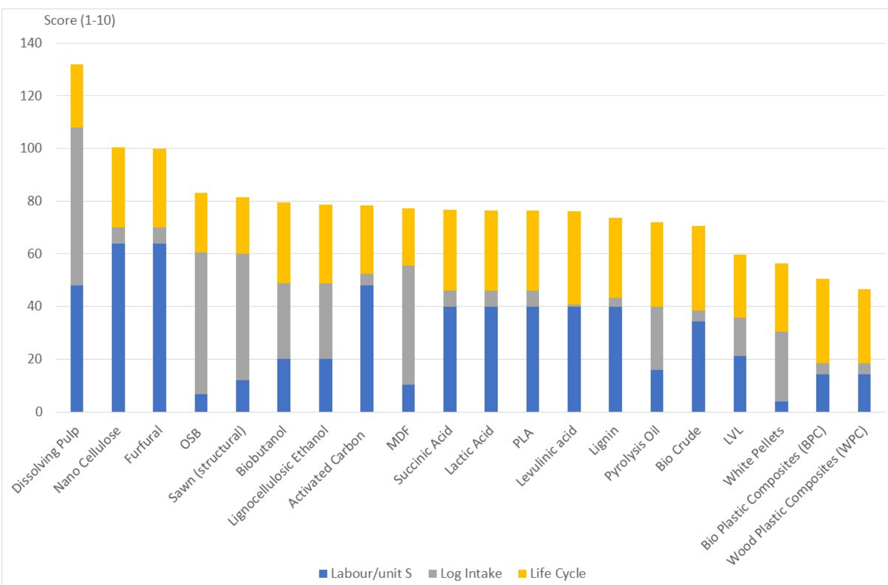
(8), followed by Scale (6) and assumed relatively limited importance to lifecycle status (4). Applying these weightings provides a different outcome than the one presented in Figure 8-4, although interestingly, the order has only slightly shifted.

Figure 8-4: Weighted Attractiveness Score



By adding the attractiveness score, we can provide an indication of the ranking of the products (Figure 8-5).

Figure 8-5: Total Combined Attractiveness Scoring



8.5 Most Attractive Products for Maine

The most attractive products for Maine will fill gaps in Maine's economy and provide the best market opportunity. These products should fit into strong or developing markets, and provide significant benefits to the forest industry cluster—and broader economy.

Adding the scores together, we can identify the total combined score and final rankings of products (Figure 8-6). The top six products were determined to be: sawn timber, dissolving pulp, OSB, nanocellulose, LVL and MDF.

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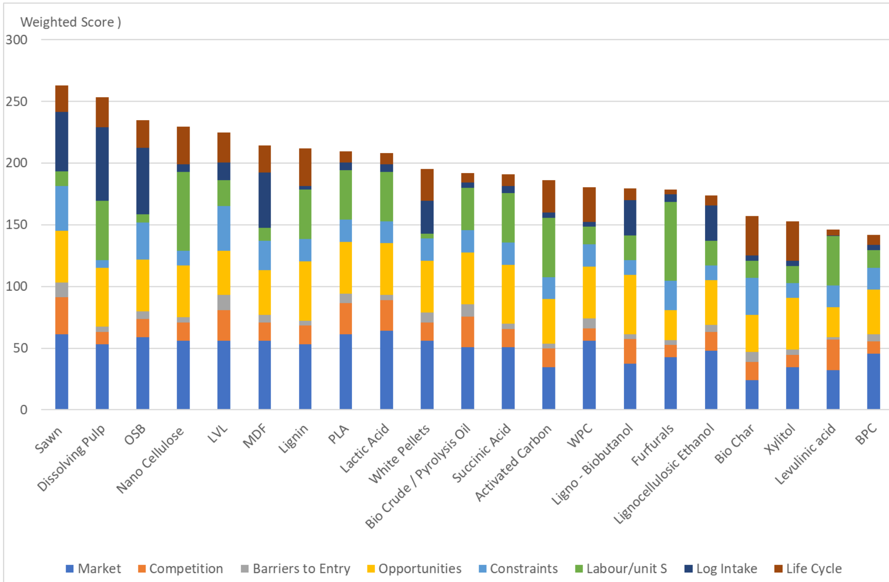
Figure 8-6: Total Combined Score of Selected Products



Although sawn timber is ranked as the highest scoring product, Indufor has suggested that due to the existing, healthy sawn timber industry, the benchmarking study will focus on lesser-known products.

During the April 26 workshop with FOR/Maine committee members, the final selection of six products for benchmarking was determined to include: dissolving pulp, nanocellulose, LVL, MDF, cellulosic sugars (which provide a base for derivatives), and pyrolysis oil. Phase 2 will benchmark these products and the regions where they are produced.

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Appendix 1

Selected Product Market Reports

Contents

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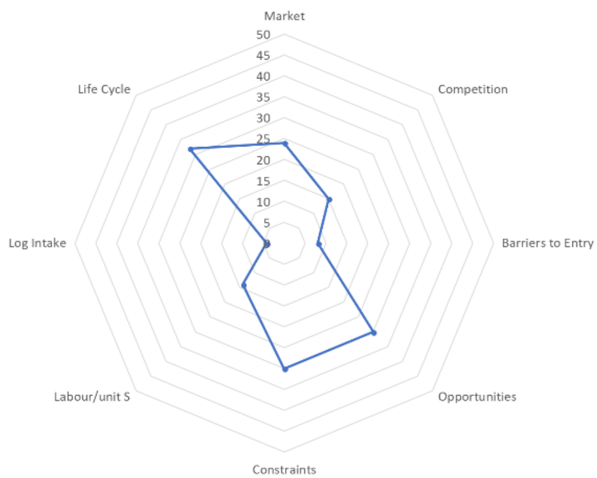
1. BIOCHAR

Biochar ranks as one of the least attractive options for Maine, with a total score of 157. Biochar's highest scores are for global and local markets (20 and 21), market growth (14) and market opportunities (30).

Figure 1-1: Bio Char Attractiveness Score



The following section outlines in detail the market opportunity for biochar for Maine

1.1 Product Description

The International Biochar Initiative (IBI) describes biochar as "*a solid material obtained from the carbonization thermochemical conversion of biomass in an oxygen-limited environment. In more technical terms, biochar is produced by thermal decomposition of organic material (biomass such as wood, manure or leaves) under limited supply of oxygen (O2), and at relatively low temperatures (<700°C)"[1]*. Biochar is a form of charcoal, made from the same generic process, (i.e by pyrolysis).[2]

What defines biochar though is a combination of how it is made, *and* what it is made from. Biochar is derived from organic feedstocks. The feedstock and the particulars of the thermal decomposition process applied produce biochar that can be tailored for specific environments and particular applications.

To date the physical and chemical characteristics of biochar is most commonly associated with its application to soil as an ameliorant[3] and/or as a means of greenhouse gas reduction through

[1] http://www.biochar-international.org/biochar/faqs#question1

[2] Pyrolysis is the process of heating biomass in an oxygen constrained environment. Parameters such as temperature, pressure and the amount of oxygen present are readily adjusted to effect different desired product outcomes. The process therefore can be understood in terms of creating a range of different products in varying amounts across a continuum of conditions described by temperature, pressure and oxygen.

[3] Most documentation refer to biochar as a soil amendment. Indufor prefers the term "ameliorant" as biochar can provide both structural enhancements to soil (improvement of soil texture, microbial activity, water retention) and can act as a slow release fertiliser. The latter function is dependant on what the biochar is made from or how it is treated and blended with fertiliser or fertiliser containing materials (compost for example)

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sequestration. Along with the IBI, The Massey University Biochar Research Centre[4] and US Biochar Initiative[5] also make extensive public reference to the use of biochar for these purposes.

The IBI have issued a standardised product definition and product testing guidelines for biochar used in soil[6]. The classification system based mostly on the testing guidelines is available and companies can go through a biochar certification programme, developed with the product definition, classification and testing guidelines in mind. Academic and Industry bodies involved in biochar, however, are careful to qualify definitions. For example the IBI definition and associated standards document applies only for biochar used in soil.

Camps Arbestain M, J.E. Amonette, B. Singh, T. Wang and H-P. Schmidt (2015) have also presented a biochar classification system with associated test methods[7] related to the use of the product as a soil amendment. It builds on previous work undertaken by the IBI as well as the Guidelines for biochar production, European Biochar Certificate (EBC, 2012), otherwise referred to the EBC biochar standards. The classification system allows users (including commercial entities to identify the most suitable biochar to fulfil the requirements for a particular soil and/or land-use; and also distinguish the application of biochar for niche end uses (such as soilless agriculture).

Other academic sources and public information available from interest groups point to the potential for biochar to be applied in hydroponics, filtration systems for potable water treatment, or in waterways. Although still at the investigative stages, biochars potentially can be engineered to act in this capacity, especially where product density or space are lesser issues. The Biochar Interest Group[8] also points to biochar's applications in water quality and effluent management. A presentation made under on behalf of the IBI and the ithaka institute[9] also points to the potential application of biochar in 3D printing, packaging materials, livestock feed, building materials and fuel cells, among other end uses already mentioned.

An article published by Hans-Peter Schmidt[10] lists 49 different applications, though the author notes that this is by no means exhaustive. Indufor notes that many of these applications are variants of soil amelioration, sequestration and water treatment. Nonetheless Schmidt lists other uses including animal feed additives, litter additive, insulation, air decontamination, humidity regulation, electrosmog reduction, as activated carbon, exhaust filters, carbon fibres and plastics, semiconductors, batteries, metal reduction, cosmetics, paints and pigments, medicines (e.g. as a carrier for active pharmaceutical ingredients), fabric additive for functional clothing (odour capture and thermal insulation), mattresses and pillows.

For the purposes of this study Indufor has preferred to limit the definition of the biochar market as a product used for soil ameliorant and sequestration of GHG's, and as a material tested in water quality management and hydroponics where bulk density is not a limiting issue. These latter uses are relatively novel applications, but ones where there is some market-related traction.

With respect to its function as a soil ameliorant biochar has many recognised applications:

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[4]http://www.massey.ac.nz/massey/learning/colleges/college-of-sciences/research/agriculture-environment-research/environmental-sciences/biochar-research-centre/about-biochar/about-biochar_home.cfm

[5] http://biochar-us.org/biochar-introduction

[6] International Biochar Initiative: Standardized Product Definition and Product Testing Guidelines for Biochar that is used in soil: IBI standard 2-1, version 2.1 23 November 2015

[7] Camps Arbestain M, J.E. Amonette, B. Singh, T. Wang, H-P. Schmidt. 2015. A Biochar Classification System and Associated Test Methods. In: Biochar for Environmental Management - Science and Technology, 2nd edition. J. Lehmann and S. Joseph (eds.). Routledge. This docment is cited and referenced in the IBI Standardized Product Definition and Product Testing Guidelines for Biochar that is used in soil: IBI standard 2-1, version 2.1 23 November 2015

[8] http://soilcarbon.org.nz/areas-of-interest/soil/

[9] The Biochar Industry: by Kathleen Draper sponsored by the IBI and the Ithaka Institute, provided to Indufor for this study. Indufor understand that Kathleen Draper is currently undertaking a biochar market survey sponsored by the US forestry service. Findings will be presented in August at the US Biochar Conference

[10] Schmidt HP 55 Uses of Biochar, Ithaka Journal 1/2012: 286–289 (2012) , cited from the Biochar Interest Group website. The article title is somewhat misleading as only 50 products are actually listed, one of which is twice repeated in the text.

- To improve water availability to plants by acting as a water reservoir;
- Retaining and/or containing and "slow releasing" fertilisers to plants;
- Moderating soil acidity;
- Providing niches for soil microbes to colonise.

Biochar can therefore physically and chemically improve soil quality. The added benefit of carbon sequestration through the incorporation of a relatively inert carbon component to the soils slows the release of GHGs. The mean residence time of biochar in soils is dependent on a number of factors, but generally the release of the more inert components can stretch from decades to millennia. In effect, a long mean residence time can potentially be monetised through carbon credits.

There is considerable debate into the efficacy of biochar as a soil ameliorant or in water treatment. Indufor understands that research in this area is expanding rapidly, bringing rigour and credibility to the subject (other than what might be claimed in promotional material drawing on personal endorsements and "customer raves" to promote the product). A comprehensive literature review is out of scope for this project. However, some observations are crucical to understand biochar and its position in the marketplace:

- There is considerable credibility attached to the notion of "engineered biochar". This (as noted in earlier sections) attempts to illustrate how the efficacy of biochar is dependent upon its base ingredients and the manner in which it is produced. The product, therefore, should be tailored to meet the specific needs of the end use in mind in the context of geographical, climatic and edaphic conditions at the point of application. Biochar developed as a nutrient delivery system or for water retention, for example, may impart significant benefit in one environment but may provide no advantage in another. Based on existing knowledge biochar is more of a custom product, and thus is not readily commoditised.
- In line with this consideration that there is "no one biochar that meets all needs", some industry commentators are also cautious not to overstate or universalise the benefits of biochar. Feedback from interviews indicated that biochar might impart significant benefit to degraded, contaminated or low fertility soils. In higher quality soils the benefits may be subtler and adding biochar to fertile soils may not make any difference. Latitude may also play a role, particularly from the perspective of water retention in soil and microbial activity. For example, it is debatable whether there is any benefit of adding biochar to fertile soils in temperate climates compared with ameliorating arid or tropical climate soils.
- A degree of commoditisation could be achieved in markets where geographic, edaphic and climatic conditions are well understood and/or where the end users have a similar objective in mind. This could include for example the application of biochar to residential gardens. Arguably a degree of regionality will dictate some of this as even if the intended purpose is the same, environmental conditions may require some customisation
- The biomass feedstock is important in end-use application considerations. In the US, the most common feedstock for biomass is wood residues. Wood-derived biochar contains less nutrients than biochar made from animal or human excrement. Therefore while the latter may prove beneficial to soils as a stand-alone product, the former may need to be combined or modified with fertilisers or combined with compost for efficacy.
- Commercial success for biochar may not necessarily lie only with the efficacy of the product. The value of other by-products of the pyrolysis process (volatiles and biocrude for example) should be taken into consideration.
- If the goal of biochar is purely carbon sequestration, then a commodity market can be readily envisioned. However, biochar is not yet seen as an acceptable approach for carbon offset, except in the state of California. At present there is no one in North America putting biochar into the ground for sequestration. The product market positioning needs to go beyond this application.

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1.2 Market Size and Growth

The range of potential applications for biochar were discussed in the previous section including some applications in water treatment and filtration where there appears to be emergent commercialisation; other emergent commercialisation uses include odour control (for example when added to kitty litter). However, it is in the application as a soil ameliorant where biochar has so far enjoyed sustained commercial exposure.

The use of biochar as a soil ameliorant (whether or not intentionally) for little or no monetary reward has happened in different parts of the world for thousands of years. The intentional employment of biochar to confer benefits on soil for a financial charge, on the other hand, is a very new concept. Only in the past decade or so an emerging industry has developed around the use of biochar in soils, and it has only been in the last five years that producers have been providing quality consistent biochar products. Along with this development, there have been ancillary and spinoff services that have started to form, including services and technology around the manufacturing process. Technology is no longer a constraint to the biochar industry[9].

The sustained commercial application of biochar as a soil ameliorant has, to date, been in residential gardens, landscapes and vegetable patches, and in specific horticultural niches. In these uses, the product has most visibility. There is also some use in industrial and municipal landscaping and turf management.

The use of biochar in commercial and industrial agriculture and ruminant farming is presently negligible. An vital inhibitor appears to be cost. Indufor understands that the cost of adding biochar in sufficient quantity to impart a benefit to agricultural and farmland could be as much as 50 times what a farmer may be prepared to pay.

Biochar as an ameliorant can act as a fertiliser or as a soil amendment depending on how it is tailored and the intended purpose. Thus, biochar competes with fertilisers and other soil amendments in the US fertiliser and amendment markets. One could segment this further by narrowing the market to residential agricultural, commercial landscaping and horticulture sectors, but there is rarely sufficient information availiable to compare biochar market shares in these segments.

Commercial biochar use is most developed in the US followed by Europe and China. The product is regional as it is expensive to transport. Local producers support local markets. Within the US, production on the West coast is most advanced, particularly within the State of California which has a state legislature that is supportive. A market in the US Northeast is also developing.

Biochar is available pure (i.e. 100% biochar), and also is available pre-loaded with nutrients and/or as a co-composted product. Co-composted products sometimes provide information on the ratio of biochar in the product.

Reliable information on the historical development and current size of the biochar market, globally and in the US is not available. The IBI was producing reports on the State of the Biochar Industry covering the sector worldwide. The last report appears to have been made in 2015, and only the 2013 report is freely available in the public domain. Various market research organisations[11] have also released reports on the biochar industry and its markets, including market size and developments. How the market is defined in such reports is an issue.

Indufor's position on the current size of the biochar market segment in North America is presently less than 5 000 tonnes per annum, with conservative estimates on the order of 1 500 tonnes. Most Biochar is produced in the US. Less than 10% is made and used in Canada. Cross-border trade is not a present feature of the biochar market.

Most of the biochar available is made from forest or wood processing residues. According to the 2013 State of the Biochar Industry report released by the IBI, at least 50% of biochar products

[11] Indufor has not reviewed such reports and there appears to be a low regard for them among at least some biochar protagonists

are made with wood, with the actual proportion to likely be higher. Recent interviews conducted by Indufor confirm that wood is still the main feedstock for biochar.

Currently, there is no firm information available on the proportion of biochar consumption by end use segment. Interviews conducted by Indufor suggest that the application of biochar to agricultural applications (primarily the residential gardener market) accounts for around 70% of current biochar use. Industrial/municipal and commercial landscaping (golf courses for example, or soil retention matting) are probably the next largest use for biochar, followed by some applications in commercial horticulture. Indufor estimates that water and odour treatment probably account for less than 5% of biochar use at present.

1.3 The Competitive Landscape

1.3.1 Competitors

There is no up to date information on the North American biochar industry producing biochar. A company database dating back to 2015 is available from the IBI. This database only covers entities that are registered with the IBI and includes entities from all around the world. As of 2015, there were 83 US and 10 Canadian companies involved in Biochar production and/or sales registered with the IBI. While they were being produced, the IBI State of the Biochar Industry reports indicated that the number of entities involved in biochar, worldwide had doubled since 2013. This does not necessarily mean that activity is increasing rapidly. The doubling of registered entities could simply have resulted from increased awareness and involvement in the International Biochar community by organisations that already existed. The available information does not say anything about the change in the number of entities commercially engaged in biochar globally or in the US.

Indufor estimates that the number of entities in North America that are currently producing Biochar for commercial purposes is of the order of 100. From interviews, Indufor understands the production capacity of individual companies can range from as little as 1-4 tonnes per year for small-scale entities up to larger producers with production capacity averaging 50 tonnes or more of biochar annually. Most entities are sole charge or employ less than ten people. Large industrial-scale biochar facilities have yet to develop. Cool Planet has stated in a presentation released by the USDA the Alexandria site in Louisiana has a capacity of between 40 000 and 70 000 cubic yards of biochar per year (between 15 000 and 27 000 tonnes per annum[12])

Most current producers are operating on the US west coast. California, with its supportively legislature and water conservation conscious population, has seen the most development. The State has also included biochar as a fertiliser in its registers.

The development of a biochar industry in the Pacific north-west has been relatively extensive on the Canadian side of the border (Quebec), but is now only emergent in the US northeast. Local players include:

- Charcoal Group (New Hampshire)
- Next char (Massachusetts)
- New England Biochar (Massachusetts)
- Vermont Biochar (Vermont)
- Green State Biochar (a start-up venture in Vermont)
- Green Tree (New York)[13]

None of the producers in the Northeast are considered large scale. Given this is a nascent industry with a tiny share of the US fertiliser and soil amendment markets Indufor does not

[12] This calculation assumes a 0.5 tonne per cubic meter bulk density.
[13] Green Tree New York may not manufacture their own biochar.

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consider the competition between biochar producers to be particularly vigorous at present. This is more likely to be the case where the industry is small scale, almost cottage appearance and where collaboration and cooperation are more valued virtues than the competition.

1.3.2 Competing and Substituting Products

Biochar as a soil amendment is an application most commonly referenced by producers and sellers. Competing amendment products include[9]:

- Peat moss
- Compost
- Coir
- Perlite
- Vermiculite

Compared with other soil amendment products in the North American market, biochar use is nascent. The US alone consumes over 75 000 tonnes of perlite in agricultural and horticultural applications annually. Similarly, some 30 000 tonnes of Vermiculite is used annually in the US within in the same industry. The US currently imports over 800 000 tonnes of peat moss from Canada on an annual basis, mostly for agricultural and horticultural use.

Biochar, when marketed as a soil fertiliser or as containing fertilising chemicals, competes with other inorganic and organic based fertilisers used in the US. As with its role as a soil amendment, biochar use for providing nutrients to plants is very small compared with competing products. For example, Canada and the US use tens of millions of tonnes of inorganic fertiliser (NPK) annually. Admittedly most of this is for commercial farming use (a more fair comparison would be to look at NPK use in the same segments that biochar compete in at present) but still demonstrates Biochar's position.

1.3.3 Barriers to Entry

From a perspective of technology, it is not particularly difficult to start up a biochar business. The technology is readily available at a wide range of scales so setting up a sole trader business or a commercial plant is feasible. The range of applications for biochar should also, in theory, provide proper scope for producers to tailor their biochar and enter different markets. However, to date, this has not happened to any great extent. Three key industry and market inhibitors have been identified by one industry participant[9]:

- Economics. The price of biochar has made market penetration an issue in many segments. For example, several industry commentators interviewed by Indufor pointed out that the cost of biochar is inhibiting its application in commercial and industrial farming and agriculture. Other commentators have noted that industry producers have been slow or unable to realise co-product benefits (for example energy generation), and except California, biochar is not seen as an acceptable sequestration mechanism, and therefore no carbon dollars are available. Some industry commentators point out that the present value of carbon in the US is not sufficiently attractive. Such observations on economics may seem incongruous given the high value that biochar products are presently trading at. But such high prices can only be realistically sustained in a retail market where the overall cost per unit sold is within an acceptable range for an individual consumer buying from a garden centre, or in niche horticultural applications where the buyer's own product is sufficiently high value to offset the cost of biochar.
- Education. Consumer awareness of biochar in the US is very low. Indufor's own experience is there is a wide range of information available on the subject from biochar producers, Biochar interest groups, organic farming advocates and industry and research initiatives. Not all the information is unbiased. It is also recognised that there still is a lot to be done on researching the efficacy of biochar and that efficacy is not well communicated

particularly among biochar manufacturers. There also appears to be a lack of manufacturer awareness of the relevance and importance of tailoring biochar for particular end uses and promoting it in this manner. It is indeed not clear whether sellers pay attention to the particular nuances of their product or even communicate that with consumers. In an environment where there is a lack of a working standard and certification programme, consumers are left uncertain which biochar will work for their particular environment.

- Markets. Finding product niches or large-scale end uses where biochar is economically competitive is one challenge. Finding and holding markets is quite another. Presently the sale of biochar for residential garden uses, horticultural applications or in landscaping is seasonally influenced and it is not always repeat business. The very nature of biochar's longevity means that, as a soil amendment is somewhat of a "one-off" product. The challenge is to develop markets where there is repeat business.

Indufor notes that other barriers include the process of getting regulatory approval for the use of Biochar in different end uses. For example, it is understood that there is as yet no approval for the use of biochar in animal feed or for humans. Similarly, the product is not yet an accepted material for application in environmental purposes within the US. It can take many years to get approvals with regulatory bodies such as the Environmental Protection Agency (EPA).

1.4 Key Drivers for Demand

Environment-specific considerations are expected to be an essential driver for biochar demand. The regulatory approval of biochar for new end uses will also support the development of the market and Legislation may also have a role to play.

Environment-specific considerations where the properties of biochar could impart significant benefit is probably the most critical driver for biochar consumption. For example in arid or low rainfall environments, the addition of the right biochar to soil can improve water retention and reduce the costs of irrigation. One interviewee provided an example of a golf course which has reduced its watering costs through the addition of biochar to the course grounds. The use of biochar in some Californian environments has similar water conservation benefits. Finding markets where there is a clear benefit to the use of biochar as an ameliorant at a cost that is competitive with alternatives, would spur demand.

Approvals for biochar use in several potential applications is presently viewed as an inhibitor to market access, and should these approvals be met, this would open up markets where biochar has the potential. But regardless biochar would still need to compete with existing products and therefore cost competitiveness would need to be demonstrated unless renewable product friendly legislation guides industry toward using the use of renewable products. This does seem unlikely.

It is presently difficult to see where Legislation could act as an enabler to the use of biochar, beyond what individual states and federal authorities have already legislated for in GHG reduction and renewable energy promotion. Specific legislation around carbon sequestration would aim at the use of biochar as a legitimate means of carbon sequestration is a potential market enabler, but alone it may not be sufficient to push demand for biochar. The economics of this form carbon sequestration will need to be demonstrated to if it is to be a viable approach compared with other mechanisms currently in operation.

1.5 Prices and Price Trends

Biochar currently reaches its customers through retail outlets such as garden centres and agricultural and horticultural suppliers. Most biochar producers also offer their product through websites, though these would typically be on an ex-mill basis. Amazon has a wide range of biochar products for sale, delivered to the customer. Biochar is offered in a wide range of product units (quarts, dry quarts, gallons, cubic feet, cubic yards, pounds and even ounces) which makes comparisons somewhat complicated. Further, biochar sells in "pure' form, whether or not inoculated or with fertiliser added or blended with compost or other materials. A broad range of product options exist. Retail prices for the product can be very high for small quantities. This is

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understandable and normal but makes it difficult to attain a realistic understanding of the value of the product for industrial scale use. Some companies (those that are large and established) offer biochar in bulk (usually one or two cubic yard bags or sometimes loaded loose into a truck). Table 1-1 summarises price information Indufor has obtained through interviews, publicly available material and company websites.

Table 1-1: Current Prices for Biochar

Company	Product	USD per cubic yard	USD per tonne biochar[1]	Price point	Notes
Vermont Biochar	Vermont Biochar	750	1 960	Ex mill on truck	
Cool Planet	Cool Terra® engineered biocarbon ™	500	1 310	Not specified	Derived from a 2017 presentation
Oregon Biochar Solutions	Rogue Biochar™	249.5	650	Ex mill on truck	
Biochar Supreme	Black owl premium biochar	350	916	Unspecified	It is not clear if this biochar is blended or augmented in any way
Wakefield Biochar	Premium biochar	237.5	700	Unspecified	
Interview	General	200-250	520-650	Unspecified	Dry biochar

Source: Indufor analysis of various documents, websites and interview notes

Note 1) per cubic yard prices have been converted through to a price per tonne assuming one cubic yard equals 0.76455 cubic meters and an assumed bulk density of 0.5 tonne per cubic meter. Where weight is known for the biochar, the cubic meter conversion is omitted. This can lead to higher per tonne prices compared with the prices on a per cubic yard.

Price ranges are quite broad and may well reflect regional differences in competition (the Vermont biochar prices are very high compared with others operating on the West coast of the US) price point or what additives may or may not be with the biochar.

Biochar prices have not changed dramatically over the last year or so. Indufor understands that these prices are unlikely to change either unless sales of scale become a regular occurrence for the industry.

1.6 Product Certification

The IBI has developed a voluntary certification programme so that companies can demonstrate their product meets the minimum criteria set in the most recent version of the IBI Biochar Standards. The programme is only for biochar. Biochar blended with other products like compost.

The goal of the certification is to create consumer and marketplace certainty around biochar regarding “fitness for purpose” and safety. The programme is currently only open to producers in the US and Canada. There are obvious benefits to certification, readily demonstrated in other industries (for example LVL or wood pellets) but to date, the response to the programme has been weak. The IBI lists only one manufacturer (the KARR Group) as holding certification and it is not clear if this company is still operating. Four other companies including Cool Planet Energy Systems, have expired certification.

One reason cited for the lack of interest by industry participants is that the standards offered by the IBI are not very well adapted to the industry. Other commentators point to the complexity of the standards, and a cumbersome and unit expensive procedure.

1.7 Outlook

1.7.1 Market Growth

Industry commentators note there is growth in the current biochar end uses, but it is expected to remain slow in these end uses over the coming years. Biochar use in residential, agricultural end uses has been sustained, but there is a perception that this has been achieved primarily as a result of promotion and the novelty aspect of the product. Once interest generated by the latter dies away, biochar consumption in current end use applications may be difficult to grow or even sustain. It may be necessary to increasingly promote biochar as a component of blended compost or augmented with fertiliser.

Entrance and growth in other market sectors (including large-scale commercial agriculture and farming) will be necessary to stimulate the development of industry at scale. This will require proven product efficacy, regulatory approval and possibly even legislation to drive biochar consumption. Above all, products will need to be cost competitive and impart real benefits for the cost incurred, especially if they are to be accepted in the end uses such as industrial and commercial agriculture and farming.

Ultimately interviewees indicated that biochar should not be considered as a stand-alone product if it is to be successful. It should be considered part of a broader renewable energy strategy, in which pyrolysis is the objective, generating energy for heat and power, bio-crude products which can be further refined, and a biochar, which depending on its nature could have application as a fuel or as an ameliorant. Indufor notes that such a pathway may be complicated, as coupling biochar with energy and biocrude generation requires maintaining an equilibrium of production and demand across the various products that renders them useful in the marketplace. Managing the broader economics of this process may mean that producing tailored biochar is not realistic.

1.7.2 Opportunities

The key opportunity for biochar in Maine would be as a by-product of a pyrolysis facility. Bio-char is a highly localised product so the target markets would be in Maine, and at best, the surrounding states. Ideally, the biochar will be tailored for specific end uses in mind.

1.7.3 Constraints

As it presently stands biochar use in Maine would lend itself only to the development of very small scale localised production capacity with limited social and economic impact—regardless of how useful and productive the product is as a soil ameliorant. The current markets are scale limited and questions remain regarding seasonality and replicability.

A large-scale market within Maine needs to be developed for biochar to be considered whether as a stand-alone product or as a process by-product. Biochar also needs to be developed with the particular customer base and end-use requirements taken into consideration. This may prove problematic. There are also regulatory constraints at present, and the absence of any specific legislation is seen as a growth inhibitor.

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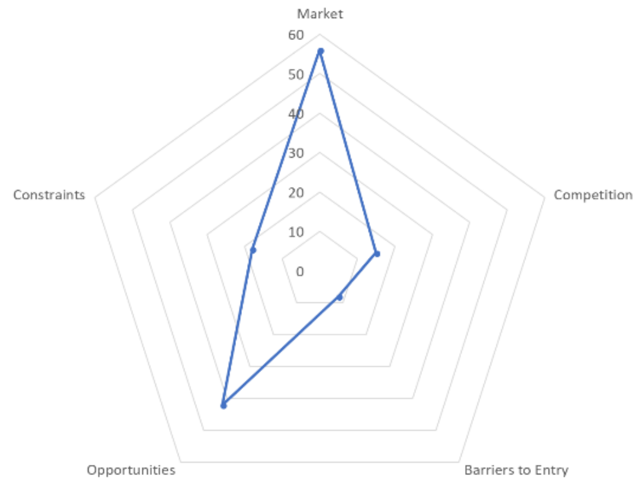
2. **WHITE PELLETS**

White pellets are average in terms of attractiveness for Maine, reaching a total score of 195. Highest scores are obtained for markets (57), and market opportunities (42).

Figure 2-1: White Pellets Attractiveness Score



The following section outlines in detail the market opportunity for white pellets for Maine.

2.1 Product Description

Pellets are a biofuel made from the compression of organic matter. The range of biomass types that can be used is broad, but wood is the biomass source most commonly associated with biofuel pellets. The term white pellet has over time been used to mean various products. In Europe, for example, white pellets were commonly associated with a product made from clean white sawmill residues that met the highest quality standards. In Asia, the term white pellets was, for a time, used to differentiate pellets made from lighter coloured wood (pines for example) not including bark, as opposed to pellets made from darker woods such as eucalyptus or acacias. The term was not used to differentiate fuel properties in any other way.

The technology for pelletising particulate material has been in commercial use for more than 100 years. It is a well-understood process and its main application was (and still is) in animal feed. Adaption to making wood pellets occurred in the early 1970's due to the global energy crisis and the search for alternatives to fossil oil. The industry and market for white pellets is now well established in North America, Europe and North Asia. Today white pellets are almost exclusively used for energy generation, whether that be in industrial, commercial or residential applications. Because of this, the market sector analysis is based on these sectors.

2.1.1 Product Differentiation/Segmentation

Today the term white pellets is most commonly applied to differentiate wood pellets (regardless of feedstock colour) made through the pelletising process from wood pellets that are made with the inclusion of a torrefaction or steam explosion step in the pelletising process, the latter producing a pellet that is very dark in appearance and presently referred to as black pellets.

In spite of the rather large body of information that has been made publicly available on black pellets for many years, through research organisations, industry associations, producers and product champions—a market has yet to develop anywhere in the world. In Europe small amounts of black pellets are used. The same is true for Canada and there are indications that black pellets are entering the Japanese market. Combined the volumes involved do not exceed 100 000 tonnes and in North America and Europe, with stagnant demand even after a decade of effort. Only in North Asia is there potentially an opportunity, but even there the potential is restricted to Japan and if certain legislation proceeds. It is unclear even if this market will develop.

The presence of black pellets in the marketplace highlights another important aspect in differentiating white pellets from other biomass sources. Globally, white pellets (or rather wood pellets) compete with other biomass types in the same end uses. These include wood in other forms (wood chips and wood briquets for example) and non-wood biomass such as pellets made from rice husks, oil palm empty fruit bunches and bagasse. There is also a lively trade in palm kernel shell for industrial energy generation and palm oil is also used for that purpose. The Asian markets are the most diverse for internationally traded biomass sources. In North America and in Europe the focus is dominated by wood pellets.

Wood pellets for energy generation can be segmented into three general end-use categories:

- Residential
- Commercial
- Industrial (combined heat and power (CHP) and dedicated power)

Each of these categories have relatively unique facets reflecting buyer behaviour and pellet quality requirements which primarily aid in segmenting the market. Residential end users are essentially private residences. The main use is for heating although in North America pellets for barbeques and for animal bedding have also been considered. Unit consumption is small. A typical household might use between 3 and 10 tonnes each year. Pellet quality is generally high as most boilers on the market are precision engineered to operate with minimal maintenance and adjustment. Pellets with very low ash content and impurities are desirable. Residents buy pellets in portable size bags from retailers or in large sacks from a local pellet mill or wholesaler.

Commercial users include industrial and commercial factories, offices, schools, hotels and apartment blocks with centralised heating. Consumption is much larger than residential users. The average use is above 100 tonnes and can range as high as 1 000 tonnes. Pellets are usually purchased directly from the supplier or in large 500 - 1 000 kg sacks. Typically the boilers using the fuel are managed by tasked staff and are more forgiving with respect to pellet quality. Ash content tolerances for example can be higher.

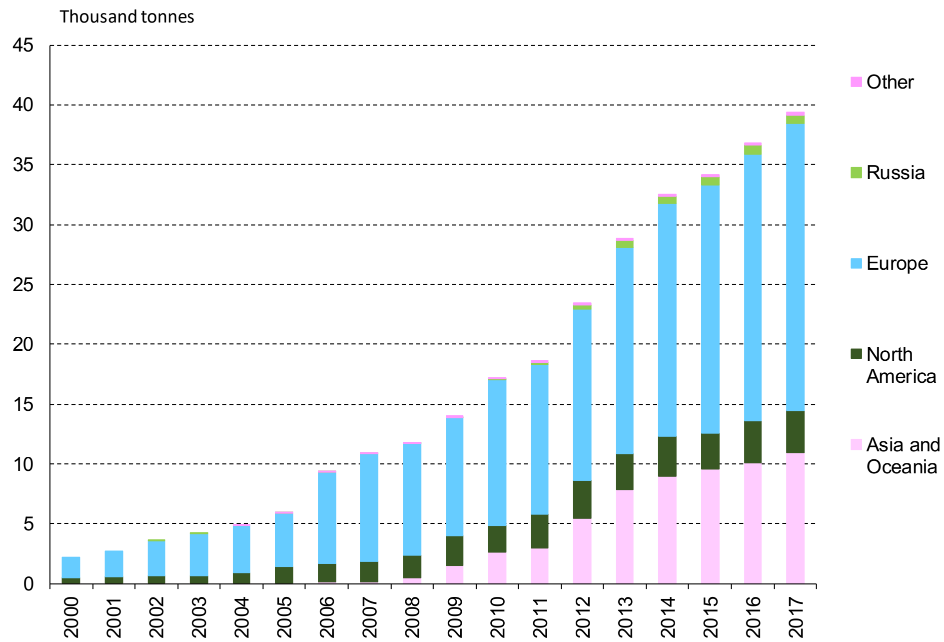
Industrial users include CHP plants, district heating plants and electricity generating power plants. The scale of consumption is typically of an order of magnitude greater than in commercial use and pellets are supplied loose and in bulk, often under long term contract with the pellet producers. Quality tolerances vary and are dependant on the specifications of the utilities boiler.

2.2 Market Size and Growth

Globally one can distinguish three broad biomass pellet markets (Figure 2-2). Europe[14] is the largest market, followed by Asia and North America. Although wood pellets have been in the marketplace for many years, they are still a product in its “growth phase”. This is largely a policy-driven phenomenon rather than a reflection of a classic product lifecycle.

[14] In this context Europe is considered to include Eastern and Western European countries and not just EU 28 members. Importantly most of Europe’s demand and wood pellet production is concentrated in the EU 28.

Figure 2-2: Global Wood Pellet Consumption



Source: Indufor analysis of a variety of publications and sources including trade data

Indufor estimates that demand for wood pellets was almost 40 million tonnes in 2017. Asia and Oceania has been an important contributor to demand in recent years.

2.2.1 North America

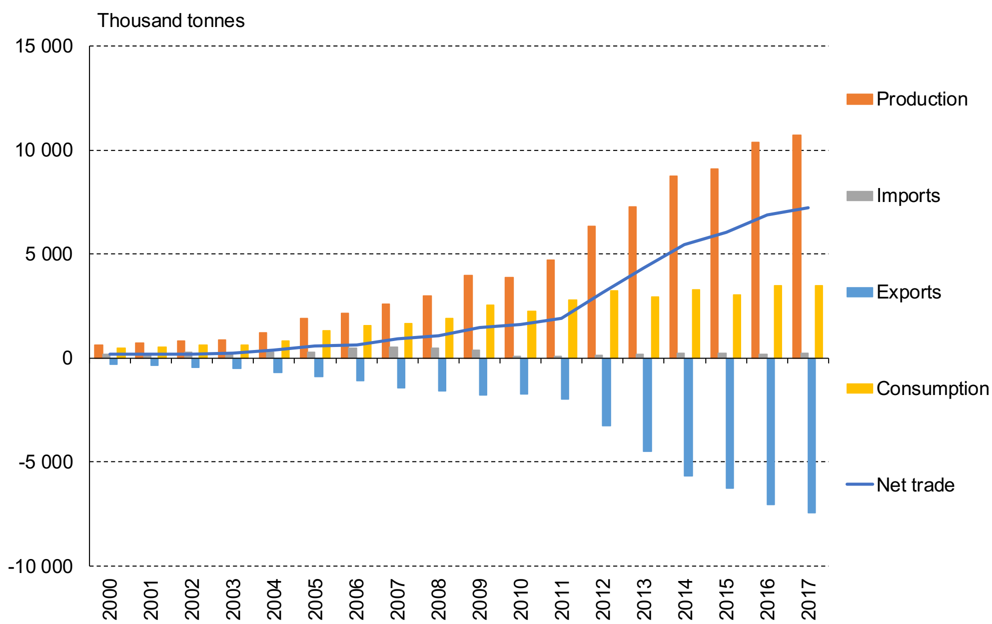
Wood pellet production has its roots in the US, introduced during the energy crisis in the 1970's, but both production and consumption of wood pellets in the US and Canada were slow to develop. Figure 2-3 shows that at the turn of the millennium wood pellet production was approximately 640 000 tonnes. Production increased to approximately 4 million tonnes after a decade. In the past seven years pellet production has more than doubled. Indufor estimates 2017 production to have reached 10.7 million tonnes.

Several observations can be made with respect to the North American market:

- From 2000 to 2007, Canadian producers made more pellets than their American counterparts. From 2007 onward, US production increased rapidly. Today Canada comprises approximately a quarter of the North American pellet production.
- Canadian producers were also the earlier "mover" on wood pellet exports. For many years, more than 90% of wood pellet exports from North America originated from Canada. From 2012 onwards that situation changed rapidly. Canadian exports have continued to increase, But US exports rose rapidly from a few hundred thousand tonnes to over 1.9 million tonnes between 2011 and 2012. Unlike the past where pellet exports were primarily to Canada, the market began to export large volumes to Europe. Indufor estimates that 70% of the 7.5 million tonnes of wood pellets exported in 2017 were from US producers.
- North American wood pellet production, particularly from Canada, is export-oriented. With the exception in 2000, more than 80% (and in some years as high as 97%) of Canadian annual production has been exported over the last 17 years. Importantly though, up until 2005 exports from Canada were largely to the US. Canadian pellet exports to the US peaked at almost 490 000 tonnes in 2007. The US was Canada's leading export market destination from 2000 to 2007.

- In contrast US production was, for many years dedicated to serving the US market. From 2000 to 2011 between 79% and 97% of annual production consistently ended up utilised in the US market. What was exported was almost exclusively to Canada from 2000-2006. From 2007 onwards, exports were increasingly directed to Europe—accelerating in 2012. The domestic market share of production has declined. Indufor estimates that in 2017 roughly 36% of US production went to supporting domestic markets.
- Whereas a lot of the early trade was essentially based in the US and Canada, 2008 onwards witnessed increasing volumes of wood pellets exported to Europe. Today more than 95% of North American trade in wood pellets is to Europe. The main export destination for the US is the UK, which receives approximately 80% of US pellet exports. Belgium and Denmark are the other major takers of US pellets at present. As of 2017 99% of the US wood pellet exports went to Europe. Despite devoted efforts, wood pellet exports to North Asia (Japan and Korea) have yet to develop.

Figure 2-3: North American Wood Pellet Production Consumption and Trade



Source: Indufor analysis of a variety of publications and sources including trade data

- Canadian wood pellet exports are primarily to Europe. In 2017, 76% of exports were directed to the EU, 69% of which was to the UK. Small amounts of wood pellets were exported to Belgium and Italy. Unlike the US pellet producers, Canadian (British Columbia, BC) producers have been exporting pellets to Japan and Korea. Currently 14% of all exports are to these two countries, but to date the volume exported as a percentage of total exports has changed little.

Key to this, is the nature of the North American wood pellet industry, which continues to be export-oriented, with Europe as a primary focus. The growth of wood pellet production in North America averaged 18% per annum[15] over the last 17 years. The CAGR (compound annual growth rate) for wood pellet exports over the same period averaged 20%.

In contrast, the North American market for wood pellets grew at 12% annually from 2000 to 2017. Currently North American pellet demand is just over 3.0 million tonnes (Figure 2-4).

[15] Compound annual growth rate

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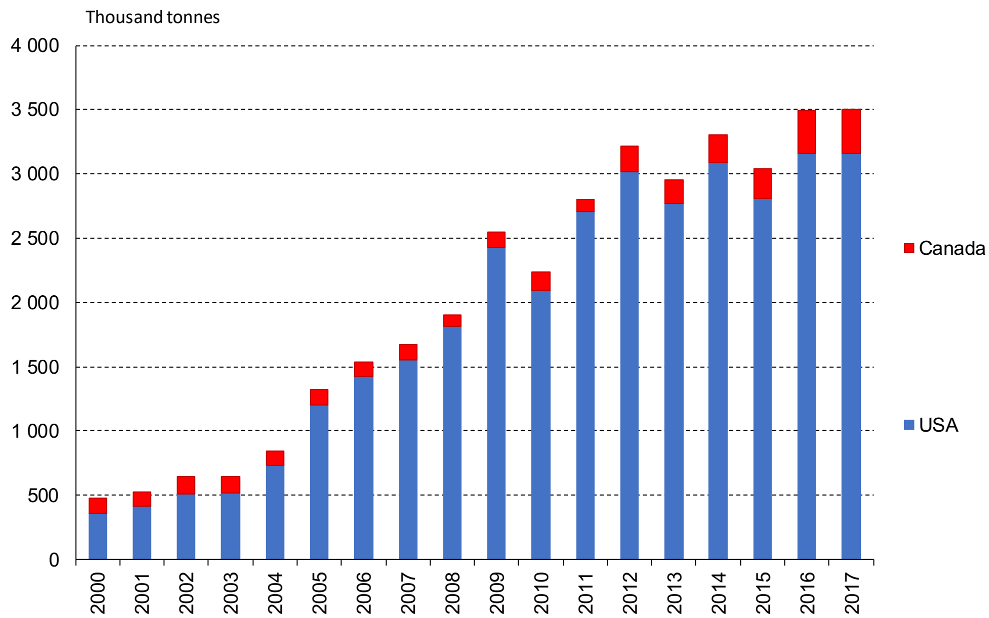
Around 90% of this market is currently in the US. Since 2005, the US has constituted more than 90% of the market.

Figure 2-4: North American Wood Pellet Demand



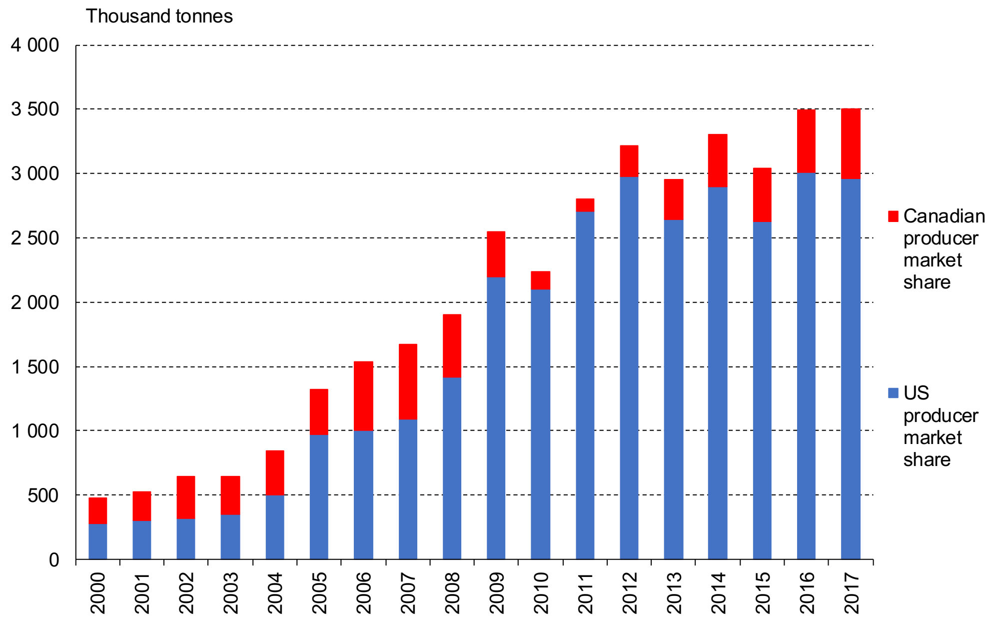
Source: Indufor analysis of a variety of publications and sources, including trade data.

Not all of the market is supplied by US pellet producers (Figure 2-5). In the early 2000s Canadian producer's market share ranged between 40% and 50%. Over time, however, the Canadian contribution has declined reaching a low of 3% in 2011. Recently Canadian markets have rebounded, with exports to the US holding around 15% of the market—with the majority dedicated to power generation.

There are very small amounts of wood pellet imports from other parts of the world to the North American market. These have been largely in the form of black pellets from Arbaflame (Norway) to Canada. Initiated from 2013 to 2016, this trade resulted in 9 000 tonnes of black pellets imported annually, for the Ontatio Power Generation plant at Thunder bay. This super peaking plant is mandated to use 15 000 tonnes of biomass annually, roughly 2% of its production capacity. Pellet imports from Arbaflame in 2017 were just 3 000 tonnes. Less than 2 000 tonnes were imported from other regions.

The North American market for wood pellets has traditionally been dominated by residental heating. Pellets for barbeques and cooking are recently gaining interest. A smaller amount of biomass is used in commercial and municipal heating (e.g. offices, schools and commercial manufacturers) and small quantities of pellets (including a sizeable component of the imports) are used for animal bedding. Until recently there has been little difference in the share of end uses for wood pellets between the US and Canada. Recent Canadian initiatives, however, have spurred industrial pellet consumption in North America. The state of Ontario implemented its stated "zero coal usage" in 2014, the first province or state in North America to do so. This was largely achieved through plant closures, but the Atikokan and Thunder Bay plants were converted to burn biomass.

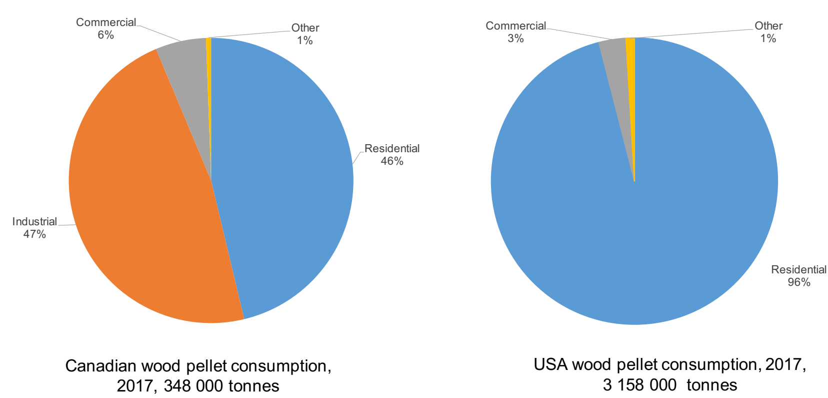
Figure 2-5: US and Canadian Split of the US Market over Time



Source: Indufor analysis

Thunder Bay operates only if and when needed and therefore biomass use has been minimal at this facility. The Atikokan plant (205 MW) has been converted over to run at 100 % biomass. When operating at full capacity this facility is expected to consume some 400 000 to 450 000 tonnes of wood pellets annually. Although there is discussion and some desire by the US Federal Government, the use of wood pellets for industrial power generation remains almost non-existant in the US. Figure 2-6 summarises Indufors estimate of current pellet consumption by end use in Canada and the US.

Figure 2-6: End Uses for Wood Pellets in Canada and the United States



Source: Indufor analysis

There is an element of regionality to the North American market. Wood pellet mills in the US and Canada that supply domestic markets have a tendency to operate on a regional basis. The inter-country trade is also relatively one way, with Canadian producers demonstrating greater capacity to place product in the US than vice versa.

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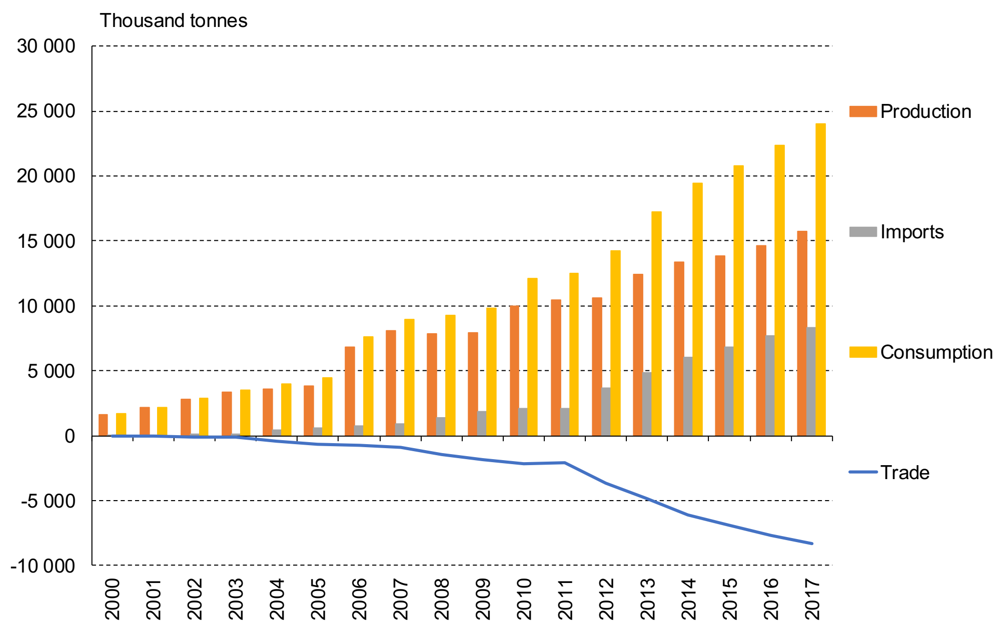
2.2.2 Europe

Europe is the world's single largest production centre for pellets (Figure 2-7). It is also the largest market for internationally traded biomass for energy generation. The next largest market, North Asia (Japan and Korea) is developing rapidly, but still comprises less than a third of the size of trade to Europe.

Indufor estimates wood pellet demand in Europe has reached 24 million tonnes in 2017. Since 2000 wood pellet consumption has been growing at a CAGR of 17%. Meanwhile, domestic production has grown at a slower pace (14% CAGR) over the same period, and increased demand has instead been satisfied by wood pellet imports, mainly from North America.

Figure 2-7: European Wood Pellet Production Consumption and Trade



Source: Indufor analysis of a variety of publications and sources, including trade data.

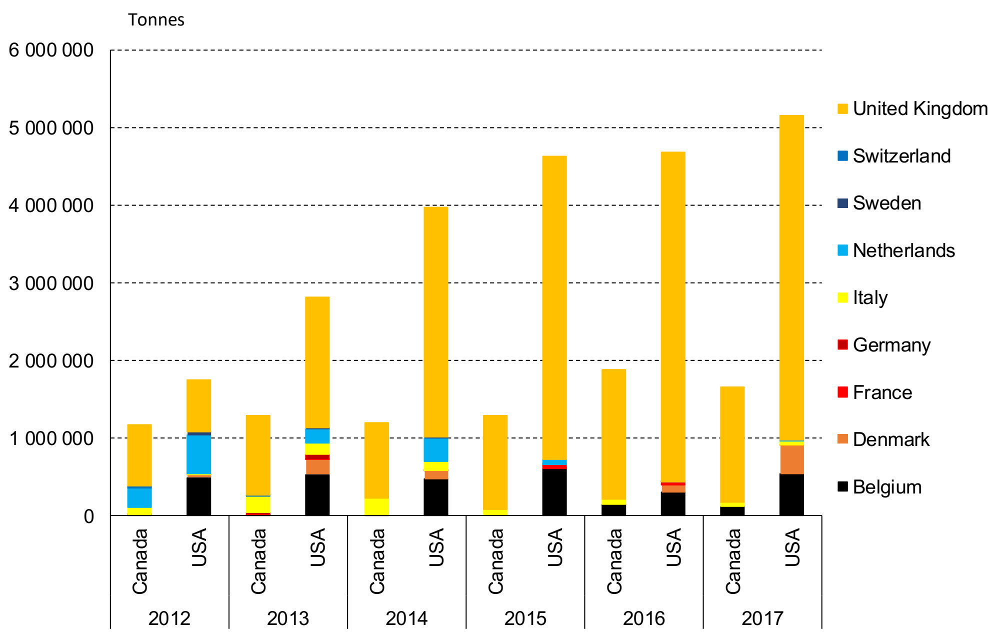
This is best highlighted in developments over the last seven years. Whereas domestic wood pellet production has increased at a CAGR of 6% from 2010 to 2017, imports have increased at an annual average rate of 18% over the same period. Much of this has been from North America and in particular there has been a substantial increase in wood pellet supply from the US. Canadian exports to Europe grew by a CAGR of 4% from 2010 to 2017. Exports from the US grew by a CAGR of 36% over the same period.

There have been interesting developments in the trade between North America and Europe since the US producers started mass exports of wood pellets. Figure 2-8 shows how the trade to Europe from Canada and the US have developed since 2012. Key observations include:

- The US wood pellet export expansion since 2012 is almost entirely due to exports to the power utility Drax in the UK. Canadian supply to Europe is also heavily weighted to the UK but the supply has been dwarfed by the US producers and, in 2017, declined.

- The Netherlands, once an important destination for wood pellets, essentially disappeared in 2016 as a market. However recent policy developments in the Netherlands has seen a return of the trade, and this is expected to develop over the coming few years.[16]
- Canadian supply to Europe has become less diversified compared with supply from the US. This may change over the coming few years but it is important to note that Canadian wood pellet exports are arguably less exposed than US exports since Canadian manufacturers have developed trade inroads with Japan, Korea and the US. Reciprocally the US producer's presence in these markets is either weak or non-existent.
- There has been a shift in supply away from residential and commercial end users in Europe toward industrial end users. Although this has not stood as a large proportion of the market, exports to commercial and residential end-use segments have declined in the last three years.

Figure 2-8: US and Canadian Exports to Europe by Country



Source: Indufor analysis of a variety of publications and sources, including trade data.

Critical to these trade developments is that exports of wood pellets to Europe are overwhelmingly in support of industrial pellet users, particularly at the large-scale biomass power plants in the UK, Belgium and Denmark. Understanding this is the key to assessing the scale (and potential vulnerability) of the trade.

Focusing on regional differences in pellet exports, most of the wood pellets exported from North America to Europe came either from British Columbia, Canada or the US South. Pellet exports from the US Northeast to Europe were nearly zero, and the volumes out of Quebec and New Brunswick were comparatively minimal when compared to the trade from the other two regions.

Considering European and imported supplies it is clear that most of the demand for wood pellets is in the UK (Figure 2-9). The other major markets are Denmark, Germany and Italy. The Danish market has grown sharply in the last year because of increased power generation. Similar events have occurred in Belgium.

[16] The latest trade statistics for Jaunary 2018 show that (in this month alone) nearly 30 000 tones of pellets were shipped from the USA to the Netherlands. This is more than double the trade between the two countries for the whole of 2017.

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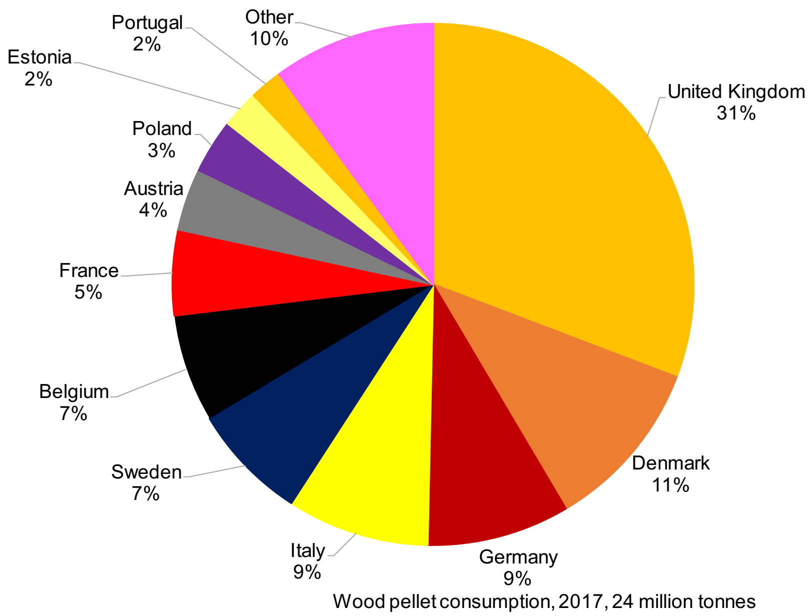
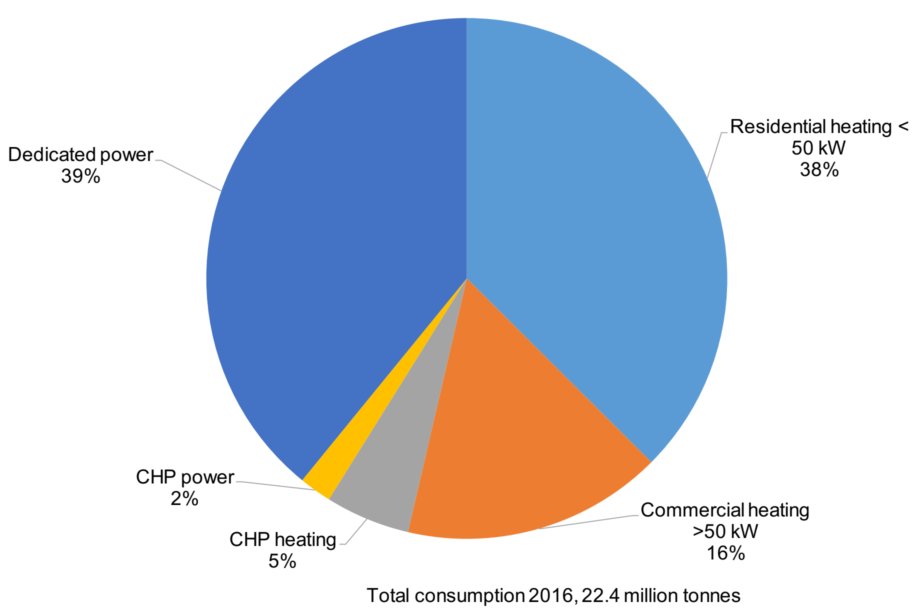
Statistics on the breakdown of wood pellet consumption by end use segment is only available through 2016. Nonetheless, this is still broadly demonstrates where pellets in the EU are typically consumed (Figure 2-10).

Figure 2-9: Wood Pellet Consumption by Country (2017)



Source: Indufor analysis of GTA trade data and European consumption

Figure 2-10: Consumption of Pellets in Europe by Segment (2016)



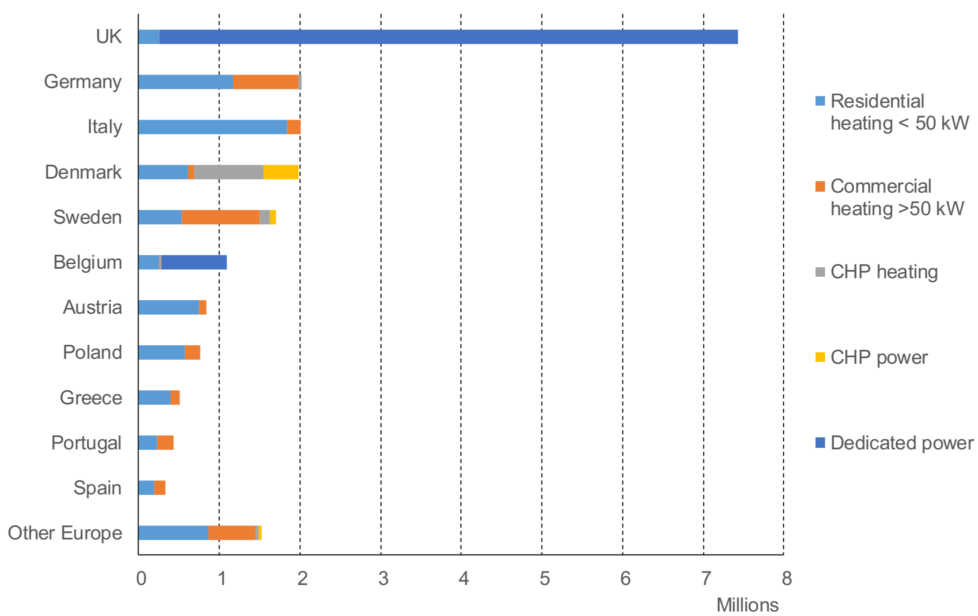
Sources: Eurostat, FAO, AEBIOM, Indufor estimates

Wood pellet consumption in Europe is driven by the heating market which comprised around 60% of the total consumption in 2016. Two-thirds of this is consumed by the residential heating sector and the remaining third by commercial and CHP heating. The electricity market consumes around 40% of pellets in Europe.

Within Europe, the UK and Belgium dominate in use of wood pellets in electricity production, where companies like Drax in the UK and (to a lesser extent) Awirs and Rodenhuize in Belgium are using substantial quantity of pellets (Figure 2-11). In comparison, Italy and France wood pellets are consumed at the residential level, driven by increasing numbers of pellet stoves. In Scandinavia, existing district heating systems form a strong base for pellet demand. In Central Europe the large number of existing pellet boilers, residential and commercial create the pellet demand.

The relative importance of the different market segments has changed over time. A decade ago, wood pellet demand in residential and commercial end-use segments approached 70% of total demand. Since then there has been a perceptible shift in share toward industrial pellets for segments of industrial power generation. As of 2016, the market share of residential and commercial wood pellet utilisation had dropped to around 40%. Indufor estimates this fell further in 2017.

Figure 2-11: Consumption of Wood Pellets in Tonnes by Country and Segments (2016)



Sources: Eurostat, FAO, AEBIOM, Indufor estimates

2.3 The Competitive Landscape

2.3.1 Competitors

North America

There are more than 190 individual companies currently operating wood pellet mills in North America, however, over 40 of these plants have a limited pellet producing capacity of less than 10 000 tones per annum. The pellet mill landscape can be segmented into those operations that are focused on exporting wood pellets to Europe (the so-called “Industrial pellet” producers as

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embodied in the United States Industrial Pellet Association (USIPA) and those producing wood pellets for the domestic market.

The Industrial pellet producers can be generally described as being:

- Relatively concentrated (Enviva, Drax, Pinnacle Pellets, Georgia Biomass, Westervelt and Pacific Bioenergy Corp);
- Having multiple facilities and/or very large-scale facilities;
- Generally located in the East and the South of the US, and in British Columbia, Canada.

Enviva, the largest industrial pellet producer, operates seven facilities (including one joint venture). The average mill capacity is 486 000 tonnes per annum and the largest mill (the former GreenCircle plant) is believed to have a capacity of 700 000 tonnes per annum. Drax, with around 1.5 million tonne per annum installed capacity operates 3 facilities, the smallest of which has a capacity of 450 000 tonnes per annum. Other large producers include Pinnacle Pellets in Canada, which operates several facilities in British Columbia. Although their average mill capacity is smaller than their US counterparts, Pinnacle is still the third largest of the industrial pellet producers in North America. RWE owns the largest pellet production facility (750 000 tonnes per annum capacity) in the country (Georgia).

Domestic-oriented pellet producers are:

- Much more numerous,
- Much smaller,
- Are in closer proximity to the market they serve.

The overall average for mill capacity in North America is 76 000 tonnes per annum, indicating that in general, mills that are focused on the domestic market are much smaller than the international, export-oriented facilities.

The North East

There are a surprising number of pellet mills in operation in the northeast of America.

Europe

There are hundreds of wood pellet producers spread across the European continent and Russia, West of the Ural mountains. Germany leads European producers both in terms of installed capacity and in the number of mills operating. There is also significant production capacity in Sweden, France, Austria, Latvia and Estonia.

While it may seem that the European market is highly competitive, overcapacity in the region is chronic. Capacity utilisation has typically been below 70% over the last decade. Such broad measures, however, hide important facets of pellet production capacity and market focus. Most of the pellet mills in the European region are small capacity. Across the region the average mill capacity is well below 50 000 tonnes, which means there are numerous small pellet mills in operation. The main focus of these mills is in the residential and commercial market segment. Competition in this market segment is high and is worthwhile to note that North American supply into this market segment has waned over the last few years, particularly in Italy, where Russian supply has appeared to supplant Canadian wood pellets.

European pellet producers are less active in the industrial wood pellet segment, which is dominated by a limited number of large power utilities. European producers currently hold less than 20% of this market. The main European players focussed on this market operate in Germany, Estonia, Latvia and France. The majority of competition in this sector is derived from international suppliers, (i.e. Russian, Canadian and US producers) whom are export focused. Current rivalries between the US-block and Canadian producers are especially intense.

2.3.2 Competing and Substituting Products

North America

The key end-use for wood pellets is in energy generation, whether for Industrial power generation or residential and commercial heating. In non-mandated markets such as Canada and the US, the key competing and substituting products are other sources of energy, namely coal, petroleum, and natural gas—as well as other less expensive forms of renewable energy such as nuclear power and hydroelectricity. Wood pellets also compete with other forms of wood products such as wood chip, solid wood and briquets. Considerable quantities of biomass (and heat generation) are already in existence in the US, however, nearly all of it is from unprocessed solid wood biomass residues. This is expected as a large segment of energy use is within the forest industry sector.

A large reason that there is relatively slow demand growth for wood pellets in the Canadian residential and commercial market segments is due to their cost as a fuel. When natural gas and other affordable forms of power and heat generation are availiable at a lower cost, wood pellets often struggle to gain market traction. Along the same lines, demand for wood pellets in the US has been largely influenced by the cost of alternative energy sources, both renewable and non-renewable. Weather has also played its role in influencing wood pellet demand, and during mild winter periods, demand can fluctuate significantly.

Europe

Market segmentation is important when considering competing and substituting products in Europe. The use of biomass for heat has undoubtedly been an important element in Europe's overall drive to lower its carbon footprint. Currently more than 90% of the biomass used in this sector is in the form of what the AEBIOM terms as solid biomass fuels. Other competing products (biogas, municipal waste, liquid biofuels and charcoal) make up less than 9% of the energy sources. Most of the solid biomass is woody biomass, primarily sourced from wood processing facilities and from forest management (e.g. harvesting residues and thinnings). Woody pellets are an important component in this sector but also compete with solid wood blocks, briquets, and wood chips, which are still significant and cost competitive alternatives to wood pellets. Efficiency and noxious emission reduction are key factors that influence the use of wood pellets over other forms of woody biomass.

Mandated markets can play a large role in dictating the relative competion for energy sources, especially for competing forms of renewable energy and biofuels. Wood pellets compete with other forms of bioenergy (namely biogas and municipal waste) which are used in significant quantities. Wood pellets also compete with wood chips, in electricity generation.

An important consideration in relative interchangeability between different sources of biomass in the European context is that once a decision has been made to build a biobased power plant or install a bio heating facility, the biomass form or type to be employed becomes largely fixed, and remains that way over the serviceable life of the unit. This is irrespective of the size or capacity of the unit employed. Therefore only at the onset of a new plant or conversion, is this competion between products witnessed.

A Note on Black Pellets

From a quality and performance perspective black pellets should be a major element in global wood pellet markets. They are superior to white pellets in many ways. They are significantly more hydrophobic, more energy dense, create less dust in handling and transport, less susceptible to biological activity, and are generally more suited for use in coal-fired power plants.

And yet, black pellets have essentially not taken any market share from white pellets. Cost competitiveness is a key reason, but other factors have played a role including the investment in infrastructure around white pellets in Europe, the direction of technology development for residential heating units, and licencing and intellectual property issues. With the possible

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exception of a supply line to Japan, it is unlikely that black pellets will gain market traction in the coming years.

2.3.3 Barriers to Entry

North America

The North American wood pellet market is dominated by residential heating, and to a lesser extent cooking. Although this sector is supported by policies in both the US and Canada, wood pellet suppliers compete with each other in an open market where individual pellet buyer are free to choose their supply from a retailer (as long as it meets with the standards specified at the state and federal level) and are generally free of long-term contractual arrangements.

Any new biomass pellet producer seeking to establish new production for the purpose of supplying the domestic market will therefore face a strong contest from a range of existing manufacturers, some of whom have been operating in this space for many years. The main challenges are capital investment costs and the challenge of getting ones product differentiated in a commodity market where a multitude of retailers operate.

Europe

As indicated in previous sections wood pellet exports from North America to Europe have been and remain almost exclusively destined for use by a limited number of large-scale power utilities generating electricity. The target market is small, even if competition from domestic producers in Europe is limited. Contracts governing supply to these utilities have typically been on a very long-term basis (five years or greater). Indufor is aware of contracts currently in negotiation between North American suppliers and Utilities in Europe (some for projects expected to come online in the next two years). This presents a significant barrier for any new pellet producer entering this market segment. Especially given the significant capital investment requirement needed to build a pellet mill. On the other hand, this provides significant advantages to existing players to negotiate and secure contracts prior to building additional processing facilities.

Barriers resulting from contractual arrangements are less an issue in the residential and commercial heating segments, where the key barriers to entry are the competitive nature of the European market along and the necessity to establish and develop networks to facilitate wood pellets reaching a multitude of individual end users. Supply chain consolidation in some markets (such as Italy) has placed negative pressure on supply from exporting countries. Ultimately this is a matter of market growth and cost competitiveness. In regard to the latter, there is likely potential for some North American suppliers (those that can easily scale operations) to compete effectively with the much smaller scale European counterparts.

In future terms, it is likely that official thinking and public perception around demand for wood pellets will shift to in-country supply chains. Central to this thinking are concerns around carbon footprint and sustainability. Although this may not be practical for meeting the demand from large-scale power projects like those that have been converted over by Drax, it is an important consideration in the supply of wood pellets to residential and commercial heating sectors.

2.4 Key Drivers for Demand

The chief drivers for wood pellet demand in global markets are the policy instruments directed at encouraging the use of renewable energy. Nearly all biomass consumption in Japan, Korea and Europe is driven by renewable energy policies in some form or another. They are also responsible for almost all currently observable international trade in wood pellets.[17] Policy instruments to encourage renewable energy can be broadly categorized into:

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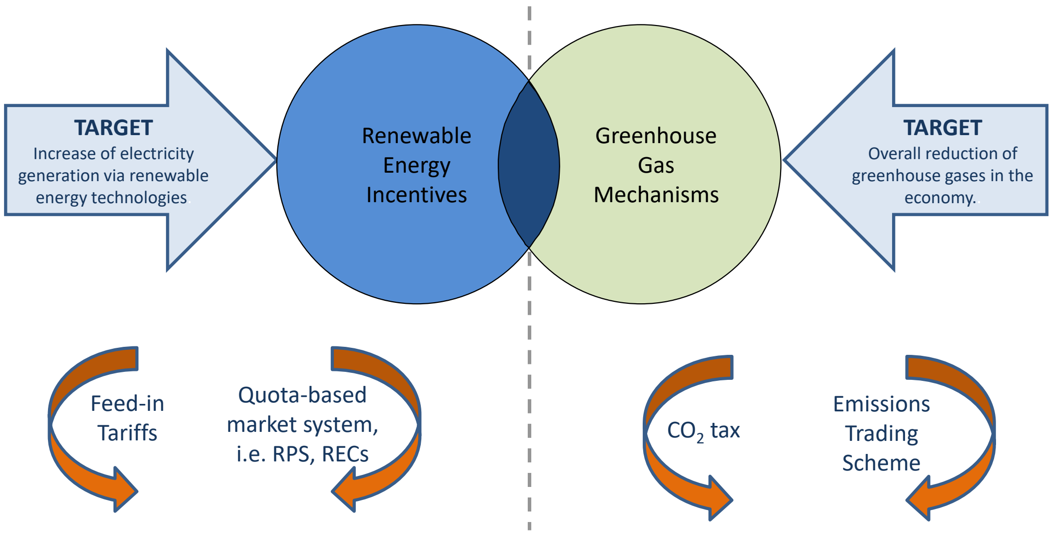
[17] For energy generation purposes

- Renewable energy incentives, or
- Greenhouse gas mechanisms.

These policy instruments can be either market based or fixed design options (Figure 2-12).

Figure 2-12: Policy Instruments Aimed at Encouraging Renewable Energy



Source: Indufor

North America

There are no incentives at the federal level in Canada or the US aimed directly at incentivising the use of wood pellets. However there are a number of existing provincial and state level incentives that indirectly provide support to individuals and companies either consuming or producing pellets for the domestic market. Incentive schemes have very much been a key factor in driving domestic wood pellet demand in residential heating and cooking.

In Canada, federal support has been limited to research grants for renewable energy, largely excluding biomass as an energy source. Provincial incentives are, however, more comprehensive.

The government of British Columbia has a bioenergy policy and has funded several biomass power projects. In Quebec a new energy policy action plan was released in 2017 covering the period up to 2020.

Alberta's Bioenergy producer programme has been extended to March 2020, which is aimed at providing partial funding for electricity generation as well as development of liquid biofuels. The programme provides limited scope support covering only the programme period.

Nova Scotia has a renewable portfolio standard aimed at requiring 40% of electricity generation by 2020. The plan however caps the use of biomass to 150 000 oven dry tonnes and does not directly support the use of pellets in energy generation. In 2012 the Province also ran a small incentive scheme to promote residential purchases of wood pellet stoves. This scheme has been quite limited in reach, however, covering less than 1 000 households (equating to less than 5 000 tonnes of wood pellet consumption annually.

Elsewhere in Canada the biggest development in policy-driven pellet consumption has been in the State of Ontario. More than a decade ago the state had mandated the phasing out of coal for electricity generation in combination with feed-in tariffs for renewable electricity. The policy has however led to the closure (but not conversion) of most of the states coal power plants.

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Only Thunder Bay and the Atikokan plant have been converted over to pellets, with Thunder bay operating only as a peak demand supplier. There are plans now to consider local wood pellet supply to Thunder Bay in lieu of pellets imported from Norway. The WPAC has pressed the Ontario Government to put incentives in for the use of wood pellets in residential and commercial heating, but this has not yet been implemented.

In the North-east, the State of New Brunswick introduced a policy in 2008 whereby harvest residues could be made available for bio energy projects. Policies have been through reviews including the latest around 2011 which placed emphasis on the use of wood pellets. Policy initiatives were more structural and logistics-oriented but there has been indication of incentives being made available for commercial and residential companies choosing or demonstrating energy efficiency. Other policies support the generation of heat (or CHP) through biomass, but are not explicit on the use of wood pellets.

Like Canada there is no policy instruments at the Federal level aimed directly at encouraging the use of wood pellets. The US Internal Revenue Service (IRS) operates the Federal Residential Energy Efficiency Tax Credit which offers a tax credit of up to USD 500 for a residence installing a high-efficiency heating/cooling or water heating system. The policy instrument expired at the end of 2017 and it is not entirely clear if the policy has been renewed. The Biomass Crop Assistance Program (BCAP) continues at the federal level but it is generally aimed at biofuels and advanced bio-based economies rather than supporting the development od short rotation wood coppice plantations for energy or pellet production.

The USDA administers the Rural Energy for America Program (REAP) aimed at encouraging rural small businesses to install renewable energy systems and make energy efficiency improvements. The program also offers assistance to Tribal, local government, higher education facilities, rural community energy cooperatives, councils and public power entities seeking to evaluate energy efficiency options and incorporate renewable energy technologies into their operations. Support can be up to 15 years for machinery and equipment. Grants, loans and Guarantees are available at the federal level and have, in the past been used to support pellet mill investments in different States including Maine (2010).

The Clean Power Plan (a federal initiative announced in 2015) was aimed at reducing carbon emissions from electrical power generation by 32% by 2030 (i.e. back to 2005 emission levels). The focus was on reducing emissions from coal-fired power plants, while incentivising renewable energy and energy conservation. The plan set standards to be met by each state but left the individual states to determine how that would be done. The policy has been reviewed under the current administration and is to be repealed. It is presently not clear yet what policy (if any) will replace it but consultations are underway.

In meantime individual states continue to operate various state-level policy instruments aimed at incentivising renewable energy or lowering GHG emissions. Presently there are 29 states in the US (and three territories) that have adopted Renewable Portfolio Standards (RPS). Another 8 states have set renewable energy goals. The goals and standards are aimed at supporting the development of renewable electricity. Individual states set their targets. Biomass power plants are included in mandates but co-firing in coal-fired power plants is not supported. To date the various RPS's have not led to any significant development in wood pellet use in electricity generation. America's coal-fired power plants are being closed, but in their place has been a surge in natural gas-fired power plants, which generate inexpensive electricity.

Several states around the US have offered (and continue to offer) tax credits, exemptions and/or loans and grants to residents buying wood pellet boilers or other pellet appliances. The nature and structure of rebates differ between states but generally are up to a certain percentage of the cost of equipment and installation and are often capped. In some states the sale of wood pellets is tax exempted.

In recent years some incentive schemes have expired and have not been renewed. For example Oregon has phased out Residential Energy Tax Credits in December 2017. Renewable energy Development Grants are still available but only until funds run out. Indufor understands that incentives in the US North East (New York, Massachusetts, Connecticut, Vermont, Maine and New Hampshire) are still in place.

Europe

In the European market, policies aimed at renewable energy goals have been central to the development and use of wood pellets in electricity generation. In contrast, the use of biomass for residential and commercial heat generation (which is still the most important segment in the European market) has occured largely without long-term direct subsidies. Other policy instruments such as carbon tax have provided the necessary motivation instead.

The EU Renewable Energy Directive serves as the main framework for intensification of the renewable energy consumption in the EU and sets a target of reaching a 20% share of renewables in the EU energy consumption by 2020. The common framework extends to the national level through national renewable energy action plans and country-specific targets. A proposal for a recast version of the EU Renewable Energy Directive II covering the period from 2020 to 2030 has been published and member state consultations concluded in 2017. The European Parliament has recently confirmed and improved the revision of the Renewable Energy Directive (as well as the Energy Efficiency Directive). This will support sustainability of bioenergy consumed in the EU over the period from 2021 to 2030. AEBIOM has noted that this will allow solid biomass to keep playing a key role in European renewable energy targets.

In addition, a new 2030 Framework for climate and energy specifying a set of EU targets and policy objectives has been adopted. The EU is also part of the Kyoto Protocol and Paris Agreement and is committed to reduce its emissions and fulfil the actions in line with the obligations set in these agreements.

Other important policy developments include:

- A renewable target in the heating and cooling (H&C) sector, and improved energy performance for buildings. This could lead to important market opportunities for wood pellets, especially at residential level. There are concerns however over biomass emissions and air quality.
- Discussions are also ongoing over restrictions on power production from biomass used in CHP. This could negatively impact, the use of biomass in energy generation and also curtail co-firing in many member states.

The EU legislation is also supplemented by various national initiatives, policy instruments, subsidies and other background trends affecting wood pellet consumption in member states. For example, in the UK the demand for wood pellets is influenced by the Levy Control Framework and the Renewable Heat Incentive aimed at controlling the cost of decarbonising electricity and heat production, respectively. These are in addition to carbon budgets aimed at moderating GHG emissions. In the long run, the Brexit process will also have an effect on the pellet market in the UK as the government will need to decide on if and how policy instruments will be supported post-departure.

In the Netherlands, a legal framework for assessment and control of biomass sustainability is under development and obtaining the SDE+ subsidies (subsidies for renewable energy) now presumes demonstrating sustainability of the consumed raw material. In addition, the Dutch wood pellet market is awaiting pending government decisions on coal power plant closures which are expected to be adopted in autumn 2017. Increasing pressure on sustainability and government subsidies/energy taxes are also applicable to Belgium, where the Flemish government (overseeing the Flemish region of Belgium) withdrew approved subsidies for the 215MW biomass plant in Ghent due to controversial sustainability of supplied wood pellets as well as considerable costs mainly at the expense of energy taxes from households and small businesses.

In Denmark, one of the main policy documents shaping consumption of wood pellets is the Energy Strategy 2050 setting steps for reducing GHG emissions and improving the energy self-sufficiency by 2050. Currently there are premium tariffs available for electricity generation from renewable sources and tax exemption for heat production from renewables in the country. Energy and climate policy of Germany is set in the Energy Concept extending for the period up to 2050 and the main support policy instruments include feed-in and premium tariffs in the electricity sector and subsidies in the heating segment. Italy also supports renewable energy production by providing feed-in and premium tariffs, price-based mechanisms, as well as energy efficiency certificates. A number of other EU member states have various support policies for renewables ranging from tariffs and premiums to investment grants, soft loans and other fiscal instruments.

2.5 Prices and Price Trends

2.5.1 North America

Wood pellet prices ex-mill are not commonly available but various departments in US states publish wood pellet price information as a service to retailers hoping to make informed pellet purchases based on price. The New Hampshire state government publishes wood pellet prices on a regular basis. As of March 15 2018 the following prices were surveyed:[18]

- 1-5 ton bulk shipment: the range is USD 269 to USD 285/ ton, the mid-price being USD 275/ton (USD 297/tonne to USD 313/tonne, mid price is USD 304/tonne)
- 5-10 tonne bulk shipment: the range is USD 226 to USD 270/ton, the mid-price being USD 264/ton (USD 249/tonne to USD 297/tonne, mid price is USD 291/tonne)
- Bag price per tonne: the range is USD 220 to USD 369/ton, the mid-price being USD 260/ton (USD 243/tonne to USD 407/tonne, mid price is USD 287/tonne)

Available data is usually short-term and historic information is not readily available,

The Massachusetts Department of Energy and Resources offers wood pellet pricing information for bulk or bagged supply. Winter 2018 prices are USD 260/ton (USD 287/tonne[19]) for bulk pellets or USD 290/ton (USD 320/tonne) for bags in retail store. Prices during Winter 2017 were higher (USD 293/tonne for bulk purchases and USD 323/tonne for bags).

2.5.2 Europe

Wood pellet prices in the European market are relatively commonly published although the main indexes are available for a small and regular fee. One of the more well-known reports is prepared by Argus Media Ltd. Recent prices delivered ARA in USD per tonne, have been on an upward trajectory after having declined, since 2014 and stagnated over much of 2015-2017. Indicative current prices are as follows:

- USD 135/t CIF ARA June 2017
- USD 144-146/t CIF ARA Sept 2017
- Approximately USD 160/t CIF ARA December 2017 , and
- USD 176/t CIF ARA April 2017.

Prices have more or less recovered to pre-2015 levels. Prospects for prices are to remain relatively stable up until at least 2020 when there could be another cyclical trend. It should be noted that this price increase is not entirely driven by pellet demand, and that shipping costs have also increased around the world in recent months.

[18] Bulk order prices include delivery and are based on a sample of 4. Bagged orders are retail in store and based on a sample of 26 respondents

[19] Prices are aggregated from Massachusetts Department of Energy and Resources telephone surveys of pellet dealers. Prices do not include delivery and have been converted to tones at a conversion rate of 1 ton = 0.907185 tonne

2.6 Product Certification

There are several different national and internationally recognised quality standards for wood pellets. Historically there was a plethora of individual nation-state standards in Europe, but with the introduction of the European pellets Standard EN 14961[20], national standards were required to be withdrawn. The International Organisation for Standardisation (ISO) have also developed a range of standards covering solid biofuels and graded wood pellets (ISO 17225-2). Since the ISO is supported by a large number of individual nations it is probably the range of standards with the widest geographical relevance. In the United States and Canada there are no official standards governing wood pellet quality.

Standards provide a set of requirements that a product or service must meet for it to be recognised as being of a specified quality. Certification is the means by which consumers can recognise a product or service meeting the standard.

The European Biomass Association (AEBIOM) have developed the ENplus® quality certification scheme for wood pellets and is based on the ISO 17225-2 standard (Solid biofuels – Fuel specifications and classes – Part 2: Graded wood pellets) but also reference a number of relevant EN and ISO standards in the certification scheme, including EN 14961-2 Solid biofuels – Fuel specification and classes – Part 2: Wood pellets for non-industrial use. ENplus® was introduced in Germany during 2010 and as of today it is recognised across the EU and internationally. Wood pellet producer's, traders and service providers in 44 countries across the world have been certified. The latest quality requirements for ENplus® certification were issued in the 2015. Table 2-1 summarises selected parameters for the three recognised pellet grades under the certification scheme.

CANplus® is the quality certification scheme administered by the Wood Pellet Association of Canada (WPAC) and is identical to the ENplus® quality certification scheme in all aspects except that CANplus®, as a national wood pellet quality certification programme must be governed from within Canada. All standards relevant to ENplus® are also relevant to CANplus®.

In the US the US Pellet Fuels Institute have also developed a national wood pellet certification scheme, known as PFI Standards Programme. The programme is based on a number of American Society for Testing and Materials (ASTM) standards, but also references ISO 17225-2. Table 2-1 summarises selected parameters for the three recognised pellet grades under the certification scheme.

Sustainability is now a reality in the production, use and trade of wood pellets in Europe—with Japan and Korean markets following suit. ENplus® and CANplus® schemes reference sustainability requirements and are explicit in stating that sustainability is not audited under the schemes. The ENplus® Handbook[21] states the following"

> "The ENplus certification scheme does not compete with established forest sustainability schemes but acknowledges the certificates from PEFC, FSC or equivalent forest management systems including their chain-of-custody certificates.
>
> ENplus-Certified Producers are required to document the origin and the share of certified wood materials. Furthermore the chain-of-custody certified raw material shall be documented. The International Management monitors the sustainability state of the raw material. International Management may publish the aggregated results for specific countries (where a minimum of 5 certified producers are situated in a country) or for specific regions."

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[20] EN 14961-1, EN 14961-2 and EN 14961-6 are the relevant specific standards

[21] http://www.enplus-pellets.eu/wp/content/uploads/2016/03/ENplusHandbook_part4_V3.0_Sustainability_EPCinternational.pdf

Similar (though in less detail and less certification specific) statements are available from the CANplus® handbook. PFI standards make no mention of sustainability.

Table 2-1: Selected ENplus® and PFI Standards Requirements

<table>
<tr><th rowspan="2">Standard</th><th rowspan="2">Country</th><th colspan="8">Requirement</th></tr>
<tr><th>Diameter mm</th><th>Length mm</th><th>Moisture content %</th><th>Ash %</th><th>Fines content %</th><th>Sulphur %</th><th>Nitrogen %</th><th>Chlorine %</th></tr>
<tr><td>ENplus/ CANplus-A1</td><td rowspan="3">EU/ Canada</td><td rowspan="3">6-8 ±1</td><td rowspan="3">3.15-40</td><td rowspan="3">≤10</td><td>≤0.7</td><td rowspan="3">≤1.0 when loading on truck or ≤0.5 when loading into bags</td><td>≤0.04</td><td>≤0.3</td><td rowspan="2">≤0.02</td></tr>
<tr><td>ENplus/ CANplus-A2</td><td>≤1.2</td><td rowspan="2">≤0.05</td><td>≤0.5</td></tr>
<tr><td>ENplus/ CANplus-B</td><td>≤2</td><td>≤1.0</td><td>≤0.03</td></tr>
<tr><td>PFI Premium</td><td rowspan="3">US</td><td rowspan="3">5.84-7.25</td><td rowspan="3">≤38.1</td><td>≤8</td><td>≤1</td><td>≤0.5</td><td colspan="2" rowspan="3"></td><td rowspan="3">≤300 ppm</td></tr>
<tr><td>PFI Standard</td><td rowspan="2">≤10</td><td>≤2</td><td rowspan="2">≤1</td></tr>
<tr><td>PFI Utility</td><td>≤6</td></tr>
</table>

Source: ENplus, WPAC and USPFI

An interesting aspect of the European scheme is that the certification scheme is stating although sustainability certification is not part of the scheme, it is nevertheless required if a supplier is to be ENplus® certified. The European Commission has not issued any unifying statement on the requirement for sustainability to be demonstrated as a criterion of biomass use within the EU, Instead it has preferred to leave it up to the individual member states to set their own rules. This has led to a somewhat eclectic set of laws across all member states. Some nations such as the Netherlands and NTA 8080 have developed their own certification schemes. The implication is that sustainability certification is essentially mandatory for pellets exported to and used in Europe.

Internationally recognised sustainability schemes covering forest management and Chain of Custody (CoC) are available from the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC). Generally speaking, these schemes have been most commonly referenced by pellet producers claiming sustainability certification.

More recently the Sustainable Biomass Program (SBP) was initiated to provide a certification system designed for woody biomass used in industrial large-scale energy production. The program also sought to address the need for a unifying scheme applicable across all European countries. The key members of the program are careful to point out that the certification system is not meant to replicate or compete with FSC or PEFC schemes. Instead the SBP has been developed to address specific industry-related issues that are not necessarily addressed by the more traditional sustainable forestry and forest product systems. To date more than 140 entities hold SBP certification.

Supplying pellets to Europe requires sustainability certification (especially for companies looking to supply industrial pellets to large-scale power utilities). The North American market is still free of the requirement. Potentially due to the high proportion of forests in Canada and the US that already carry sustainability certifications, and the national laws of governance over forest resources, it is likely that most biomass used in the domestic market would be deemed sustainable. In reality most sustainability certification schemes dealing with forests and wood products do not recognise “association” or any other approach to implying sustainability. Instead the certification of individual wood products, even if it is a residue, is a requirement. Therefore only North American wood pellet producers already holding sustainability certification for the purpose of exporting to Europe, can legitimately claim sustainability status for any product they sell into the North American market.

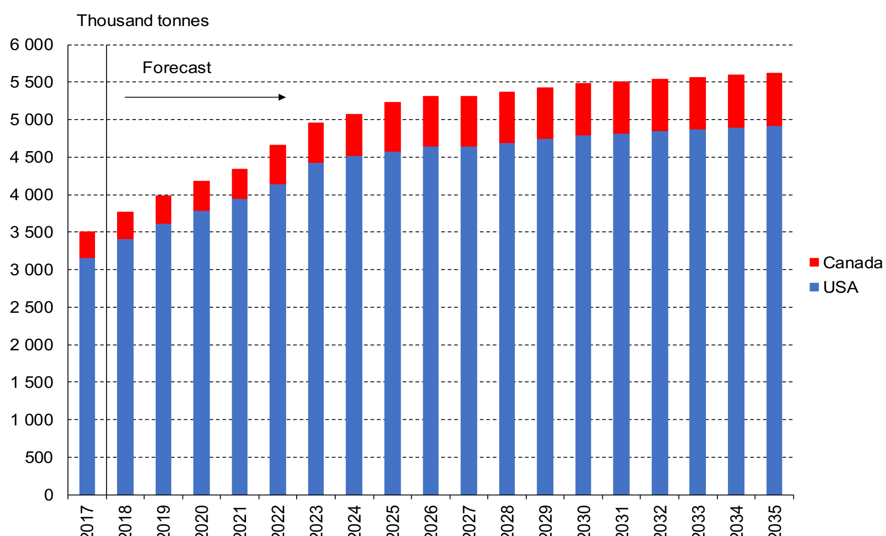
2.7 Outlook

2.7.1 Market Growth

North America

Policy and policy instruments will continue to shape North American demand, but not in the manner or to the extent seen in the EU. Much of this depends on policy implementation and it is clear that as of today, there has been no policy instrument at the federal level in either the US or Canada that will drive wood pellet demand in the electricity generation segments of the market. Even the policies that are focussed on renewable energy at the state level, do not overtly support biomass pellet use. Because of the lack of policies, and no immediate prospect of their development, it is likely that wood pellet consumption for electricity generation will gain further traction in North American markets than it already claims. The more likely demand growth will come from residential and commercial heating. Policy instruments are still actively supporting the conversion of residential heating to cleaner and more efficient options. Pellet demand will therefore be driven primarily by this sector, and beyond 2020 demand growth is expected to start tailing off.

Figure 2-13: Wood Pellet Demand Growth in North America



Source: Indufor analysis

Demand growth is expected to be around 8% over the next eight years in Canada, mainly based around the likelihood of more biomass pellet fuelled power projects under development. The CAGR for the US is expected to be much lower and Indufor does not consider a high possibility of biomass power plant developments using wood pellets in the future. From 2025 onwards Indufor's position is that pellet demand will settle down into an incremental growth pattern, unless new policy development nudges demand in a different direction. The projections show a smooth incremental demand increase year on year. In reality, demand will rise and fall (as it has in previous years) mainly due to the influence weather has on pellet demand in any one season.

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Europe

Policy drives demand for wood pellets in Europe. Without the EU policies, wood pellet demand would not exist as it does today. Many have argued that wood pellet demand would likely have not been developed at all, beyond highly localised areas where biomass can compete effectively with other forms of energy, renewable or otherwise.

Europe has made many announcements for power plants using wood pellets as a fuel for next couple of years. If realized, they would increase pellet consumption by 6.8-7.0 million tonnes (Table 2-2). There are still numerous hurdles ahead on some of these announcements, most important being the fluctuating EU bioenergy policy. For example the recent announcement by Drax to convert over the fourth unit comes with the caveat that the facility will be operating as a peak power supply unit and therefore with lower availability. Therefore, how much of this announced demand will realised in new pellet demand is not certain.

The United Kingdom is, and will likely remain, a predominant pellet user for power production with Drax being the only player today. Out of the six Drax units initially running on coal, two units were fully converted to use pellets in 2013 and in 2014, respectively. The 3rd unit started co-firing pellets in 2015. A full conversion of the 3rd unit occurred in December 2016 when the clearance for state aid was received from the EU. The 4th unit will be converted in the near future based on state support. Other projects like Lynemouth (EPH, power plant conversion) and Teesside (MGT Power, CHP) are likely to be completed in 2018 and 2020, respectively. Both plants would represent a total consumption of 2.5 million tonnes per year. Several other projects such as Southampton (Helios Energy), Us mouth (SIMEC), Iron bridge (UNIPER) and the Real Venture project remain fairly uncertain.

The Netherlands used to be an important player in the industrial use of pellets until 2012 but due to subsidy regime change industrial pellet consumption decreased drastically and in 2015 not a single tonne of pellets were burned in any large-scale power plant. The situation will change as Amer plant (RWE) and Massvlakte Rotterdam (ENGIE) won a new subsidy auction in 2016. The amer plant has started using wood pellets (in early 2017) while Rotterdam may start in 2018. Unfortunately, there are still some uncertainties as the first grants for co-firing have been limited to 25 % of the maximum support obtainable. Secondly, the Dutch regulator has set a sustainability verification protocol. This means that the pellet suppliers have to pass the sustainability measures outlined in said protocol in order for utility companies to use their product. Lastly, a clarification from the Dutch government is required in order for RWE to restart using pellets as they announced willingness to close down some additional coal plants before 2020 which would also affect Amer co-firing plant. The Dutch government has also set a 3.25 million tonne cap for pellet use by 2020.

In Belgium, two converted coal power plants; Unit 4 (less Awirs, converted in 2005) and Max Green (Rodenhuize, converted in 2011) are using pellets, the future of the industrial pellet use in Belgium is uncertain as Rodenhuize MaxGreen is still running at present but the Les Awirs Unit is slated to close by 2020. The Langerlo coal plant acquired by Graanul Invest had plans to start using pellets, but filed bankruptcy in April 2017 due to discontinued subsidies by the Flemish Energy Agency.

Denmark's renewable energy policies aim at ending the use of coal by 2030, and even sooner in the case of the capital, Copenhagen. The main factor encouraging the switch to biomass is the carbon tax on fossil fuel, a support scheme for renewable electricity and low electricity prices in Northern Europe. As a result, several large coal-fired CHP plants have been converted to burn biomass, exclusively wood pellets and wood chips. DONG Energy plants like Avedøre and Studstrup are co-firing pellets. In Amager plant, HOFOR is currently building BIO4, a biomass CHP, that will replace Unit 3, a coal-fired CHP plant.

In addition to pellet demand for electricity the demand of pellets for heat production is expanding, largely driven by new stove and boiler instalments. The annual growth rate in the number of installed stoves and boilers varies between 7-8% depending on stove and boiler type. Statistics on installed pellet stoves and boilers in European countries are presented in Table 2-3.

The growth in the number of stoves is expected to be especially fast in France with 18% annual growth rate and the amount of pellet stoves is expected to exceed one million before 2020. The number of residential boilers is expected to grow fastest in Germany and almost 90 000 new residential boilers are expected to be installed till 2020. The growth in the number of commercial boilers is fastest in UK and Germany with 7 000 and 5 000 new installed boilers respectively.

Table 2-2: Announced Plans for Power Plants in Europe

Country/Company	Timeline	Type of raw material	Additional demand for pellets (million tonnes)
UK			
Drax	Q3-Q4 2019	wood pellets	~2.0
Lynmouth/EPH	2018	wood pellets	1.4
Teesside/MGT Power	2020	wood pellets and chips	1.0
Netherlands			
Massvlakte Rotterdam/ENGIE	2018	wood pellets	0.3
Netherlands (other)	2028-2020	Wood pellets	1.0-1.2
Denmark			
Avedøre	Started Q1 2017	wood pellets	0.5
Studstrup	Started Q1 2017	wood pellets	0.6
TOTAL additional demand for wood pellets			6.8-7.0

Source: Public announcements

Table 2-3: Installed Pellet Boilers and Stoves in Europe

Country	Pellet stoves			Boilers < 50 kW			Boilers > 50 kW		
	2016	2020	CAGR	2016	2020	CAGR	2016	2020	CAGR
Austria	48 000	60 000	6%	120 000	145 000	5%	8 700	10 000	4%
Czech Rep.	3 500	6 000	16%	27 000	38 000	11%	na	na	
Germany	151 000	250 887	14%	265 000	356 853	8%	12 500	17 449	9%
Greece	16 000	20 000	7%	6 000	8 000	10%	1 400	1 600	6%
Spain	163 000	300 000	17%	13 560	20 000	12%	9 850	13 450	8%
Finland	1 800	3 000	13%	25 000	28 000	3%	3 300	4 000	5%
France	600 000	1 120 000	18%	56 000	90 000	12%	2 800	na	
Italy	2 480 000	2 800 000	4%	90 000	110 000	6%	7 000	8 000	4%
Lithuania	60	124	20%	5 000	7 000	8%	na	na	
Latvia	1 500	3 000	18%	8 000	12 000	9%	1 700	2 600	12%
Poland	na	na		41 635	60 000	10%	2 746	4 000	10%
Sweden	16 064	na		86 099	na		na	na	
Slovenia	600	700	5%	6 350	6 800	2%	na	na	
UK	26 710	na		12 500	15 571	6%	15 300	22 440	10%
Other Europe									
Switzerland	10 800	12 650	4%	14 900	17 400	4%	1 060	1 250	4%
Serbia	22 000	30 000	10%	7 200	12 000	15%	40	100	34%
Europe	3 541 034	4 649 135	8%	785 194	1 015 723	7%	67 738	93 771	8%

Source: Indufor and AEBIOM

The European pellet market is therefore expected to grow an additional 9 million tonnes till 2025, at a 4% CAGR and reaching 33 million tonnes (Figure 2-14). The growth is driven by electricity

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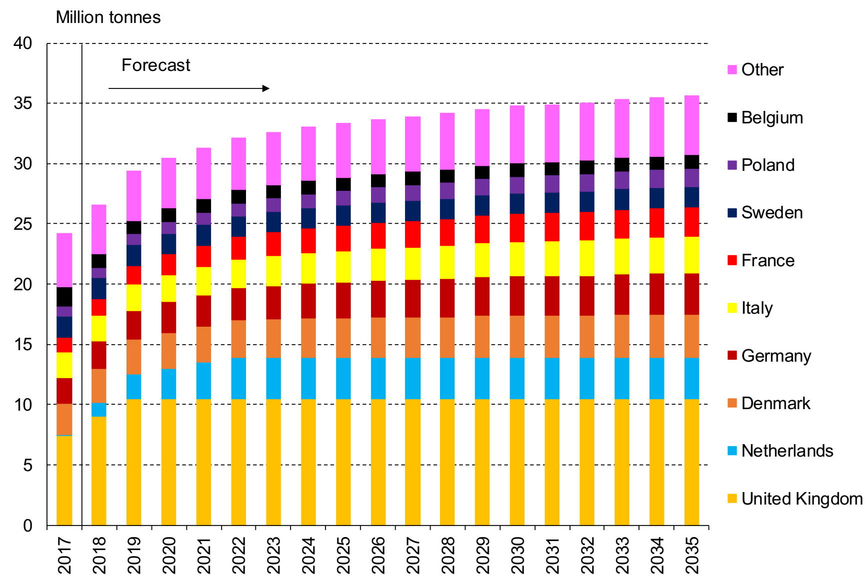
pellet market. The UK and the Netherlands are each expected to grow 3.1 million tonnes followed by Denmark with expected growth of 1.3 million tonnes. The overall profile of demand growth in the next 8 years is one of initial demand burst, followed by relatively stable demand growth.

While the heating market in Europe has exhibited slow growth in the past years, this is expected to change going forward. The heating pellet market is expected grow with France and Germany leading the way with 0.9 million tonnes of growth each. This development is expected to accelerate between 2016-2020 and decline after 2020.

Beyond 2025 growth is expected to be significantly lower. The consumption is expected to be about 36 million tonnes in 2035 and the growth rate about 1% per annum. The growth is driven by heating pellet market[22].

Figure 2-14: Forecast for Pellet Consumption in Europe (2018-2044)



Source: Indufor analysis

2.7.2 Opportunities

The European market is substantial and there are opportunities to supply both the large-scale power utilities with industrial wood pellets and supply higher grade pellets to the commercial and residential heating sectors. The North American residential and commercial heating markets, like their European counterparts are more regional in nature but nonetheless are of a size and growth rate that is attractive for new investment. The options for a new wood pellet mill in Maine are therefore dictated by the nature of the markets and by scale. Logical options include:

- Focusing exclusively on the domestic market with small-medium scale production capacity,
- Focusing on the European pellet market with a large scale facility and targeting the domestic market as a secondary option.

[22] Indufor are aware that other industry commentators express a similar view for short term demand development. One Industry commentator suggests that by 2027 demand for wood pellets could contract on the basis that UK support will be withdrawn at that time. Indufor understands the rationale around this position and it is possible that the contraction will happen. But as all industry commentators point out, everything depends on how policies will develop.

2.7.3 Constraints

Significant constraints are present in both markets however. Indufor's viewpoint is that market opportunities are sufficiently challenged to make a US Northeast mill an unlikely prospect unless a producer can secure a long-term supply contract with an EU or UK utility prior to starting mill investment and construction.

North America

The domestic market is already crowded with medium scale producers all vying to supply their respective markets. While the US supply network and retail structure is conducive to providing less restrictive access to end users, it also makes it more difficult for a supplier to differentiate themselves. Any new entrant to this market will need to be cost competitive and will have to contend with existing suppliers, some of whom are operating fully depreciated facilities. Market growth in the residential and commercial heating sector is expected to be fairly strong over the next 8 years and this could support a new investment of around 100 000 tonnes per annum to 150 0000 tonnes per annum. Any investor would need to be aware that other producers are also likely thinking of new investments.

Europe

Europe's market for wood pellets should be considered in two parts. The first and by far the largest and fastest growing segment (in terms of North American suppliers) is for industrial pellet production for power generation. With a relatively small number of buyers and large-scale industrial pellet producers supplying them, coupled with firm large-scale growth prospects over the next few years, this segment looks highly attractive. A facility of 250 000 tones per annum to 500 000 tonnes per annum could be easily supported. Key to this is securing contracts prior to construction. On this point, however, Indufor believes there is low potential to develop these relationships due to market saturation. Although it is not certain for all capacity involved, it is likely that most of the contracts for biomass pellet supply to EU power utilities are either being negotiated/renegotiated or have been settled. Regardless, developing a large scale project in Maine should not be considered without a negotiated and secured offtake agreement for more than 80% of the supply potential.

The other market segment, the EU residential and commercial heating market, while substantial is also significantly more competitive, and, in terms of supply chain significantly more challenging than the US and Canadian domestic markets, particularly for a new entrant. US and Canadian suppliers have been struggling to get traction in this market segment and Indufor believes that basing a new investment entirely on the growth prospects of this segment alone would be a flawed business model.

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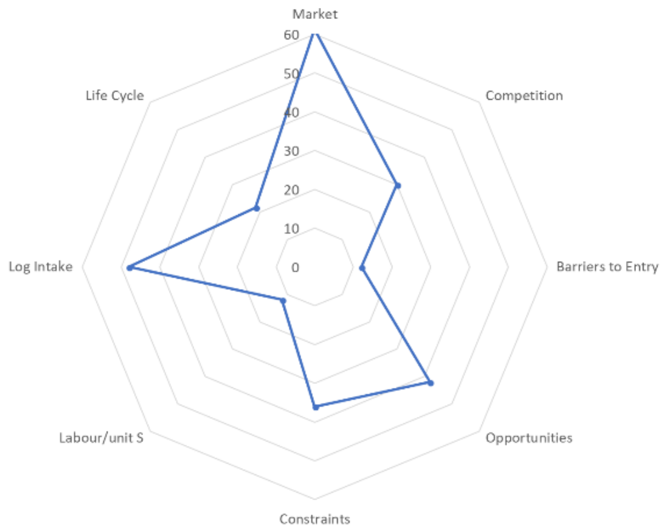
3. SAWN (STRUCTURAL) LUMBER

Sawn softwood lumber is among the most attractive options for Maine, reaching a total score of 263. Highest scores are obtained for markets (61) and log intake (48).

Figure 3-1: Sawn Lumber Attractiveness Score



The following section outlines in detail the market opportunity for sawn softwood lumber for Maine.

3.1 Product Description

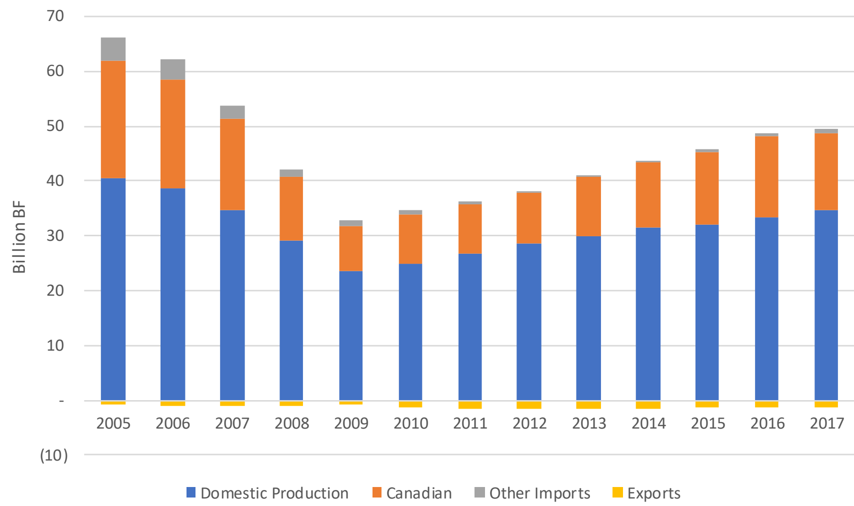
Structural sawn lumber is considered as softwood lumber that is approved for structural construction use. Since, in excess of 95% of North American softwood lumber meets this criterium, Indufor has considered all softwood lumber in North America as structural (i.e. in production and trade statistics). However, when discussing lumber prices, non-structural prices are excluded.

3.2 Market Size and Growth

The US market is considered to be the most relevant option for the softwood lumber produced in Maine. The US lumber exports are insignificant in volume and the domestic market is the only market that is economically within reach. While there are some significant consumption centres relatively close in Canada, this market is served by domestic producers. This is in part due to the unfavourable exchange rate between the US and Canada. There have been no exports of softwood lumber from Maine to Canada in the last several years.

The US softwood lumber market has experienced continued growth since the low of 2009 which was caused by the financial crisis and a subsequent drop in housing starts. The average annual growth rate in softwood lumber consumption between 2009 and 2017 has been approximately 5.5%, but it has yet to reach the peak figures of the mid-2000's.

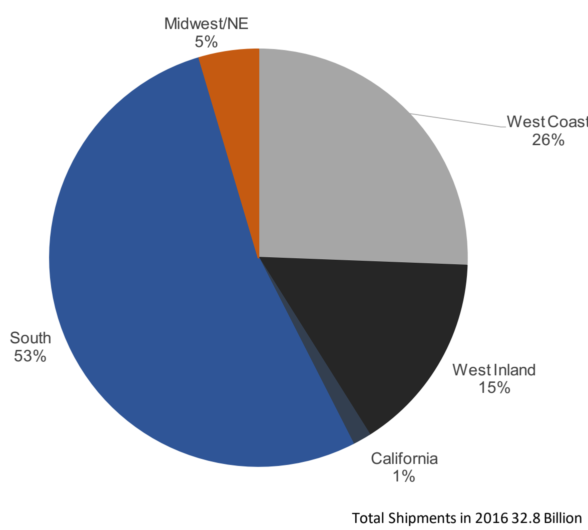
Figure 3-2: Softwood Lumber Market Growth by Source of Origin



As the graph indicates, approximately one-third of the softwood lumber demand in the US is supplied by Canadian produced lumber and almost two-thirds of the volume is domestic. Imports from outside of Canada are small but increasing (again) after coming to almost a complete halt in 2011. A large proportion of these imports originate from countries with fast-growing plantations such as Chile, Brazil and New Zealand. However, these plantation pine imports go mainly to non-structural end-uses, such as millwork and mouldings.

Within the US, there are two large lumber producing regions, the West and the South. Smaller volumes are produced in the Midwest and the Northeast jointly account for about 5% of the US production.

Figure 3-3: US Softwood Lumber Production by Region (2016)



3.3 The Competitive Landscape

Lumber production generally exists wherever there is raw material. In the US the West (mainly OR, WA, ID, MT, CA), the available raw material base is used close to its maximum possible extent as the mills have limited capability to increase production (unless the USFS reverses its policies and increases harvests on their lands). Western Canadian provinces (especially interior British Columbia and Alberta) are facing reductions in lumber production and timber harvest due to damage caused the pine beetle epidemic. Eastern Canadian provinces also have limited ability to increase lumber production due to timber supply limitations. The US South (Southern states from Eastern Texas to Virginia) has potential to increase its harvest, and several new regional sawmills have been announced in the last year. Some of these will be owned by Canadian lumber companies.

Table 3.1: Announced New Sawmills in the US South (2018)

Company	Location	CAPEX (USD Million)	Capacity (MMBF)	Capacity ('000 m^3)	Start-up
Rex Lumber	Pike County, AL	110	240	560	2018/19
Hunt Forest Products & Tolko Industries	Urania, LA	115	NA	NA	January 2019
Canfor Corp.	Washington, GA	120	275	650	Q3 2018
Georgia-Pacific	Warren County, GA	135	NA	NA	Spring 2019

The western US and western Canadian mills serve mainly the western half of the continent (West Texas, Colorado, Dakotas – and west from there), while the southern mills generally serve the South and the East – facing increasing competition from Eastern Canada the further north they go. The mills in the US Midwest and Northeast generally serve the "local" markets within their regions.

3.3.1 Competitors

The lumber market consists of both large public companies based in the key production regions, as well as small and medium-sized independents. While there are hundreds of softwood lumber producing companies in the US and Canada, the top 20 companies in the US account for more than 60% of the production in the country. Likewise, the top 20 Canadian companies account for more than 70% of the production there. There are however, fewer than 10 companies that have more than ten mills. More typically, the large companies have from three to eight mills.

Due to the larger number of companies in the market, no single company has major control over the lumber market. The same is generally true in their log sourcing market as well especially in the US.

Table 3.2: Top US and Canadian Sawmill Companies by Production (2016)

	Top US Lumber Companies		Top Canadian Lumber Companies	
Rank	**Company**	**No. of Mills**	**Company**	**No. of Mills**
1.	Weyerhaeuser Co.	16	West Fraser	13
2.	Georgia-Pacific	17	Canfor	13
3.	West Fraser*	15	Tolko	8
4.	Sierra Pacific	13	Resolute FP	15
5.	Interfor*	13	Western FP	8
6.	Canfor*	11	Weyerhaeuser Co.	3
7.	Hampton FP	6	Interfor	5
8.	Idaho Forest Group	5	EACOM	7
9.	Potlatch FP	4	J.D. Irving	5
10.	Stimson Timber	6	Tembec	7
11.	Gilman Building Products	6	Arbec	4
12.	Seneca Sawmill	4	Dunkley Lumber	1
13.	Roseburg FP	2	Conifex	2
14.	Hood Industries	4	Millar Western	2
15.	Rex Lumber	3	Carrier Lumber	2
16.	Jordan Lumber	2	Aspen Planers	1
17.	Swanson Group	2	Hampton FP	2
18.	Deltic Timber	2	Materiaux Blanchet	2
19.	The Westervelt Company	1	Barrette Chapais	2
20.	Boise Cascade	4	Groupe Lebel	8

* Canadian companies, with mills in the US includes the US mills in the US column.

In addition to competition in the market, any possible new mill in Maine would compete with existing mills for raw material.

3.3.2 Competing and Substituting Products

Using wood framing is by far the most common construction method in the US residential construction. Singly-family housing accounts for more than 90% of the market. In multifamily housing, wood has a somewhat lower, but still a dominant, share at 73% (2016). Steel and concrete account for the rest. Steel framing and concrete are much more common in non-residential construction (such as industrial and commercial facilities).

While, steel has been making slow gains in residential construction, the current trend is favouring wood use. Wood is considered a more natural product and has a much better carbon footprint in the manufacturing process than steel or concrete. This, combined with new product development (e.g. Cross-laminated timber – CLT), has enabled the emergence of a new mass timber construction boom, in which wood products (Laminated Veneer Lumber- LVL and CLT) are used as the structural material in high-rise apartment and commercial buildings. CLT is composed of structural lumber boards and the growing use of this product has also increased the total use of lumber.

Overall, Indufor does not see a significant threat of other substitute materials gaining on lumber markets in the construction sector.

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3.3.3 Barriers to Entry

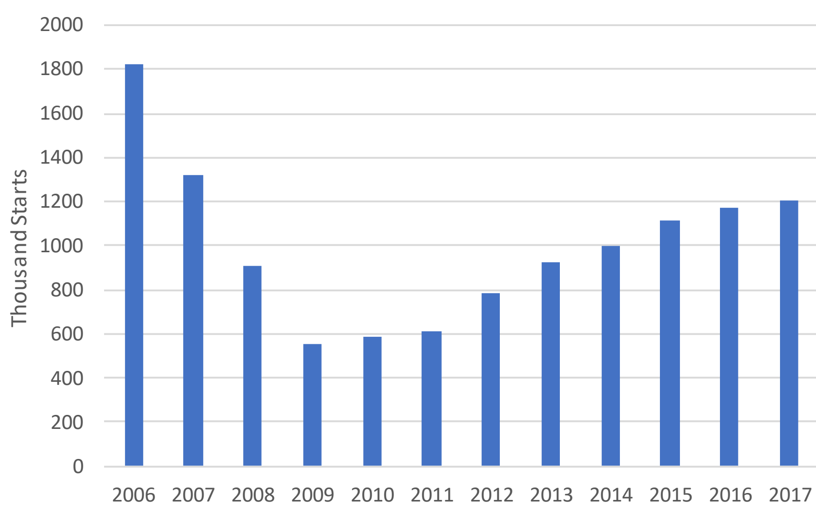
Barries to entry in the sawmill business are moderate, if the raw material supply is available. In the US, distribution systems are well developed and companies have relatively easy market access. The capital costs depend heavily on the size of the planned mill. The capital costs for a large-scale modern industrial mill range from USD 50 to 125 million. If the mill is located in a reasonably equpied region (market), it usually does not face significant difficulty in finding financing/investors for the mill. Most mills are built by existing sawmill companies and entirely new companies are rare.

Product certification/approval processes for new sawmills are also quite straightforward and do not cause a barrier to entry.

3.4 Key Drivers for Demand

The softwood lumber demand in the US is largely driven by the number of housing starts. The level of housing starts is still considerably lower than in the early 2000's and considered still to be below its long-term average demand level, which is determined by population growth and the level of household formation. There is a shortage of housing inventory and the housing start increase is hampered by various reasons such as lack of available lots, labour shortages and problems in financing. Overall, lumber demand is expected to continue to strengthen in the next several years as the housing market slowly approaches its long-term trend levels.

Figure 3-4: Historical Housing Starts in the US



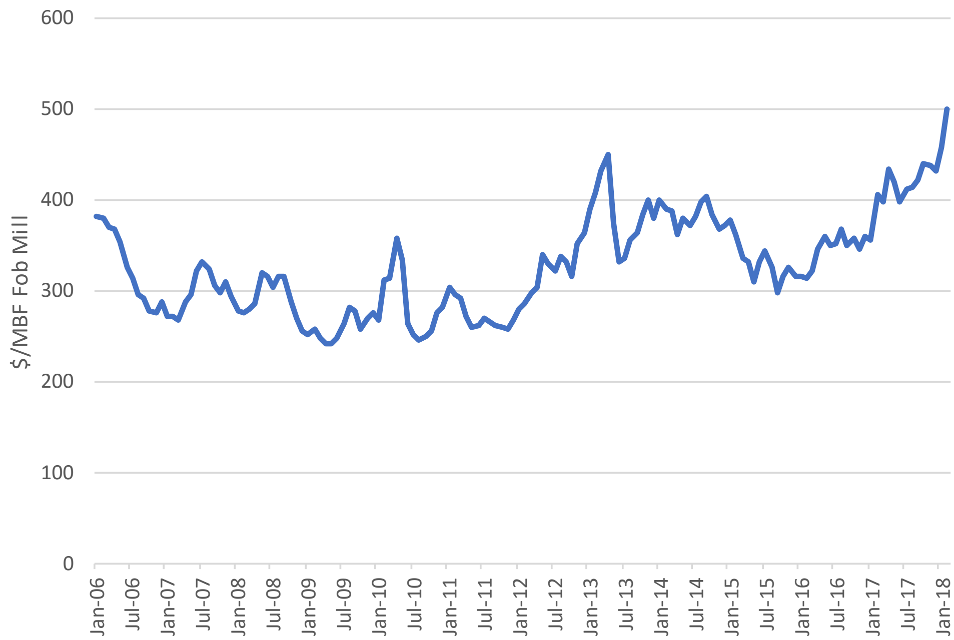
The other driver for lumber demand is the level of housing renovation and remodelling, although this has a somewhat lower impact on total demand. The renovation and remodelling demand generally follows economic trends. In recent years, spending on renovating and remodelling has grown at an annual rate of 5-7%. In the next several years the growth is expected to slow down to some extent, to due cyclical economic conditions (Harvard Joint Center of Housing Studies).

3.5 Prices and Price Trends

Softwood lumber prices are quite volatile and react quickly to changes in demand, supply and inventory levels. The prices were at very low levels for an extended period from 2008 to 2014. During that period, many sawmills struggled financially and production levels were low. In the last few years demand has picked up again and lumber prices have now reached historic highs. In addition to the improved demand, the current high prices are in part due to lumber import taxes levied on Canadian softwood lumber in 2017. The softwood lumber trade agreement between the US and Canada has expired and the countries are in negotiations for a new agreement. The duties will remain in place at least until a new agreement is reached.

Another reason for high lumber prices in the US is that softwood lumber production has not kept up with the demand growth. Supply from Western Canada is declining and production growth in the US West is also hampered by availability of timber.

Figure 3-5: Framing Lumber Composite Average Price in the US



Source: Random Lengths International

It is expected that the lumber prices will stagnate some in 2018, but will still remain strong. In the longer run (up to 2022), it is likely that the normal volatility will continue, but the overall trend projects lumber prices to remain higher than in the previous five years. This is due to expected continuation of demand growth, due to increasing housing levels, but limited increase in lumber supply.

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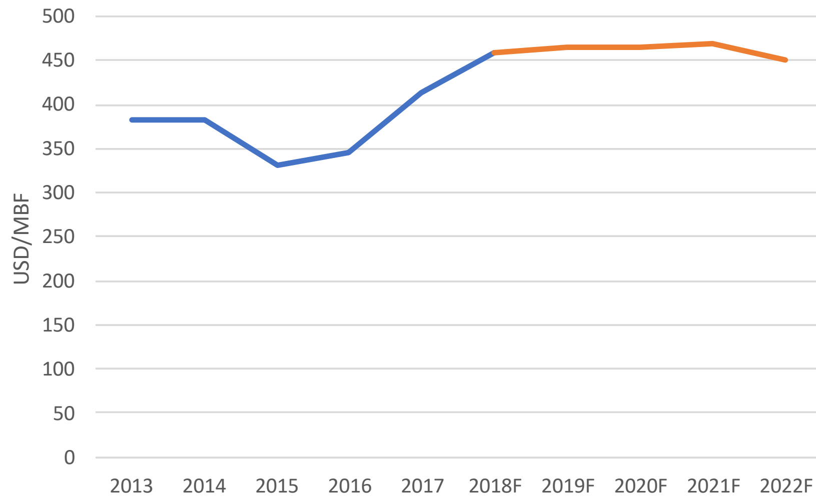
Figure 3-6: US Framing Lumber Composite Average Forecast



3.6 Product Certification

In the US there are two major forest certification schemes, Sustainable Forest Initiative (SFI) and Forest Stewardship Council (FSC) certifications. In addition, there is the smaller American Tree Farm System (ATFS). The SFI system was developed by commercial timberland owners and the industry and has wide acceptance within the industry. While the SFI and ATFS system are accepted by the international Programme for Environmental Certification Schemes (PEFC), some environmental groups do not think they are adequate for ensuring sustainability in forestry and endorse the FSC only. However, this system has gained market acceptance within major distribution chains and is the norm in the country. FSC certified softwood lumber products are less commonly available.

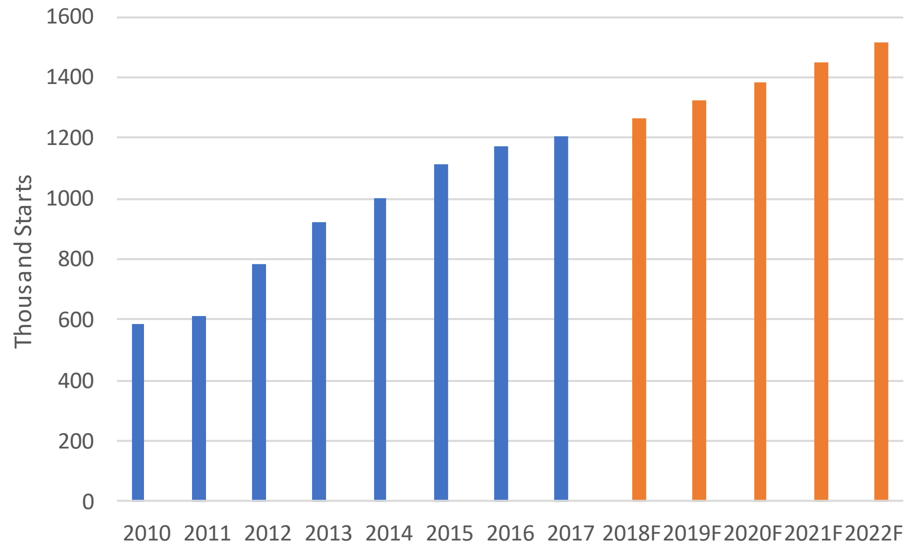
While green-certified products are growing in volume and common in the market, they are not required by all customer groups. Typically, the large DIY chains require certification (typically SFI), but wood that goes through distributors direct to builders is not always green certified.

In addition to environmental certification, structural lumber must be approved for structural use. In the Northeast, softwood lumber is normally graded using Northeastern Lumber Manufacturers Association (NELMA) grading system. Products that use and meet this grading system meet the American Lumber Standard committee’s approval for structural or other uses.

3.7 Outlook

The outlook for softwood lumber products in the US looks strong. The growth in housing starts drives the demand growth and while the housing market is not expected to reach the highs of the mid-2000’s, it is expected that the housing market will continue to have moderate to strong growth (4-5%) for the next five years. The impact of the recent federal US tax cuts may accelerate housing start growth in the next year or two, but may potentially reduce the long-term growth rate. In developing its housing forecast Indufor reviewed forecasts by leading housing authorities such as the National Association of Homebuilders (NAHB), Freddie Mac, Fannie Mae and the National Association of Realtors (NAR).

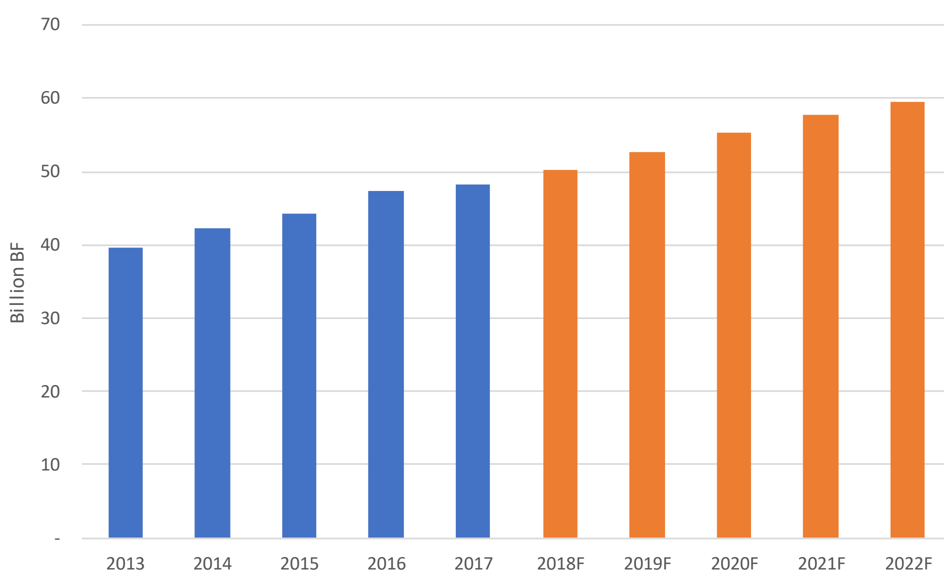
Figure 3-7: US Housing Starts Forecast



3.7.1 Market Growth

The growth in the housing market should translate into strong growth in lumber consumption. Projections expect consumption in the US to grow by more than 2 billion BF this year, and close to 3 billion BF in the following year. Unless, there is a cyclical downturn in the economy, the growth is expected to continue to be strong (partially due to demographic and housing demand increases). However, the current economic growth cycle has continued for an extended period and a downturn in the economy is possible.

Figure 3-8: US Lumber Consumption Forecast



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3.7.2 Opportunities

In Indufor's view, there is a strong opportunity to increase lumber production in Maine for the following reasons:

- Lumber demand growth is expected to continue to be strong;
- The only major supply area where lumber production can be increased is the US South, however, it is expected that the projected growth in the South will not be adequate to offset the decrease from Western Canada and to satisfy the demand growth;
- The supply from Eastern Canada (particularly Quebec and Ontario) has grown in recent years, but harvest reductions can be expected in both provinces due to reductions in allowable annual cut (AAC) set by the provinces. In addition, recent closures of pulp mills have reduced the mills by-product revenues.

3.7.3 Constraints

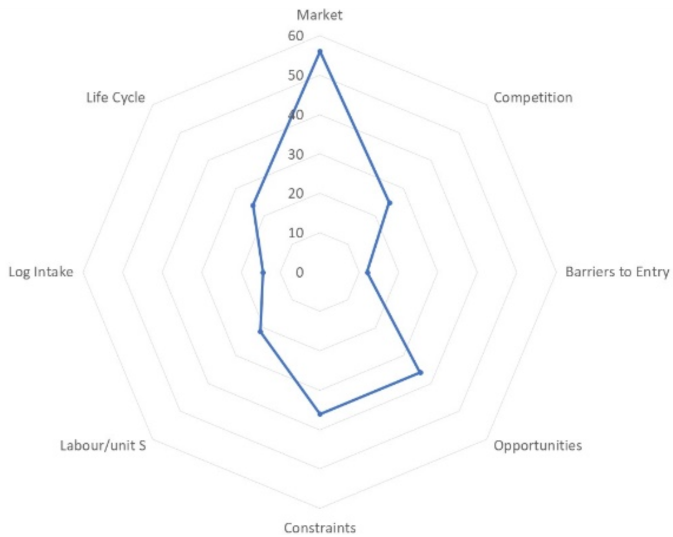
While the market outlook for softwood lumber production looks promising, there are several constraints to be considered as well:

- How can the sawmill by-products from sawmills in Maine be used, or who would purchase them? The possibility for increasing sawmill production is heavily tied to an increase of industrial capacity using softwood wood chips.
- Any new sawmill capacity will need to be located with attention to the raw material basket. Analysis on possible timber supply will need to be completed.
- Geographically, Maine is relatively far from the main population growth/construction growth areas in the US. The Northeastern parts of the country are not expected to have the fastest population growth in the country, and mills may need to sell the products in a larger geographic area than before.

4. LAMINATED VENEER LUMBER

LVL scores high as an attractive option for Maine, with a total score of 225. LVL's highest scores are for markets (56) and market opportunities (36).

Figure 4-1: LVL Attractiveness Score



The following section outlines in detail the market opportunity for LVL for Maine.

4.1 Product Description

Laminated veneer lumber (LVL) is an engineered wood product that uses multiple layers of dried wood veneer, commonly oriented in the longitudinal direction of the grain and bonded together under heat and pressure using glue on the veneer face. Individual wood veneers can vary in thickness. The thickness is dependent on the physical properties of the species from where the veneer is derived and the intended purpose of the LVL. Individual veneer thicknesses of 2 mm to 4 mm are common. LVL shares a number of properties in common with plywood. A key difference is the orientation of veneers in the longitudinal direction (in plywood the direction of the grain of each veneer is alternated at right angles), the ability to produce very long lengths at depths which are well in excess of what is produced in plywood manufacture. Although normal practice is to orient the veneers in the longitudinal direction there are some long-length, thick dimensioned cross veneer LVL products available in the market.

4.1.1 Product Differentiation/Segmentation

Non-Structural LVL

Non-structural LVL is most commonly used for furniture components, interior joinery, stairs and balustrades. Most of the LVL made in China, Japan and the Philippines is non-structural. A sizeable amount of LVL made in New Zealand, Indonesia and Malaysia is also for non-structural applications. Panels are commonly 2.44 m or less in length. Non-structural LVL is made from softwoods and temperate hardwoods (such as poplar). There is some usage of non-structural LVL in joinery applications, but the volume is not significant.

Structural LVL

Structural LVL is for use in construction and in particular where there is a load bearing requirement. Essentially all LVL manufactured in North America, Europe, Russia and Australia is structural LVL. Structural end uses are further differentiated into:

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- I-joist flanges;
- Solid section beams, headers, columns and industrial rim board.

Structural LVL dimensions vary widely depending on the intended end use and the characteristics of the geographic market that the product is aimed at. Virtually every structural LVL producer in Europe, North America, Australia, Japan, New Zealand and Russia have guidelines and brochures outlining the product grades and dimensions they produce or have available for sale.

For example In North America, 2.0E Microllam® LVL (Weyerhaeuser) is available in 44.5 mm (1.75 inch) width and depths ranging from 139.7 mm to 508 mm (5.5 inch to 20 inch). Boise Cascade's VERSA-LAM® 1.8 LVL beams and headers for the US east market (as printed in the Eastern Specifier Guide) are offered in widths from 88.9 mm to 133.4 mm (3.5 inch to 5.25 inch) and depths from 88.9 mm to 184.2 mm (3.5 inch to 7.25 inch). Common lengths for LVL are 14.6 to 20.1 m (48-66 ft), widths ranging from 19.5 mm to 63.5 mm (0.75 inches to 2.5 inches), and depths of up to 609.6 mm.

In Europe, common LVL dimensions are:

- 33mm x 200/225/260mm;
- 39mm x 200/225/260/300mm;
- 45mm x 200/225/260/300/360mm;
- 51mm x 200/225/260/300/360/400mm;
- 57mm x 200/225/260/300/360/400/450mm;
- 63mm x 200/225/260/300/360/400/450/500mm;
- 75mm x 200/225/260/300/360/400/450/500/600 mm.

Nearly all structural LVL is made with softwoods. Common species include douglas fir, larch, hemlock (in recent years), southern yellow pine, spruce, and radiata pine. There are some notable exceptions of LVL mills using hardwood. Pollmeier Furnierwerkstoffe manufacture LVL from beech wood. The Amos mill and the Ville-Marie mill in Canada apparently use some Aspen in manufacture. Poplar has also been mentioned, and in South East Asia some structural LVL is made with mixed tropical hardwood.

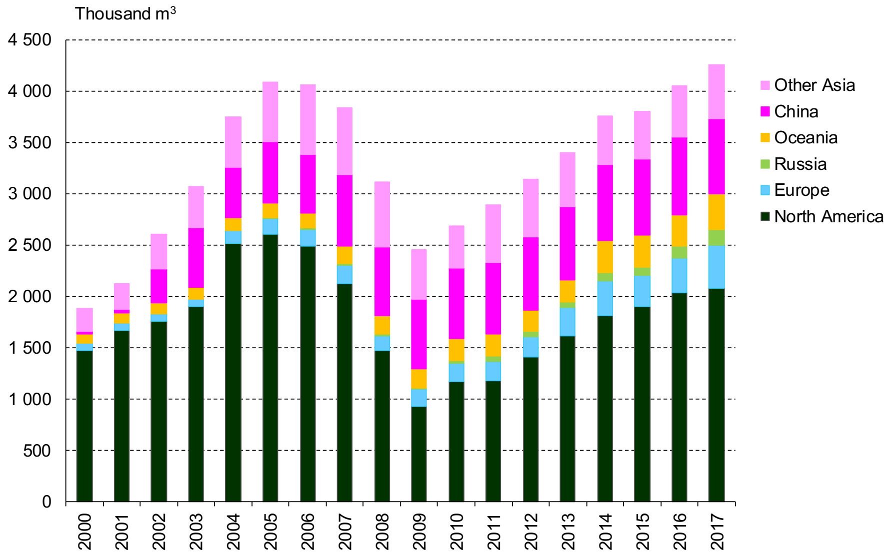
4.2 Market Size and Growth

LVL as a commercial product has been manufactured from the early 1970s. Demand for the product has steadily increased over the years but uptake did not meet the initial enthusiasm to develop production capacity during the 1980s and 1990s. Figure 4-2 shows global LVL demand development for both structural and non-structural LVL. Global demand is estimated to be 4.26 million m^3 in 2017. Since 2009 LVL markets have grown on average 7% per year.[23]

North America is the largest market, currently estimated to be just over 2 million m^3. Other significant markets include China and Japan, though these are largely non-structural markets. Europe (420 000 m^3 or roughly around 10% of the global market at present) is the second largest structural LVL market behind North America. The markets most relevant to Maine are North America and Europe.

[23] Compound annual growth rate (CAGR)

Figure 4-2: Global LVL Consumption



Source: Indufor analysis, based on a wide variety of public data, interviews, interpretation of trade data and publicly available production and consumption statistics.

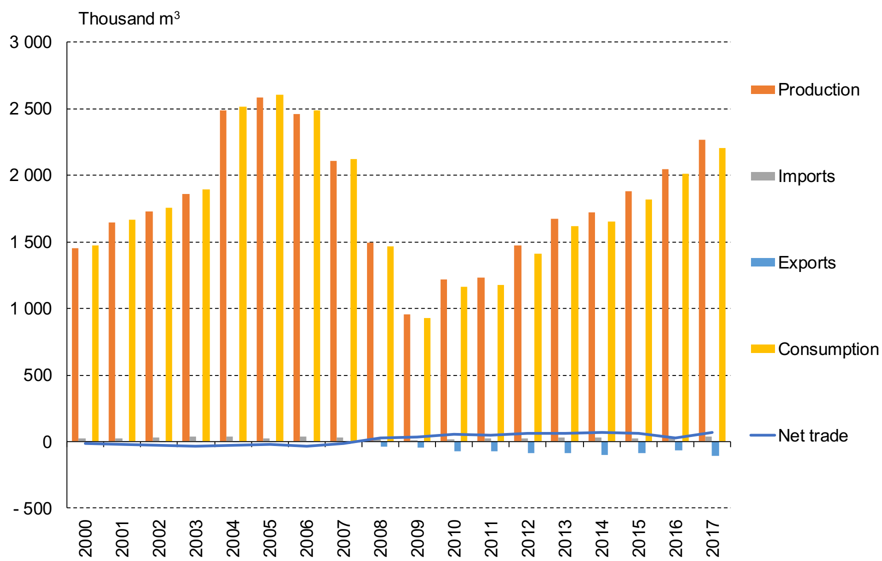
4.2.1 North America

The North American market for LVL can be considered mature or approaching maturity in its life cycle as changes in demand are increasingly tied to the fortune of the construction market.[24] The North American market peaked in 2005 at around 2.58 million m^3, subsequently crashing to the market low of around 930 000 m^3 in 2009. Since then, the market has been experiencing strong growth (11 % CAGR since 2009, Figure 4-3). Growth in the North American market has slowed in recent years.

Nearly all North American consumption (98-99%) is satisfied by domestic production. LVL imports have fluctuated over the years in line with the market, but to date have never exceeded 40 000 m^3 or 2% of the total market. The largest recorded total share was in 2017, with imports reaching 38 000 m^3. Finnish LVL producers have been the main suppliers. US producers manufacture more LVL than is consumed in the country. Although only comprising a small proportion of the overall output, more than 100 000 m^3 of LVL was exported from North America in 2017. Most of this is exported to Australia. Exports to Europe have yet been negligible.

[24] The argument here is that a product in growth stages of the life cycle can still develop strongly in an adverse demand driver situation, because of substitution. As the substitution maxima is approached, fluctuation in demand for the product more closely follows driver trends.

Figure 4-3: LVL Production, Consumption and Trade in North America



Source: Indufor analysis, based on a wide variety of public data, interviews, interpretation of trade data and publicly available production and consumption statistics.

The North American market is a 'regional market'. LVL itself is a relatively mobile product, travelling long distances to reach end-user markets. But this is not necessarily the case for the end use products it is converted into i-joists, beams, rim boards, and columns, tend to be produced and consumed in relatively tight regions.

Most of the LVL consumed in North America (around 80%) is used in new home construction in the residential market. Single-family housing as defined by the US Census Bureau is the main residential construction sector where the LVL is used. The balance is used in Industrial construction as well as miscellaneous other uses such as scaffolding planks (a non-structural application). Other end uses exist but are minor.

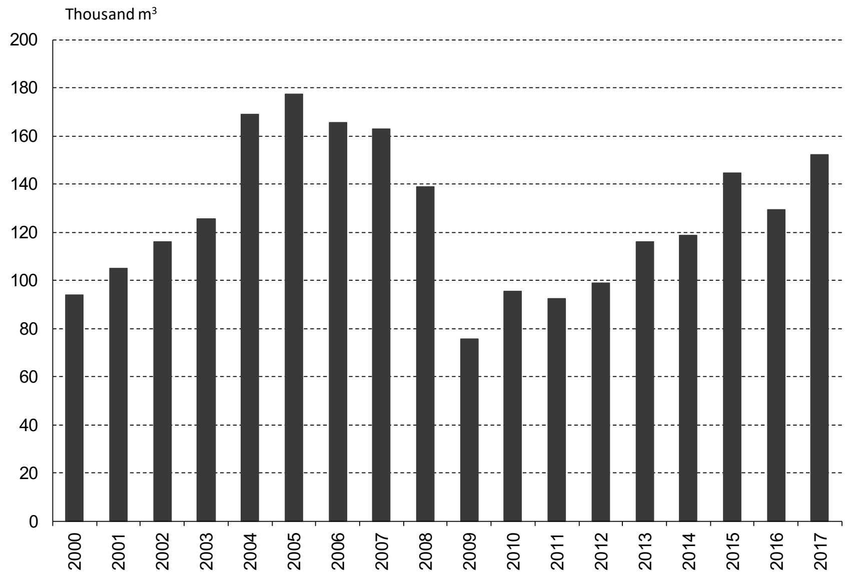
According to The Engineered Wood Association (the APA) and other Industry commentators between 70% and 75% of LVL use is for beams, headers and industrial rim boards. The balance (25%-30%) is used in i-joists. There has been a steady increase in the use of LVL as beams, headers and industrial rim boards since the 1990s, but since 2008 – 2009 this appears that the split of LVL use between i-joists, beams, headers, and rim boards roughly settled to current ratios.

The American North East

The Northeast of North America, encompassing the US Northeast states, and eastern Canadian states[25], is estimated to currently consume around 140 000 m^3 of LVL. Figure 4-4 shows demand development of LVL in this region. Since 2009 demand growth for LVL in North East has averaged about 9% CAGR. This is slightly lower than the national average.

[25] The North American North East includes the following states: New York, Vermont, New Hampshire, Massachusetts, Connecticut, Maine , Rhode Island, Nova Scotia, Quebec, Newfoundland and Labrador and New Brunswick.

Figure 4-4: LVL Consumption in the North East



Source: Indufor analysis of LVL consumption and construction data from the US and Canada

4.2.2 Europe

The region with the longest market history for LVL is Europe. Demand for LVL did not develop, however, in rapid sucession when it reached European markets. Even as recent as 2000 demand for LVL in Europe was less than a twentieth of the US demand at that time. Since 2004 LVL demand has steadily improved with a strong demand surge in the last five years (Figure 4-5). Current LVL demand is about 420 000 m^3 This is still only a fifth of the US market, but certainly more significant than a decade ago. House construction methods (in France and Germany for example), the availability of competitively priced softwood lumber and the strength of the solid wood glulam industry in Europe providing structural building components, are the key reasons why LVL demand has not been embraced as much as it has in the US. Developing interest in CLT, however, appears to have stimulated interest and demand for LVL. Official support for wood use in construction (e.g. in the UK) has supported LVL demand.

Like the US, nearly all of the LVL made in the continent is consumed there. Additionally, a sizeable proportion of Russian made LVL enters into the European market, but mostly as already fabricated components and therefore is not visible in trade statistics as purely LVL. A small volume of LVL is exported, mainly to the US. Even though this trade is not particularly large in terms of LVL demand in the US, it still represents a significant (albeit diminishing) proportion of European output.

Scandinavia is the main LVL consuming region in Europe, currently accounting for between 35 and 45% of European demand. The second largest market is the UK where it is estimated that the current consumption of LVL is between 80 000 and 100 000 m^3 per annum. Germany and France are smaller but nonetheless steadily growing markets. The other two European markets of sufficiently distinguishable size are Switzerland and Austria.

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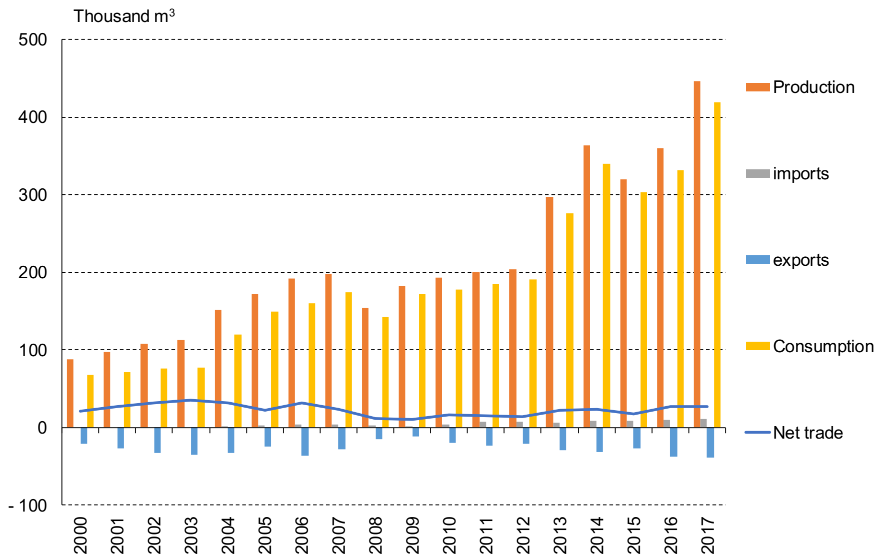
Figure 4-5: LVL Production, Consumption and Trade in Europe



Source: Indufor analysis, based on a wide variety of public data, interviews, interpretation of trade data, and publicly available production and consumption statistics.

LVL in Europe is more mobile than in the US as it is considered a speciality product with a premium value in the marketplace. Almost 80% of LVL consumption in Europe is in the Scandinavian countries, the UK, and the Germanic countries of Europe

In Europe, LVL is used in all types of construction projects, from new buildings to renovation and repair. The main end users are more or less the same as in North America, namely

- Beams and joists;
- Trusses and frames;
- Components of roof, floor and wall elements;
- Components for the door and vehicle industry;
- Concrete formwork;
- Scaffold planking;
- Studs.

In Northern Europe especially, LVL is also used as wall studs in rooms with higher cellings. LVL is considered a straight, evenly strong product with little deviation in quality. While it is significantly more expensive than lumber, it performs especially well in large room applications, where space limits the dimensions of the stud.

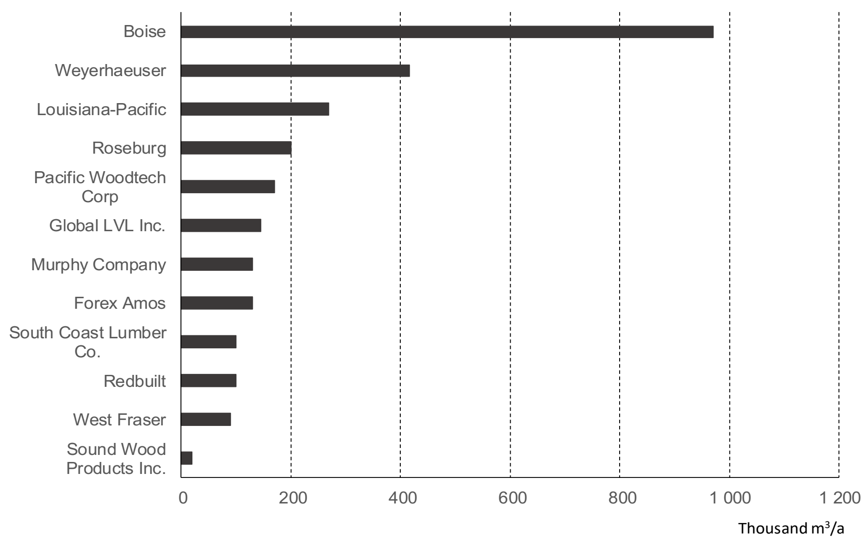
Of interest is the development of use of LVL in mass timber structures, whereby LVL, CLT and plywood is used in combination to take advantage of each of the different products key strengths. As noted, this has been an important factor in the recent acceleration in the use of LVL in Europe—and is most visible in the new Stora Enso mill in Finland where mass timber was featured prominently in the rationale for establishing this production facility.

4.3 The Competitive Landscape

4.3.1 North America

There are presently 12 companies in North America operating an estimated 2.74 million m^3 per annum of installed LVL capacity.[26] The three largest companies (Boise-Cascade, Weyerhaeuser and Louisiana-Pacific) account for 60% of the installed capacity. Boise Cascade has four facilities. Weyerhaeuser have six facilities. Most other companies are single mill operations.

Figure 4-6: LVL Mill Owners in North America



Source: Indufor based on interviews, internal databases, and publicly available data.

In total there are 21 separate LVL mills in the country, of which 18 or 19 are believed to be currently operating. Indufor understands that the Roxboro mill (Boise Cascade) is still idle as is Weyerhaeuser's Valdosta mill. There is some uncertainty over whether Weyerhaeuser's Simsboro mill has re-opened.

[26] This includes mills that have been mothballed since 2009. Though these remain idle, it is likely they will be recommissioned once demand increases to a point that warrants it.

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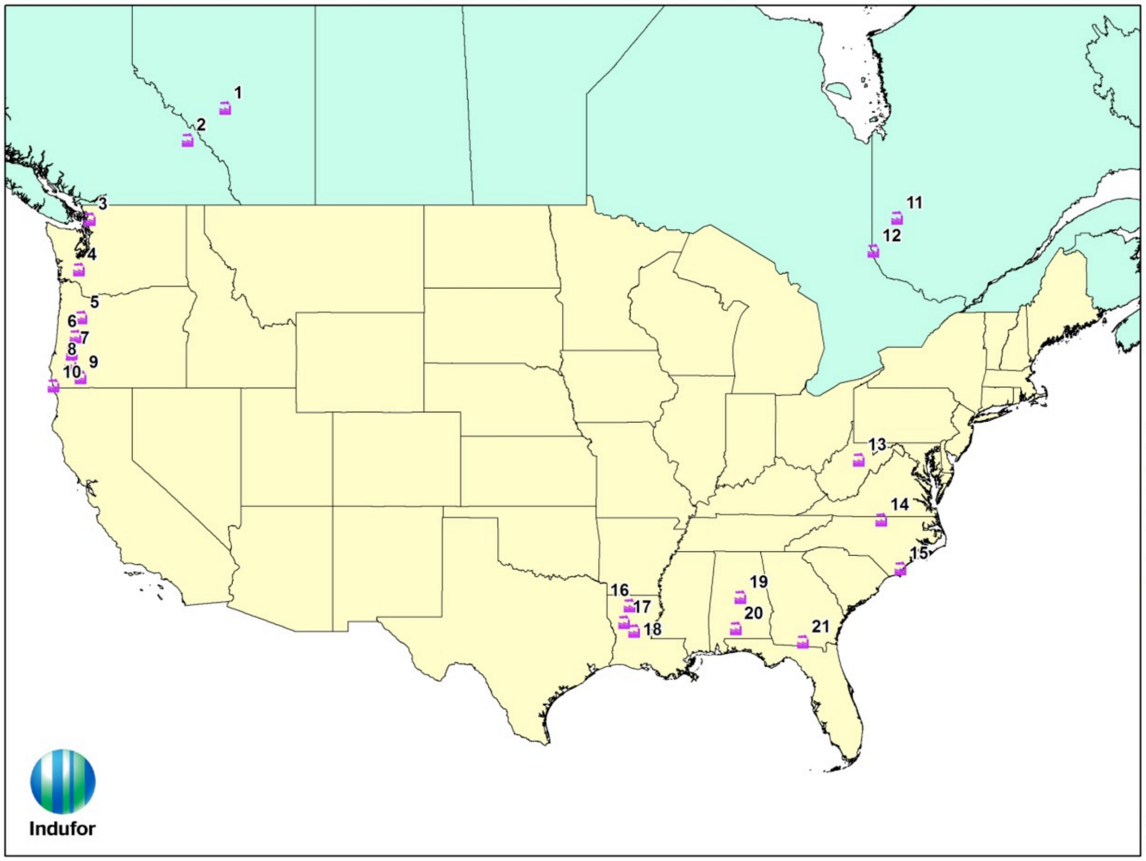
Figure 4-7 shows the location of operating and mothballed LVL plants in North America. Only two mills (Forex Amos and Global LVL Inc.) are in the Northeast. Most of the installed capacity is located in and around the Pacific Northwest and the US South. Installed capacity in the northeast is estimated at around 275 000 m^3 per annum and another 330 000 m^3 per annum is located in the east of the US (North Carolina and West Virginia).

Figure 4-7: LVL mill location in North America



LVL Mill

1, West Fraser (Rocky Mt House)
2, Louisiana-Pacific (Golden)
3, Pacific Woodtech Company (Burlington)
4, Sound Wood Products Inc. (Chehalis)
5, Redbuilt (Stayton)
6, Weyerhaeuser (Eugene)
7, Murphy Company (Sutherlin)
8, Roseburg Forest Products (Riddle)
9, Boise Cascade (White City)
10, Pacific Wood Laminates Inc. (Brookings)
11, Forex (Amos)
12, Global LVL Inc. (Ville-Marie)
13, Weyerhaeuser(Buckhannon
14, Boise Cascade (Roxboro)
15, Louisiana-Pacific (Wilmington)
16, Weyerhaeuser (Simsboro)
17, Weyerhaeuser (Natchitoches)
18, Boise Cascade (Alexandria)
19, Boise Cascade (Thorsby)
20, Weyerhaeuser (Evergreen)
21, Weyerhaeuser (Valdosta)

Source: Indufor

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The North American market can be described as competitive. Capacity utilisation has been steadily improving since 2009 and is presently at 83% if one includes idled capacity, or 93% if it is excluded. The market is on the rise, as recenty (the first time in almost a decade) new capacity was announced. Roseburg are planning to build a 285 000 m^3 per annum facility (their second LVL mill) in Chester County, South Carolina. This will undoubtedly raise competitive tensions within the region, however, the real extent of this depends significantly on the fate of existing mothballed facilities (if they remain idle or are dismantled forever).

The situation in the Northeast can be described as more competitive than the North American situation as a whole. Demand for LVL in the Northeast is currently estimated at just over 140 000 m^3 per annum. This represents only 55% of the installed LVL capacity in the region. Geographic considerations may however play an important moderating effect. Both of the Northeast located mills are in Quebec, on or close to the Ontario border. Residential construction activity (which is the main driver for North American LVL demand) in Ontario is currently 1.4 times larger than all corresponding activity in Quebec, Labrador and Newfoundland, Nova Scotia, and New Brunswick combined. Housing starts in the whole of the Northeast as defined herein, are roughly equal to that of Ontario alone. When other likely target market spheres (Michigan, Indiana and Wisconsin) are added, the Northeast as a market diminishes in importance. Market focus for these two mills will therefore drift to the West and Southwest in a greater extent than is currently seen in the Northeast.

More relevant, is the presence of the Louisiana-Pacific laminated strand lumber (LSL) mill in Houlton Maine. Capable of producing a product that has similar performance characteristics to LVL, this mill is well situated to supply the Northeast as well as markets in states to the south and east of the US. It is also of a capacity that is comparable to most of the other LVL individual LVL mills in the US and has the potential to match the current LVL consumption in the Northeast.

4.3.2 Europe

There are four LVL producers in Europe and two in Russia who would likely compete with LVL supplies from the US. Metsäliitto is the largest producer operating several lines at two sites in Finland. Pollmeier Furnierwerkstoffe operates the single largest line in the region. The competitive market environment in Europe can be described as tougher than North American markets. This is due to the smaller market, and higher ratio of installed capacity to consumption. Historically production as a proportion of installed capacity has never been above 75% in the last decade and a half. Despite this chronic overcapacity situation there are plans for LVL capacity to increase. The Steico Group is adding an additional 80 000 m^3 per annum of production capacity to their plant in Czarna in Poland. This will begin operation in 2018. Metsäliitto has only recently completed an upgrade in Lohja (2017) and will add another 65 000 m^3 per annum capacity to Punkaharju mill, slated to begin operating in 2019.

Even though the added capacity is less than what is planned for the US, it still greater in proportion to European demand. This will likely ensure that the European market remains competitive.

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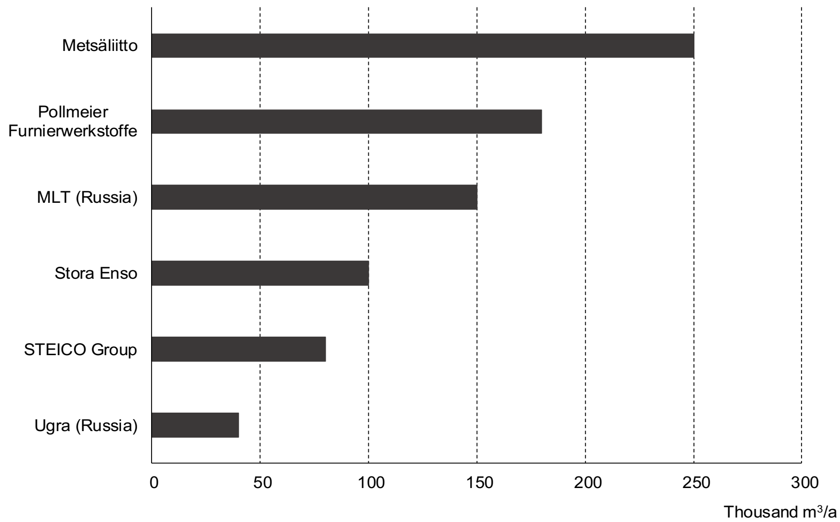
Figure 4-8: LVL Mill Owners in Europe and Russia



Source: Indufor based on interviews, internal databases and publicly available data

4.3.3 Competing and Substituting Products

North America

The growth of LVL consumption in residential, commercial and Industrial construction has been at the expense of large solid wood members and framing, and multiple dimension lumber in beam and header applications.

LVL is not without contenders, however, as there is competition from solid wood which can be a cheaper option for construction. Black spruce from Canada is being used for the I-joist flanges in lieu of LVL. Open web solid wood trusses are a competing product in roofing. Other structural composite lumber products such as oriented strand lumber (OSL), laminated strand lumber (LSL), and parallel strand lumber (PSL) compete with LVL in structural load-bearing applications such as beams and headers. To date the penetration of competing engineered wood products (even if they are lower cost) has overall not been significant, partially because many of the planned developments happened at the time of the market downturn in the US and have yet to be re-initiated.

According to the APA LVL held about 30% market share of the beams, headers and columns market in 2016.[27] Built-up lumber held the leading share of the market at 36%. Indufor understands there is still considerable opportunities for LVL use to continue making inroads in this market segment. Glulam is present in the market, but not to the same extent as LVL or built-up lumber.

For I-joists, market penetration is now approaching its maxima. More than 60% of the North American I-joist flange market is currently held by LVL. This share has fluctuated in the past, being as high as 75% or more in the late 1990s and lower (around 50%) in the mid-2000s.

Europe

A similar situation exists in Europe with respect to the main competing products, however, the strength of glulam in the marketplace has been seen as a key inhibitor to LVL demand development in the past. Consumption of glulam in Europe has been relatively stable in recent years. Although LVL use has been rising, it is still less than a quarter of Glulam consumption. Price always is an underlying consideration, especially when markets are less buoyant, opening options for the use of solid wood.

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[27] Rimboard falls into this category but in reality it is considered a very small scale end use application

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The increased awareness and use of mass timber products in construction has opened the possibility for LVL to gain a foothold and increase its share of this segment of the construction market, in Europe (a development that already appears to be happening) and potentially in North America, where mass timber use is gaining momentum.

4.3.4 Barriers to Entry

North America

The key barriers to market entry involving new capital investment can be identified as:

- Investment cost,
- Cost competitiveness,
- Competition from existing LVL producers,
- Market structures

Investment cost is a function of the size of a facility and LVL plants like many other wood processing plants are relatively expensive investments. Table 4-1 summarises investment evidence and compares this with capital investment costs in competing products.

Table 4-1: Recent Planned and Completed LVL Investments in North America and Europe

Company	Mill location	Announcement date	Capacity (m^3/a) at time of announcement	Investment announcement (millions)	Investment in (USD million)[1]	Investment USD/m^3 capacity
Roseburg	Chester	2017	280 000	USD 200	200	1 400
Murphy Company	Sutherlin	2005/2006	100 000	USD 52	59.5	595
Stora Enso	Varkus	2015	100 000	EUR 43	50.4	504
Steico Group	Czarna I	2015	80 000	EUR 60	69.1	863
Steico Group	Czarna II	2017	80 000	EUR 45	50.7	634
Pollmeier Furnierwerkstoffe	Creuzburg	2012	200 000	EUR 105	144.8	805
Competing products						
Structural sawn lumber						150-250
OSB/OSL						900 -1 300

Source: Indufor analysis based on publicly announced information

Note 1) The conversion of announced investments in EUR to USD has been done at the time of announcement. Historic data has been adjusted using IMF USD CPI data.

Naturally, investments range in value, depending on what each company needs to invest in to build the plant. Based on the available data (Table 4-1) the investment cost for a new LVL mill is between USD 500 and USD 900 per cubic meter of installed capacity. The Roseburg investment in Chester County appears to be an outlier. This is believed to be an all-in cost and probably includes investment in other wood processing options.[28] Available data suggests that investments in sawmilling are typically less than half that of LVL on a per cubic meter basis, though investing in OSL, another competing product is comparable or possibly more expensive than LVL.

Not only is LVL capital investment more expensive than sawmilling on a unit basis, the cost of manufacturing LVL is more expensive. The lack of cost competitiveness is often more than outweighed by the advantages that LVL has over products such as solid lumber. These include greater strength to weight ratios, lighter overall weight (with respect to use in I-joists), ability to span distances without compromising load capacity, and better dimensional stability. In end

[28] Understandably media announcements are not clear about what constitutes the investment.

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uses where there is no requirement for such advantages, cost would be a more important factor in material selection for the intended purpose. The threat of market entry barriers from strand lumber products (OSL/LSL/PSL) is probably greater however, because such products offer similar performance advantages as LVL, at a lower price, and are manufactured with equipment of comparable capital investment. It is worth noting that Louisiana-Pacific operate the only LSL mill in the US (to date there has been no investment in OSL in the US) in Houlton, Maine. Sales over the last three years have been increasing. In 2017 around 93 000 m^3 was sold from this facilities, at unit prices 25% less than that of LVL from other Louisiana-Pacific facilities.

The competitive environment can be seen as an important influencing factor in market entry decisions. Section 6.3.3 discusses this issue in some detail, and while the US market is competitive, this may be less of an entry barrier, assuming future demand for LVL picks up with new housing starts and, correspondingly, new investments over the coming years are limited to the Roseburg announcement. If however, mothballed plants restart operations then the consideration of an LVL mill to serve the Northeast markets will need fresh analysis.

Market structure is probably the least important barrier to entry. Most (but not all) LVL producers are integrated with I-joist production and many have their own product distribution networks. But the US wholesale and retail timber networks are well established independently owned businesses, making it relatively straightforward to place approved products into this network. Further there are a number of I-joist manufacturers that are not integrated with LVL production capacity, many of which are located in the northeast (Quebec, New Brunswick). In this commodity market the challenge is to differentiate oneself from the other producers.

Europe

Europe as an export market is accessible to any producer in North America whose product is able to meet the relevant standards and is produced in the dimensions desired and required by the market. The market smaller than North America and, In Indufor's opinion, more competitive. However, these factors should not inhibit sales if a North American supplier can be as competitive as a European supplier. The key issue then is cost competitiveness, and, in this regard, a North American supplier would face strong competition from local and regional competitors LVL as well as having to accommodate shipping costs and import duties.

European markets may therefore be difficult to penetrate, but with the exit of the UK from the EU, this market may open opportunities for North American LVL producers.

LVL imported to the EU (which the UK is still a part of) faces an import duty of around 10%, applied ad valorem to the CIF price. There is no indication, yet if this will change once the UK leaves the EU, presumably this will be applied to European and North American producers alike. Assuming there are no preferential tariff agreements, North American suppliers on the East Coast will be in a better position to compete with European suppliers in this market.

4.4 Key Drivers for Demand

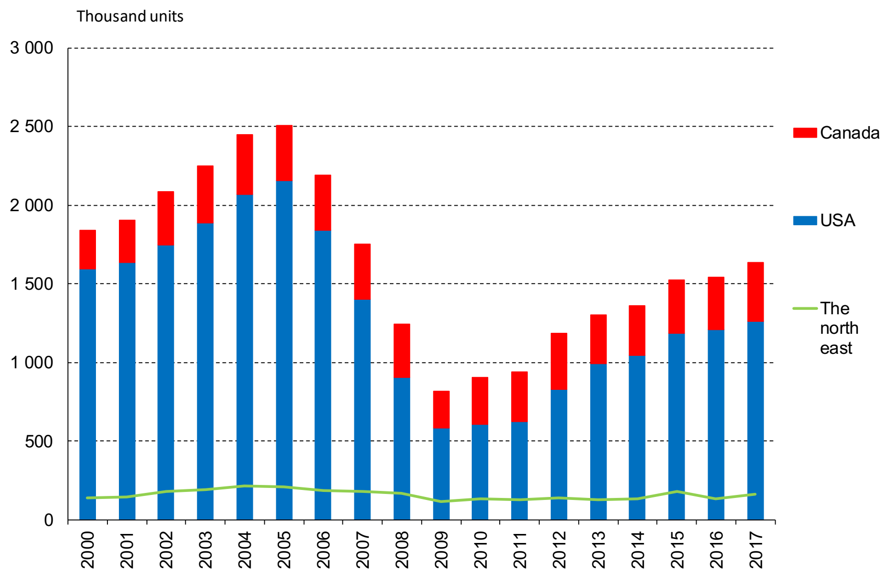
According to various industry commentators and participants, construction is the key driver for demand for LVL. Specifically, it is the residential construction industry and in particular (in North America) single-family household construction that is important to LVL demand. Indufor's own research has supported this relationship between single-family home construction and LVL consumption.

4.4.1 North America

The historic pattern of housing starts in North America and the northeast is shown Figure 4-9. It is clear that the decline in new housing starts from 2006 to 2009 was largely a US phenomenon and that housing starts nationwide have yet to recover to the "pre-crisis" levels of the early 2000s. In contrast, Canadian housing starts dipped sharply only in 2009 (following the general global response to the US financial crisis) and have already returned to follow historic trends. Broadly speaking the pattern of LVL demand in North America (Figure 4-3) follows US housing starts.

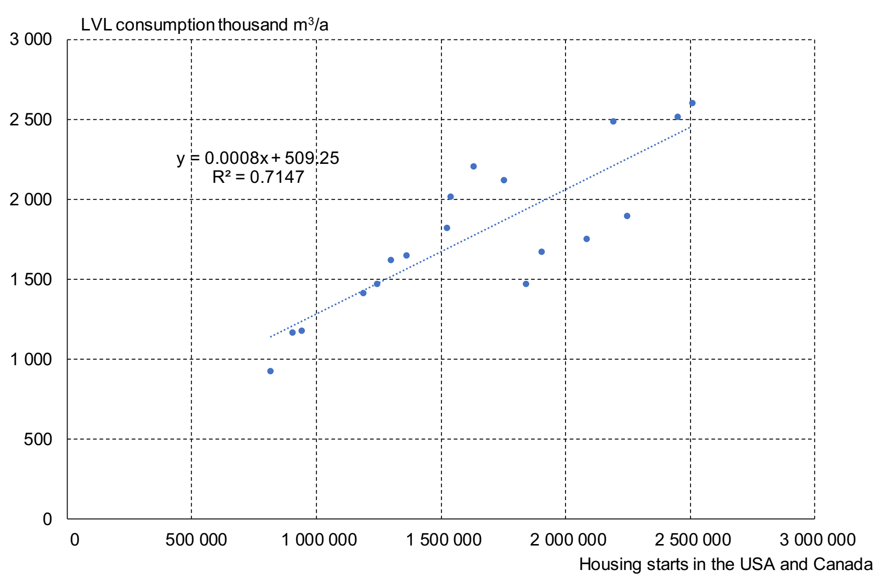
Over the last decade and a half, there are indications of a correlation between North American housing starts and LVL consumption (Figure 4-10). The correlation is not particularly convincing and is weaker when North American LVL consumption is compared with just US housing starts, and with US single home housing starts. Imprecision and estimates in the data may partially explain these inconsistencies.

Figure 4-9: Housing Starts in North America and the North East



Source: US Census Bureau and Statistics Canada

Figure 4-10: LVL Consumption and Housing Starts in North America (2000-2017)



Source: Indufor analysis

Another complicating factor is that new housing starts are not the exclusive domain for LVL consumption. Some are used in residential remodelling, and in commercial, industrial, and infrastructure builds. Unfortunately, it is not a straightforward process to isolate LVL demand by sector or obtain reliable metrics that demonstrate LVL demand change with changes in remodelling or industrial/commercial, and infrastructural activity.

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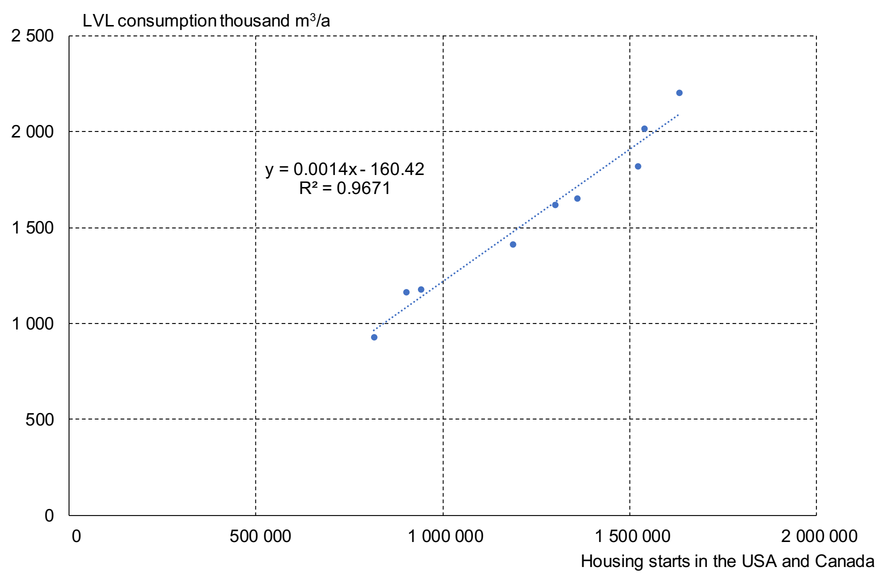
Interestingly, since 2009 LVL consumption and North American housing starts have been highly correlated (Figure 4-11), suggesting that other factors such as substitution, (which is not necessarily a function of housing starts) have in the past, had a stronger influence on LVL consumption than is observable today. In effect Figure 4-11 suggests that substitution with respect to LVL end uses in residential construction are approaching a maxima and changes in LVL demand are becoming more closely aligned with changes in housing starts.

This observation has important implications for predicting future LVL consumption in North America. Unfortunately forward-looking observations of housing starts in the US and Canada beyond a set period are not readily available. In the US various industry commentators suggest that new housing starts will accelerate in 2018 and 2019, but the viewpoint is not unanimous with some disagreeing and instead suggesting a decline in housing starts through to the end of 2019. Beyond that it is likely that new house construction will slow. Indufor believes a year on year CAGR of between 4.5 and 6% over the next five years would not be unreasonable.

Less information is available with respect to predictions in the growth of remodelling activity or commercial/industrial/infrastructure building. Typically changes in these sectors has been linked with changes in GDP growth. Based on this assumption Indufor believes remodelling or Industrial/commercial and infrastructural activity is expected to increase at a year on year CAGR of around 2-2.6%

In Canada, forecasts provided by various institutions are fairly unanimous in suggesting that near-term demand will either be flat or will decline slightly. This is not entirely unexpected given that housing starts have recovered to historic trends and have changed little over the last few years. The long-term outlook is relatively flat. Indufor therefore believes a relatively stable construction profile would be appropriate for the Canadian situation over the next five years

Figure 4-11: LVL Consumption and Housing Starts in North America (2009-2017)



Source: Indufor analysis

4.4.2 Europe

Like North America, development construction is seen the key driver for LVL demand but the relationship between LVL consumption and construction is much more complex, as multiple factors across many countries influence LVL use. This includes the impact of regulation and government support on LVL demand, substitution and the choice of the construction type that will influence demand. All in all, wooden construction is expected to continue to gain market share in Europe especially in France and the UK, and this will be positive for LVL.

The trend in house construction in Europe overall has followed a pattern similar to the US, though importantly industry activity continued to decline through to 2013, and has only very recently shown renewed vigour. There is now strong activity both in the Netherlands and in Spain. The German market has also shown reasonable performance. Confidence is improving.

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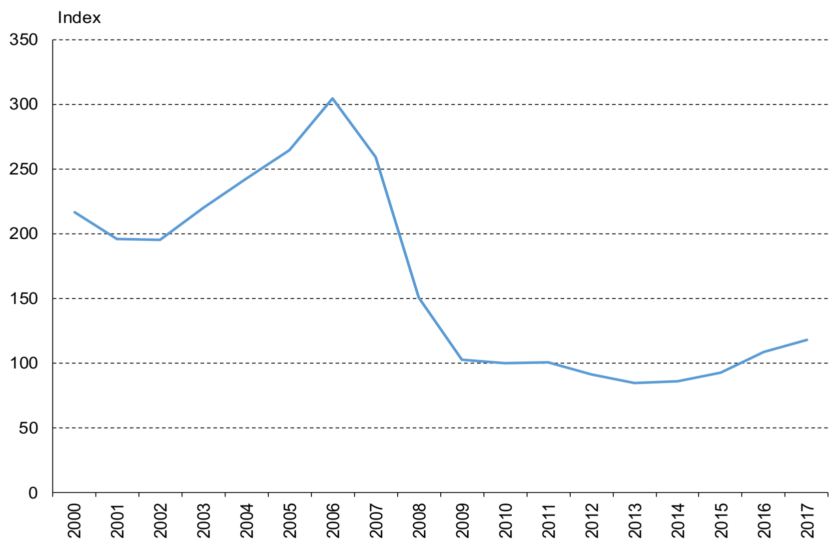
According to Euroconstruct, housing start outlook indicates positive development for France, the UK and Sweden whereas the market is forecast to show more limited growth in Finland, Norway, Germany and Italy and remain rather stagnant in Switzerland and Spain. Predictions assert that there will be an overall relatively slow recovery, and it is likely that construction activity will not reach pre GFC levels till around 2025.

The implication is that change in construction (whether residential, commercial, industrial, or infrastructural) will have less influence on LVL demand. It is more likely that changing shares in wood construction and substitution will influence consumption growth.

Figure 4-12: Residential Housing Permits in the EU (2010= 100)



Source: Eurostat

4.5 Prices and Price Trends

LVL prices are generally not published in North America. However, it is possible to get an indication of selling prices through reported accounts of many of the larger forest industry companies whom (through obligation or desire) make such information available to investors. Such information comes with important caveats; sales price point is not disclosed, nor is there any granularity with respect dimensions and grades or markets. It is nonetheless useful to provide indicative price trends.

Information available from Boise Cascade (Figure 4-13) shows that prices in the US have been steadily increasing over the last seven years. Quarterly data over the last three years also points to prices being overall very stable, though it is difficult to apply such an observation to regional markets. Louisiana-Pacific LVL and LSL prices have similarly shown an increasing trend (Table 4-2).

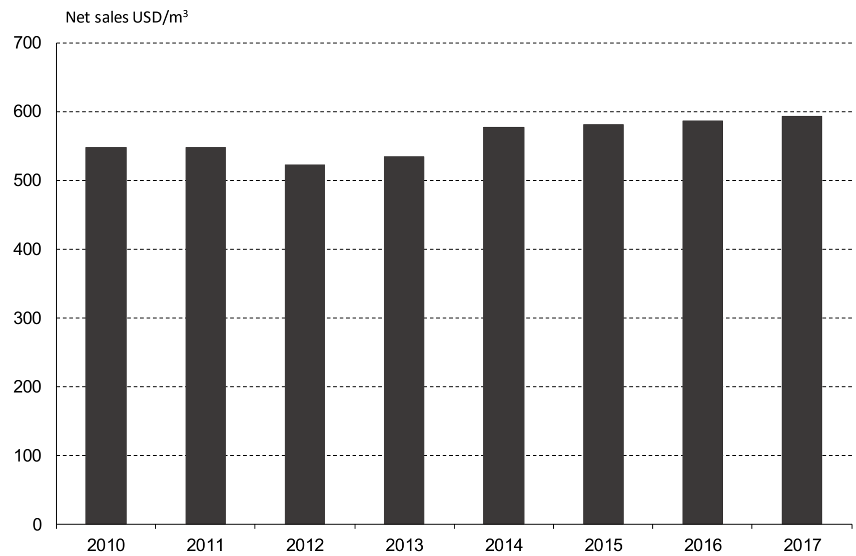
Table 4-2: Louisiana-Pacific Price Information (USD/m^3 nominal)[1]

Year	LVL	LSL
2017	632	505
2016	629	493
2015	598	482

Source: Louisiana Pacific (annual report https://lpcorp.gcs-web.com/static-files/b16fb6c3-1838-4903-a851-a9a263fc51ec)

Note 1) Price information is derived from production and sales data which is reported separately. Production data does include third party purchases, so the derivation of selling prices are in cubic meter terms (after conversion from cubic foot data at a conversion rate of 0.0283) and thus somewhat distorted.

Figure 4-13: Boise Cascade Published Price Information[1]



Source: Boise Cascade (https://www.bc.com/resources/bcc-2017-4th-quarter-statistical-info/)

Note 1) the original price information has been provided on a per cubic ft basis and has been adjusted to a price per cubic meter using the conversion rate of 0.0283. Prices are nominal

Prices in Europe are also not published readily, and not always convertible to a cubic meter basis for comparative purposes. Steico regularly publish prices for their LVL R and LVL X product. Prices for LVL R are in Euro per running meter (rm) and for LVL X, they are quoted on a per square meter basis. Prices for Steico UK are for large volume (half or full truck) deliveries, and are a net of transport cost, VAT or tolls, depending on where the sale is made. There is sufficient information available to convert prices through to a per cubic meter basis. Table 4-3 illustrates LVL "asking" prices, which are considerably higher than in the US.

Table 4-3: Steico 2016 Price List Converted to USD/m^3 [1]

Product	Dimension	Price
LVL R	12m x 39-90 mm x 200-400 mm	1 220 – 1 221
LVL X	6/12m x 21-75 mm x 1.25 m	1 294 – 1 298

Source:Steico (http://www.steico.com/fileadmin/steico/content/pdf/Marketing/UK/Price_List/STEICO_pricelist_int_i.pdf)

Note1) Prices converted from EUR to USD at 0.90372 (year 2016 average provided by OANDA)

4.6 Product Certification

In North America, LVL is not standardized the way other wood products are. Instead, each company has to get their products tested to meet the criteria set by various building and residential codes, such as International Building Code (IBC) and International Residential Code (IRC). Each manufacturer gets its products tested by an accredited testing laboratory and then gets a product report for its products. This specifies the sizes, uses and characteristics of their product. Testing needs to be done for each product lay-up (number of veneers, veneer thickness, grade and species) separately.

LVL is covered by two European standards – EN 14374 and EN 14279. Under Mandate M/112 'Structural timber products and ancillaries', LVL is a material used for manufacturing structural products. However, under Mandate M/113 'Wood-based panels', LVL is a classified as a product. Therefore, EN 14279 applies to LVL products for general purpose as well as for use in construction, while EN 14374 covers the use of LVL for structural applications. Indufor assumes these standards, which are already incorporated in the British standard system will remain applicable post-UK exit from the EU.

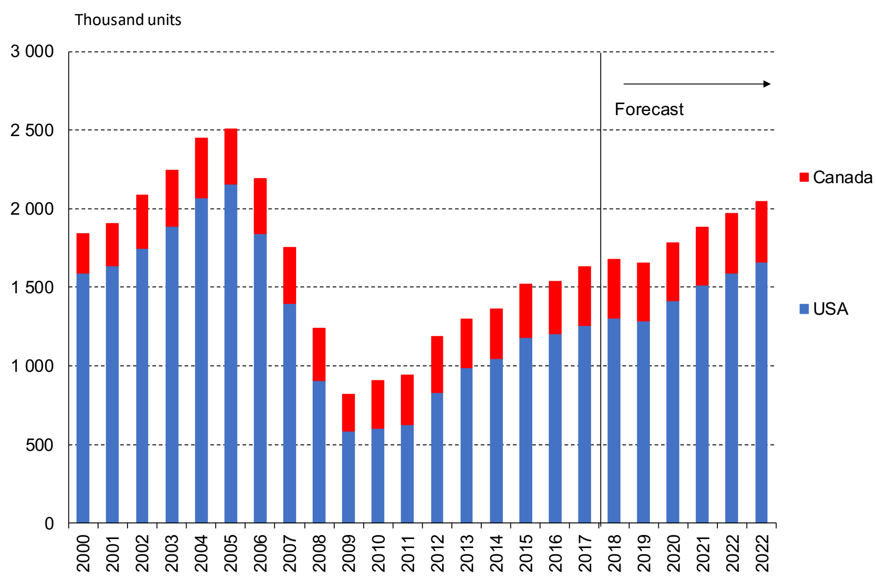
4.7 Outlook

4.7.1 Market Growth

North America

Indufor anticipates that LVL consumption will continue to grow over the coming five years. The primary driver will be the expected continued recovery in the US housing market. Figure 4-14 show's Indufor's interpretation of how housing starts may develop over the coming five years.

Figure 4-14: Development in Residential Housing Starts in North America



Source: Indufor analysis

Correspondingly, this development is expected to translate into increased demand for LVL in North America, and in the northeast[29]. Figure 4-15 shows the expected LVL consumption trajectory for North America. Over the coming five years the expectation is that LVL demand will recover to around the same level of demand as was observed in 2005. This may at first appear incongruous given that housing starts in 2022 are expected to still be well below the peak levels in 2005, however, there are important differences between LVL consumption in housing then and now. Crucially, the amount of LVL consumed as a proportion of houses built has increased. Demand for LVL is therefore are more sensitive to predicted changes in housing starts.

No doubt developments in the remodelling sector of housing construction and increased use of LVL in commercial, industrial and infrastructure builds will contribute to future demand. Indufor anticipates that LVL use in commercial and infrastructural developments is likely to increase at a rate higher than anticipated construction developments in these sectors, adding more to LVL consumption. The effect is likely to be more pronounced after 2020.

One other area of particular interest is how the mass timber market may impact (negatively or positively) LVL consumption. Indufor's position is that overall the effect will be positive and

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[29] Indufor does not have specific forecast data on housing demand development by state and therefore the prediction for the north east is based on the North American situation

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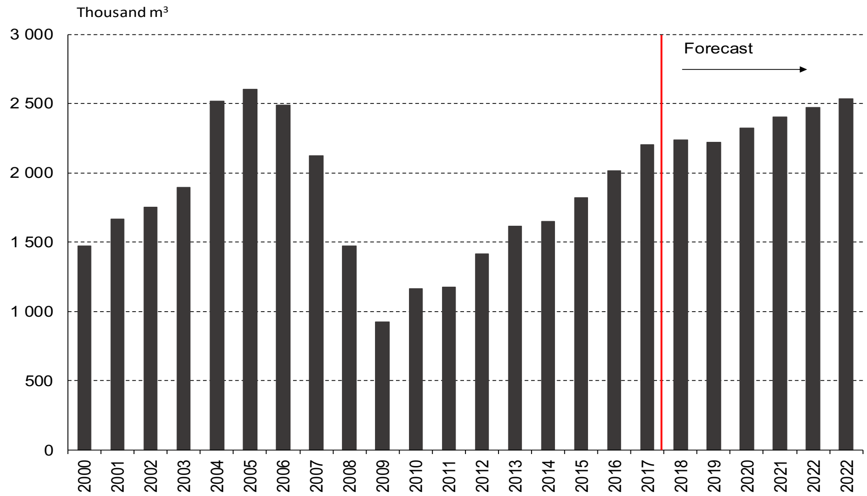
could make an important contribution to driving LVL demand. It remains to be seen, however, how the development may progress and in any case Indufor does not believe the effects will be immediate or even near term.

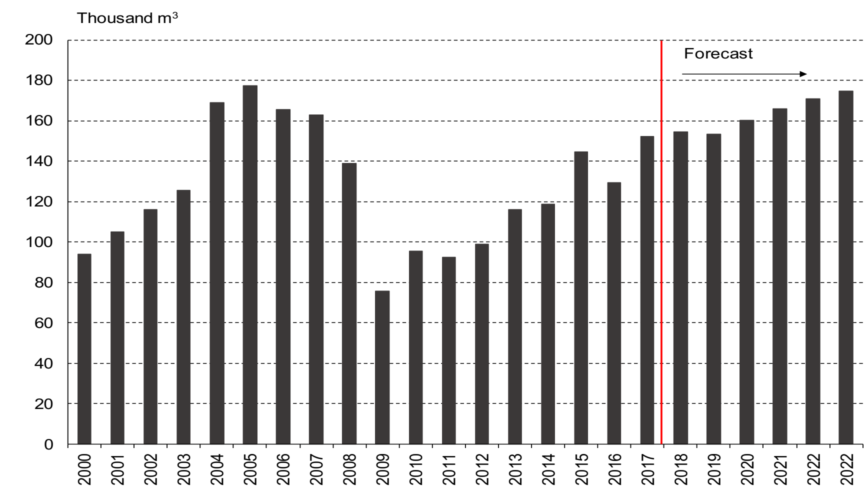
Figure 4-15: LVL Demand Development in North America



Source: Indufor Analysis

Figure 4-16 shows Indufor's projected LVL consumption expectation for the northeast. Anticipated LVL demand is not expected to return to 2005 levels but nonetheless growth over the next five years is expected to be of the order of 25 000 m^3.

Figure 4-16: LVL Demand Development in the North East



Source: Indufor Analysis

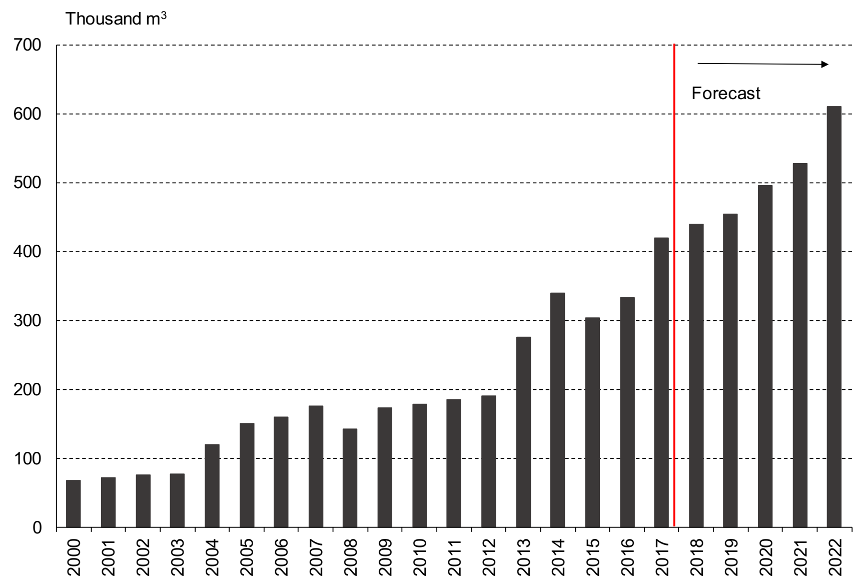
Europe

Demand for LVL in Europe will also continue to increase over the next five years. Positive impacts include the following:

- Continued substitution of wood, steel, and concrete in traditional structural applications in residential and commercial/industrial applications;
- Continued official support for the use of LVL in construction;
- Developments in mass timber and multi-story construction where LVL will be used in structural and non-structural ways that compliment other wood materials construction form.

By 2022 demand for LVL could reach 600 000 m^3 per annum. It is expected that most of the demand growth will be in the UK, Scandinavia, and to a lesser extent Germany and France.

Figure 4-17: LVL Demand Development in Europe



Source: Indufor Analysis

4.7.2 Opportunities

Indufor believes there is a market opportunity for an additional LVL mill located within Maine. There is likely strong potential for exports to the soon to be ex EU member, the UK, that could provide the rationale for a new LVL facility.

The northeast market of North America is currently around 150 000 m^3 and this is expected to grow over the next five years by another 25 000 m^3. In reality, this is not a development that would warrant an investment focused on the northeast alone. Therefore, the market-based argument for an investment must draw upon wider opportunities.

This is available in the regional markets around the North East (Delaware, Michigan, Ohio, West Virginia, the District of Columbia, New Jersey, and Pennsylvania). Demand growth for LVL in these regions would provide opportunities of similar scale to the northeast. It could be expected then that LVL consumption increase in these regions would be of the order of 20 000 m^3 per annum to 30 000 m^3 per annum. Supply out of Maine would face competition from producers located in the central east and south of the country.

Looking to export markets, even though the UK market is expected to develop strongly over the coming five years, it is unrealistic to expect an LVL mill in Maine would completely dominate that market. Gaining a sizeable portion of the market (of the order of 50 000 m^3 for example) is however, not outside the realms of possibility. This market could be the single largest, supporting a mill development in Maine.

One further consideration is the I-joist investments in the northeast and their relative importance in supplying construction materials to the rest of North America. Although this metric has not been explored here, it could serve as a market factor in support of a new mill build.

Timing of the build may be an issue but predictions on demand development in North America, the Northeast and Europe would support the notion of a construction after 2020.

4.7.3 Constraints

Ideally the facility should be developed to a size that would be as cost competitive as possible through economies of scale. However market size and competition in the Northeast would place

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limitations on the size of the facility. The discussion on market opportunity in Section 6.7.2 suggests a mill capacity of around 100 000m^3 per annum would be a reasonable consideration.

Supply out of Maine from a new facility would face competition from producers located in the central east and south of the country as well as the PSL facility at Houston and LVL operations in Quebec. Indufor has previously described the Northeast as being an environment more competitive than the region as a whole, therefore any investment consideration should take into account the potentially aggressive regional competition.

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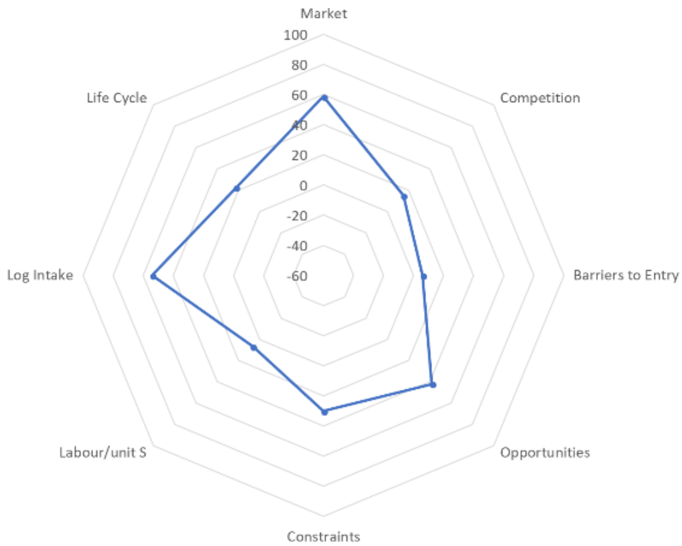
5. OSB

OSB is one of the most attractive options for Maine, with a total score of 235. OSB's highest scores are for markets (59), market opportunities (42) and log intake (54).

Figure 5-1: OSB Attractiveness Score



The following section outlines in detail the market opportunity for OSB production in Maine.

5.1 Product Description

Orientated Strand Board (OSB) is a structural re-constituted wood panel product. The product was developed as an alternative to plywood, utilising layers of wood stands/flakes which are orientated perpendicular – mimicking the traditional layup of plywood. This approach to building an engineered wood panel was invented by Armin Elmendorf in California in 1963. Panels have typically 3 or 5 distinct orientated layers.

Photo 5-1: Orientated Strand Board

Utilising strands allowed for the use of pulpwood type material to produce a competing product against structural plywood, which at the time required large peeler logs. This provided OSB with a significant cost competitive advantage in the raw material it could utilise.

OSB is used extensively as a structural panel in construction, where it is used as a sheathing, flooring and roofing material. In addition, it has become a major source for webbing in the production of sawn timber or LVL I-beams. Besides its structural applications, OSB is also used widely in packaging and other non-structural applications.

The manufacturing process consists of the following key steps.

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1. logs (typically pulp logs) are debarked,
2. Logs are "stranded" to create strands,
3. Strands are dried,
4. Strands are resonated,
5. Strands orientated in layers and formed into a matt with perpendicular layers,
6. The matt is pressed in a hot press. This can be a multi-daylight press or a continuous press,
7. Following the hot press – the panels are cooled,
8. Cut to standard dimensions and/or custom dimensions,
9. Packed and dispatched.

Both softwoods and hardwoods are used in the manufacture of OSB. Key species used include Aspen and Pine. The process requires Roundwood to produce the strands. Key resins used in its manufacture are mostly Phenol-Formaldehyde (PF) or Isocyanate.

Current scale mills have capacities of well over 500 000 m^3 per annum (500 000MSF per annum 7/16 inch)

The global market for OSB is currently around 30 million m^3 per annum most of which (24 million m^3 per annum) is consumed in the North American market. The state of Maine has one OSB mill, operated by JM Huber in Easton.

OSB's second key market, after North America, is Europe with a total installed capacity of some 8 million m^3.

5.2 Market Size and Growth

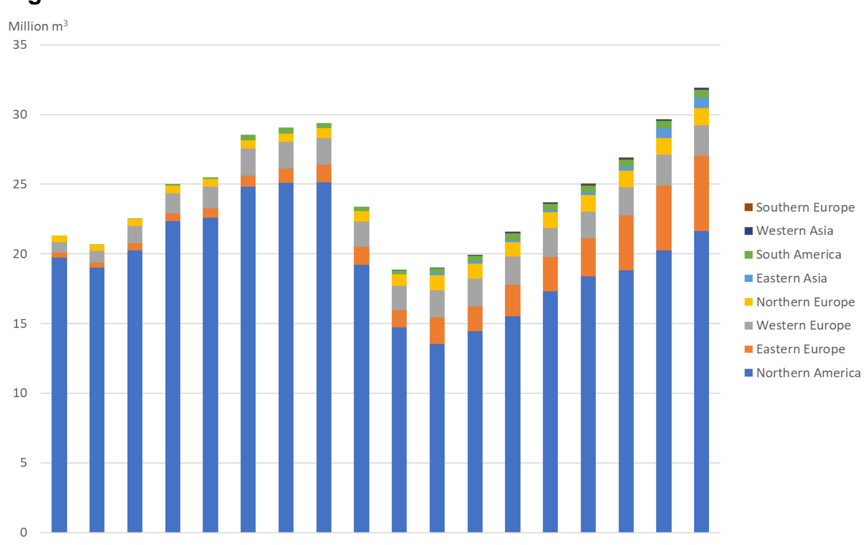
With the North American market being the dominant market globally, any developments in this market have directly impacted on the global OSB markets (Figure 5-2).

Western Europe was one of the early markets outside of North America to accept and adopt OSB as a structural building product. Although the traditional 2x4 house construction system as used in North America is not widely used, Central and Northern European house construction methods are wood intensive, and OSB has been accepted in several applications.

OSB as a product is typically domestically produced and consumed with a region, with only very small trades between regions. Key inter-trade regions include supply of Canadian sourced OSB to the Japanese market, at volumes of some 150 to 200 000 m^3 per annum.

When new producers started building their first mills within a country/region, they typically prime the market by importing initial volumes of OSB.

Figure 5-2: Global OSB Production



Source: Indufor Analysis

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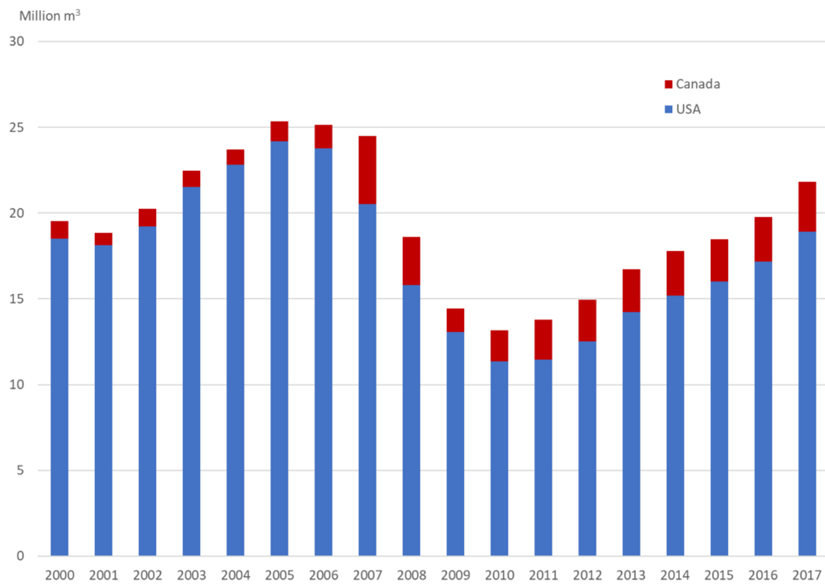
5.2.1 North America

The North American demand for OSB peaked in 2005/2006, in line with the peak in residential house construction. The decline in building activity resulted in a sharp decline of OSB demand, followed by the slow rebuild when construction activity picked up again (Figure 5-3).

During this difficult period, mills reduced production and a number of closures occured. During the 2005 to 2011 period and some 16 mills permanently closed down, reducing total installed capacity by some 5 million m^3 per annum.

Figure 5-3: US and Canadian OSB Consumption



Source: Indufor Analysis

As mentioned previously, the key end use for OSB in North America is construction, which includes such applications as roofs, floors and sheeting accounting for some 70% of all OSB use (Figure 5-4). Webbing in the production of I-beams is another major end use, as is temporary construction use, such as concrete formwork, fencing etc. Other end uses includes furniture (mainly framing for upholstered furniture), packaging and storage.

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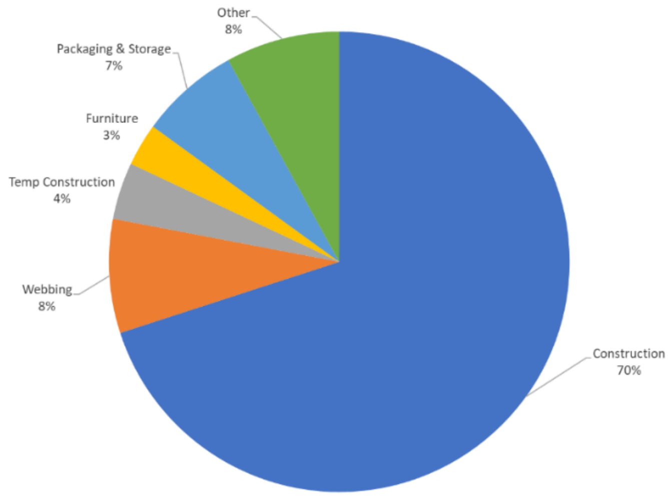
Figure 5-4: End Uses Estimates for OSB in the US and Canada

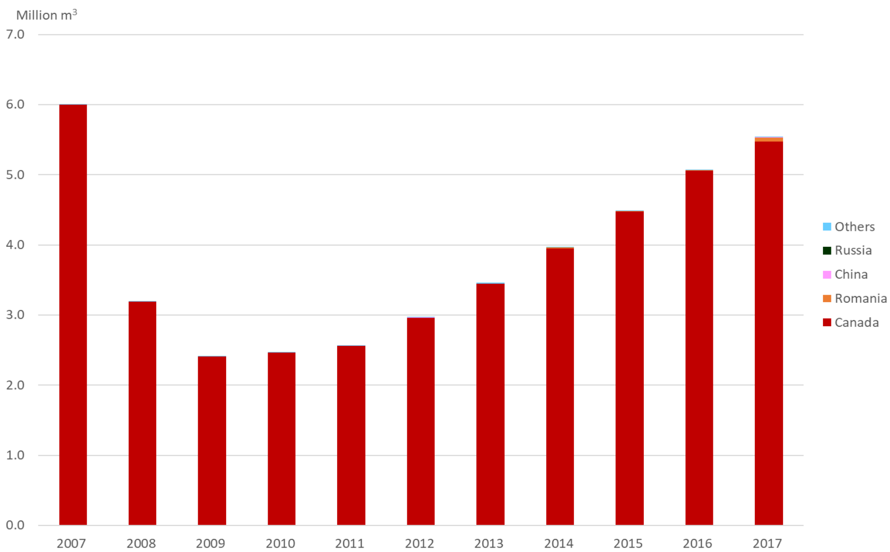


Source: Indufor Research

5.2.2 Trade

The US imported over 5 million m^3 of OSB in 2017 (Figure 5-5), practically all supplied by Canada. Many of the producers in North America operate mills in both Canada and the US and treat the North American market as one.

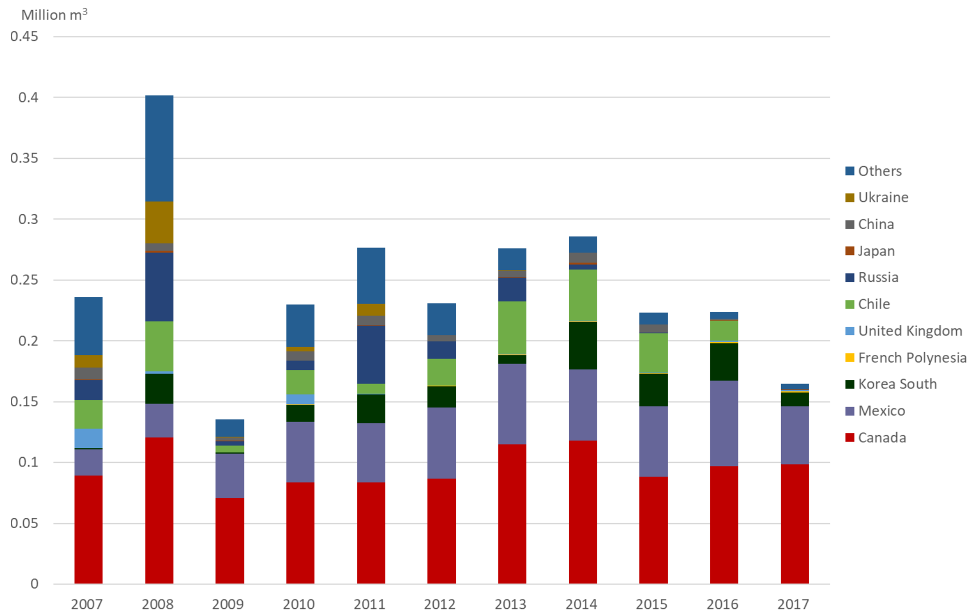
Figure 5-5: US OSB Imports



Source: GTA

The US exports small volumes of OSB to a wide range of countries (Figure 5-6). As mentioned previously, many of the new companies that have built mills outside of North America have primed and developed the local market for OSB with imported product.

Figure 5-6: US OSB Exports by destination



Source: Indufor Analysis

5.3 The Competitive Landscape

OSB is a commodity product, with little differentiating the product between different suppliers. OSB comes in a range of standard performance qualities thickness and standard sizes.

As such, the producer's ability to differentiate the product is limited, and marketing is focused on product price, reliability, sustainability, and availability.

Initially, OSB was developed as an alternative to plywood. Today, there are still a number of applications where both products can be used, but OSB is typically the more cost-effective solution. OSB manufacturers continue to develop OSB to allow it to perform and compete in higher value end use markets which are currently still dominated by plywood.

In Europe, OSB has competed much more against flooring grades of particleboard. This competition has been much stronger, as flooring grade particleboard is a relatively low cost to produce.

5.3.1 Competitors

In North America the industry has been consolidating and the number of companies producing OSB has declined in recent years. Currently, there are nine OSB producing companies. The top three companies account for 66% of the installed capacity. Norbord has become the leading producer, with an installed capacity of some 5.5 million m^3 per annum, followed closely by Louisiana Pacific, with an installed capacity of 5.1 million m^3 per annum. Both leading producers operate a total of 11 mills (

Figure 5-7).

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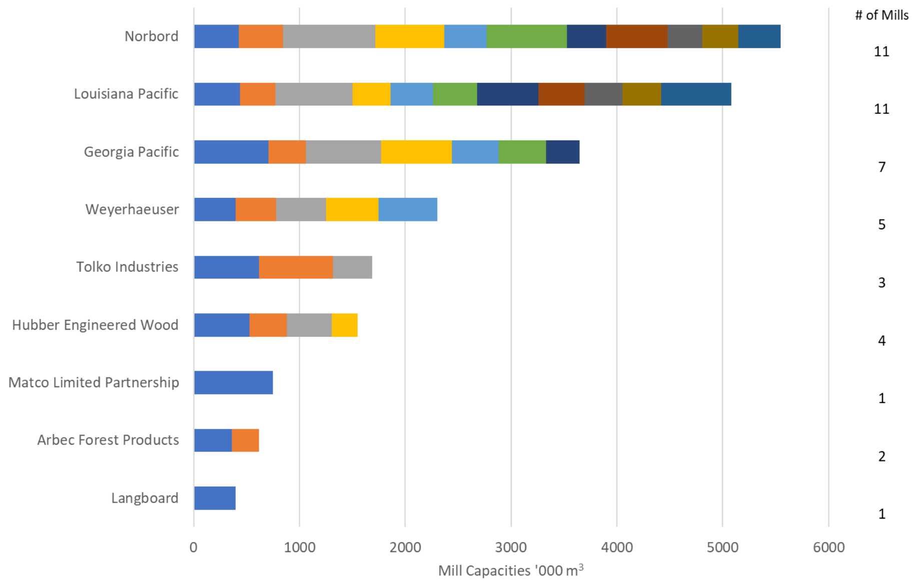
Figure 5-7: North American OSB Producers, Capacity and Mill Numbers



Source: Indufor Analysis

Competitive advantages for producers are obtained by low production costs and low shipping costs to key markets.

Production costs are dominated by the cost of raw material (pulp grade logs) and resin costs. Resin costs are relatively similar around the globe, making the log (mill gate) costs the crucial competitive factor for producers.

In addition, shipping costs can add significantly to the delivered costs, and thus mills located close to market have a real competitive advantage.

5.3.2 Competing and Substituting Products

OSB main competing product within the North American markets is structural plywood in structural end uses and non-structural plywood in a range of other end uses.

OSB has typically provided a more cost-effective solution compared to plywood, although cheap imported plywood has from time to time been a cheaper solution in the non-structural end uses.

5.3.3 Barriers to Entry

Within North America, the key barrier to entry for a new producer to enter the OSB market is in relation to the availability and costs of the raw material.

As a new producers, it would be essential to be highly competitive against existing producers, which would require the new operator to find a highly suitable location for a new mill, providing sufficient low-cost raw material to set up a world scale mill, while being located as close as possible to the market. In addition, a new producer would need to build its distribution channels and displace existing suppliers within the merchants yards. Although not impossible, this would require significant investment and effort.

It is relatively easy for existing manufacturers to expand their operations and invest in additional capacity if and when the market demand is sufficient, and they can identify a suitable location.

5.4 Key Drivers for Demand

As construction is such a dominant end use of OSB, the key driver for demand for OSB is the activity in the construction industry. Specifically, the residential construction industry and (in North America) single-family household construction that is the key driver for OSB demand.

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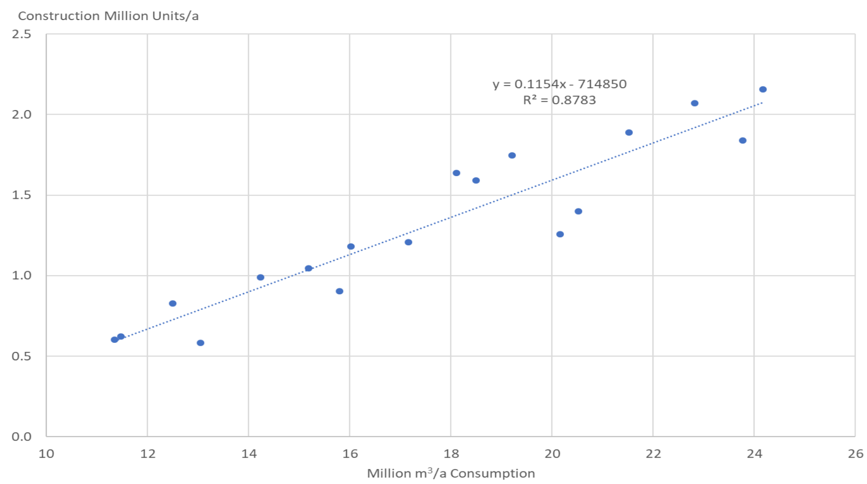
Indufor's own observations on the relationship with construction and OSB consumption concur. This close correlation can be observed from Figure 5-8 below.

Figure 5-8: US OSB and Construction Correlation



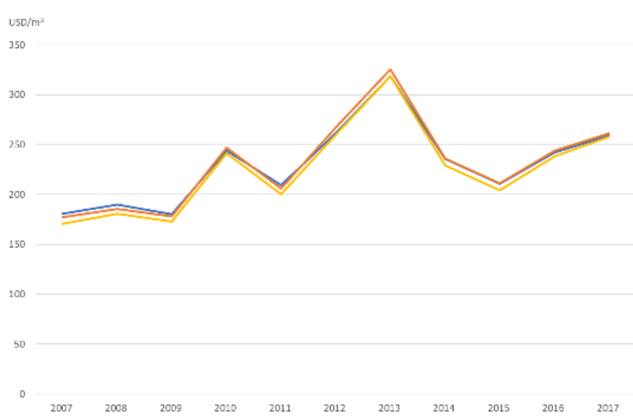
Source: Indufor Analysis

5.5 Prices and Price Trends

OSB prices have recovered over the past 10 years. Current average price levels (ex-mill) are approximately USD250/m^3 and trending up (Figure 5-9). This trend is expected to hold while demand for OSB remains strong.

Uncertainty in the market late last year resulted in a drop, but prices have since recovered as overall demand for OSB has remained strong.

Figure 5-9: Average Annual and Monthly North American OSB Pricing



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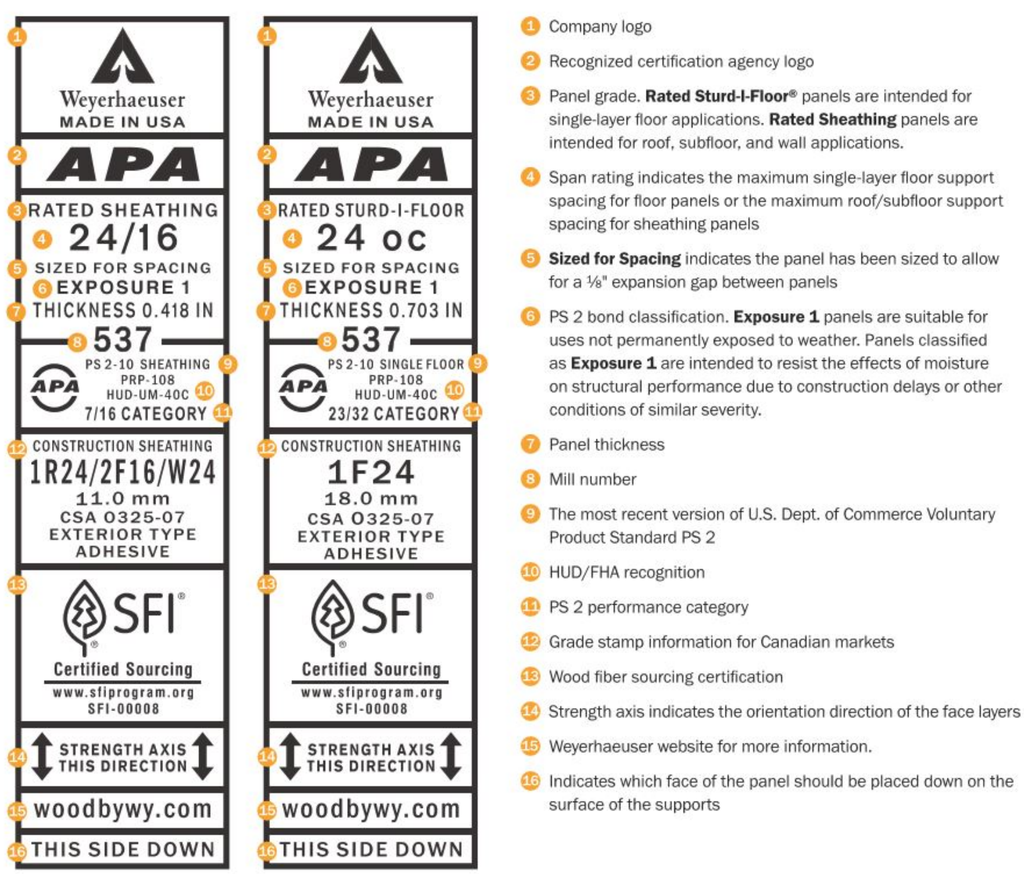
Source: Indufor Analysis

5.6 Product Certification

In North America, OSB is standardized. Each company has to get their products tested to meet the criteria set by various building and residential codes, such as International Building Code (IBC) and International Residential Code (IRC). Each manufacturer gets its products tested by an accredited testing laboratory and then gets a product report for its products. This specifies the sizes, uses and characteristics of their product. Testing needs to be done for each product separately. A sample of the grade stamps and explanation of details on the grade stamp are presented below in Figure 5-10.

Figure 5-10: Sample of OSB Grade Stamp



Source: Weyerhaeuser Technical Bulletin April 2015

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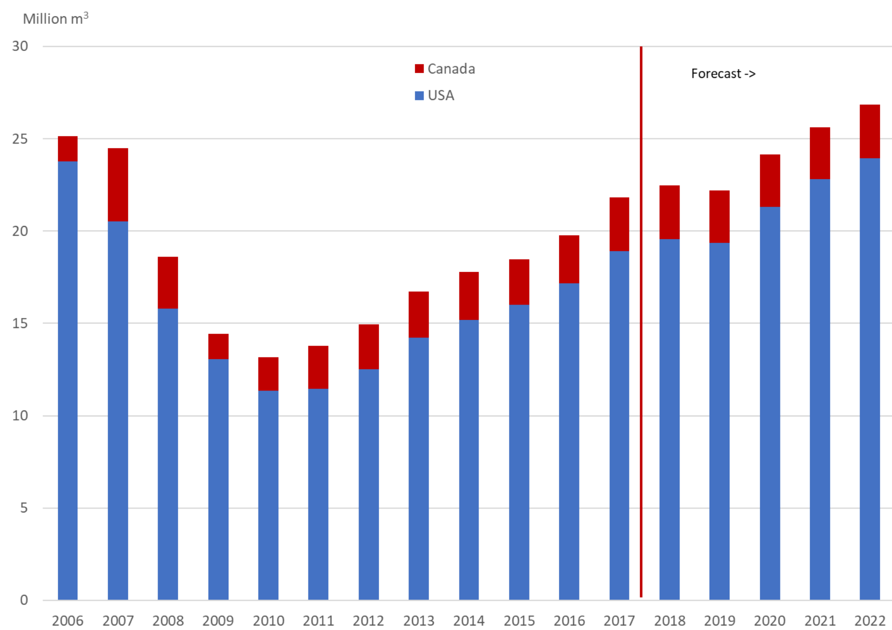
5.7 Outlook

Figure 5-11 shows the expected OSB consumption trajectory for North America. Over the coming five years it is expected that OSB demand will recover to similar levels of demand as in 2006. Construction activity will still be below the levels observed in 2006, but greater use of OSB in all construction application is expected.

Developments in the remodelling sector of housing construction and increased use of OSB in commercial, industrial and infrastructure builds will contribute to future demand.

One other area of particular interest is how the mass timber market may impact (negatively or positively) on OSB consumption. Indufor's position is that overall the effect will be positive and could make an important contribution to driving overall OSB demand. It remains to be seen, however, how the development of mass timber may progress over time.

Figure 5-11: OSB Demand Development in the US and Canada



Source: Indufor Analysis

5.7.1 Market Growth

The total market in North America is expected to expand by some 5 million m^3 over the coming years. Current installed capacity in North America is not sufficient to supply the expected future demand and new capacity will need to be added over the coming years.

This is likely to result in a relatively tight supply of OSB to the market in North America over the coming years and should support positive development of prices in the US.

5.7.2 Opportunities

There required capacity expansion in the industry will present opportunities for locating an OSB mill in Maine. Maine is well located to supply the US East Coast markets and has significant availability of pulpwood type material.

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5.7.3 Constraints

Maine's main constraint for a new OSB operation would be its efficiency of the rail infrastructure in the state. Manufacturers of OSB would need to have the ability to ship nationwide efficiently, as rail is used extensively for OSB shipments.

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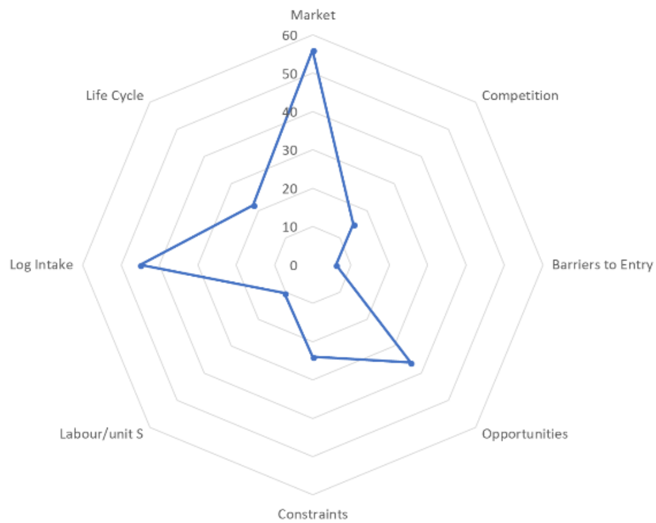
6. MDF

MDF is a moderately attractive option for Maine, with a total score of 214. MDF's highest scores are for markets (56), market opportunities (36), and log intake (45).

Figure 6-1: MDF Attractiveness Score



The following section outlines in detail the market opportunity for MDF from Maine.

6.1 Product Description

Medium Density Fibreboard (MDF) is a reconstituted wood-based panel product. MDF was first developed in the 1960's in the United States as an alternative to the wet process hardboard produced at the time. The board has a density of some 600-700 kg/m^3, with higher density MDF produced specifically for laminated flooring at densities of 800 to 1 000kg/m^3.

MDF is a very popular panel product with global manufacturers using both softwood and hardwood raw material to produce a total of 90 million m^3 of MDF in 2017.

One of the main advantages of MDF is its homogeneous structure, which allows the panel to be worked, moulded and formed while maintaining a surface quality that allows for a high-quality finish. This has caused MDF to be used extensively by the furniture industries worldwide.

In addition, MDF has expanded its end uses in interior joinery application, competing directly with solid wood feedstock (Photo 6-1).

Photo 6-1: MDF

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Over the past 20 years, laminate flooring (Photo 6-2) has become a major end use for MDF. Typically, a higher density MDF is used in this end use. Laminate flooring, first developed in Europe, has become a globally accepted alternative to solid wood and parquet flooring.

Photo 6-2: Laminate Flooring Samples

Manufacture Process

The first step in the production of MDF is the preparation of the wood fibre (Photo 6-3). Raw material is supplied to MDF mills typically in either Roundwood or chip form. This is reduced to a homogeneous chip size which is then defibrated to form the fibre. This is a wet process and following defibration the fibre is dried. Resin is typically applied when the fibre is still wet before drying. The dry, resinated fibre is formed into a matt of a predetermined thickness, which is then pre-pressed and final pressed in a hot press, setting the resin. Depending on the mill's capability, MDF can be produced in thickness of 1.5 to over 45 mm and at different targeted densities of the final product.

The resin used in MDF manufacture is typically Urea Formaldehyde (UF) or Melamine Urea Formaldehyde (mUF).

Photo 6-3: MDF Fibre

6.2 Market Size and Growth

The global production of MDF has developed to become very strong over the years, with China emerging as the dominant producer and consumer of MDF.

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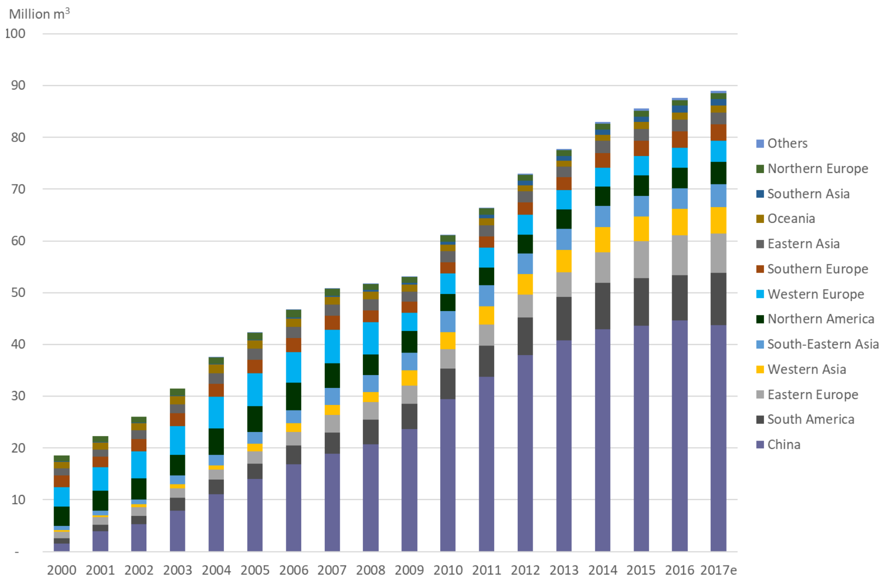
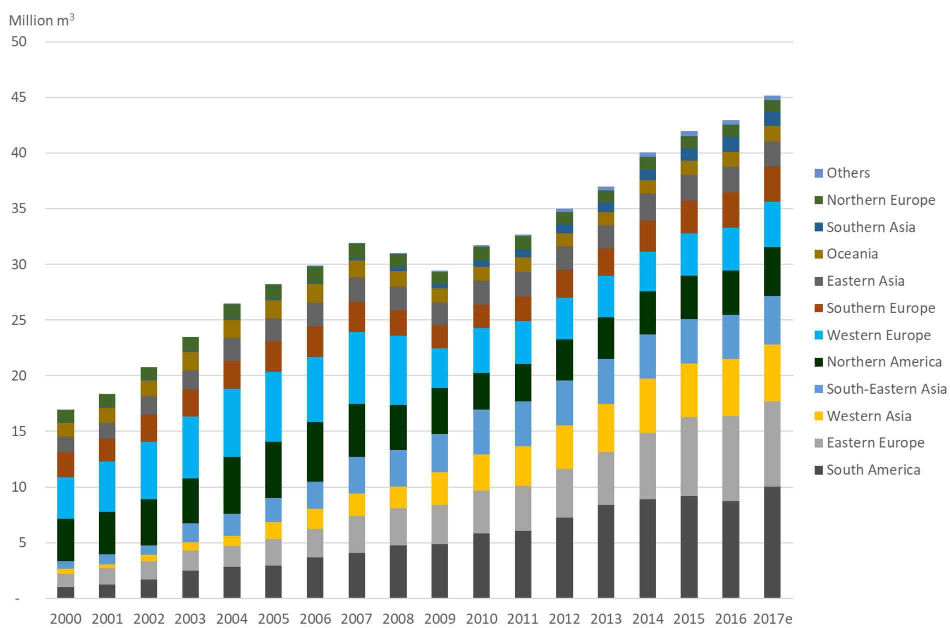
Figure 6-2: Global MDF Production by Region



Source: Indufor Analysis

Evaluating the market, with China removed, provides greater detail as to which other regions are important within the global MDF markets (Figure 6-3). All regions have seen their production expand, with Western Europe as a notable exception.

Figure 6-3: Global (excluding China) MDF Production by Region



Source: Indufor Analysis

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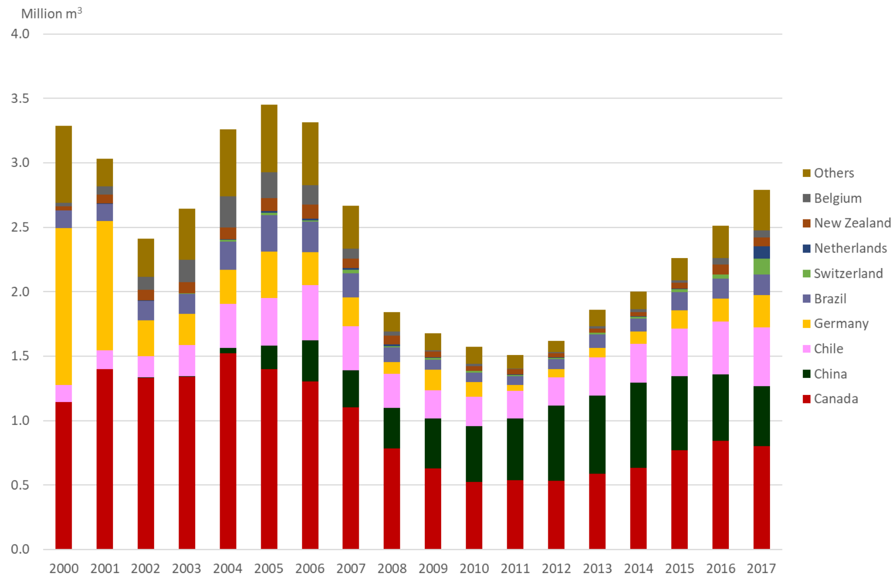
6.2.1 Trade

With producers located globally, trade between regions of MDF is limited. Today's major trade flows witness MDF transported from Eastern Europe to Western Europe and from Oceania into Asia. In addition, the US is a major importer of MDF. In 2017, The US imported some 2.8 million m^3 primarily supplied by Canada, China, South America and Europe (Figure 6-4).

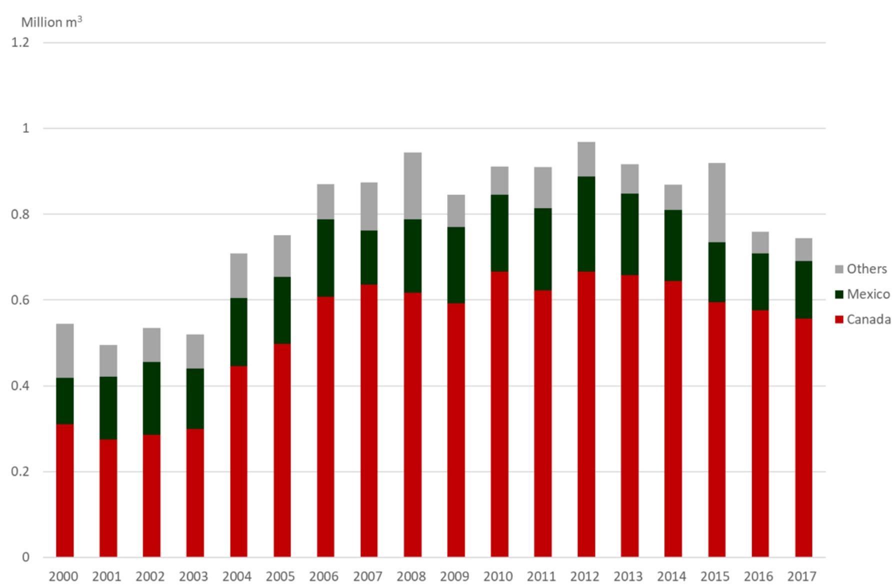
Figure 6-4: Imports of MDF into the US



Source: GTA and Indufor Analysis

The US exports small volumes of MDF, mainly to neighbouring NAFTA countries, Canada and Mexico (Figure 6-5). Notably exports of MDF are declining, as domestic demand takes precedent for American producers.

Figure 6-5: Exports of MDF by US



Source: GTA and Indufor Analysis

6.3 The Competitive Landscape

MDF is a commodity product, with little to differentiate between products from individual manufacturers.

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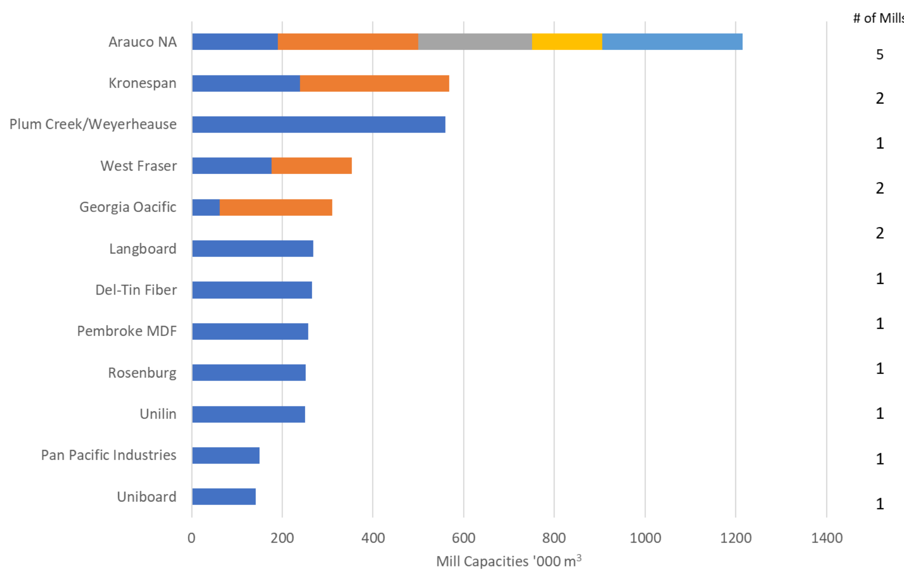
The current manufacturers differentiate their product by branding, environmental certification, and supply capability.

The market is fragmented with a total of twelve individual companies supplying the market (Figure 6-6). Of those twelve companies, only three operate more than one mill.

Most mills have a capacity of around 200 000 m^3 per annum (Figure 6-7). New scale mills are today reaching well over 500 000 m3 per annum, providing further scale advantages in the process.

Figure 6-6: US and Canadian MDF Companies and Mills



Source: Indufor Analysi

In addition, the US market is importing considerable volumes of MDF from outside the region.

In terms of manufacturing economics, key input costs for MDF are wood, electricity and resins. As resin costs/prices are relatively similar throughout North America and most of the world, it is the wood and power costs that remain key to the cost competitive position for manufacturers.

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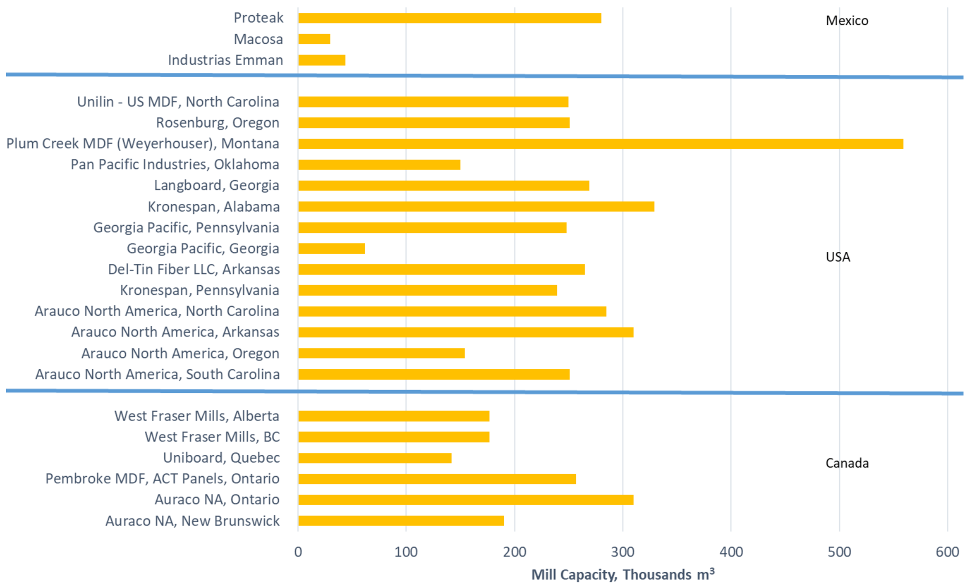
Figure 6-7: North American MDF Mills and Mill Capacity



Source: GTA and Indufor Analysis

6.3.1 Competitors

Besides the local competition, overseas suppliers compete directly in the US market. Of the international competitors, Chinese suppliers are typically the most price competitive, although the quality of MDF supplied is typically low.

The MDF supplied from Chile is to a large extent supplied by Arauco SA, a sister company of Arauco NA. Kronespan and Unilin are European based manufacturers with significant operations in Europe, allowing them, if required, to utilise US supply channels to market both North American and European produced product.

6.3.2 Competing and Substituting Products

MDF competes in different end uses against different product. Key substituting products by end use are:

- Joinery and mouldings – solid wood;
- Laminate flooring – engineered wood flooring, lino and tiles;
- Furniture doors – solid wood;
- Furniture carcass – particleboard;
- Furniture backs – hardboard and thin plywood;
- Drawers – solid wood, plywood and hardboard;
- Door skins – solid wood, hardboard and thin plywood.

In general, MDF is more expensive when compared to particleboard—therefore if particleboard cannot perform in the end use selected, MDF is used.

MDF is typically cheaper compared to plywood and solid wood. As such, MDF is used unless the specific quality and appearance of either solid wood or plywood is used if required.

6.3.3 Barriers to Entry

MDF manufacture requires sufficient power and wood fibre (in residue or pulpwood type format) to establish a mill capable of operating for world markets. Additionally, such a mill would require

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a significant investment, with an estimate of 250 to 300 million USD for a mill processing 500 000 m^3 per annum.

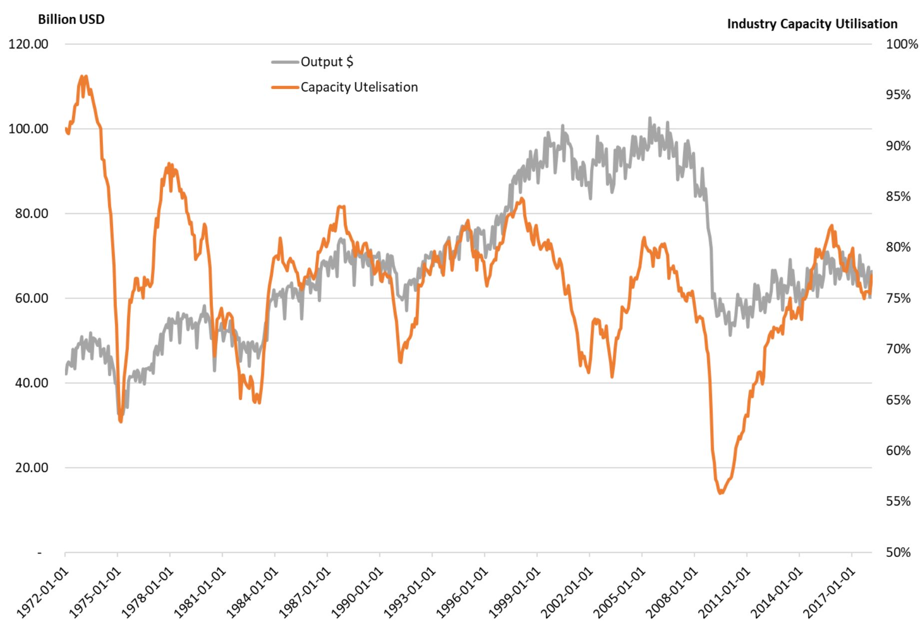
6.4 Key Drivers for Demand

The main end uses for MDF are in furniture production, as in joinery, build-in furniture, and flooring applications in new construction and repair/remodelling of residential and commercial (office) properties.

The outlook for construction has been discussed in previous chapters.

In terms of furniture production, the US industry appears to have not been able to recover from the decline encountered during the GFC (Figure 6-8). Although production has been increasing over the past years, actual value of the output by the furniture industry in the US is only USD 60 billion compared to a peak of 100 Billion in 2005/2006. According to industry commentators, furniture production in the US is expected to gradually improve over time, and this is especially the case for office furniture and flat pack type furniture, both major end uses of MDF.

Figure 6-8: Furniture Industry Output and Industry Capacity Utilization



Source: US Fed

6.5 Prices and Price Trends

MDF prices have shown a gradual positive trend, except for 2016 (Figure 6-9). Current average MDF (ex-mill) prices are above USD300/m^3.

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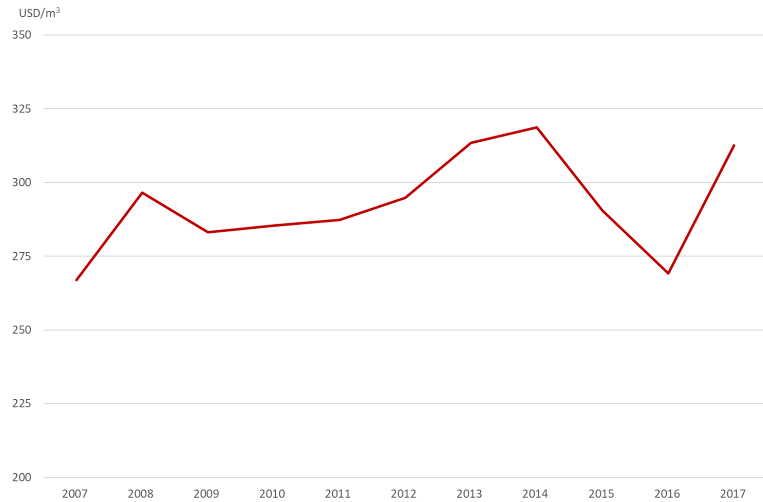
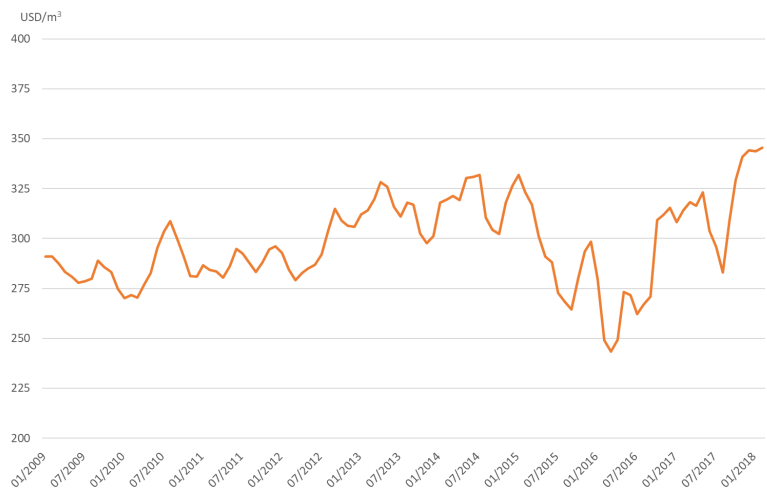
Figure 6-9: Annual and Monthly Average Ex Mill MDF Prices





Source: GTA

Monthly pricing has shown greater variability over the past years as markets remain relatively nervous regarding overall economic developments within the US.

6.6 Product Certification

MDF, like other wood-based panel products are required to adhere to specific formaldehyde emission regulations. Within the US, MDF, as of December 17, needs to be compliant in accordance with TSCA Title VI. This is the equivalent of CARB ATCM Phase 2 emission levels

The actual emission levels are set at 0.11 ppm for standard MDF and 0.13 ppm for thin MDF.

Most producers also provide additional environmental certification, such as FSC, SFI or ECC.

This certification requirement is for all MDF sold in the US, regardless if it's imported or locally produced.

TSCA Title VI requires that composite wood products be measured for compliance with the statutory emission standards by quarterly tests pursuant to test methods ASTM E1333-96 (2002) or ASTM D6007-02 (Refs. 39, 64). TSCA Title VI also requires that quality control tests be conducted pursuant to ASTM D6007-02, ASTM D-5582 (Ref. 65), or such other test methods as may be established by EPA through rulemaking. Under the statute, test results conducted using any test method other than ASTM E1333-96 (2002) must include a showing of equivalence by means that EPA must establish through rulemaking. Under TSCA Title VI, EPA must also establish, through rulemaking, the number and frequency of tests required to

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demonstrate compliance with the emission standards. This unit of the preamble discusses EPA's rulemaking on each of these statutory elements.

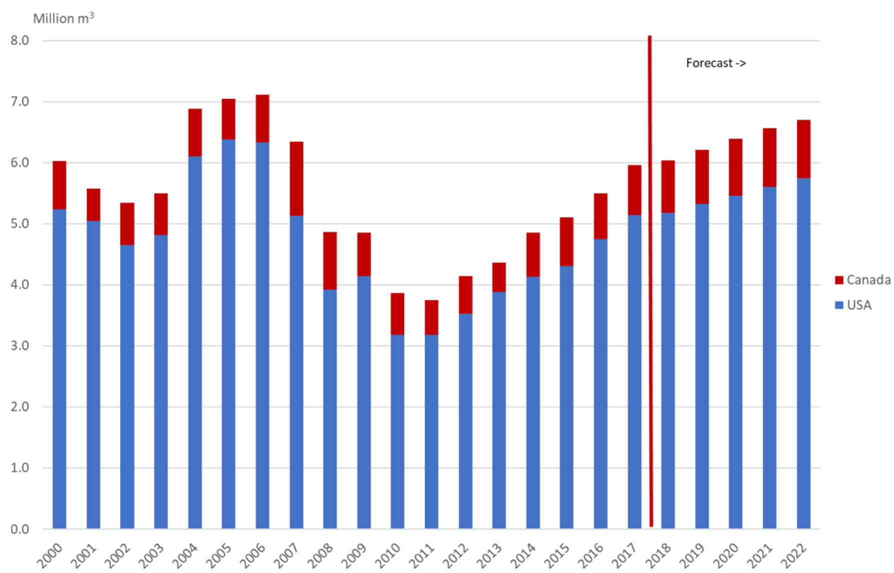
6.7 Outlook

The outlook for MDF demand within the US is positive. Total consumption is expected to continue to develop, driven by a combination of increased local furniture production and growth within the construction sector.

6.7.1 Market Growth

Based on a combination of expected growth and usage rate within the furniture sector, as well as increased demand for joinery and flooring use, overall MDF demand in the US and Canada is forecast to increase by 3% per annum between 2017 and 2022 (Figure 6-10).

Figure 6-10: MDF Demand Forecast (US and Canada)



Source: Indufor Analysis

6.7.2 Opportunities

As demand increases, there will be an increasing opportunity for domestic expansion of the industry. Softwood is very suitable for the production of a good quality MDF, and Maine is well located to serve as a supply base to the East Coast markets.

The availability of both pulpwood and sawmill residues will further support the attractiveness for locating an MDF mill in Maine.

6.7.3 Constraints

Modern MDF mills have increased significantly in scale, and today's world-scale mills have an installed capacity of some 500 to 750 000m^3. Fibre requirement for those mills can exceed 1 million m^3 per annum.

MDF manufacture is energy intensive. Power consumption per m^3 of product produced is some 300 to 400 kWh. As such, having access to competitively priced power is essential.

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Effective supply routes into the key markets are essential to ensure supplied costs is competitive.

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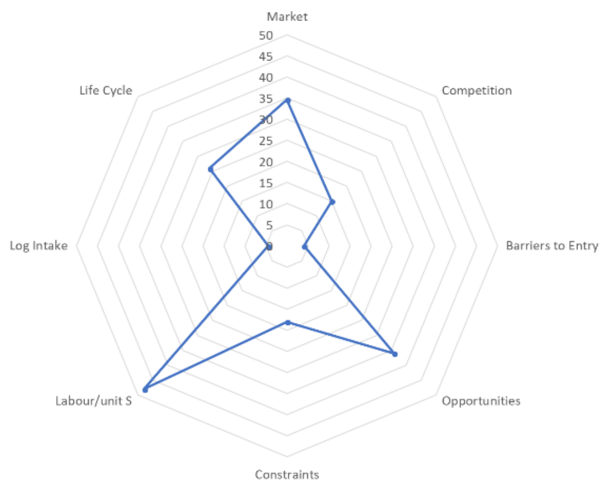
7. ACTIVATED CARBON

Activated carbon is moderately active to Maine, with a total score of 186. Activated carbon's highest scores are for markets (35) Opportunities (36) and labour intensity (48).

Figure 7-1: Activated Carbon Attractiveness Score



The following section outlines in detail the market opportunity for Activated Carbon in Maine.

7.1 Product Description

Activated Carbon is manufactured from high-quality coconut shell charcoal, wood and carbonized coal. When processed, activated carbons posses an exceptionally high developed pore structure to maximize their effectiveness—because of this they show a very high degree of durability and resistance to abrasion and associated breakdowns. The different characteristics of different forms and grades of activated carbons determine which application each type of product is best suited for.

Production

Activated carbon is carbon produced from carbonaceous source materials, including bamboo, coconut husk/shell, wood, lignite, coal, and petroleum pitch. It is produced by one of the following processes:

Physical activation: The source material is developed into activated carbons using hot gases. Air is then introduced to burn out the gasses, creating a graded, screened and de-dusted form of activated carbon. This is generally done by using one or a combination of the following processes:

- Carbonization: Material with carbon content is pyrolyzed at temperatures in the range 600–900 °C, usually in inert atmosphere with gases like argon or nitrogen
- Activation/Oxidation: Raw material or carbonized material is exposed to oxidizing atmospheres (oxygen or steam) at temperatures above 250 °C, usually in the temperature range of 600–1200 °C.

Chemical activation: Prior to carbonization, the raw material is impregnated with certain chemicals. The chemical is typically an acid, strong base, or a salt (phosphoric acid, potassium hydroxide, sodium hydroxide, calcium chloride, and zinc chloride 25%). Following impregnation, the raw material is carbonized at lower temperatures (450–900 °C). It is believed that the carbonisation/activation step proceeds simultaneously with

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the chemical activation. Chemical activation is preferred over physical activation, owed mainly to the lower temperatures and shorter time needed for activating material

Through this process, a pore structure is created, and the usable surface area of the carbon greatly increases.

Organic chemicals are the most attracted to carbon. Very few inorganic chemicals will be removed by carbon. The molecular weight, polarity, solubility in water, temperature of the fluid stream and concentration in the stream are all factors that affect the capacity of the carbon for the material to be removed. VOCs such as Benzene, Toluene, Xylene, oils and some chlorinated compounds are common target chemicals removed through use of carbon. Other large uses for activated carbon are the removal of odours and colour contamination.

Porosity plays a vital role in choosing the right type of carbon. While coconut activated carbon contains many micropores, coal activated carbon contains mainly mesopores as well as-as micropores. Wood activated carbon contains mesopores and macropores only. If the molecular size of the impurities are less than 100 angstroms then coconut carbon is preferred. Likewise, if the molecular size of the impurities are between 100 and 1000 angstroms coal carbon is used. And if the molecular size of the impurities is greater than 1000 angstroms, wood carbon can be considered.

In general:

- Wood activated carbon is most suitable for decolourization in powder form,
- Coal activated carbon is suitable for odour removal,
- Coconut activated carbon is suitable for dechlorination.

In term of cost, coconut activated carbon is the most expensive when compared to coal and wood activated carbon. A key benefit of coconut shell activated carbon is that there is a negligible loss of material during backwashing due to its high level of hardness. This results in lower operating costs. Wettability is very high, and ash content is very low in coconut activated carbon. Since it is a renewable source, it is preferred for drinking water treatment.

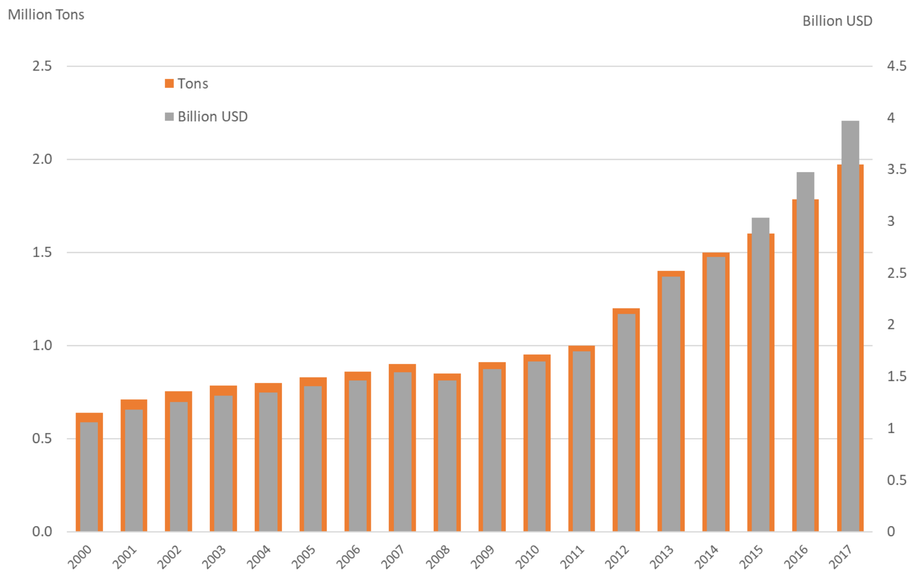
Coal activated carbon is also used for drinking water projects. Apart from that, there are few other industrial applications like effluent treatment and wastewater treatment. This type of carbon is best suited for odour removal and is a cost-effective application.

Wood carbon is mainly used in powder applications where “decolourization” plays a vital role.

7.2 Market Size and Growth

The global market for activated carbon has been estimated to have reached close to USD 4 billion in 2017, accounting for some 2 million tons. The markets have seen continued strong growth.

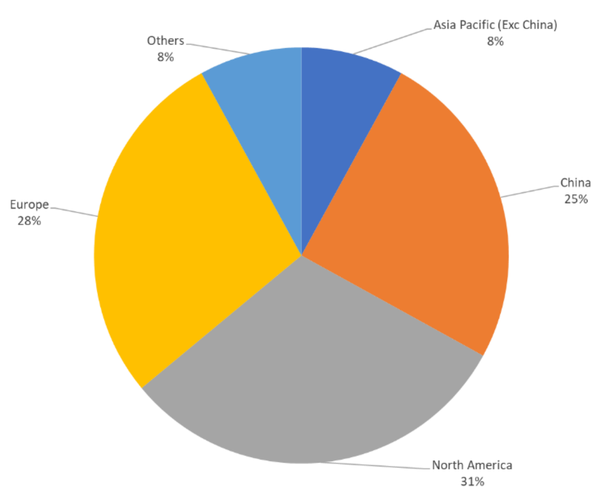
Figure 7-2: Global Activated Carbon Demand



Source: Indufor Analysis

Geographically, the North American, European, and Chinese markets dominate current consumption (Figure 7-3), however, strong growth is observed in other markets as the dominant use for AC is in water treatment.

Figure 7-3: Regional Markets for Activated Carbon



Source: Indufor Analysis

With increased global economic development, water treatment is increasingly becoming the standard in cities and countries worldwide. Currently, water treatment accounts for 49% of all activated carbon demand globally (Figure 7-4). In addition, the usage of activated carbon filters in air treatment is developing as air treatment in air-conditioning units is increasingly becoming standard.

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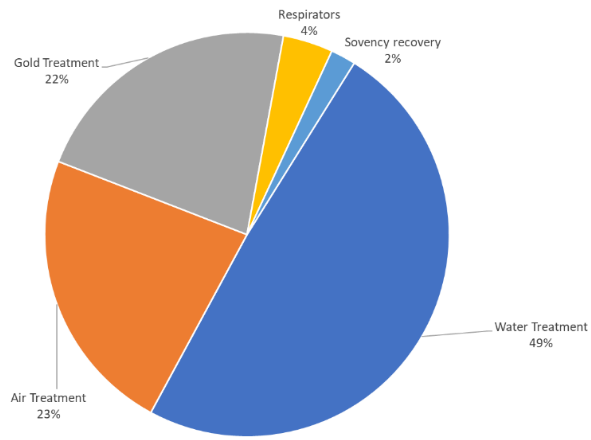
Figure 7-4: Key Global End Uses for Activated Carbon



Source: Indufor Research

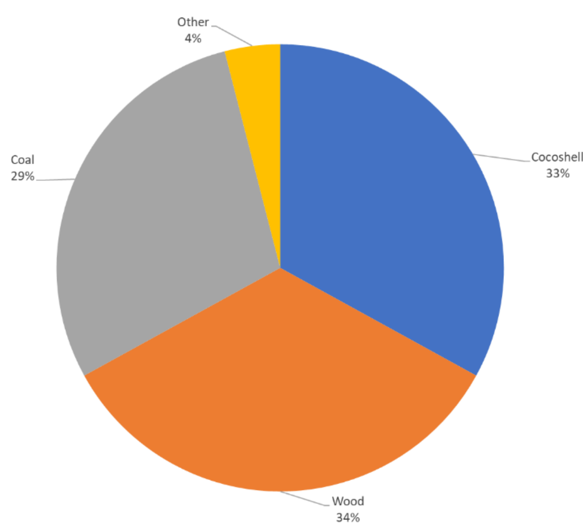
The US market for activated carbon is estimated at some 500 million tons in 2017, and is expanding at well over 10% per annum.

7.3 The Competitive Landscape

The main competition within the activated carbon markets is between the three distinct different types of activated carbon, produced from coconut shell, woody material, and coal.

Current the global supply of activated carbon is shared between coconut shell, wood-based and coal-based activated carbon (Figure 7-5). Coconut shell availability is sufficient for current demand, but future growth is likely to see supply issues emerge for coconut shell based activated carbon.

Figure 7-5: Activated Carbon by Source Material



Source: Indufor Analysis

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7.3.1 Competitors

Globally there are many companies supplying activated carbon to the markets. As activated carbon is a relatively high-value product, suppliers can target global markets and supply customers from afar.

Supplying companies are typically specialised in supplying certain end-use markets with activated carbon filter technologies. This can be either liquid or gas filtering focused, and/or specific end uses, such as water treatment, air treatment etc.

Coconut shell activated carbon is typically regarded as being among the highest quality product, but the various products each have specific end-use areas where they can perform better.

Worldwide, production units are relatively small, producing up to 5 – 10 000 tons per annum.

Producers continue to develop the basic activated carbon products to enhance its performance with the aim to develop higher quality products for demand end uses.

7.3.2 Competing and Substituting Products

The major competition with the activated carbon market is between various activated carbon materials, and different activated versions of activated carbon.

To date, alternative filter options for both liquid and gaseous treatment have been proven more expensive.

7.3.3 Barriers to Entry

The single largest barrier to entry for activated carbon producers is in control of the supply chain. In addition, the products are increasingly specialised, and significant IP claims have been developed by the existing companies (tailor-making activated carbon for specific end uses).

For existing companies, it is relatively easy to open and new supply sources, as long as their IP is suitable for the available raw material.

Of note are recent developments where activated carbon is produced from lignin. The US-based company Sweetwater Energy (http://sweetwater.us/) has developed lignin-based activated carbon, that has superior properties to those of coconut shell based activated carbon.

7.4 Key Drivers for Demand

Global demand for activated carbon is developing strongly. Key demand drivers include:

- Increased worldwide water (potable, irrigation and wastewater) treatment;
- Regulatory requirements to reduce mercury emissions by coal-fired power stations and petrochemical industries in the US and Europe;
- Increased usage of activated carbon filters in air-conditioning units;
- Increased usage of activated carbon filters in the food and beverage producing industries worldwide;
- Improved economic conditions in third world countries where availability of safe drinking water, food and beverages has been limited in the past, and is increasingly required and demanded.

The demand drivers mentioned above are expected to cause strong, continued growth in demand for all grades of activated carbon over the coming years.

7.5 Prices and Price Trends

Prices of activated carbon are not generally published. However, at wholesale level activated carbon is traded at prices of some 1.5 to 2 000 USD/ton. Coconut shell-based activated carbon

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prices are consistently at USD2 000/ton and above, while lower grades and quality of activated carbon can trade at price levels of below 1 500 USD/ton.

Open market prices are reported to be trending up, as raw material costs are increasing.

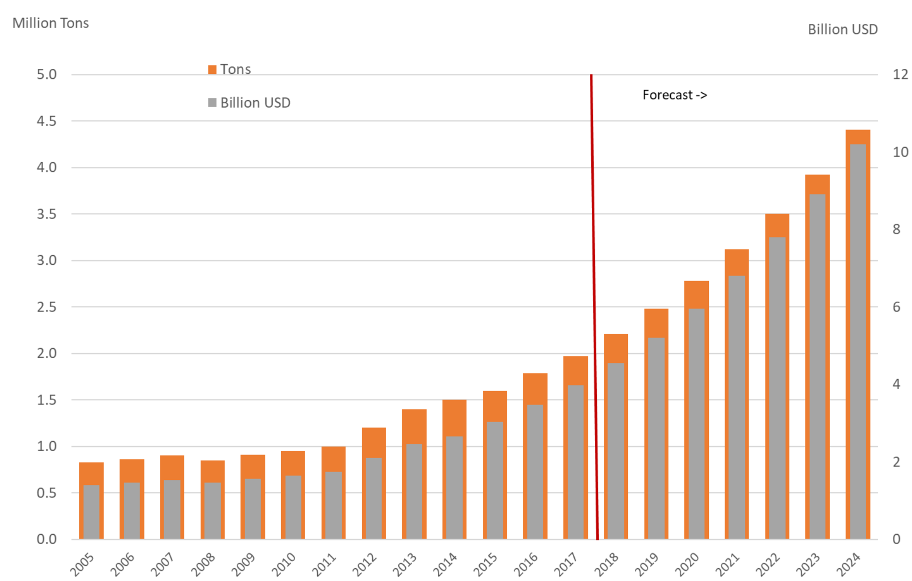
7.6 Product Certification

There is no specific certification in place for activated carbon. However, many of the wood and coconut shell-based activated carbon suppliers market their product as being sustainably sourced and produced from a renewable resource.

7.7 Outlook

Demand for activated carbon is forecast to develop strongly over the coming decade. Total demand is expected to expand at an average annual growth rate exceeding 12% per annum. Total demand is expected to double between 2017 and 2024, reaching some 4.5 million tons per annum.

Figure 7-6: Activated Carbon Global Demand Forecast



Source: Indufor Analysis

7.7.1 Opportunities

There are good opportunities for development of activated carbon products in Maine. The opportunities are likely to be within the high end, specialised areas, where research capabilities available within Maine will support developments.

As the company Sweetwater has shown, it is likely that highly specialised (and highly valued) activated carbon products can be developed, based on using by products from other forest industry operations in Maine.

7.7.2 Constraints

Maine is unlikely to be competitive in basic wood-based activated carbon products.

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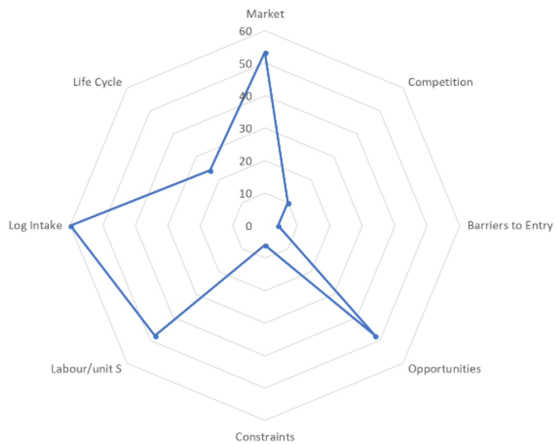
8. DISSOLVING PULP

Dissolving pulp is a moderately attractive option for Maine, with a total score of 253. Dissolving pulp's highest scores are for markets (53), market opportunities (48) and log intake (60).

Figure 8-1: Dissolving Pulp Attractiveness Score



The following section outlines in detail the market opportunity for dissolving pulp for Maine.

8.1 Product Description

Dissolving wood pulp (DWP) is chemically produced bleached wood pulp, as a purer form of cellulose than other paper grade pulps. Dissolving pulp can be split into low alpha cellulose pulps (alpha cellulose content < 93%) and high alpha cellulose pulps. There are many factors which make dissolving pulp hard to produce. The most important of these are the high alpha cellulose content, low ash content, high purity, and uniform degree of polymerization needed. The cost disadvantage is the low yield of dissolving pulp. About 20% more wood may be needed to produce dissolving pulp compared with paper grade chemical pulps, increasing the total round wood demand significantly. Nearly 70% of dissolving wood pulp is produced from hardwood species, but it can also be made from softwoods.

The main uses of dissolving pulp are viscose staple fibre (VSF), acetate, ethers, filament, as well as some certain specialities (e.g. MCC, casings, tire cord, cellophane etc.).

Dissolving pulp is produced using either a pre-hydrolysis kraft process (PHK) or acid-sulfite pulping (AS). Such softwoods as pines, douglas fir and larches are not suitable for AS pulping due to their richness in resins—phenolics of these tree species (pinosylvin of pines, taxifolin of Douglas firs, and flavanones of larches) can enter into reaction with lignin and may block delignification. In the PHK process both soft and hardwoods can be used as resin content of the raw material as this is not as critical as in the AS process, although the efficiency of PHK of hardwood species is higher than softwoods.

From the point of view of final products, the length of fibres and their shape have predetermined the use of softwood dissolving pulp mostly for subsequent production of ethers (through AS process) and acetate (through PHK). Viscose is the preferred application of hardwood dissolving pulps (AS/PHK).

Borregaard's mill in Sarpsborg, Norway produces dissolving pulp from spruce, Domsjö Fabriker (Swedish mill belonging to Aditya Birla Group) from spruce and pine, while Neucel from western hemlock. Stora Enso's Enocell mill, Aditya Birla's Atholville mill and Rayonier's Jesup mill serve as examples of mills which can produce both softwood and hardwood dissolving pulp.

Some softwood dissolving pulp mills are integrated with production of other products (e.g. Borregaard with bioethanol, Domsjö Fabriker with lignin and bioethanol). Stora Enso is also

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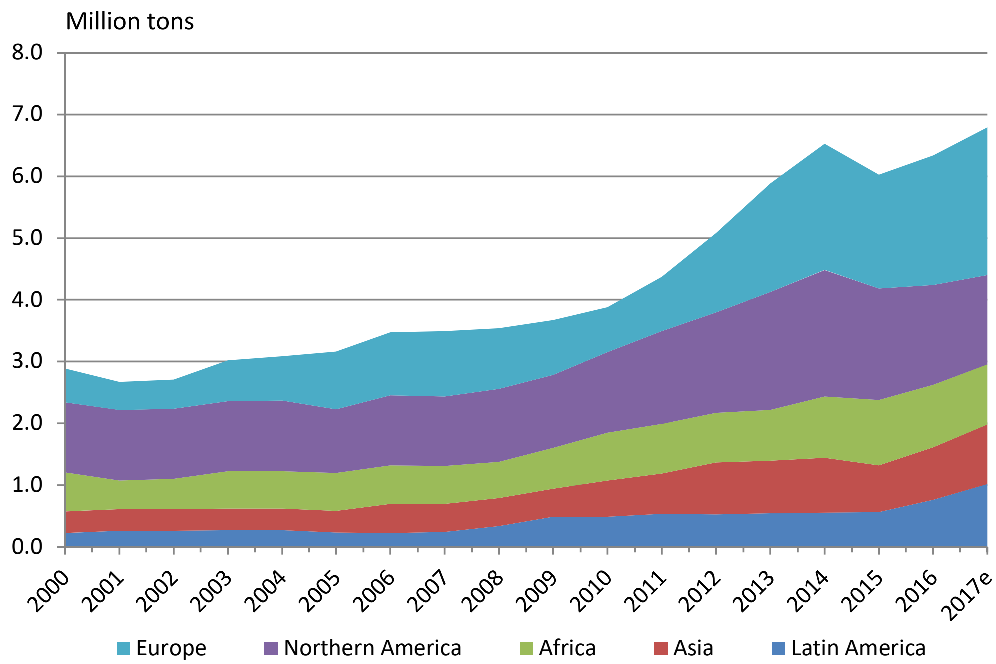
planning to gradually convert Enocell into a biorefinery. This path could potentially be considered for Maine.

8.2 Market Size and Growth

The global capacity of dissolving pulp mills is estimated at 7 million tons, with global production in 2016 estimated to be 6.34 million tonnes. The market has been rapidly increasing, especially since 2010, at 9% per annum. Almost 60% of the total dissolving wood pulp is produced in Europe (Sweden, Austria and Finland) and North America (Figure 8-2). Additionally, significant volumes of dissolving pulp are produced in South Africa and Brazil.

Figure 8-2: Global Production of Dissolving Pulp



Source: FAO

Asia is the largest consumer of dissolving pulp, holding a 63% share of the global DWP consumption (Figure 8-3). During the past 15 years, DWP consumption has grown at 8% per annum. In the past few years, the supply of cotton (a competitor of viscose) and cotton linter pulp (a competitor of DWP in the VSF segment) has been decreasing or remained flat, contributing to the growth of DWP demand.

China alone consumes 40% of the global dissolving wood pulp production, making it the world leader in the textile industry, the largest end-use segment of DWP.

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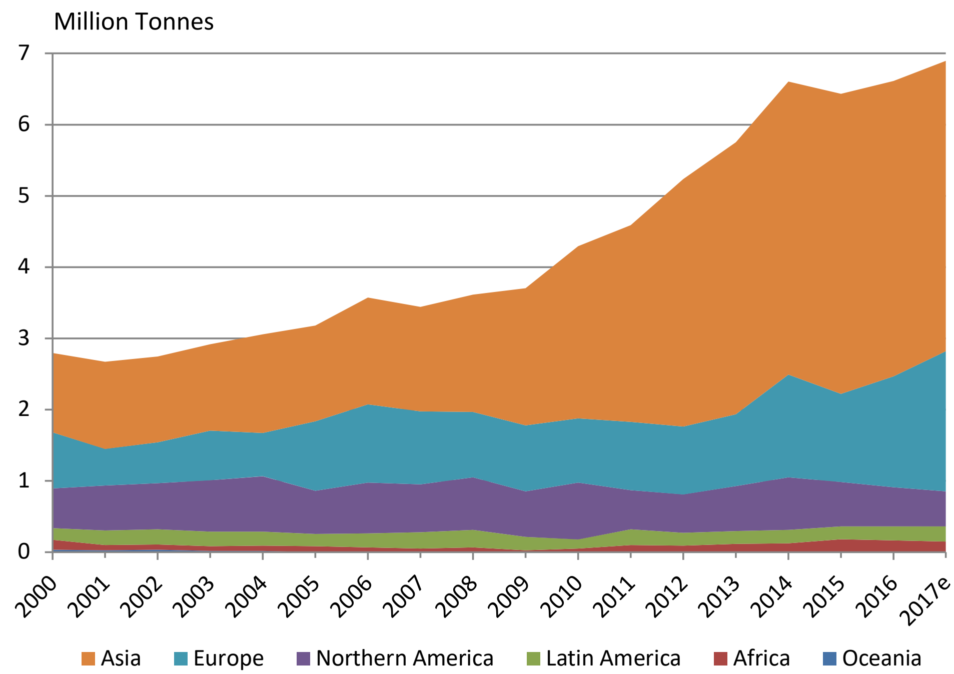
Figure 8-3: Global Consumption of Dissolving Pulp



Source: FAO

8.3 The Competitive Landscape

8.3.1 Competitors

The largest dissolving pulp producers are Sappi, Aditya Birla, Lenzing, Bracell and Rayonier, accounting for slightly over half of global dissolving pulp production. Dissolving pulp is mainly an export product, with nearly 70% designated for export.

Sappi

The largest producer of dissolving wood pulp is Sappi, with an annual capacity of 1.4 million tonnes, supplying nearly 17% of global demand. Dissolving pulp is produced at three Sappi mills—Saiccor (South Africa), Ngodwana (South Africa), and Cloquet (Minnesota, United States).

Saiccor has a capacity of 800 000 tons of sulphite dissolving wood pulp, produced from eucalyptus and acacia; Ngodwana has a capacity of 210 000 tons of pre-hydrolysed kraft dissolving wood pulp, produced 100% from eucalyptus; and Cloquet has a capacity of 340 000 tons of kraft dissolving wood pulp, produced from aspen (65%) and maple (35%). The Cloquet mill can switch from dissolving pulp to hardwood paper pulp.

Sappi is actively working on scaling-up its capacities at all mills producing dissolving pulp. By August 2018 the capacity of Ngodwana Mill will increase by 50 000 tons and by the end of 2018 the capacity of Saiccor mill will increase by 10 000 tons as the result of “debottlenecking”. Additionally, in December 2017 Sappi announced its intention to further expand capacity of Saiccor mill by 250 000 tons by 2020, and had scheduled delivery and installation of the wood yard equipment as a first step towards this ambitious expansion. The environmental impact

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assessment work for this project is already underway. At the Cloquet mill, an additional 30 000 tons capacity might be introduced by mid 2019.

Sappi's pulp has a purity range from 91% alpha to 96% alpha and the pulp is used globally in a range of various applications (e.g. fabrics, viscose staple fibre (Rayon), lyocell, microcrystalline cellulose, ethers, cellophane and acetate). Most of the products are, however, sold to the textile industry.

Bracell

The second largest producer of dissolving pulp is Bahia Specialty Cellulose (BSC)/Copener. It belongs to Bracell Limited and the company's share of global production is approximately 7%. BSC is a producer of rayon grades (viscose staple fibre, lyocell and viscose filament, cellophane, sponges) and speciality grades (acetates, icrocrystalline cellulose, industrial filament and other speciality applications) of dissolving wood pulp. BSC's Camaçari mill has an annual capacity of 485 000 tons of dissolving pulp, produced from eucalyptus. The average purity is 97% of alpha-cellulose.

Lenzing

Lenzing is an Austrian group of companies producing dissolving pulp in its mills in Lenzing (Austria) with an annual capacity of 300 000 tons, and Paskov (Czech Republic) 270 000 tons. Production at Lenzing is integrated, benefitting from savings in logistics, drying and packaging. The main species used for DWP production in Lenzing is beech, however, spruce, ash and maple are also utilised. Spruce dominates the raw material mix in Paskov.

In autumn 2016, Lenzing announced plans for capacity expansion at both mills, resulting in 35 000 tons of additional capacity by 2019.

Rayonier

Rayonier has been one of the quality leaders in the dissolving pulp industry, focusing on high-alpha products, ethers and acetate, as well as high strength viscose (e.g. tires and casings).

In November 2017, Rayonier announced completion of the acquisition of Canadian Tembec, raising Rayonier's capacity. Prior to the acquisition, Rayonier's capacity in cellulose specialities amounted to 485 000 tons at its two mills—Jesup mill in Georgia and the Fernandina Beach mill in Florida. Approximately 81% of Rayonier's cellulose specialities are acetate, 6% are high-value ethers, and 13% are other cellulose specialities. As for Tembec, dissolving pulp (or speciality cellulose) is produced at Temiscaming mill in Quebec, Canada with an annual capacity of 195 000 tons, and at Tartas mill, France with a capacity of 150 000 tons.

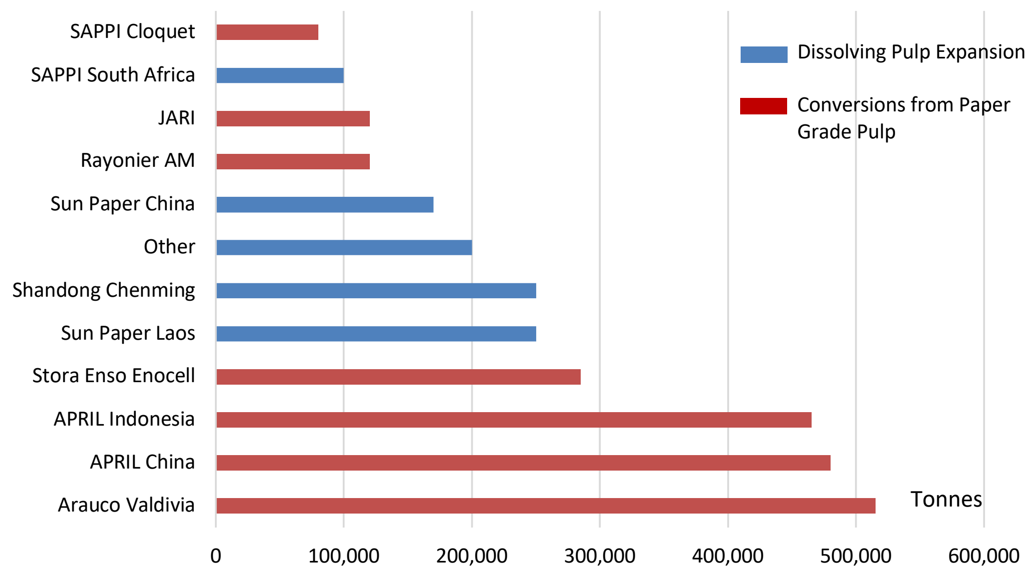
Aditya Birla Group

The Aditya Birla Group is an Indian conglomerate which started as a textile manufacturer in 1948. The group's business portfolio includes viscose staple fibre, metals, cement, viscose filament yarn, branded apparel, carbon black, chemicals, fertilisers, insulators, financial services, telecom, BPO and IT services. The group owns seven viscose mills and five dissolving pulp mills. Dissolving pulp is currently produced in AB Group mills in Atholville and Nackawic in Canada, with an annual capacity of 315 000 tons of dissolving pulp, Domsjö in Fabriker AB in Sweden, with capacity of 255 000 tons, and Birla Cellulose in India, with capacity of 70 000 tons. Additional dissolving pulp capacity will be realised either from opening a new mill in Laos (Birla Lao Pulp and Plantations Company Limited) with capacity of 200 000 tons, or from converting the mill in Terrace Bay, Canada (Terrance Bay Pulp Mill) from paper to dissolving pulp with a capacity of 280 000 tons. Aditya Birla uses various tree species (e.g. spruce, fir, pine, as well as eucalyptus, acacia, ash, aspen, oak, poplar, beech, birch, and maple).

Capacity expansions

In addition to the investment plans previously mentioned, there are several other planned conversions from paper grade pulps (swings) and brownfield/greenfield investments into dissolving pulp production around the globe.

Figure 8-4: Announced Capacity Expansions of Dissolving Pulp Mills (2016-2021)

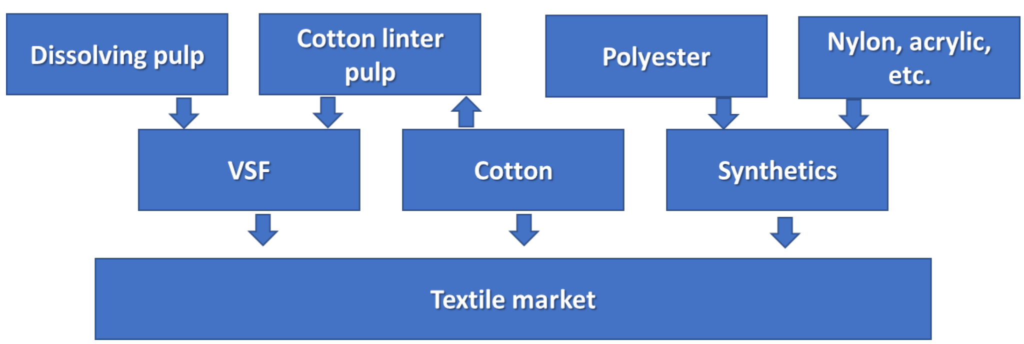


Source: Hawkins Wright

8.3.2 Competing and Substituting Products

In production of viscose staple fibre, dissolving pulp is competing with cotton linter pulp. At the higher levels of the supply chain, dissolving pulp-based viscose is competing with cotton and synthetics (nylon, acrylic and other materials).

Figure 8-7: Products Competing and Substituting Dissolving Pulp in the Textile Sector



Source: Fortress Paper

Regarding properties, rayon (viscose) is similar to cotton and is only inferior in terms of abrasive resistance and stability (Figure 8-7). In comparison to synthetic materials, it is better performing in terms of absorbency and resistance to static electricity, pilling and heat—however, it is not so strong, stable, and resistant to abrasion and wrinkles.

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Table 8-1: Properties of Various Materials

Properties	Rayon	Cotton	Wool	Acetate	Nylon	Polyester	Acrylic	Moda crylic	Olefin
Bulk and loft	-	-	+++		-	-	+++	+++	
Wrinkle recovery	-	-	+++	++	++	+++	++	++	++
Press (wet) retention	-	-	-	+	++	+++			
Absorbency	+++	+++	+++	+	-	-	-	-	-
Static resistance	+++	+++	++	+	+	-	+	+	++
Resistance to pilling	+++	+++	+	+++	+				++
Strength	+	++	+	+	+++	+++	+	+	+++
Abrasion resistance	-	+	++	-	+++	+++	+	+	+++
Stability	-	++	-	+++	+++	+++	+++	+++	+++
Resistance to heat	+++	+++	++	+	+	+	++	-	-

+++ Excellent, ++ Good, + Fair, - Deficient
Source: Journal of the Textile Association

8.3.3 Barriers to Entry

There are certain barriers to enter the dissolving wood pulp business. First, production of dissolving wood pulp has higher costs than production of paper grade pulps, due to lower raw material yield, higher costs of chemicals, and lower digester throughout. On average, a ton of rayon-grade dissolving pulp requires an extra ton of wood when compared to paper grade pulp.

Most dissolving wood pulp is produced from hardwood species, although the use of softwoods is also possible, especially spruce and pine. However, the yield is different—1 ton of dissolving pulp requires 6.1 m^3 of solid under bark per air-dry ton of softwoods or 4.5 m^3 of eucalyptus. Another difference between the two raw material types is length of fibres and their shape, both before and after pulping, these characteristics have favoured the use of softwood dissolving pulp, mostly for production of ethers and acetate.

Stora Enso's Enocell mill and Aditya Birla's Atholville mill serve as examples of mills which can produce both softwood and hardwood dissolving pulp. The annual capacity of Stora Enso's Enocell mill, which is expected to be fully converted by the second half of 2019, will be 245 000 of softwood and 185 000 tonnes of hardwood dissolving pulp. Aditya Birla's Atholville mill produces 127 000 tons of dissolving pulp from a blend of hardwoods and softwoods.

Production of dissolving pulp requires technical expertise and high capital costs, thus the majority of volume is produced by relatively few companies. Environmental concerns related to the intensive discharge of effluents in production of dissolving pulp might also pose a constraint and present a certain barrier to entry.

Duties on imports of dissolving pulp to China, the largest consumer of this type of pulp in the world, are one of the main market barriers to entry. In 2014, the Ministry of Commerce of the People's Republic of China (MOFCOM) introduced duties on imports of hardwood dissolving pulp, cotton linters and bamboo pulp from the US, Canada, and Brazil for a period of five years. The duties on dissolving pulp imports are:

- US 16.9 – 33.5%
- Canada 0 – 23.7%
- Brazil 6.8 – 11.5%

Canada's Neucel Specialty Cellulose and Brazil's Bahia Specialty Cellulose are exempt from anti-dumping duties. The World Trade Organization (WTO) has conducted investigations of anti-dumping allegations, and in 2017 concluded that in the case of Canada, China has failed to carry out a diligent WTO-compliant investigation prior to imposing such duties. Despite the low transportation costs of Chinese dissolving pulp producers in comparison to foreign ones, Chinese DWP is less competitive than imported DWP, due to the high dependence of Chinese

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producers on costly imported wood fibre, severe competition for wood from other industries, overexpansion of DWP production capacities and increasing labour costs.

The high-quality requirements of customers mean they are likely to continue working with reliable suppliers with whom they have had long relationships, creating a barrier to new entrants. Furthermore, many customers have specific requirements on certain properties of dissolving pulp, making it a narrow business segment.

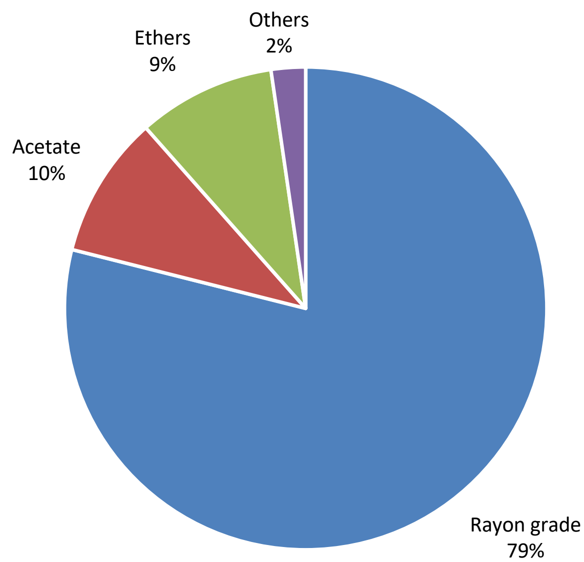
8.4 Key Drivers for Demand

The market has been driven by strong demand for rayon filament for the textile industry and thus, for viscose pulp. The main end-use product of dissolving pulp is viscose, which is used to produce rayon filament, rayon staple fibre, rayon cord and cellophane. The largest end-use segment is rayon filament, which has similar properties to silk, wool and especially cotton. It is therefore used by the textile industry to produce different kinds of fabrics and represents 79% of the dissolving pulp market. Low alpha cellulose pulp is applied for viscose production.

The speciality end uses for dissolving pulp consists of ethers and acetate, which in total form 19% of the dissolving pulp end use. High alpha cellulose is applied for the speciality products.

Other uses of dissolving pulp have a 2% share (Figure 8-).

Figure 8-6: End uses of Dissolving Pulp



Source: Hawkins Wright

Viscose

- The growing middle class and their increasing purchasing power, especially in Asia has increased the demand for textiles in general and of viscose in particular;
- Fashion trends have a strong impact on viscose fibre demand and the current move to natural fibres away from artificial ones is expected to continue;
- Harvest levels of cotton vary annually and can cause major fluctuation in demand for viscose fibres;
- Fire retardant fibre demand is growing strongly. The demand has suffered somewhat due to slow building activity in the US;
- Rayon cord demand has been restored in the tire industry.

Acetate

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- Increase in filtered cigarettes in Asia, although cigarette smoking is a declining trend in the Western world;
- The transition from polypropylene filter towards acetate filters is on-going in China, practically the only place where the polypropylene filters are still used;
- Fire retardant fibre demand is growing strongly.

Ethers

- Dissolving pulp products are increasingly used in the food industry, pharmaceuticals, cosmetics, special paints, binders and glues;
- CMC is used in food industry but also in new emerging applications.

8.5 Prices and Price Trends

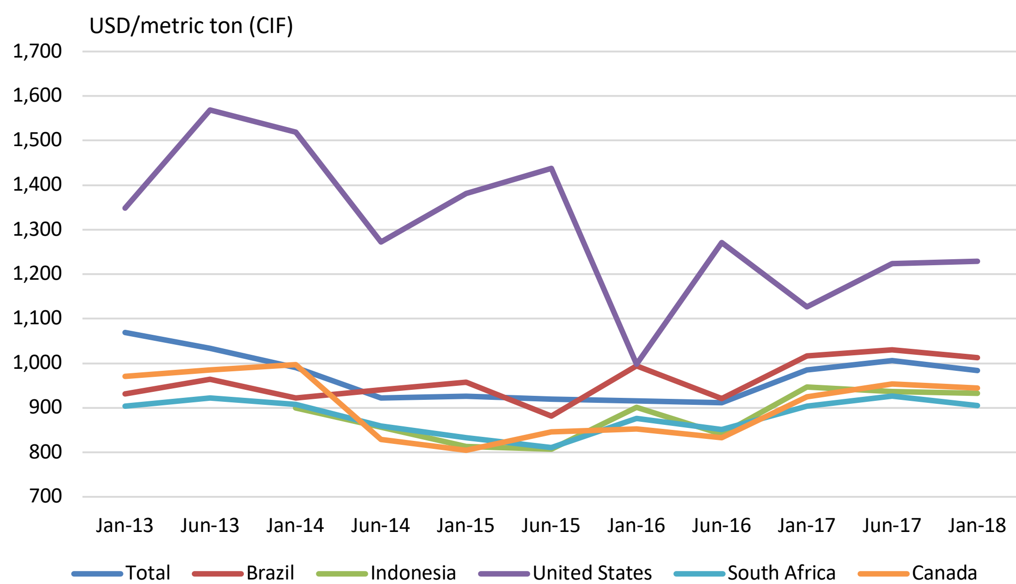
Prices for dissolving wood pulp depends on two key factors:

- The lower yield of wood per ton in manufacturing sets a price premium for dissolving wood pulp in comparison to paper grade pulps,
- The price is influenced by the fact that many fluff and paper producers can switch (swing) to dissolving wood pulp when prices for DWP are more favourable than those for paper grade pulps.

On the other hand, prices for DWP are determined by prices for textiles. Moreover, additional variables in the global demand and supply situation, as well as prices and availability of different alternative cellulose sources (e.g. cotton linter pulp) for the viscose staple fibre. For example, during the past six years, the cotton linter pulp capacity in China has reduced by half, due to the introduction of stricter environmental standards.

After a period of multiple capacity additions and slightly lower prices for DWP during the past couple of years, the pace of dissolving pulp mill expansions has recently slowed down, and prices have flattened. In January 2018, the average price for imported DWP in China stood at 984 USD per ton (Figure 8-78). Prices of dissolving pulp from the US were 25% higher and 11% lower than the average import price from South Africa 11%. During the past five years, the average import price has been decreasing by 1% per annum. Price growth has been slightly positive for the dissolving pulp imported from Brazil only.

Figure 8-78 Prices for Imported Chemical Wood Pulp (dissolving grades) in China



Source: China Wood

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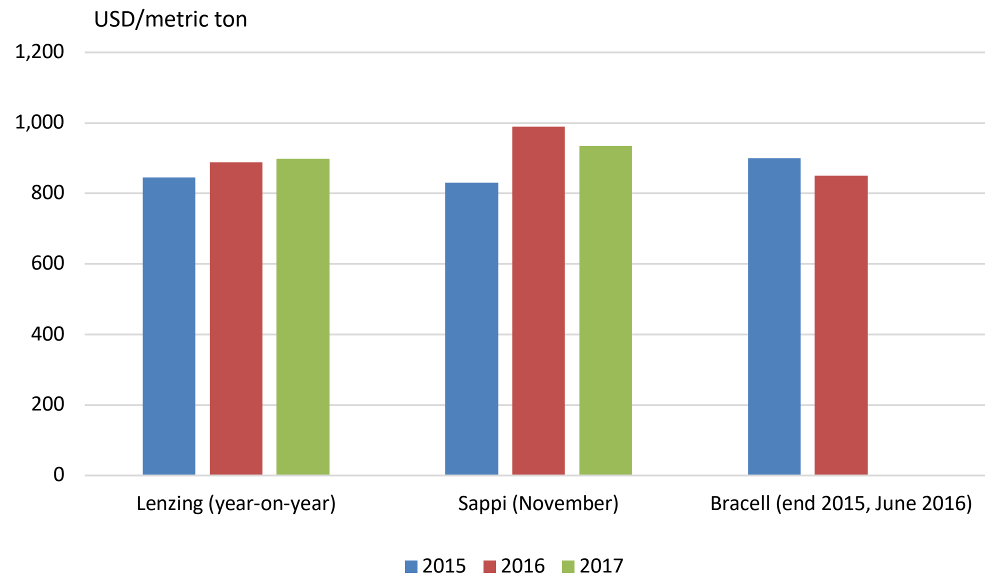
Figure 8-8: Spot Prices for Dissolving Pulp



Source: Annual reports

It is expected that spot prices for dissolving pulp will increase in the short-term due to the switch from production of DWP to production of hardwood paper pulp. In addition, the availability of cotton linter pulp is expected to decline causing additional demand for DWP. The demand for dissolving wood pulp, especially in China, is expected to continue growing, thus narrowing the availability of dissolving pulp on the global market and raising prices.

8.6 Product Certification

Forest Stewardship Council (FSC), the Program for the Endorsement of Forest Certification (PEFC) and the Sustainable Forestry Initiative programme (SFI) are the major certification schemes for dissolving wood pulp. Some DWP producers also acquire ISO and OHSAS certificates which mostly cover safe manufacturing and management systems. For example:

- Bahia Specialty Cellulose is certified to ISO 9001 (quality management at the mill), ISO 14001 (environmental management) and PEFC Forest Management and Chain of Custody. BSC has also obtained a Halal certificate (of qualification) for its dissolving pulp;
- Sappi is also certified to ISO 9001, ISO 14001, as well as to ISO 22000 (food safety management systems), ISO 50001 (energy management systems), OHSAS 18001 (Occupational Health and Safety Assessment Series), and EMAS (European Eco-Management and Audit Scheme). Sappi's raw material and final products are certified under the PEFC, FSC and the SFI schemes;
- All pulp production sites of Lenzing are certified to ISO 9001, ISO 14001 and OHSAS 18001. Wood and pulp are certified to FSC and PEFC.

8.7 Outlook

8.7.1 Market Growth

With the growth of GDP and population in developing countries, the dissolving pulp market is expected to continue growing at about 4-5% per year (Figure 8-). The welfare of consumers in

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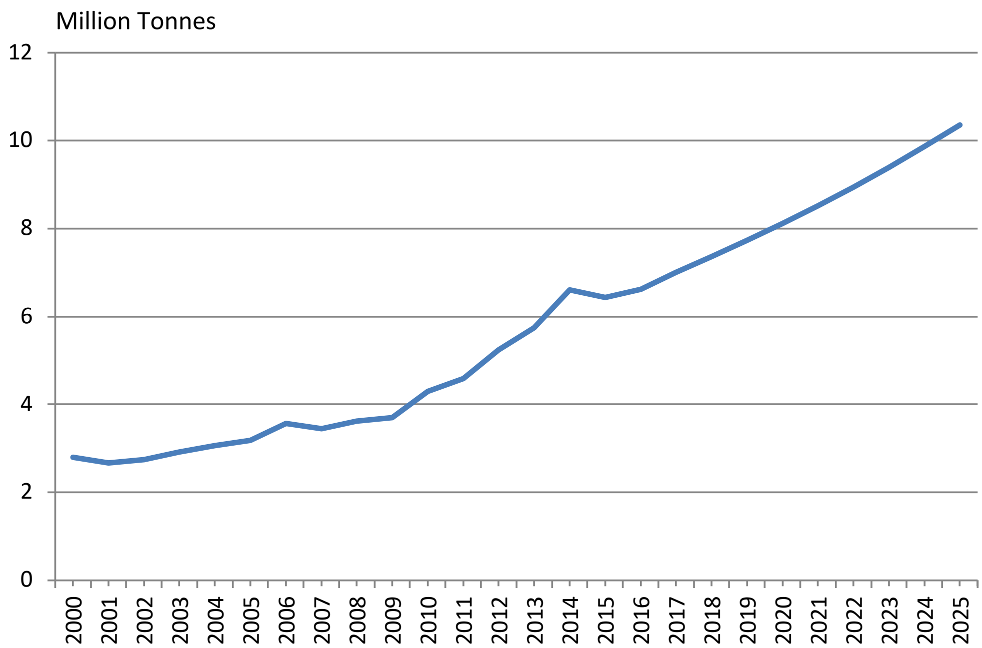
developing countries (e.g. China, India and Indonesia) is increasing, thus boosting the demand for personal-care items, textiles, packaging, foods and other products for which dissolving pulp is used. In addition, the textile industry has been moving away from cotton fibres which has also contributed to a growing demand for dissolving rayon pulp. Cotton consumption is expected to continue to exceed production, potentially causing a shortage in cotton, boosting viscose and DWP demand.

It is expected that the fastest growth will be for viscose and lyocell (exceeding 9% per annum). Ethers will experience a growth of 3.5% and acetate 1.5% per annum.

Figure 8-9: Forecast for global consumption of dissolving pulp



Source: Indufor Research

8.7.2 Opportunities

In Indufor's view, there is a good opportunity for dissolving pulp production in Maine for the following reasons:

- It is expected that the total fibre market will grow at an average of 3% per annum for the period to 2021. According to some estimates, half of the world cotton demand will not be satisfied by supply by 2030, resulting in more demand for viscose and subsequently DWP. Furthermore, there is less arable land available for cotton growing.
- In general, viscose fibres are perceived to be more comfortable than synthetic fibres. Viscose is easy to mix with other fibres, it has good moisture absorption and colour wash endurance, reproduction of printing pattern, viscose does not electrify (static), shrink and wrinkle. There are few substitutes for viscose fibres.
- Economic feasibility and sustainability of viscose production in comparison to cotton and polyester are expected to improve, along with technology development and gradual market acceptance.
- Conversion of an existing paper grade mill takes two to four years and requires less investment when compared to greenfield/brownfield construction, which takes three to seven years and is very capital intensive.

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8.7.3 Constraints

While the market outlook for dissolving pulp consumption looks promising, there are several constraints to be considered:

- Dissolving pulp is a low yield product and difficulties remain to maintain high levels of preserving the cellulose content, while removing other components of wood fibre is a challenge. Production of dissolving pulp requires not only access to significant wood resources, but also competitive wood costs. In addition, production from softwood species has a lower yield in comparison to hardwoods.
- The competition in dissolving pulp markets is strong and the price is volatile to changes in the demand and supply situation.
- China is the biggest consumer of dissolving pulp in the world—however, China has a high level of governmental control and regulations in cotton production and trade of dissolving wood pulp.

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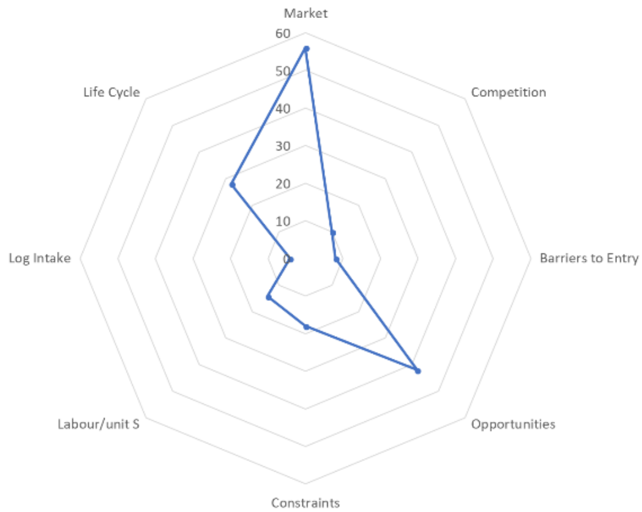
9. WOOD PLASTIC COMPOSITE (WPC)

WPC is among the more attractive options for Maine, with a total score of 180. WPC's highest scores are for markets (56) and market opportunities (48).

Figure 9-1: WPC Attractiveness Score



The following section outlines in detail the market opportunity for WPC for Maine.

9.1 Product Description

Wood plastic composite (WPC) is composite material made from waste or virgin wood and plastic. In WPC, polyethylene, polyvinyl chloride, polypropylene and other types of plastic are most often combined with high-quality wood flour free of dirt and bark, or by-products of papermaking (e.g. bleached fibre by-products). Sometimes mineral fillers (e.g. calcium carbonate or talc) and coupling agents (e.g. maleated polyolefins, organosilanes, and acrylic-modified polytetrafluoroethylene) are also added to enhance the properties of WPCs. WPC production is highly automated and is well adapted to different species and forms. Other benefits include sustainability, high durability and relative strength, lower prices compared to other materials, resistance to biological defects, and good thermal and creep performance when compared to unfilled plastics. WPC are used in outdoor decking, benches, window/door frames, railings, fences, mouldings, trim, cladding, siding, as well as some indoor furniture.

There are capped and uncapped WPCs—capped WPCs have a resin layer which increases resistance to rot, mildew, mould, and splintering.

9.2 Market Size and Growth

The market for wood-plastic composites is segmented by region, type, and application.

By region

North America is the largest producer and market for WPCs, especially composite decking and railings. In recent years, the main drivers for growth have been recovery of the residential market and growing demand for building products which require little maintenance. Asia-Pacific (especially China) is the second largest producer of WPCs accounting for about one-third of global production. Europe accounts for around 9%, with Germany the dominant producer, both in volume and number of manufacturers. Russia, Southeast Asia, South America, and India are the main emerging markets for WPCs.

Trade in WPC's is mainly domestic or regional (e.g. traded within North America or Europe) due to its relatively low unit value.

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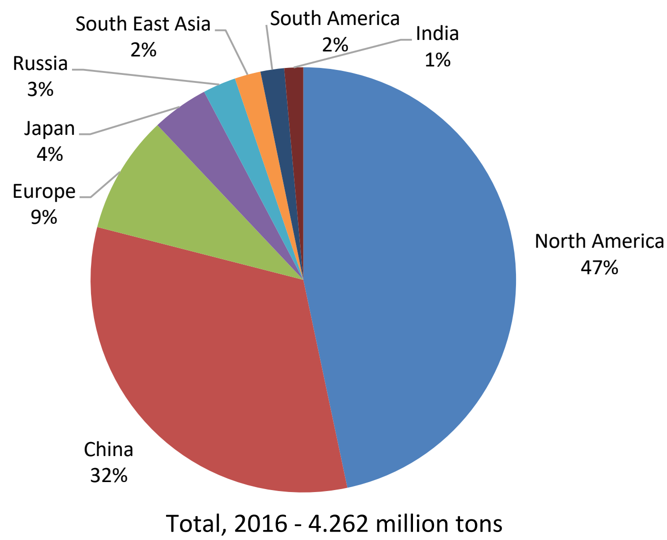
Figure 9-2: Estimated Breakdown of Global WPC Production

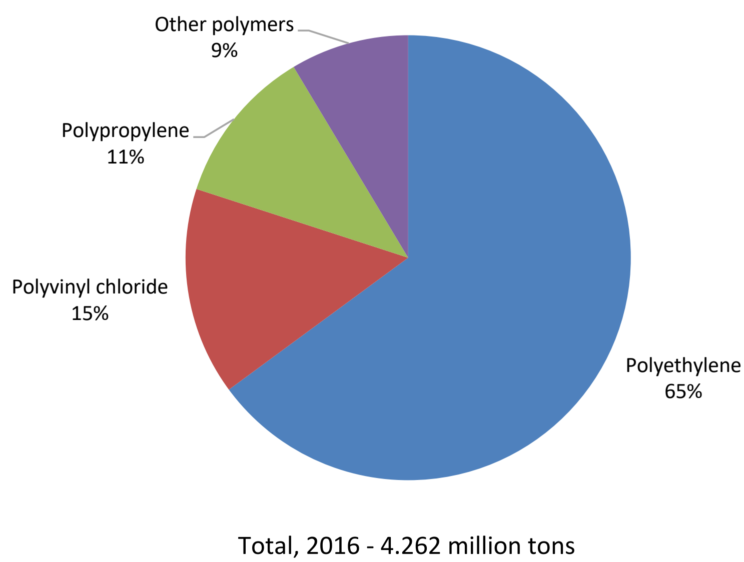


Source: Bioplastics magazine, Indufor

By type

According to estimates, 65% of the global market of WPCs is polyethylene-based (PE), 15% polyvinyl chloride-based (PVC) and the rest are manufactured using polypropylene (PP) or other polymers.

Figure 9-3: Breakdown of Global WPC Production



Source: Technavio

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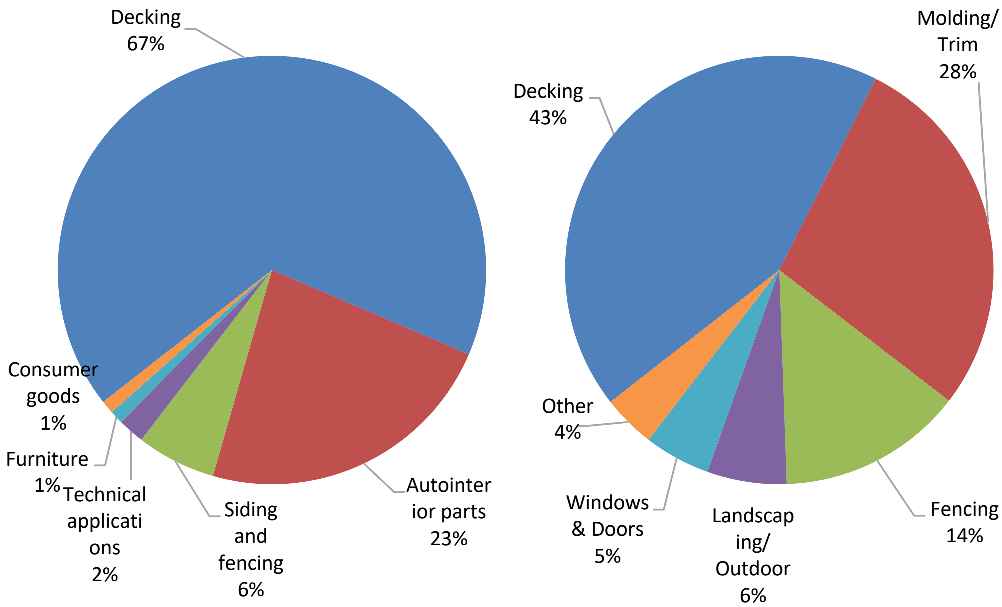
By application

Decking is the main application for WPCs both in the United States and Europe, however the shares of other applications differ between these two regions. In North America, the building and construction segment is the second strongest segment, while in Europe, (especially Germany) there is strong demand in the automobile industry (BMW, Opel, Audi, Volkswagen and other producers). In China, WPCs are used mainly in building/construction and the automobile industries.

Figure 9-4: End Uses of WPCs in Europe (left) and the United States (right)



Sources: Textiles update, WPC market research

9.3 The Competitive Landscape

The main producers of WPCs for decking and railing are: Trex Company Inc., TimberTech and Azek, Fiberon LLC, and Advanced Environment Recycling Technologies Inc. Other players are Tamko Building Products, Fiber Composites LLC, Beologic N.V., and CertainTeed Corporation.

9.3.1 Competitors

Trex Company Inc.

Trex is the largest producer of WPC railing and decking in the world, selling its products in more than 42 countries. In 2016, it accounted for 45% of global composite decking production, up from 36% in 2012. Trex mills in the US that produce railing and decking from wood particles are in Winchester, Virginia and Fernley, Nevada. Trex sources include reclaimed wood fibre from cabinets, flooring manufacturers, and purchases of large volumes of recycled polyethylene—making the company one of the largest recyclers of plastic bags in the United States. The share of recycled wood in decking products is 95%. Trex is a publicly-owned company, with net sales in 2017 of USD 565 million.

AZEK Building Products (TimberTech and Azek)

According to estimates, Azek Building Products accounts for 30% of the WPC market. Azek Building Products has two brands of WPCs, TimberTech and Azek. Azek uses PVC, while TimberTech manufactures capped composites. Azek Building Products' headquarters are in Skokie, Illinois, with mills in Scranton, Pennsylvania, and Wilmington, Ohio.

Fiberon LLC.

Fiberon produces WPC decking, railing and fencing which are sold across North, South and Central America, Asia, Australia and in more than 30 countries in Europe. Fiberon has two production facilities in the US—New London, North Carolina and Meridian, Idaho.

Advanced Environment Recycling Technologies Inc. (AERT)

Recently acquired by Oldcastle Architectural, Inc., AERT produces composite products with almost equal shares of recycled wood fibre and polyethylene plastic at the company's mill in Springdale, Arkansas. The product portfolio includes commercial and residential decking planks and accessories, exterior door components, as well as green recycled plastic resin compounds. AERT's brands are ChoiceDek and MoistureShield. In 2016, the net sales of the company were USD 85 million.

9.3.2 Competing and Substituting Products

The advantages and properties of WPC's, together with environmental regulations and customer awareness, have led them to substitute for conventional wood and wood-based panels. In its main end-use segment, WPCs mainly compete with solid wood, treated wood, plywood, MDF and particleboards. As shown in Table 9-1, WPC's have considerable advantages in anti-corrosive properties and maintenance requirements when compared to solid and anticorrosive wood.

Table 9-1: WPC vs Anticorrosive Wood vs Wood

Indicator	WPC	Anticorrosive wood	Wood
Appearance	Any colour can be modulated. Variety of surfaces	Simple shape, visible knots. Colour cannot be changed	Single colour, visible knots
Anti-corrosive property	Resistance to moisture, rot, termites, slip and cracking	Cracking, decay. Short-lived	High water absorption, cracking and decay
Applied Fireproofing	Fire-resistant	Flammability	Flammability
Processability	Cut, drilling, nailing	Cut, planing	Cut, planing, drilling, nailing
Maintenance	No coating and maintenance	Requires regular maintenance (e.g., protective coatings)	Requires regular maintenance
Environmental friendliness	No harmful substances.	Might contain harmful substances	No harmful substances
Recycling	100% recyclable	Cannot be recycled	Recyclable

Although WPCs can be used in the same applications as wood (drilled, screwed, fixed), WPCs have some clear advantages over wood, as they can be extruded and moulded like plastic, providing a uniform material and appearance. Other advantages include:

- Increasing volumes of recycled materials,
- Low maintenance,
- More thermal stability than plastic,
- Dimensional stability,
- Low water absorption,
- Engineered profiles,
- Lower variability than wood,
- Does not warp or splinter,
- Tailored products,
- Lightweight foamed WPC.

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Moreover, WPC products possess superior properties when compared to wood-based panels in terms of resistance to external factors, such as humidity, pest, fire, corrosion, and maintenance requirements (Table 9-2). On the negative side, the surface of PWC decking may become hot in the summer, especially for darker colours.

Table 9-2: WPC vs Wood-based Panels

Indicator	WPC	Plywood	MDF	Particleboard
Water & moisture proof	+	-	-	-
Termite & pest proof	+	-	-	-
No shrinking or swelling	+	-	-	-
Fire retardant	+	-	+-	-
Corrosion resistance	+	+	+	+
Light weight	+	+	+	+
Splinter free	+	-	-	-
Maintenance free	+	-	-	-
Smooth surface	Very smooth	Less smooth	Less smooth	Less smooth
Outdoor adaptability	+	-	-	-
Gluing & lamination	+	+	+	+
Weather & Aging resistance	+	-	-	-
High screw & nail handling capacity	+	+	+	+
Sawing & cutting	+	+	+	+
Use of traditional tools	+	+	+	+

9.3.3 Barriers to Entry

Barriers to entry can be divided into three categories: market barriers, confidence barriers and technical issues (Table 9.3):

Table 9.3: Barriers to Entry for WPCs

Issues	Description
Market	• Escalating costs of resins, oil derivates and additives; • Feedstock supply – high competition for wood component from biomass energy, animal bedding, landscaping and surfacing materials.
Confidence	• Negative perceptions amongst manufacturers in some sectors, • Conservative consumers, • How to test durability and other properties, • No regulations for end-of-life options.
Technical issues	• Product shortcomings such as exterior durability and impact strength, • Combusting and technical properties for construction products

Market barriers are associated mostly with availability and costs of the main inputs. A WPC production facility requires secured uninterrupted supplies of plastic material in sufficient volumes. Even though post-consumer recyclables are growing, and collection systems continue to develop, it is still uncertain how a manufacturer should deal with managing mixed and variable sources of plastic materials. The wood raw material supply chain is well-established, but there is high competition for wood from other sectors (e.g. wood-based panels, bioenergy sector, animal bedding, etc.). Also, input costs for resins and additives are becoming more expensive.

Confidence issues have produced negative perceptions from some industrial sectors, as well as conservative consumers. In addition, there appear to be no regulations for end-of-life options even though the product is 100% recyclable.

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There are still some technical difficulties in reaching desired levels of exterior durability and ultraviolet (UV) stability.

9.4 Key Drivers for Demand

WPC demand is mainly affected by the development of building and construction applications (especially decking, moulding, siding and fencing), demand for recyclable material in the automobile industry and a ban on the use of toxins copper, chromium, and arsenic affecting competing products. The main end-use driver of demand is repair and remodelling. Decking additions and new fencing are very common in remodelling projects, especially in the US.

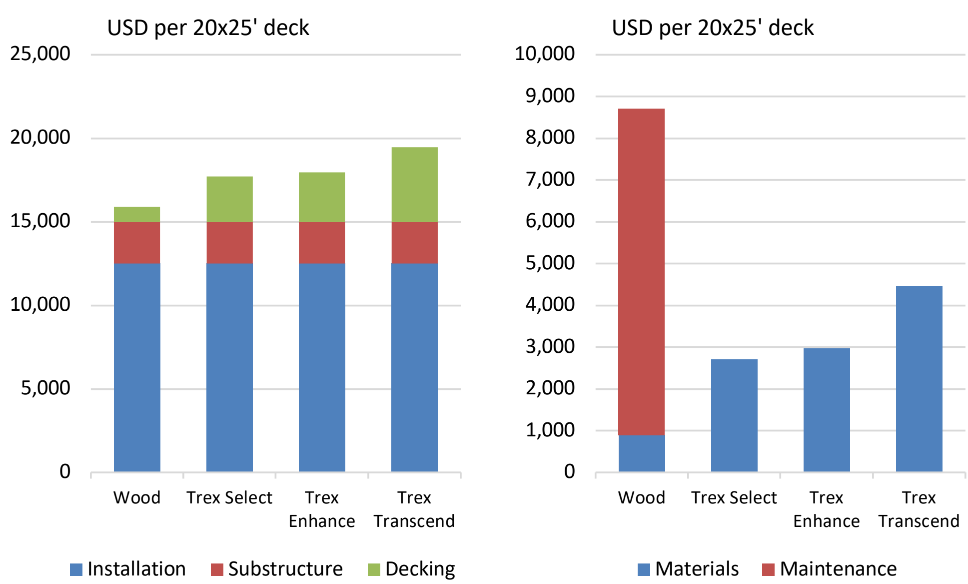
WPCs are widely used in the construction industry due to superior performance qualities, durability and low maintenance costs compared to conventional materials. This can be attributed to increased infrastructure development activities, especially in developing countries, and growing demand for aesthetically appealing flooring and furniture solutions across the world. In addition, there is increasing use of WPCs in applications including garden furniture, benches, docks, sheet pilings, doors and sidings.

Paint and automobile makers prefer components from recyclable materials as they help to reduce manufacturing costs. WPCs are eco-friendly materials, which are used in seat backs, headliners, front and rear door linens, boot linens, and parcel shelves.

9.5 Prices and Price Trends

WPC decking prices are usually considerably higher than for pressure-treated wood decking. For comparison, a 500 ft^2 WPC deck itself costs USD 2 500 compared to a wooden deck costing around USD 890. However, as less maintenance (in sanding, painting, staining, sealing) is required, within five to ten years the cost of WPC decking becomes equal to that of wood. In the longer-run, WPC is more cost-competitive (Figure 9-5).

Figure 9-5: Trex WPC Installed Cost vs. Wood (left) and Estimated Costs in 25 Years (right)



Source: Trex presentation

Retail prices for WPC decking in the US range between USD 3.2 and 6.2 per linear foot (Figure 9-6). The most competitively priced WPC decks are offered by Trex, while Azek's WPC decks

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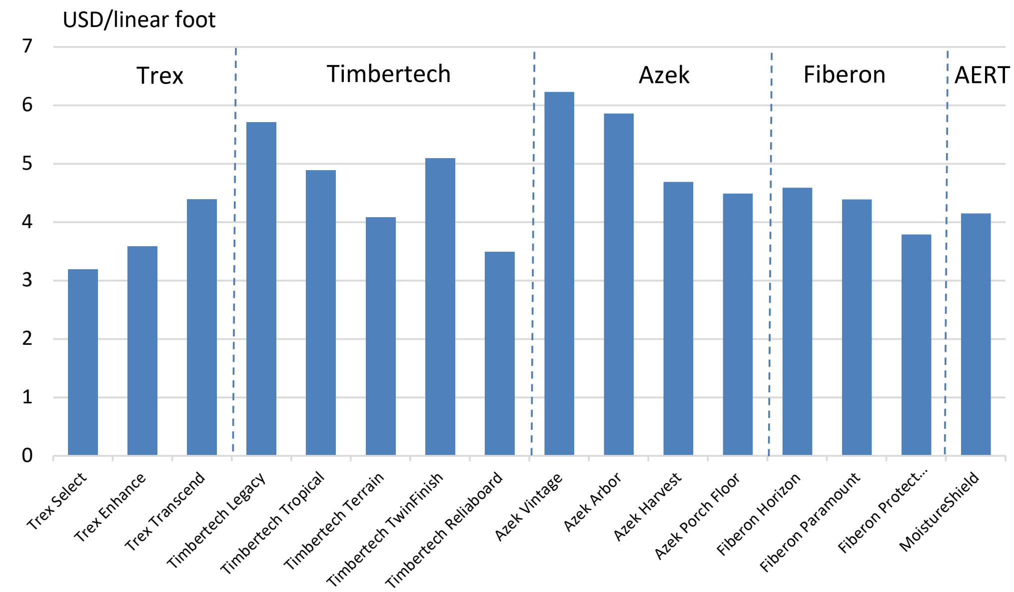
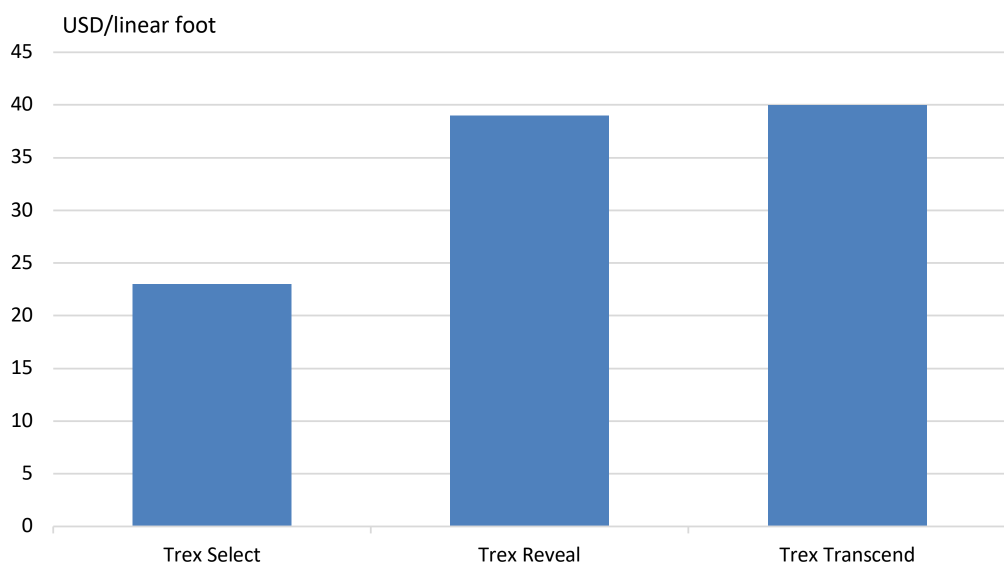
are among the most expensive. Trex's WPC railings are sold at USD 23-40 per linear foot (Figure 9-7).

Figure 9-6: Retail WPC Decking Prices



Source: The Deck Store Online

Figure 9-7: Trex Retail WPC Railing Prices



Source: Trex presentation

9.6 Product Certification

Wood fibres for WPCs can be certified to Forest Stewardship Council (FSC), the Program for the Endorsement of Forest Certification (PEFC) and/or the Sustainable Forestry Initiative programme (SFI).

Some wood plastic compounds can be issued a biobased certificate. For instance, WPCs conforming to the EU standard "CEN/TS 16137:2011 Plastics – determination of biobased carbon content" can be certified and a biobased label can be issued by two organizations in Europe. "OK biobased label" issued by TÜV AUSTRIA and founded by Vinçotte applies to raw materials and final products with a minimum of 30% organic carbon fraction and 20% biobased carbon content. The label has one to four stars depending on the share of biobased content. In Germany, the DIN CERTCODIN-Geprüft Biobased certification scheme is managed by TÜV Rheinland Group and DIN, the German Institute for Standardization. For example, European WPC producer Biology is FSC, PEFC, OK biobased-certified, in addition to having an FDA certificate respectively in accordance with EU and US regulations.

A number of standards cover wood-plastic composites in different countries. For instance:

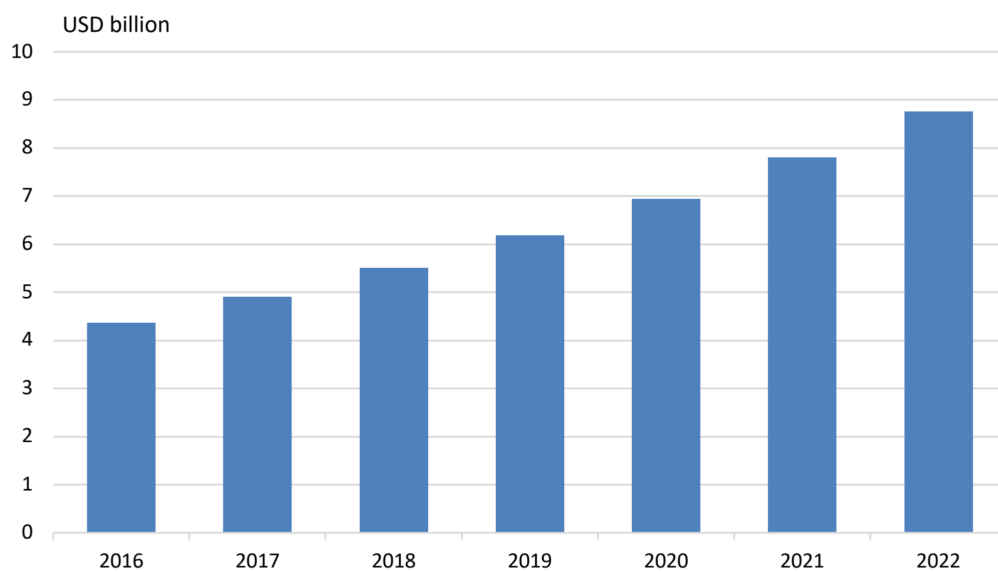
- European CEN/TC 411 "Bio-based Products",
- North American ASTM WPC standards,
- Germany: Quality and Testing Specifications for Production Control for Terrace Decking made from Wood-Polymer Composites (Version 2017-03-01),
- Austrian OENORM WPC standards,
- French standard: Reinforcement fibres – Flax fibres for plastics composites.

9.7 Outlook

9.7.1 Market Growth

The market for WPCs as an economically and ecologically sustainable alternative to construction components made of steel is expected to continue growing. In 2016, the WPC market was estimated at USD 4.37 billion and 4.262 million tons. At the annual growth rate of 12.3%, by 2022 it is forecast to reach USD 8.76 billion (Figure 9-8). Changing prices for petrochemicals, tightening environmental regulations and rapid technological development are expected to have a positive impact on the global WPC market. Composite materials are expected to continue further substitution of some more traditional materials due to the enhanced properties they possess (e.g. resistance to rot, mildew and mould and colour fading).

Figure 9-8: Global WPC market



Source: Zion Market Research

It is expected that the building and construction segment will remain dominant among end uses for WPCs, however the strongest growth is forecast for the automotive segment, as the result of increasing demand for lightweight vehicles and consequently for WPCs. Other non-residential applications (flooring, docks, boardwalks, patios and marinas) are also expected to experience

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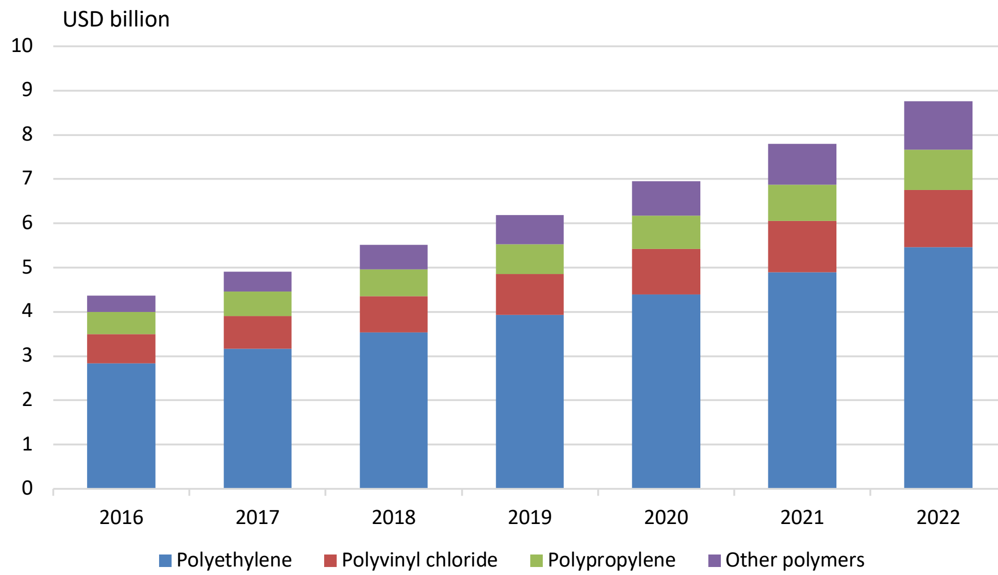
significant growth. In contrast, the growth of the electrical segment is expected to be rather moderate.

Within the building and construction segment, decking is expected to remain the main end use. The composite decking and railing market is forecast to grow at 12.6% per annum and reach USD 3.09 billion by 2020, up from USD 1.6 billion in 2015. It is anticipated that new applications will also develop (e.g. WPC as comfortable and durable backing material for luxury vinyl tile (LVT) flooring). WPC is forecast to be used even more intensively in fencing and landscaping products.

In the short term, North America will continue to lead the WPC market, with increasing demand for flooring and decking, in addition to other sectors, such as automotive, construction, electronics etc. The US repair and remodelling sector and new construction are expected to see healthy growth in the next several years, and the share of WPC is expected to continue its growth in the main end-uses. Demand outlook in the US is strong.

PE-based WPCs are expected to retain the dominant position in the market, followed by PVC (Figure 9-9). However, the forecast annual growth of PVC will exceed that of PEs (11.89% vs. 11.54%). PP-based WPCs will show more moderate growth at a CAGR of 10.49%.

Figure 9-9: Global WPC Market by Type



Source: Zion Market Research, Technavio

9.7.2 Opportunities

- Wood processing and plastic manufacturers are expected to shift towards wood plastic composite manufacturing because of the similarities in manufacturing technology and lower production costs. WPC manufacturers are expected to benefit from development of technical know-how. The moisture absorption properties of wood and susceptibility to fungi and moulds, resulting in decreased lifespans, are expected to further hamper the market growth of wood and create favourable conditions for the increased popularity of WPCs. A 1% gain in the market share from wood, results in more than USD 50 million annual revenues for the composite market.
- There is a high potential for increased use of WPCs in outdoor living spaces – the main home improvement market segment currently. Home improvement (repair and remodelling) and construction segments are forecast to experience gradual growth.
- WPC demand is expected to grow steadily both in the core North American and other markets.

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- Wood plastic composite production is well suited for areas where there is little, or no use, for wood residues from sawmills and other wood processing plants and where the value of the residual wood raw material is low (such as in Maine).

9.7.3 Constraints

Lack of rigidity, the impact of heavy load, and lack of well-defined quality standards are the major factors hindering the global WPC market. Wood is treated with thermoplastics and a few additives, which makes the WPC stiffer and causes loss of flexibility. WPC easily adopts a given shape, however is difficult to reshape. Most wood-plastic composites are manufactured using plastic recyclates. Therefore, issues regarding the quality of WPCs have become a major concern for end-users.

Other concerns include:

- Relatively high costs,
- Unable to paint,
- Lower stiffness than wood,
- Thermal expansion,
- Whether it is rot free material,
- Issues regarding recyclability,
- Aesthetics,
- Creep under load,
- Heavyweight or high density.

In addition, the cost development of recycled plastic is a real concern and may make WPCs less competitive in the future.

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10. BIO PLASTIC COMPOSITES

Bio Plastic Composites (BPC) are a relatively unattractive option for Maine, with a total score of 142. Bioplastics' highest scores are for markets (45) and market opportunities (36).

Figure 10-1: BPC Attractiveness Score

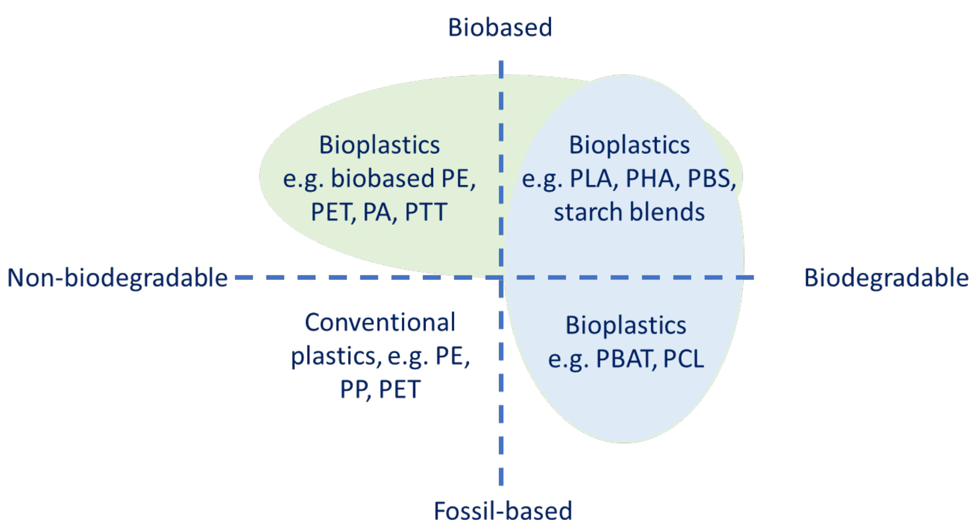
The following section outlines in detail the market opportunity for BPC for Maine

10.1 Product Description

Bioplastics are polymers blended with (non-)organic additives (mineral fillers, UV stabilizers, colour pigments, flame retardants, processing aids, and plasticizers) and further processed into composites. Wood-based bioplastics are mainly cellulose- and lignin-based.

Bioplastic material can be biodegradable and non-biodegradable, and can be based on renewable or petrochemical raw materials:

Figure 10-2: Types of Bioplastics



Source: European Bioplastics

The scope of the present chapter will be on bioplastics in general and whenever possible specifically on bioplastics made from renewable materials, such as PLA (polylactide), PHA (polyhydroxyalkanoates), PBS (polybutylene succinate) and starch blends, being biodegradable, and bio-based PE (polypropylene), PET (polyethylene terephthalate), PA (polyamides) and PTT (polytrimethylene terephthalate) being non-biodegradable.

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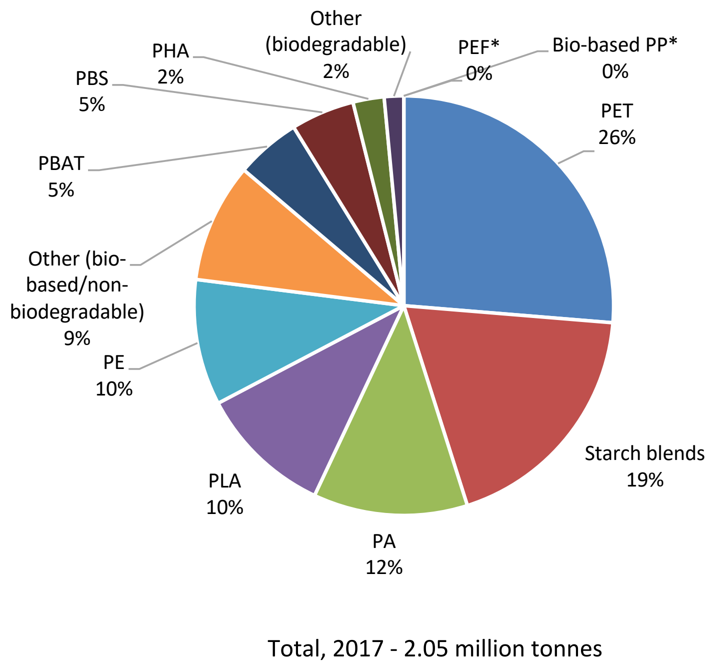
10.2 Market Size and Growth

Currently, bioplastics account for 1% of global plastic production and manufacturing capacity is estimated at 2.05 million tonnes. Approximately, 56% are bio-based, non-biodegradable plastics, while the rest are biodegradables.

Slightly more than one-fourth of bioplastics are made of PET. Starch blends are the second most wide-spread, followed by PA, PLA and PE. Bio-based PP and PEF are at the development stage and are expected to be commercialized by 2020 (Figure 10-3).

Figure 10-3: Global Production Capacities of Bioplastics, by Material Type (2017)



Source: European Bioplastics

Packaging is the largest end-use segment of bioplastics, currently holds an almost 60% share. About 11% of bioplastics are used in textiles, and 7% in both consumer goods and the transportation industry. The remaining applications are agriculture and horticulture, building and construction, electrics and electronics. Biodegradable bioplastics are used especially in flexible and rigid packaging, as well as agriculture and horticulture.

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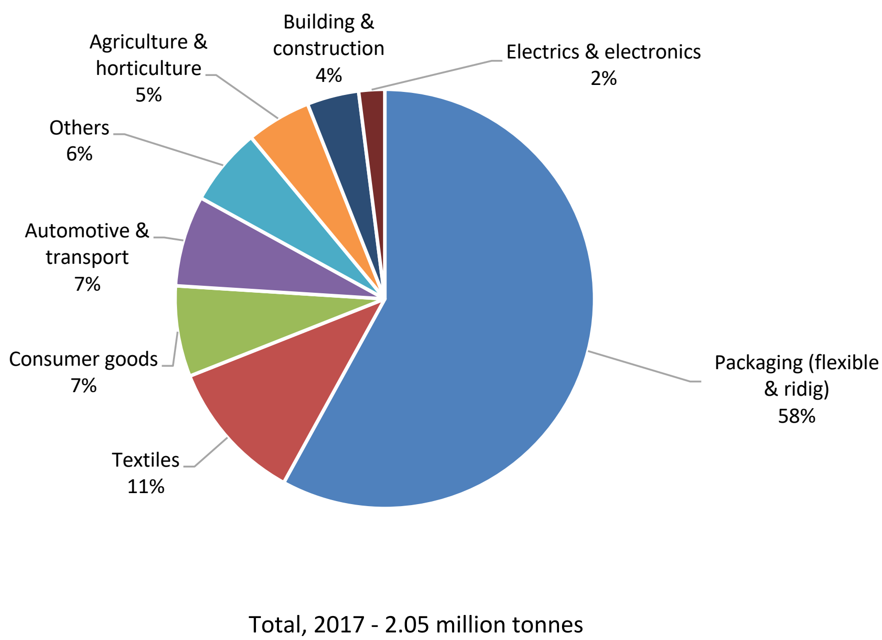
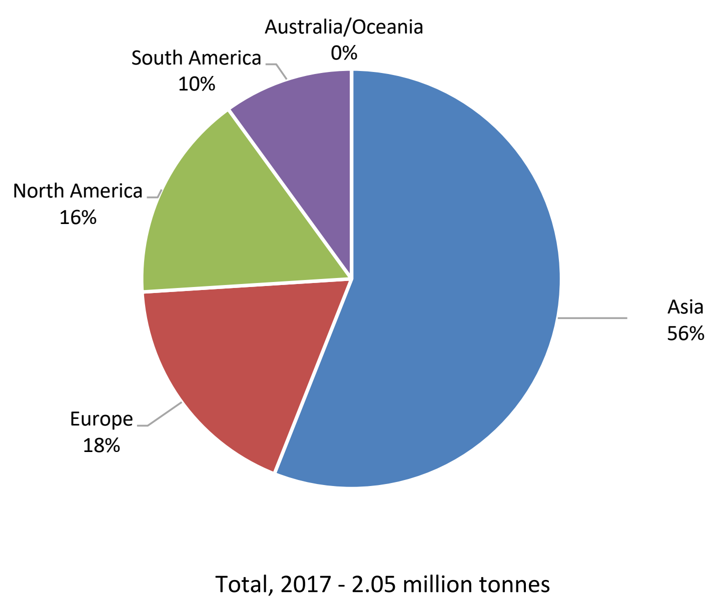
Figure 10-4: Global Production Capacities of Bioplastics, by Market Segment (2017)



Source: European Bioplastics

Asia is the largest producer of bioplastics, Figure 10-5; although Europe is the largest consumer, accounting for almost half of the global demand. After Europe, North and South America, bioplastic production volumes in Australia and Oceania are marginal.

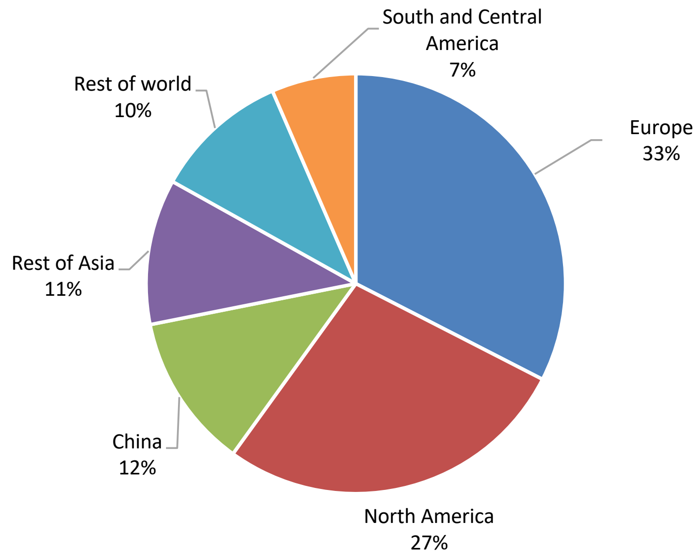
Figure 10-5: Global Production Capacities of Bioplastics, by Region (2017)



Source: European Bioplastics

Europe is also the largest market for bioplastic packaging, consuming nearly one third. North America is also a significant consumer of bioplastic packaging. North and South America, as well as Asian countries are expected to increase their demand for bioplastic packaging at a faster pace than in Europe, due to changing consumer behaviour and governmental efforts aimed at promoting recyclable packaging.

Figure 10-6: Global Consumption of Bioplastics for Packaging, by Region



Source: Smithers Pira

10.3 The Competitive Landscape

10.3.1 Competitors

BASF

BASF, a German company, is one of the largest producers of plastics in the world, with two bioplastic products in its portfolio. BASF Ecovio bioplastic is compostable, consists of biodegradable polymer (Ecoflex) and sugar-based PLA. Ecovio is used in organic waste bags and agricultural films, as well as coffee capsules and outer packaging. BASF's Ecoflex is fossil-based and its main benefit in comparison to some conventional plastics is its certified compostability. It has been commercialized for over 25 years. Both bioplastics are produced at the BASF plant in Ludwigshafen, Germany. The annual production capacity of Ecoflex at Ludwigshafen is 74 000 metric tons. Ecovio is also produced at BASF's partner plant in Picayune, Mississippi by Heritage Plastics.

Braskem

The annual commercial capacity production of Braskem's "I'm green Polyethylene" located in Triunfo Petrochemical Complex in Rio Grande do Sul, Brazil is 200 000 tons. This product is manufactured from ethanol sugarcane and is used in rigid and flexible packaging, (e.g. caps, closures, bags, films). Braskem's "I'm green Polyethylene" is sold to several partners in Brazil.

NatureWorks

NatureWorks is a joint venture of Cargill and PTT Global Chemical from Thailand. It is specialized in the production of Ingeo biopolymer polylactic acid (PLA) at its plant in Blair, Nebraska with the annual capacity of 150 000 metric tons. The main feedstock for Ingeo are agricultural crops (dextrose and sucrose from cassava, cornstarch, sugar cane, or beets). Ingeo

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is used in 3D printing, beauty and household applications, building and construction, food and beverage packaging, electronics and appliances, and medical and hygiene applications.

Telles

Telles is a joint venture between Metabolix Inc. and Archer Daniels Midland Company (ADM) producing biobased biodegradable sugar-based plastic (PHA) at its site in Clinton, Iowa. Its main application segments are retail, compost bags, packaging, agriculture, horticulture, as well as marine/aquatic applications.

Novamont

Novamont is an Italian producer of biodegradable and compostable bioplastics under the Mater-Bi brand. The main feedstock are starches, cellulose, vegetable oils and their combinations. Like other bioplastics, Mater-Bi is used in agriculture, packaging, automotive sector, hygiene and personal care etc. and is produced at Novamont's Terni facility in Italy.

Meredian Holdings Group

Meridian Holdings Group is the result of a merger between Meredian Inc. (a large PHA producer) and DaniMer Scientific. The Group produces biopolymers based on PHA and PLA technologies for the use in additives, aqueous coatings, extrusion coatings, extrusion laminations, fibres, film resins, hot melt adhesives, injection moulding, thermoforming, and wax replacement polymers.

Bioplastics produced from lignocellulosic feedstocks have not yet been commercialized at a large scale. However, many companies, e.g. Natureworks, BASF, Total and others are currently looking into options of using cellulosic raw materials for production of bioplastics. A Pennsylvania-based company Renmatix has secured funding from Bill Gates, as well as Total and BASF to help it commercialize its Platrose technology in Canada, India, Malaysia and the United States. The technology uses hydrolysis to break-down biomass (wood waste, agricultural residues, etc.) and convert it to cellulosic sugars serving as a base for bioplastics.

10.3.2 Competing and Substituting Products

The main competition bioplastics face is from conventional plastics. In comparison, bioplastics have clear environmental advantages and a positive image among customers. However, bioplastics can fall short in terms of price, use of GMOs and food crops, as well as some technical characteristics (which can cause a narrow processing window), and being prone to thermal degradation and characterized by brittleness (Table 10-1).

Table 10-1: Advantages and Disadvantages of Conventional Plastics vs. Bioplastics

	Advantages	Disadvantages
Conventional plastics	Low cost	Based on petrochemicals
	Good and excellent technical properties	Difficult to recycle
	Easy processability	Mostly not biodegradable
	Can save energy and resources compared with other materials, depending on application	Uncontrolled combustion can release toxic substances
	Thermal recycling possible (cascade use)	Ecotoxicity, particularly microplastics in the marine environment
		Partly toxic raw materials and additives
Bioplastics	(Partly) biodegradable	Costly
	(Partly) based on natural feedstock, hence reducing the emission of GHG and the dependence on crude oil	(Partly) use of genetically modified organisms
	Some bioplastics have more advanced properties than conventional plastics. For example, contrary to PET, PEF is biobased, transparent, recyclable, more efficient in blocking dioxygen, CO_2 and water vapour, has high glass transition temperature of over 12 ^{o}C and melting temperature lower than 30 ^{o}C.	Use of land, fertilizers, and pesticides for crops, potential food competition

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	Generally, standard manufacturing processes and plants can be used for biobased feedstock, and standard processing machines can be used for biobased plastics	Narrow processing window (lower melting temperature)
	Positive image among consumers	Brittleness
		Thermal degradation

Source: Kirk-Othmer Encyclopedia of Chemical Technology

10.3.3 Barriers to Entry

As the competition bioplastic producers face from conventional plastic is severe, typical bioplastic producers have smaller production scales.

Industrial consumers might be reluctant to switch from familiar conventional plastics, since they may lack experience in their processing (e.g. required lower temperatures). Overall consumer awareness still needs to mature.

10.4 Key Drivers for Demand

The main drivers of bioplastic demand are: consumer preference for sustainable materials, bioplastics have a positive image regarding emission reductions and reducing dependency on fossil fuels; and their favourable properties and standardized manufacturing process.

Bio-PE and bio-PET are currently used for rigid cosmetics packaging and beverage bottles e.g. Coca-Cola, Heinz, Vittel, Volvic use bio-PET bottles; Procter & Gamble and Johnson & Johnson use bio-PE cosmetic packaging. PLA is also becoming more popular in the rigid packaging sector. Bioplastics have gained a share in the flexible packaging segment, resulting from changing eating and drinking habits (e.g. used for cups, trays, plates and cutlery).

Demand for bioplastics is also driven by demand for sustainable and practical solutions in the agriculture and horticulture segments, especially for biodegradable mulching films, films for banana bushes, plant pots, fertiliser rods, pheromone traps, etc.

Bioplastics have a niche in the consumer electronics segment, e.g. in computer and mobile phone casings, speakers, keyboards, and vacuum cleaners. Durability and light-weight contribute to their demand in the automotive industry in the form of dashboard and other elements, covers for seats and airbags, steering wheels etc.

There are several supportive mechanisms for bioplastics, namely national investment programmes in several South-East Asian countries and the “BioPreferred programme” in the US. The latter was developed as part of the Farm Bill of 2002 to promote development of bio-based products and was further expanded in the 2014 Farm Bill.

There are many policy incentives supporting the bioplastic sector. For example, in the EU the most important initiatives are:

- Europe 2020 / Innovation Union,
- Lead Markets Initiative for Bio-based Products,
- Resource Efficiency Strategy,
- Key Enabling Technologies,
- FP7 & Horizon 2020,
- Bioeconomy Strategy,
- Circular Economy Package.

10.5 Prices and Price Trends

Low oil prices and corresponding cheap conventional fossil-based plastics have had a negative impact on the competitiveness of bioplastics:

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Table 10-2: Prices of Conventional Plastics and Bioplastics, USD per pound

Bioplastics				Conventional plastics				
PLA	Plastarch	Bio-HDPE	Bio-PET	HDPE	PP	PET	PS	PVC
1.25	1.50	1.80	1.10	1.00	1.06	0.97	1.16	1.05

Source: US Bioplastics

Nevertheless, the price competitiveness of bioplastics has improved during the past several years. Three years ago, the bioplastic industry representative, Cereplast, estimated the breakeven point for bioplastic to be competitive with conventional plastics was at an oil price of USD 130-140 per barrel; today, the breakeven point is USD 50 per barrel (Source: CEO of Renmatix).

The survey conducted by Nova-Institute has demonstrated that consumers are nevertheless willing to pay an additional price for bioplastics. Approximately 85% of experts believe that a price premium exists and 60% of respondents considered it to range from 10 – 20%.

10.6 Product Certification

There are several certification schemes related to compostability of bioplastics, in the US they are administered by BPI, in Japan by JBPA, in Australia by ABA, in Europe by Belgian Vinçotte and German DIN CERTCO. Certification of bioplastics can be obtained under:

- ISO 17088,
- EN 13432 / 14995,
- ASTM 6400 or 6868.

In the US, environmental claims are controlled by the Federal Trade Commission (16 CFR Part 260 - Guides for the Use of Environmental Marketing Claims) and the biobased content of a product to be classified as biobased is determined by the United States Department of Agriculture (USDA).

Bio-based carbon content of bioplastics in the US is regulated by the standard ASTM 6866, while in the EU by CEN/TS 16137. The French Association Chimie du Végétal (ACDV) has developed a certification scheme for an alternative biobased mass content measurement and a respective standard is being developed by the European Committee for Standardization (CEN).

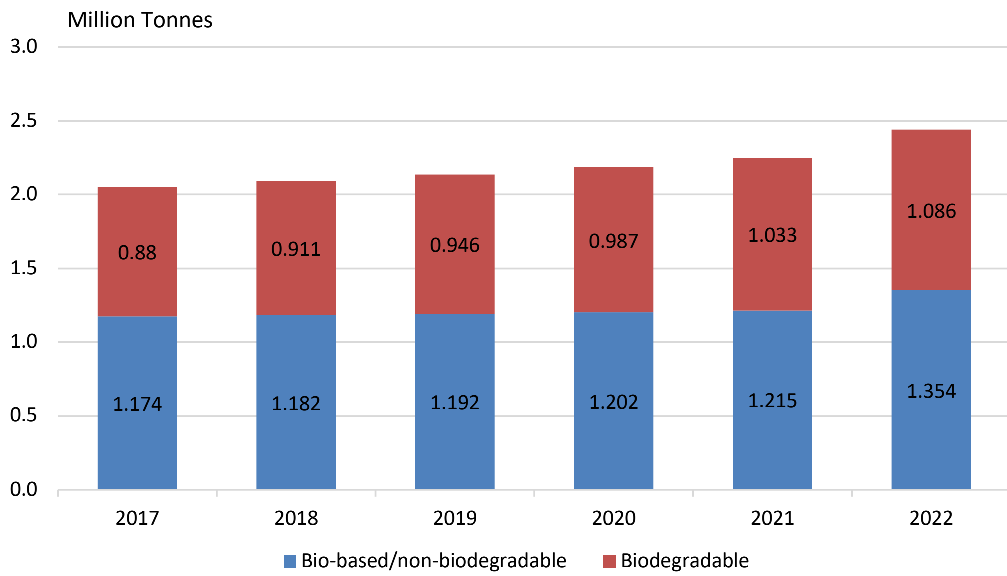
The labels which are currently available for bioplastics are, for example, a BioPreferred label of USDA, a Seedling label of Vinçotte or DIN CERTCO or an OK compost label of Vinçotte.

10.7 Outlook

10.7.1 Market Growth

According to estimates, by 2022 bioplastic production capacity will increase by nearly 20% to reach 2.44 million tonnes (Figure 10-7).

Figure 10-7: Global Production Capacities of Bioplastics (2017-2022)



Source: European Bioplastics

The fastest growth is forecast for biodegradable bioplastics driven by innovative PLA and PHA products. After a development stage, PHA is now becoming commercialized; during the next five years its production capacities are expected to triple. During the same timeframe, PLA capacities are expected to increase by 50%.

Among non-biodegradables, bio-based PEs will retain their growth, due to the start-up of new capacity in Europe. Bio-based PET will lose some market share, as more attention will be given to development of PEF (polyethylene furanoate), which will come onto the market in 2020. Like PET, PEF is 100% based on renewable materials and has advantageous properties (barrier and thermal), having a promising future for packaging applications. Bio-based PP is expected to be commercialized by 2022. Bio-based PUR (polyurethanes) are also expected to have good growth potential.

The position of renewable-based non-biodegradable and fossil-based biodegradable bioplastics is expected to deteriorate in favour of biobased biodegradables (Figure 10-8).

Lignin- and cellulose-based bioplastics are forecast to become more widespread due to increasing pressure against using first generation feedstocks (food crops), which can affect food security.

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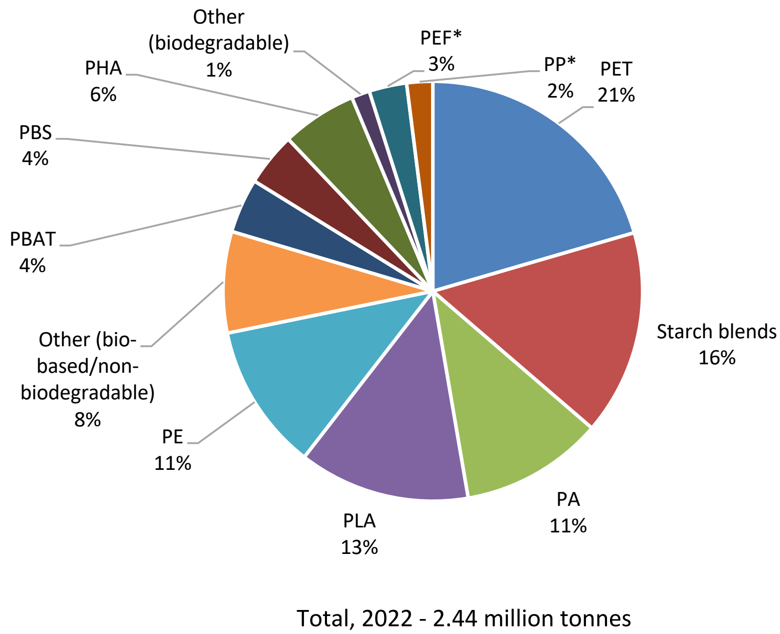
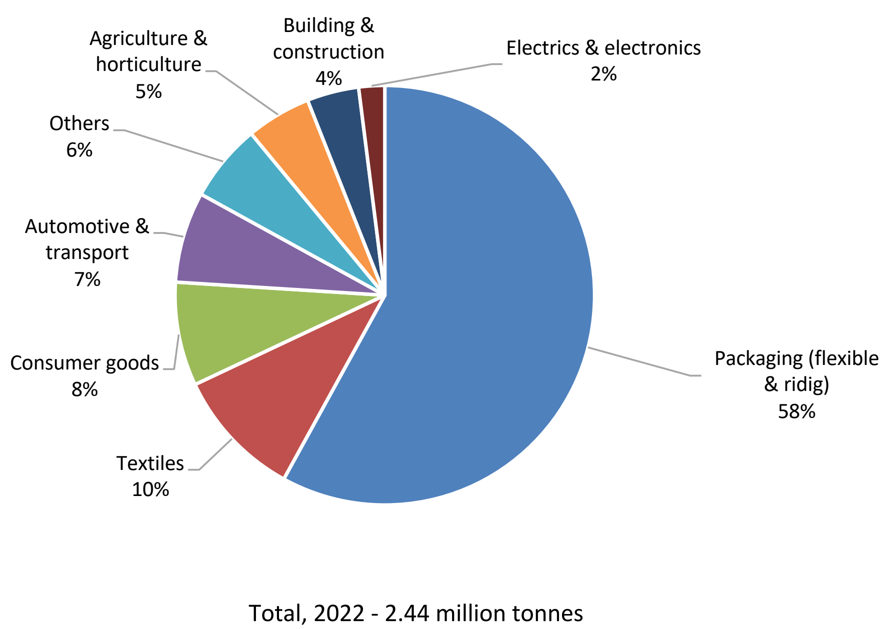
Figure 10-8: Global Production Capacities of Bioplastics, by Material Type (2022)



Source: European Bioplastics

By 2022, the composition of the bioplastic market segments is expected to change little from 2017, the textile industry will experience a 1% decline in favour of consumer goods (Figure 10-9).

Figure 10-9: Global Production Capacities of Bioplastics, by Market Segment (2022)



Source: European Bioplastics

Over the next five years it is forecast that Asia will keep its leading position in production of bioplastics, however, its share will decrease by 4%. The share of Europe will increase at the expense of Asia, and North and South America (Figure 10-10).

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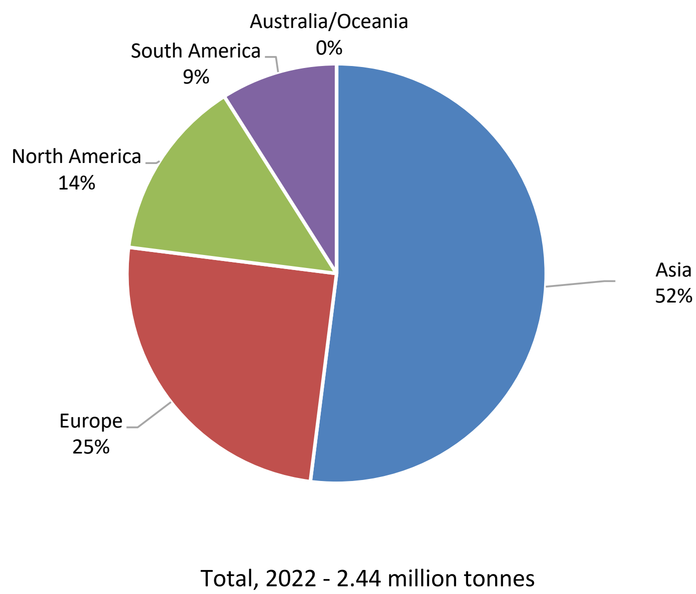
Figure 10-10: Global Production Capacities of Bioplastics, by Region (2022)



Source: European Bioplastics

10.7.2 Opportunities

- According to some estimates, as much as 85% of plastics could be substituted with bioplastics from a technical viewpoint. The market demand for bioplastics is growing and there are a wide range of bioplastics available for numerous end-use applications. Rising environmental awareness and sustainability concerns make bioplastics a good alternative to conventional plastics.
- Use of first-generation feedstock (food crops) is currently most efficient for production of bioplastics, however opportunities for the use of second and third generation feedstock (e.g. cellulose) are also being investigated by companies and researchers. There are already some commercial technologies available for production of cellulose-based plastics, (e.g. by Renmatix).
- Some well-known brands, such as Procter & Gamble, Coca-Cola, Danone, Puma, Samsung, IKEA, Tetra Pak, Heinz, Toyota, and Lego, have already, at least to some extent, adopted bioplastic solutions, and more companies are expected to follow their example soon.

10.7.3 Constraints

- The cost of bioplastics are one of the main constraints when compared to conventional plastics. In addition, bioplastics have some property limitations, such as thermal instability, high water vapour, poor heat sealability, brittleness, and low melt strength, etc.
- Sustainability of feedstocks, especially regarding first generation feedstock, which face competition from food production is an issue. Lignocellulose feedstock might be a solution.
- There is a lack of unified certification and labelling practices and standards, as well as industry cohesiveness. Additional legislation and regulations favouring bioplastics are required.

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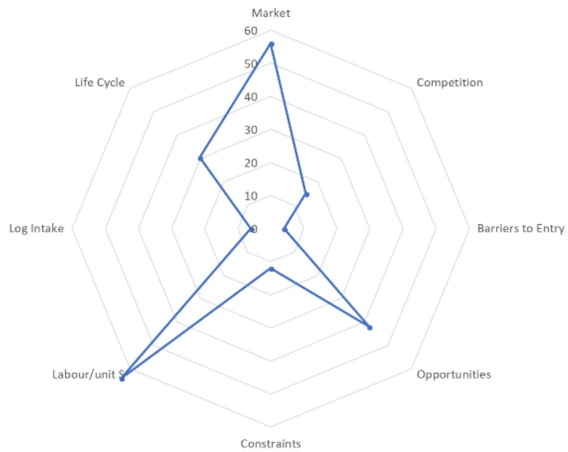
11. NANOCELLULOSE

Nanocellulose is among the more attractive options for Maine, reaching a total score of 229. Highest scores are obtained for markets (56), and market opportunities (42).

Figure 11-1: Nanocellulose Attractiveness Score



The following section outlines in detail the market opportunity for Nanocellulose for Maine.

11.1 Product Description

Nanocelluloses are a group of materials that are defined as having at least one of its fibrous dimensions in nano-scale. According to the European Union definition, nanocellulose is a natural, incidental or manufactured material containing particles (in an unbound, aggregate or agglomerate state), where for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm - 100 nm.

Nanocelluloses are most commonly divided into three different groups:

- Nanofibrillar cellulose
- Cellulose nanocrystals
- Bacterial cellulose

The terminology related to nanocelluloses is not standardized and there many of synonyms for nanofibrillar cellulose, cellulose nanocrystals and bacterial cellulose. Some producers also use product name microfibrillar cellulose for mixtures of microfibrillar and nanofibrillar celluloses. In this report, microfibrillar cellulose is discussed together with nanofibrillar cellulose.

Nanocellulose includes a diverse field of nano-sized materials and possible applications (Figure 11-2). Nanocelluloses are in the majority of the applications added as filler or additives functioning as property enhancers (e.g. rheology enhancer, stabilizer or oxygen barrier enhancer). Presently, materials close to commercial stage are mixtures of microfibrillar and nanofibrillar and are mainly used as fillers and additives in existing applications such as packaging.

Selection of raw material depends on which product is produced. In bulk quality applications lower-priced raw materials are favourable. Kraft pulp is typically feasible in paper and board applications, whereas more expensive raw materials such as dissolving pulp can be used in higher-quality end uses such as cosmetics or food-grade. Unbleached kraft pulp offers favourable properties in several low-grade applications such as cement and composite applications as there tends to be some lignin left in the matrix. Lignin eases the fibrillation process resulting in lower energy consumption and can improve hydrofobity of the material.

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Figure 11-2: Potential Nanocellulose Application Areas, Typical Raw Materials and Role of Nanocellulose

Raw materials

- Dissolving pulp
- Bleached kraft pulp
- Unbleached kraft pulp
- Non-wood, annual plants

Application areas

Role and application

- Strength additive (light materials)
- Films (e.g. electronic displays)
- Reactive network structures: membranes, porous structures (filters, insulation)
- Barrier properties (oxygen, grease)
- Rheology and stability modifier, thickener etc.
- Functionality (hydrophobicity, antimicrobial properties, conductivity), security
- Water binding, retaining and

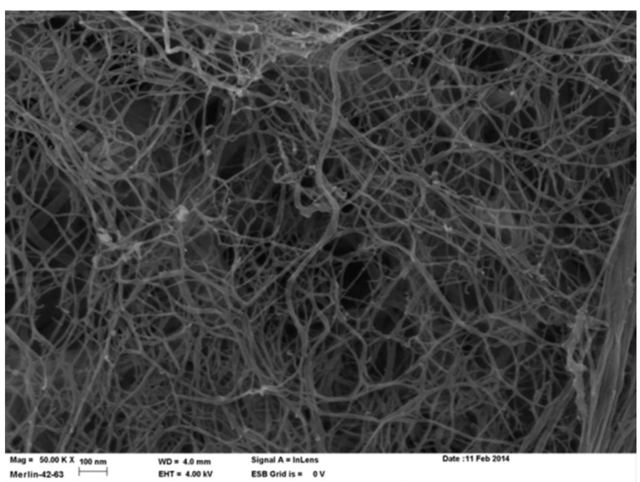
Sources: VTT, Neste Engineering Solutions

11.1.1 Nanofibrillar Cellulose

Nanofibrillar cellulose is produced primarily of wood and pulp. Other possible raw materials include annual plants and by-products of plant processing.

Nanofibrillar cellulose consists of fibers with typical dimensions of 20-300 nm in width and up to several microns in length. They are long, branched and bendy, and have high aspect ratio. They also have a high tendency of forming aggregates. Due to these properties, nanofibrillar cellulose is particularly suitable for strength, reinforcement and rheology modification.

Figure 11-3: Scanning Electron Microscope Picture of Nanofibrillar Cellulose



Source: VTT - Scale 100 nm

The main applications of nanofibrillar cellulose include paper and paperboard manufacture, composites, coatings, porous and light materials, for example in construction materials, and rheology modification in paint. (Source: VTT)

11.1.2 Cellulose Nanocrystals

Cellulose nanocrystals are rod-like in shape with typical dimensions of 2-20 nm in width and length ranging from 100-600 nm to even above 1 µm in length. Cellulose nanocrystals aspect ratio is high, but smaller than in nanofibrillar cellulose. They are also not as branched or bendy as nanofibrillar cellulose. Cellulose nanocrystals differ from nanofibrillar cellulose also with its ability to form liquid crystalline dispersions (Figure 11-4).

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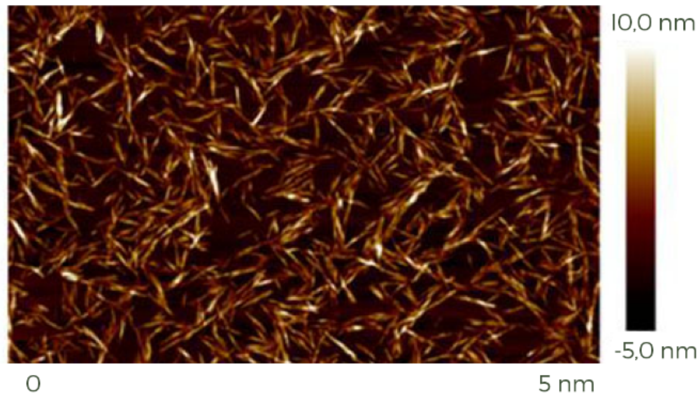
Figure 11-4 Atomic Force Microscope Image of Cellulose Nanocrystals



(Source: CelluForce)

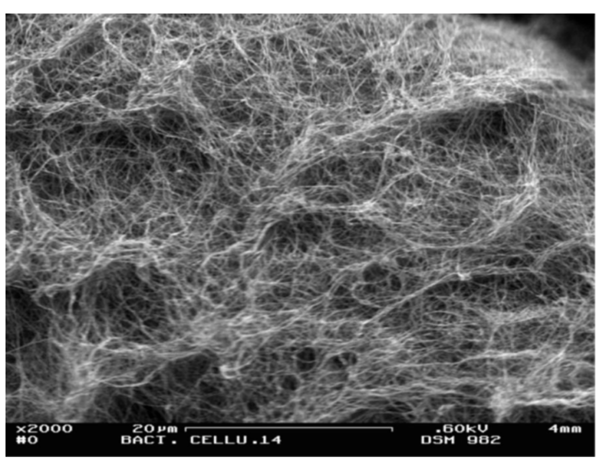
Cellulose nanocrystals suits for strength, reinforcement and rheology modification, but has also notable optical, electrical and chemical properties. Its size, shape and ability to have surface charge leads to unique behaviour in solutions. High chemical reactivity of the surface makes it also customizable for various applications. They can also be used in high-temperature applications due to its heat stability.

The terms, whiskers and rods are also used in literature to refer to cellulose nanocrystals.

11.1.3 Bacterial Cellulose

Bacterial cellulose is a thick gel-like substance with a fine and pure fibre net. It is produced by bacterial biosynthesis. The bacterial cellulose fibre net consists of 20-100 nm fibrils, which is built of 2-4 nm nanofibrils (Figure 11-5). Bacterial cellulose is very pure, hydrophilic, and has high mechanical strength, while at the same time elastic and moldable. Because of its high purity and special physiochemical characteristics, bacterial cellulose has applications in a wide range of sectors including, food, bio-medical, and tissue engineering (nanocomposites).

Figure 11-5: Scanning Electron Microscope Picture of Bacterial Cellulose (Scale 20 µm)



(Source: VTT)

11.2 Manufacturing Process

There are several production routes for nanocellulose. Depending on raw material type, nanocellulose fibre type and product properties desired, the selected production process can

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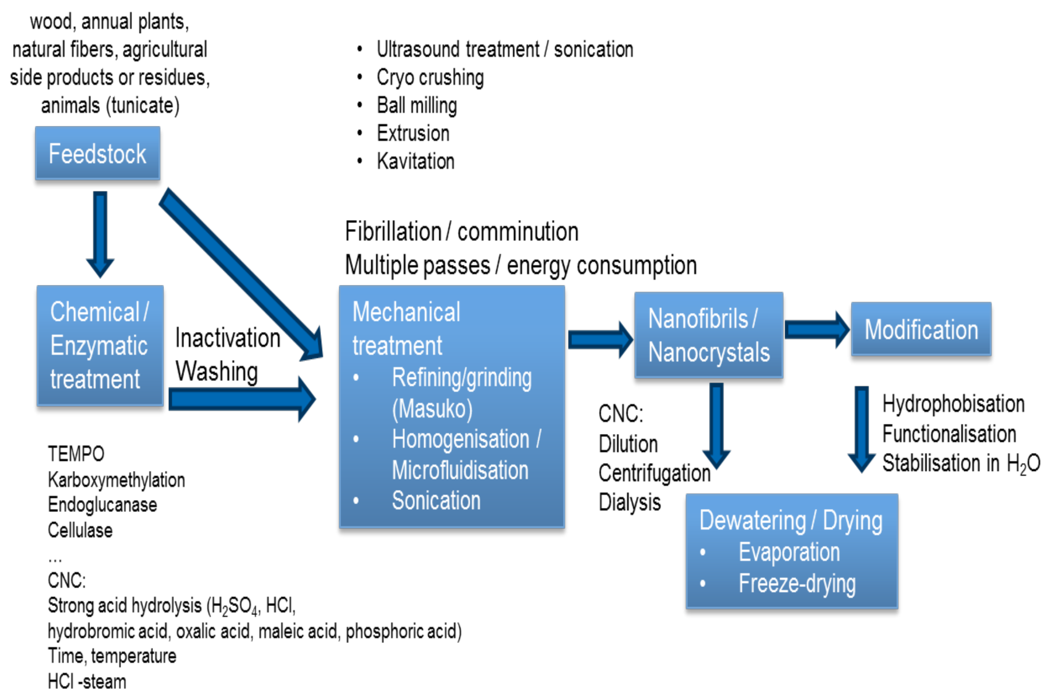
vary significantly. Nanofibrillar cellulose, cellulose nanocrystals and bacterial cellulose all have their own characteristic production processes. Further process steps can be added to achieve specific properties through modifications of the fibre matrix.

Figure 11-6: Manufacturing Process Steps for Nanocellulose Production



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Manufacturing Process of Nanofibrillar Cellulose

Nanofibrillar cellulose is mainly produced through mechanical sheering of fibres. In addition, various enzymatic or chemical treatments are applied to reduce process energy consumption, and also achieve specific desired properties or functionalities. One chemical process uses TEMPO-mediated oxidation, where tetramethyl-piperidine compound is used as a catalyst to produce flexible transparent films. This process is challenging, because tetramethyl-piperidine is toxic and expensive.

Manufacturing process of Cellulose Nanocrystals

Cellulose nanocrystals are typically produced through strong acid hydrolysis of cellulose fibrils, using sulphuric acid or alternatively phosphoric acid or hydrochloric acid. The yield of the acid hydrolysis is low, some 10-50%, and purification of the cellulose nanocrystals hard, which hinders the commercialization of cellulose nanocrystals. New production processes have been developed and American Process Inc. and Blue Goose Biorefineries have come out with their new processes.

Manufacturing process of Bacterial Cellulose

The production of bacterial cellulose differs significantly from nanofibrillar cellulose and cellulose nanocrystals. The production scheme is a bottom-up process where *Acetobacter xylinum* enables a cellulose biosynthesis, using glucose as a raw material. As a result, a thick gel-like substance with a fine and pure fibre net is formed. The high production costs and slow production process of bacterial cellulose are major obstacles to market growth. However, bacterial cellulose has the greatest market potential in high-value applications, which can take the high production costs.

11.3 Market Size and Growth

Currently, the nanocellulose market mainly consists of nanofibrillar cellulose as alternative to resins, synthetic thickeners, strengtheners and plastics. The cellulose nanocrystal market is growing and most companies are focusing on large-scale industries such as composites, packaging and paper. Opportunities also lie in the field of electronics, 3D printing, textiles as well as medicine. The bacterial cellulose market is the smallest of the three nanocellulose types.

11.3.1 Nanocellulose Production

The production capacity of nanofibrillar cellulose was circa 1350 tons per annum in 2016 (Figure 11-7). For microfibrillar cellulose, which is often included in the nanofibrillar cellulose market, the production capacity was nearly 10 000 tons. Vast majority of this microfibrillar cellulose capacity is accounted by FiberLean Technologies plants in Asia, US and UK.

The cellulose nanocrystals production capacity was some 580 tons per annum in 2016, majority of which was accounted by Canadian company CelluForce with their 350 tons per annum CNC plant.

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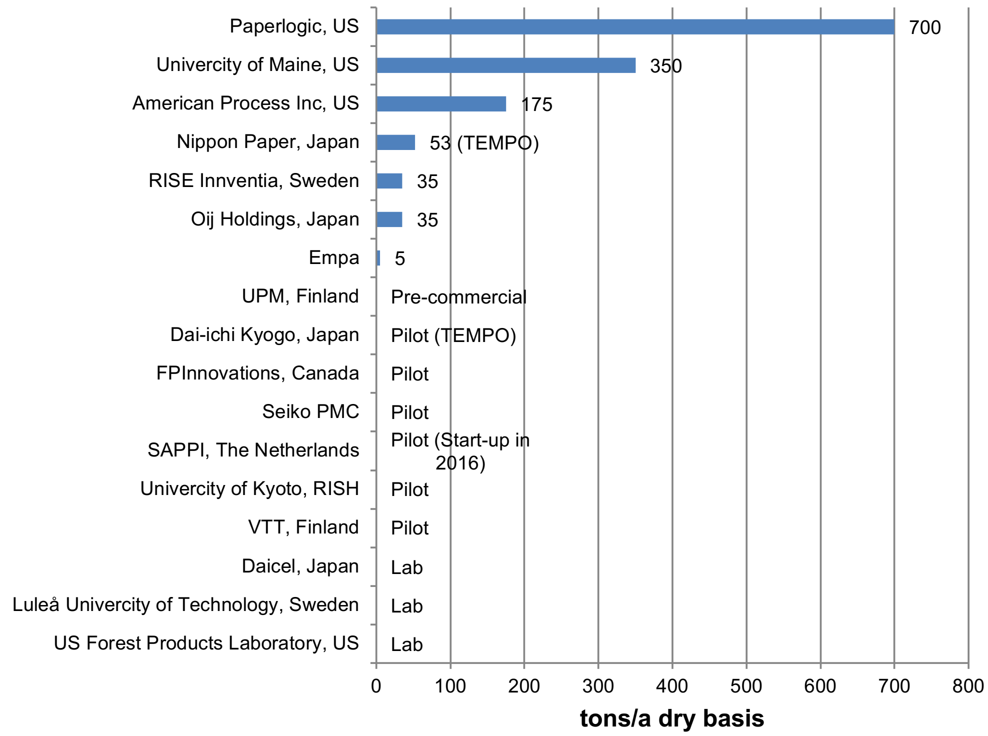
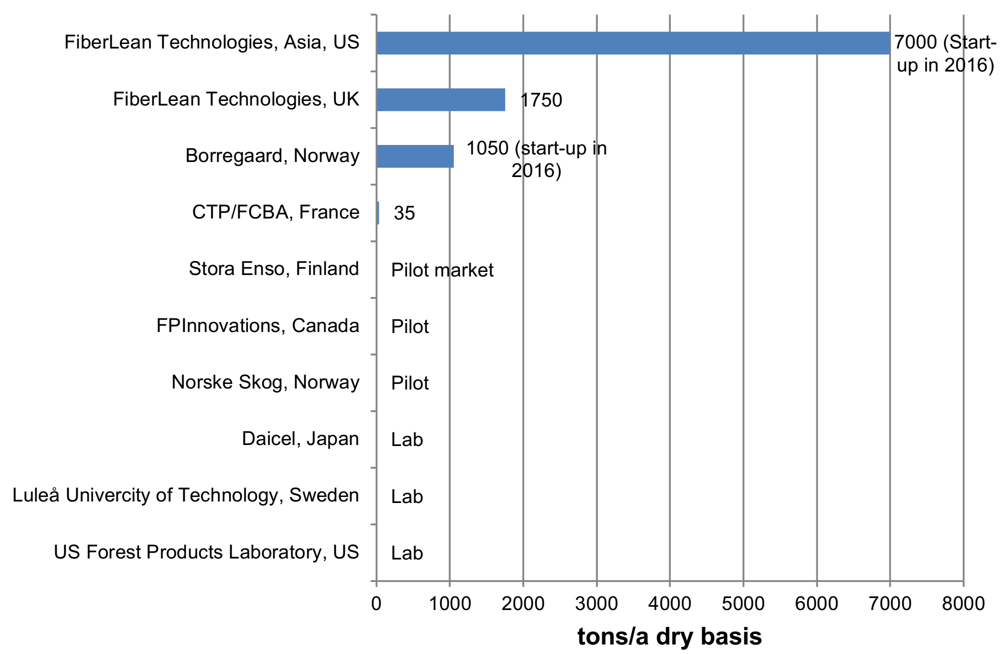
Figure 11-7: Global Nanofibrillar Cellulose Production Capacity (2016)



Source: TAPPI, 2016

Figure 11-8: Global Microfibrillar Cellulose Production Capacity (2016)



Source: TAPPI, 2016

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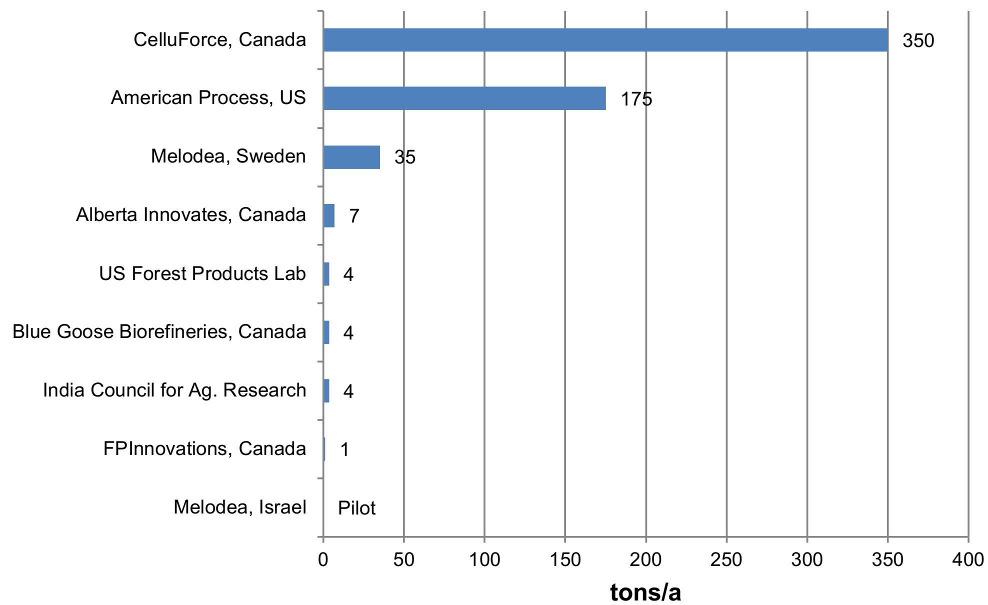
Figure 11-9: Global Cellulose Nanocrystals Production Capacity (2016)



Source: TAPPI, 2016

11.3.2 Nanocellulose Market Potential

Nanocellulose has a diverse field of possible applications. Current production is still only emerging and current capacity exceeds the demand today greatly. The market potential for nanocelluloses is forecasted as huge, totalling some 23.5 million tons. The main potential is seen in the paper and paperboard applications, where nanocellulose is expected to have the potential for grasping 5% of the market volume (Figure 11-1).

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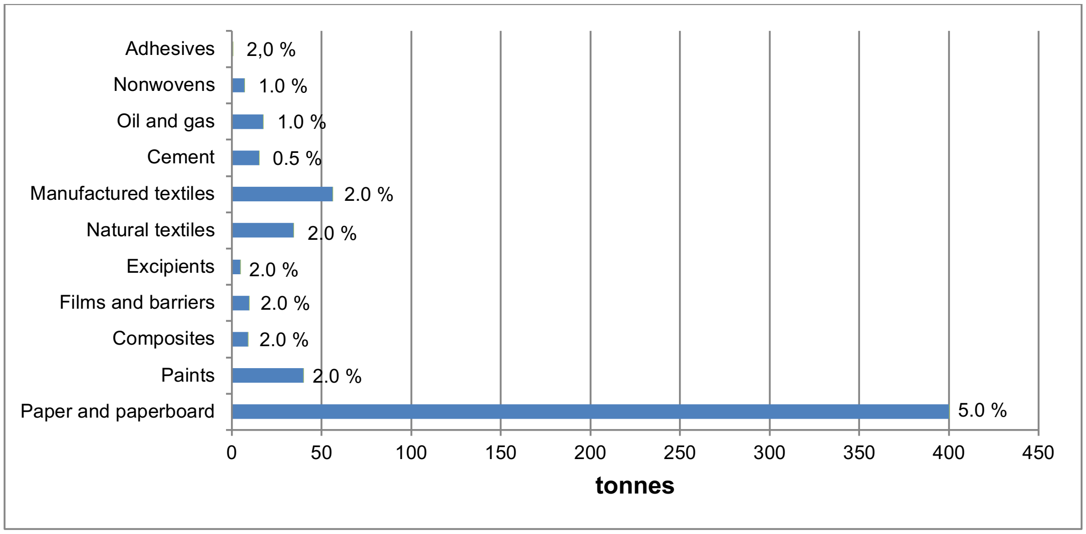
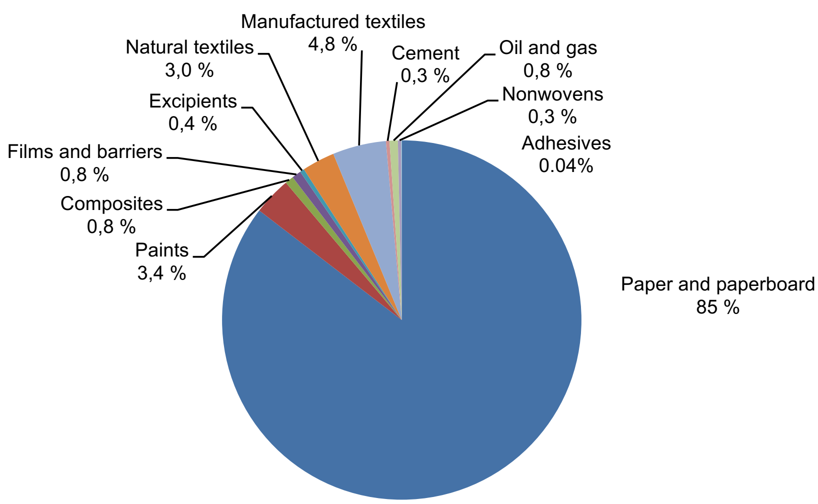
Figure 11-10: Nanocellulose End-use Market Sizes and Estimated Nanocellulose Future Potential (%) in Those Markets



Source: RISI, 2014

Figure 11-11: Future Potential of Nanocellulose by End-use Segments



Total annual market potential 23.5 million tons

Source: RISI, 2014

11.4 The Competitive Landscape

The global nanocellulose market is highly competitive. Several potential applications for nanocelluloses have been identified and developed, but there are also a high number of competing materials for those applications. Numerous companies have been exploring the possibilities of nanocelluloses. However, commercial applications are still scarce.

Nanofibrillar Cellulose

There are several active players in the field of nanofibrillar cellulose. Production is still at an early stage of commercialization, with research activities happening in all traditional forest industry regions including North America, Scandinavia, France and Japan.

The players who have significant production of nanofibrills currently are Paperlogic, Imerys with FiberLean Technologies, Borregaard, University of Maine, American Process Inc., Nippon Paper, Oji Holding and RISE Innventia.

- **Paperlogic** is a U.S. player with a 2000 kg/day (700 tons per annum) nanofibrillar cellulose demonstration plant in a Paperlogic mill in Turners Falls, MA. The demonstration plant started up in 2015 and uses technology by GL&V, first developed in conjunction with **University of Maine**
- **Imerys** is a world leader in industrial minerals. They have a **FiberLean Technology** facility for the production of FiberLean microfibrillar cellulose at Trebal, Cornwall UK with the capacity of 5000 kg/day (1750 tons per annum). In 2016, Imerys announced also signing of two commercial agreements with leading papermakers in Asia and the United States for the production of FiberLean microfibrillar cellulose. The combined capacity of these two plants is 20000 kg/day (7000 tons per annum)
- **Borregaard** is a Norwegian company that produces biochemicals, biomaterials and bioethanol that can serve as alternatives for oil-based products. Borregaard started commercial scale production of microfibrillar cellulose in Q3 2016, with the capacity of 3000 kg/day dry basis (1050 tons per annum dry basis). Borregaard has microfibrillar cellulose marketed with the name Exilva that can be used for various application areas. Borregaard pursues commercial development of Exilva in a consortium with Unilever and several research groups.
- **University of Maine** Process Development Center nanocellulose research program is part of a consortium led by the **US Forest Products Laboratory**. University of Maine has a nanofibrillar cellulose pilot plant with the capacity of 1000 kg/day at Jenness Hall. The facility opened in 2012.
- **American Process Inc.** started pre-commercial production of nanofibrillar cellulose and cellulose nanocrystals in April 2015 at the Thomaston biorefinery. The plant is a demonstration facility with the capacity 500 kg/day (175 tons per annum). American Process has joint development work with Birla Carbon on combining carbon black and nanocellulose for enhancing the sustainability and performance of tires, and with MyBiomass on the production of nanocellulose and cellulosic sugars from oil palm empty fruit-bunches.
- **Nippon Paper Crecia Co. Ltd.** is a Japanese producer of nanofibrillar cellulose with 150 kg/day (53 tons per annum) facility. They have announced that their TEMPO nanofibrillar cellulose has been commercially applied in deodorant sheets used in adult diapers.
- **Oij Holding** and **RISE Innventia** have both 100 kg/day (35 tons per annum) demonstration plants for nanofibrillar cellulose production.

Finnish forest companies **Stora Enso** and **UPM** are both exploring possibilities in the microfibrillar cellulose and nanofibrillar cellulose markets, respectively, and are at a pre-commercial phase. Stora Enso has been piloting new natural concept board grades containing microfibrillar cellulose in the Eastern Europe market with Elopak. Also **SAPPI**, a South African player in the field of nanocelluloses, started up a pilot plant in the Netherlands in 2016.

In addition, there are several initiatives with announced pilots, and numerous unreported lab scale facilities at universities, paper mills and other sites. In Japan alone, there are at least 8-10 pilot facilities with capacities ranging from a few tons up to 100 tons. Chuetsu Paper company announced a commercial plant of 3-400 tons that was to be completed in 2017. The Japanese government is very active in the field and has established a consortium including 20 governmental bodies and more than 200 companies supporting research activities in the field.

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Nanocrystalline Cellulose

There are three significant cellulose nanocrystals producers in the markets; CelluForce from Canada, American Process Inc. from US and Holmen/Melodea from Sweden.

In addition, there are several players who have small production and research in the field, including Alberta Innovates, US Forest Products Laboratory, Blue Goose Biorefineries and FPInnovations.

- **CelluForce** is a commercial leader in the production of cellulose nanocrystals. It is a joint venture between **FPInnovations** (Canadian forest products research and innovation centre), Domtar (a paper manufacturer) and recently also Schlumberger (in 2015) and Fibria (in 2016). CelluForce started up its 1 ton per year cellulose nanocrystals demonstration plant at the Domtar pulp and paper mill, Windsor QC in 2012. Recently CelluForce has joint forces with its strategic shareholders Schlumberger and Fibria for developing applications for cellulose nanocrystals. With Schlumberger, CelluForce is pursuing applications for cellulose nanocrystals in the oil and gas sector.
- **Holmen AB** is a Swedish forest industry group, which is a major shareholder of **Melodea**, a producer of cellulose nanocrystals from paper mill sludge. Holmen/Melodea started up a 100 kg per day cellulose nanocrystals pilot plant in Örnsköldsvik in 2016. The facility was first of its kind in Europe.

Cellulose Filaments

There are also players who have been active in cellulose filaments, which offer similar wood-derived products with comparable potential applications as nanocelluloses. These players include Performance BioFilaments and Kruger Inc.

- **Performance BioFilaments** is a joint venture between Mercer International and Resolute Forest Products for the commercialization of cellulose filaments. They focus on application development of high-value composite materials and chemical rheology modifiers.
- **Kruger Inc.** is a major forest industry company in North America. **FPInnovations** and Kruger Inc. built a first of a kind 5 ton/day cellulose filament demonstration plant at Kruger's Trois-Rivières Paper Mill, which started operation in March 2016.

11.5 Key Demand Drivers

One key driver of the nanocellulose market is the growing demand for packaging applications. Companies are constantly searching for sustainable, lightweight packaging materials for food and beverages, healthcare products as well as other consumer goods. This demand for feasible and sustainable packaging materials is expected to support nanocellulose market growth in the coming years.

11.6 Prices and Price Trends

Although nanocellulose has a wide range of potential applications, its high manufacturing costs inhibit its growth in markets. Low market price of pulp correlates to high potential for nanocellulose markets. As the technologies develop and markets grow, it is likely that the prices will drop in the next few years. Nanocellulose price varies a lot depending on nanocellulose type, quality, application, raw material and production process. Prices may vary from 10 to 1000 USD per kilogram.

11.7 Outlook

Nanocellulose is already used for cement manufacturing and pharmaceuticals (fillers). However, many nanocellulose applications are entering the market such as packaging barrier films and polymer composites. Emerging end uses include high-end medical and printable electronics applications. Nanocellulose is also considered as a sustainable and green alternative for flooding agents used in the oil and gas industry. The high dispersity, rheology and emulsifying properties of nanocellulose make it a viable alternative for the traditional fossil-derived flooding agents.

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11.7.1 Market Growth

The global demand for nanocellulose market was valued at USD 65 million in 2015 and it is expected to reach as high as USD 530 million 2021. The annual growth rate of the nanocellulose market is estimated to be 30 % during the forecast period 2016-2021. (Sources: Research and Markets, Market Research Store).

11.7.2 Opportunities

Nanocellulose market is emerging and nanocelluloses are considered an interesting future material with versatile potential applications due its rheology properties, lightweight and sustainable properties.

11.7.3 Constraints

The high cost of production of nanocellulose is one of the key factors limiting the growth of the industry. Nanocellulose materials are currently more expensive than traditional fossil-derived materials used in composites and foams. Manufacturers are hesitant to substitute materials with higher cost alternatives, because it leads to more expensive products, which may cause declines in product sales.

Depending on which raw material, production technology, end-product and industry is in focus, the hurdles are different. Scalability of processes, low yields, end-product drying and processing of nanocellulose in composite materials are among some of the main challenges. Moreover, nanocellulose materials are not drop-in products, which has implications for the customer processes.

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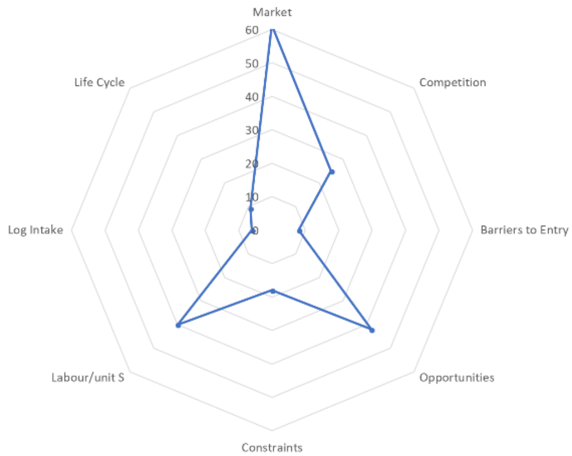
12. POLYLACTIC ACID (PLA)

Polylactic acid is among the most attractive options for Maine, reaching a total score of 210. Highest scores are for markets (61) and market opportunities (42).

Figure 12-1: PLA Attractiveness Score



The following section outlines in detail the market opportunity for polylactic acid for Maine.

12.1 Product Description

12.1.1 The Product

Polylactic acid is a compostable (biodegradable) bioplastic. In industrial composting facilities, polylactic acid decomposes to carbon dioxide, water, and biomass (humus). The plant-based polymer has a small carbon footprint (cradle-to-plant-gate carbon dioxide emissions) compared with competing fossil fuel-based plastics such as polypropylene, polystyrene, and polyethylene terephthalate. It is produced by polymerization of fermented lactic acid.

Polylactic acid applications include food service ware (e.g. transparent bakery and deli containers and lids, carry out boxes and cutlery), fresh food packaging (e.g. foam trays), coffee capsules for single-serve coffee makers, and shopping bags, among others.

Packaging made of polylactic acid has excellent tensile strength, rigidity, glossiness and clarity. Polylactic acid acts as an aroma barrier and can therefore be used for packaging material for products such as fruits and vegetables.

Development of novel applications is ongoing, including for durable applications in the automotive industry, floor coverings and electronics.

It is currently the best substrate for 3D printing of consumer goods such as toys.

12.1.2 Manufacturing Process

Fermented lactic acid is polymerized into polylactic acid. The polymerization is completed either in one step as direct polymerization or in two steps via lactic acid dimer (lactide) and ring opening polymerization.

Two-step polymerization is mostly used in commercial practice. The process comprises the following steps, as shown below:

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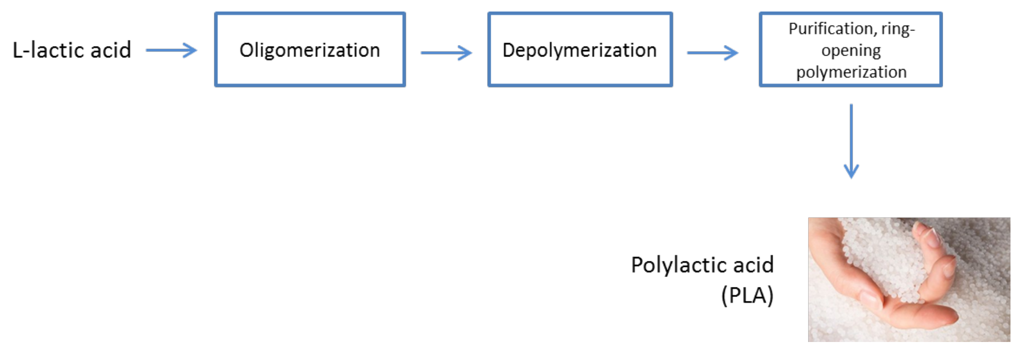
Figure 12-2: Two-step Polymerization of L-lactic Acid to Polylactic Acid



Source: IHS, Neste Engineering Solutions

L-lactic acid is first oligomerized to a linear chain with a molecular weight of 300−3,000. The oligomer is then depolymerized to lactide, a cyclic dimer. After purification, the lactide undergoes ring-opening polymerization to produce polylactic acid with a molecular weight of 50,000−100,000 or higher. Most production processes are continuous and operated at high temperatures without solvent use.

Polylactic acid can also be depolymerised to return into its original monomer state-lactic acid, which after purification, can be reused to manufacture PLA.

Most commercial grades of polylactic acid consist primarily of L-lactic acid units, with D-lactic acid units accounting for 5% or less of the polymer backbone. Modifying the level of D-lactic acid units in the base polymer has a significant impact on physical properties. Polylactic acid with moderately high levels of D-lactic acid units (i.e., 10% or more) are amorphous; these materials can serve as binders in adhesives and coatings for packaging applications.

Polylactic acid can be compounded with additives such as chain extenders, nucleating agents, impact modifiers, and melt-strength enhancers to improve performance or facilitate processing. In addition, it can be blended with polymers such as copolyesters. The resulting resins are suitable for a range of thermoplastic processing methods, including extrusion/thermoforming, injection moulding, film and sheet extrusion, fibre production, and expanded foam sheet production.

12.1.3 Polylactic Acid

In 2014, the two most important biodegradable polymers were polylactic acid and starch-based polymers, accounting for 41% and 38%, respectively, of total biodegradable polymers consumption.

Polylactic acid is the only economically viable bio-degradable and bio-based polymer enabling 100% bio-based consumer board.

12.2 Market Size and Growth

Production capacity

Polylactic acid market accounts for 275kt per annum (2015). Rigid packaging is the dominant end use for polylactic acid, (about 10% of total production capacity) followed by applications in flexible packaging, textiles, electrics and electronics, building and construction, among others.

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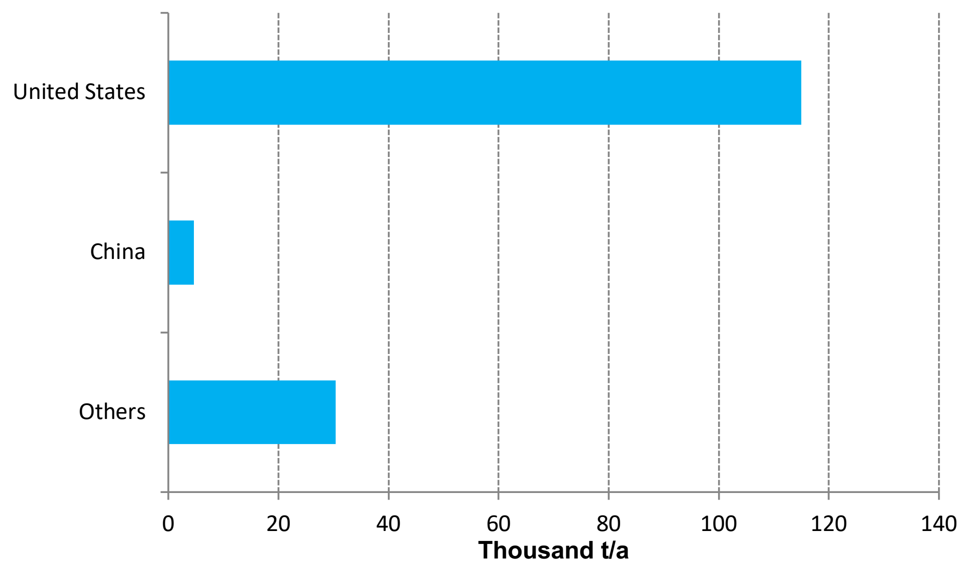
Supply

Polylactic acid supply is dominated by the United States. In 2014, production was approximately 115 kt per annum; some 30-35 kt per annum were exported, primarily to Asia and Western Europe.

China's polylactic acid production totalled 4.6 kt per annum in 2014. The industry in China remains at an early stage of development. Many companies have entered the business with the production capacity in China expanding rapidly over the last 10 years.

Figure 12-3: Polylactic Acid Supply-2014



Source: IHS, Neste Engineering Solutions

Demand

Global polylactic acid demand accounts for 150 kt per annum. North America is by far the largest consumer with a consumption of 83 kt per annum in 2014. Polylactic acid makes up 74% of biodegradable polymers consumption, with starch-based polymers and other biodegradable polymers accounting for 13% each. Food packaging is the largest end-use segment in North America.

Western Europe is the second largest polylactic acid consumer with a consumption of 30 kt per annum in 2014. It is the second dominant biodegradable polymer after starch-based biodegradable polymers. Polylactic acid consumption accounts for 16% of biodegradable polymer consumption. Food packaging is the largest end-use segment in Western Europe.

Asia and Oceania are the third largest polylactic acid consumers with a consumption of 21 kt per annum in 2014. Polylactic acid is the dominant biodegradable polymer, responsible for 56% of consumption. Starch-based polymers account for 21% of consumption, and all other biodegradable polymers make up the remaining 23%.

China is the fourth largest consumer, with 8kt per annum. The main end-uses in China are packaging and container applications, including disposable bags and various food containers, and other applications such as agricultural mulching film. There are high growth expectations in China due to improving manufacturing technology and also due to the increasingly strict environmental protection regulations that will favour biodegradable packaging in the future.

Japan is the fifth largest consumer with 6kt per annum. Polylactic acid is imported from NatureWorks (United States), while lactide used for production is mainly imported from Corbion (Thailand).

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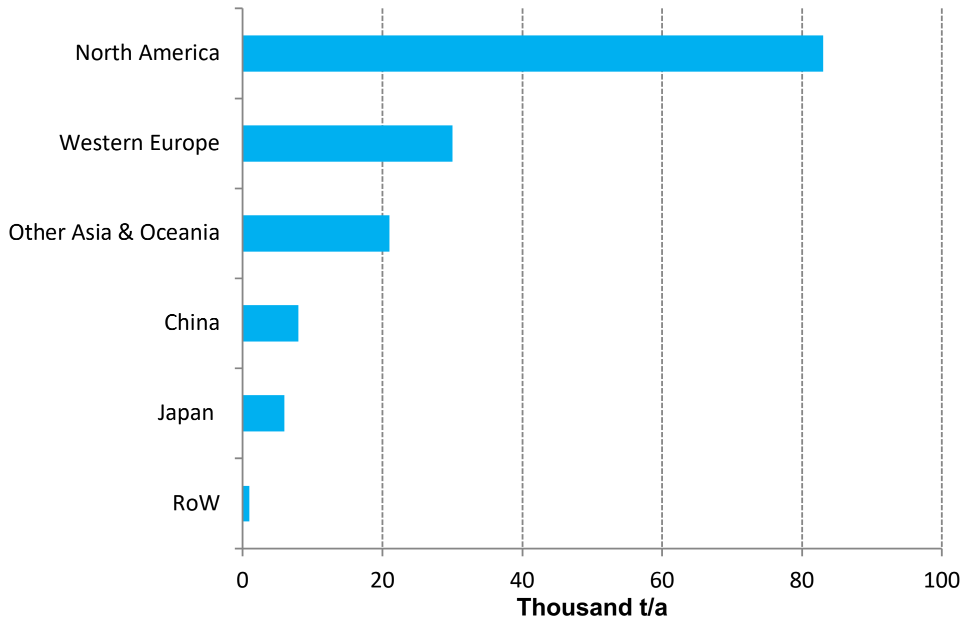
Figure 12-4: Polylactic Acid Demand-2014



Source: IHS, Neste Engineering Solutions

12.3 The Competitive Landscape

Competitors

NatureWorks LLC, a joint venture of Cargill and PTT Global Chemical Pcl, Thailand, is the largest PLA producer in the United States and the world. Its polylactic acid is sold under the Ingeo™ trade name. The company's plant in Blair, Nebraska, has an annual production capacity of 150 kt per annum (2015). Cargill, which produces lactic acid at a nearby facility, supplies the lactic acid feedstock. NatureWorks and PTT Global Chemical are considering the construction of a second plant of similar size in Thailand.

Corbion is the second largest polylactic acid producer. Corbion recently started up a production plant in Thailand with a capacity of 75 kt per annum.

Both Cargill and Corbion are also producing lactic acid.

Chinese manufacturers Hebei and SUPLA (Suqian) New Material Co. are the third and fourth largest producers.

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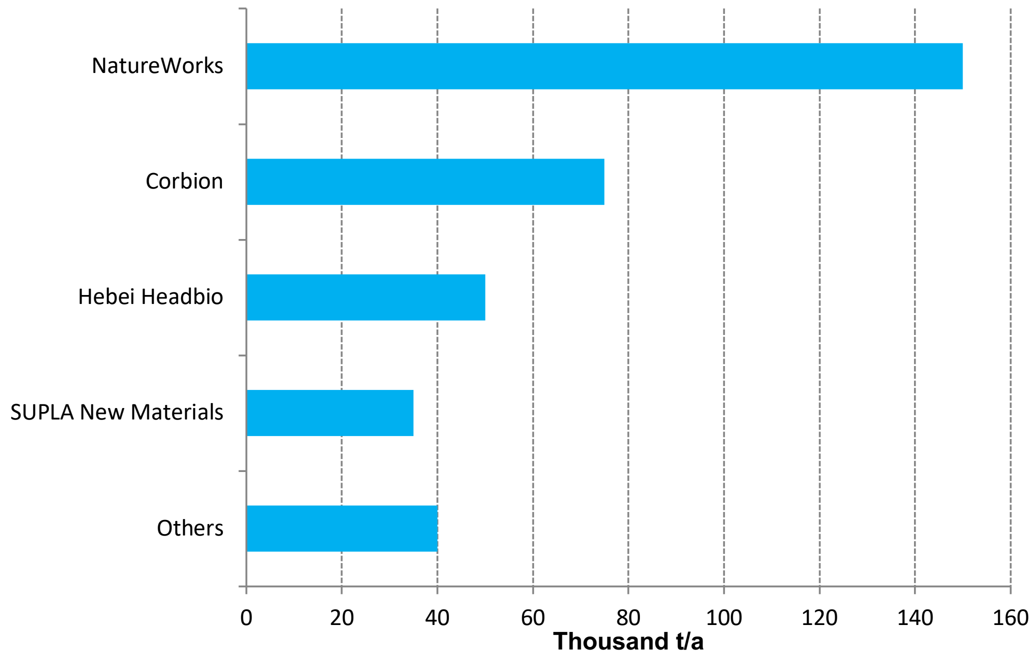
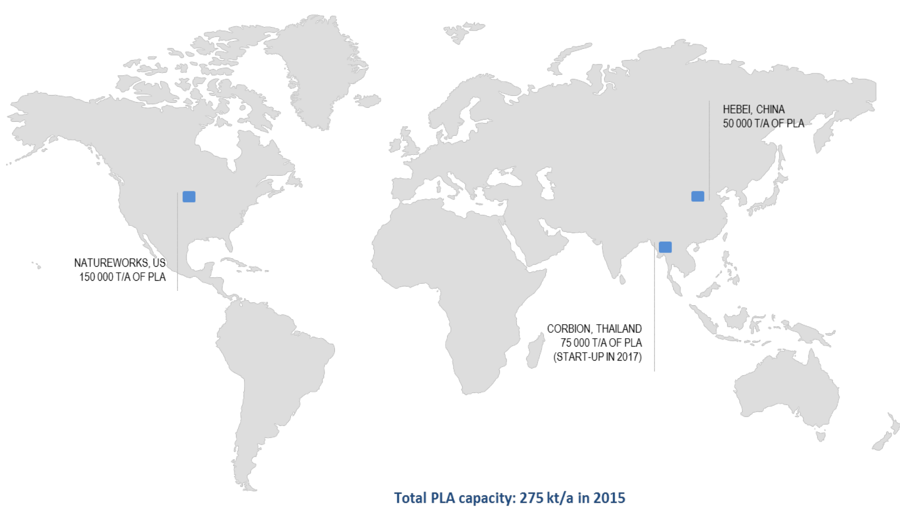
Figure 12-5: Major Producers of Polylactic Acid



Source: IHS, Neste Engineering Solutions

Figure 12-6: Map Showing Top Polylactic Acid Producers



Source: IHS, Neste Engineering Solutions

12.4 Barriers to Entry

Low crude oil and natural gas liquid prices, which result in lower prices for competing fossil fuel-based polymers, could lead to slower demand growth for polylactic acid.

The lack of composting infrastructure in many regions may be a significant obstacle to widespread use of biodegradable polymers such as polylactic acid.

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Municipal solid waste disposal costs influence local government policies and regulations for biodegradable polymers. These factors could lead to slower demand growth.

12.5 Key Demand Drivers

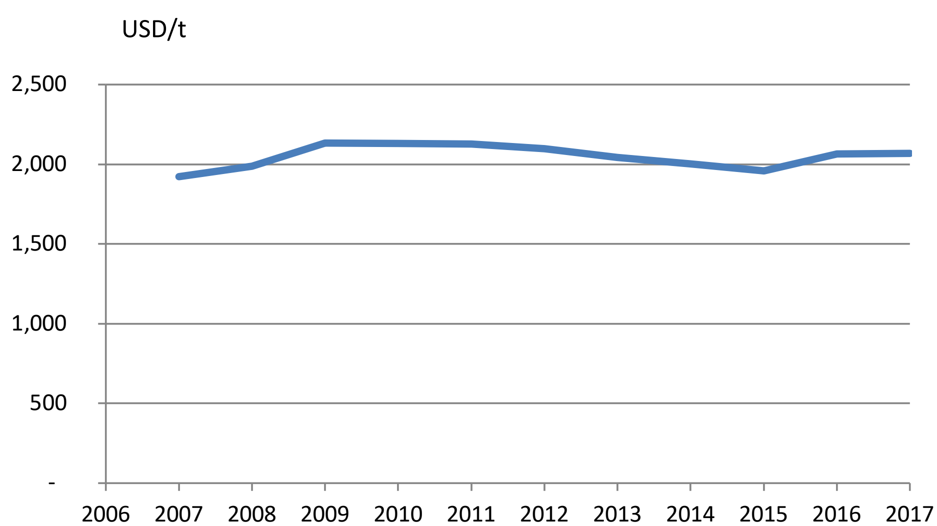
Key demand drivers for polylactic acid include:

- consumer demand for environmentally-friendly products;
- compostable (biodegradable) biopolymer properties;
- manufacturers' and retailers' interest in sustainable packaging materials to support their corporate sustainability goals such as reducing waste (particularly waste sent to landfills), decreasing greenhouse gas emissions and increasing sustainability of packaging;
- improved properties (e.g. better heat resistance, strength, etc.) and processability that allow use in a broader range of applications;
- strict environmental legislation that supports further the use of biodegradable polymers; and
- lower production costs due to technological improvements in the manufacturing process.

12.6 Prices and Price Trends

Polylactic acid price has been steady over the past ten years. Prices are expected to drop in the future as the market develops and production of increases. According to Eurostat, the average polylactic acid price in Europe was 2070 USD/t in 2017.

Figure 12-7: Polylactic Acid Prices in Europe



Source: Eurostat

12.7 Outlook & Market Growth

Overall, bio-based plastics have well-established markets globally with the markets growing by 4% per annum on average. The polylactic acid market growth is projected at 13.2% per annum

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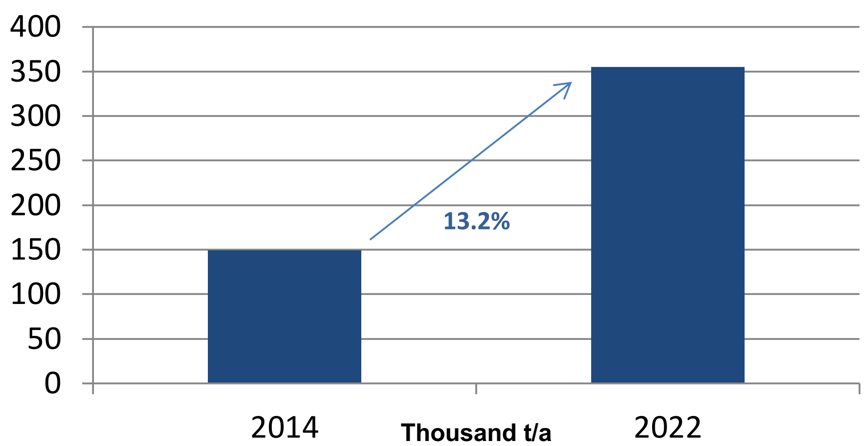
during the forecast period of 2014-2022, more than doubling the current consumption. The share of bio-based plastics is forecasted to increase the most in rigid packaging end use (incl. food service ware).

The Chinese market, in particular, is expected to expand significantly during the next decade. China's high growth is attributed to several factors, including an increase in production capacity, demand for environmentally friendly products, and the government's plastic-waste control legislation.

Figure 12-8: Polylactic Acid Global Outlook and Market Growth (2014-2022)



Source: IHS, Neste Engineering Solutions

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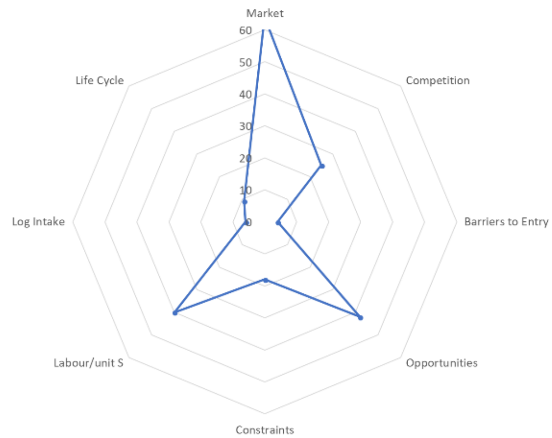
13. LACTIC ACID

Lactic acid is among the more attractive options for Maine, with a total score of 208. Highest scores are obtained for markets (64) and market opportunities (48).

Figure 13-1: Lactic Acid Attractiveness Score



The following section outlines in detail the market opportunity for lactic acid produced in Maine.

13.1 Product Description

13.1.1 The Product

Lactic acid belongs to the C3 chemical building block. Lactic acid is produced by microbial fermentation of sugars from biomass. Lactic acid is a bulk chemical with long history; traditionally it has been widely used as an acidulant, flavour enhancer and shelf-life extender and preservation enhancer in food and beverage products. Lactic acid is also used as solvent in the pharmaceutical and chemical industries. Another use of lactic acid is as an ingredient in personal care products due to its moisturizing, pH regulating and skin lightening properties. A growing use for lactic acid is in production of biodegradable polymer polylactic acid for packaging (shopping bags, packaging films, disposable cups and lids, and rigid packaging).

13.1.2 Manufacturing Process

Lactic acid is produced mainly by fermentation of glucose or sucrose originating from first generation biomass feedstocks such as corn starch, sugar cane, sugar beet and cassava.

Fermentation technology that utilizes second generation biomass fractions (e.g. bagasse, corn stover, wheat straw and wood chips) as starting materials is currently under development.

Lactic acid from fermentation is produced either as L-(+) or D-(-) optical isomers. L-(+) isomer is the dominant commercial product. A mixture of equal amounts of L-lactic and D-lactic acids may be produced by chemical synthesis.

Because of its hygroscopic nature, lactic acid is typically sold as a concentrated aqueous solution. The standard commercial product is a clear, almost colourless, syrup-like liquid containing 88% wt. lactic acid. More dilute (50%, 80%) solutions are also available.

The key process steps in lactic acid production are shown below:

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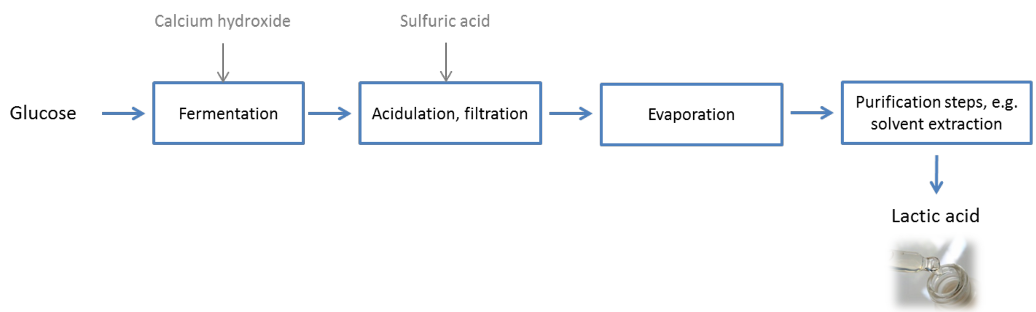
Figure 13-2: Key Steps in Lactic Acid Production



Source: IHS, Neste Engineering Solutions

Adjustment of pH in the fermentation yields calcium lactate, which is converted with sulfuric acid into crude lactic acid. Further purification gives the final concentrated product.

13.1.3 Interesting Facts

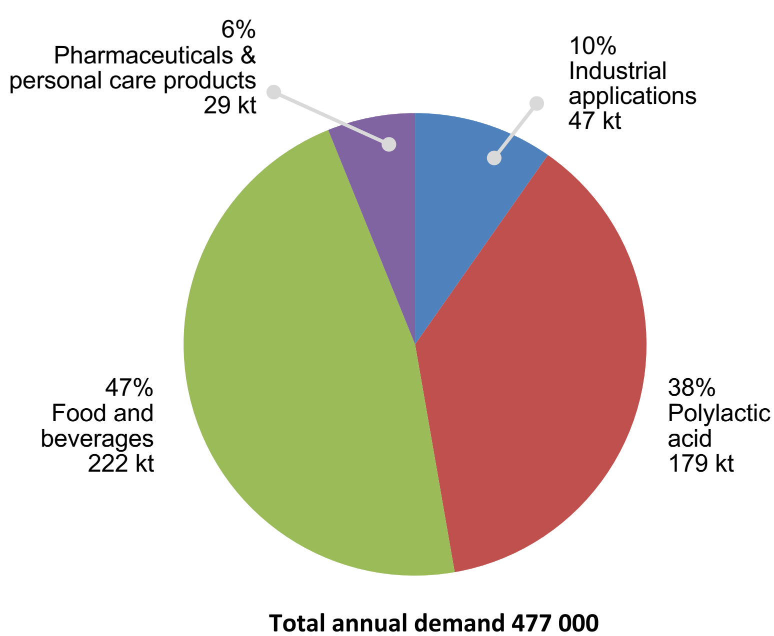
There is high market potential as lactic acid serves increasingly as a raw material for polylactic acid production.

The future demand of lactic acid will primarily be driven by increased demand for polylactic acid.

13.2 Market Size and Growth

Lactic acid market accounts for about 477kt per annum (2015). Food and beverage production is the dominant end use for lactic acid, accounting for 47% of total consumption, followed by polylactic acid production (38%), industrial applications (10%) and solvent applications in pharmaceuticals and personal care products (6%).

Figure 13-3: Lactic Acid Consumption by Application (2015)



Source: IHS, Neste Engineering Solutions

Production Capacity

Global lactic acid production capacity accounts for 717 kt per annum (2015).

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The US is the largest lactic acid producer, accounting for 38.4% (275 kt per annum) of the global lactic acid production capacity. The majority of produced lactic acid is consumed domestically. However, the United States is also a significant exporter of lactic acid. It is a major supplier to Canada and Mexico, where food and beverage applications drive lactic acid consumption.

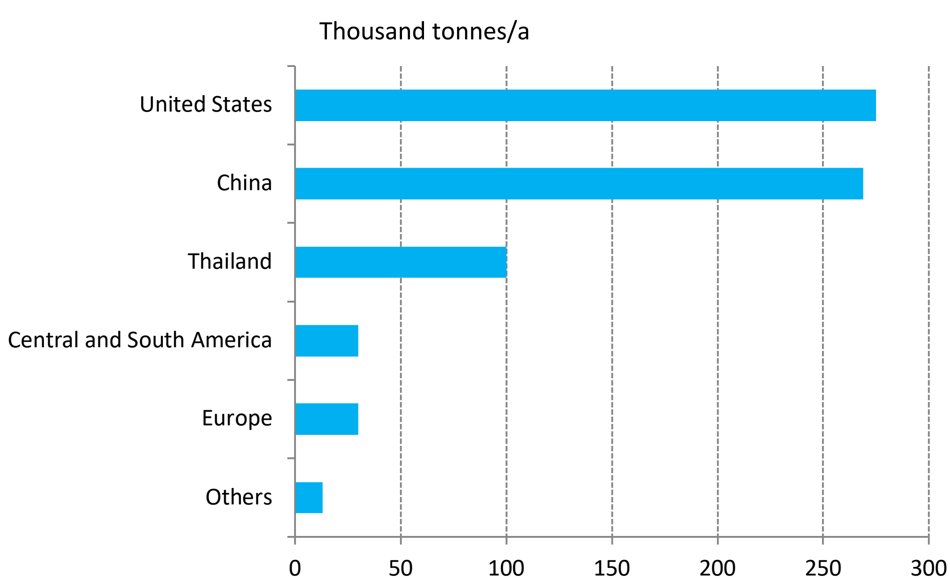
The second largest lactic acid producer is China with production capacity of 269 kt per annum (37.5% of global production capacity). Lactic acid has been produced in China since the 1950s by fermentation of feedstocks from rice, sweet potatoes, and corn. Currently there are eight lactic acid producers in China.

The third largest lactic acid producer is Thailand with a production capacity of 100 kt per annum (14% of global production capacity). Thailand has drastically increased production of lactic acid since 2007 because of the start-up of Corbion's plant. Corbion chose Thailand for the plant location because of its abundant agricultural feedstocks such as sugar or tapioca starch. Majority of lactic acid production is for export purposes. Thailand's exports are destined for more than 20 countries, including the Netherlands (38% of the total exports), Spain (32%), Japan (8%), China (5%), India (4%), and Malaysia (3%). Thailand may also become a major polylactic acid manufacturer in the future.

Production capacity of lactic acid in Central & South America is 30 kt per annum (4% of global production capacity). There are four major producers of lactic acid derivatives (ammonium lactate, calcium lactate, sodium lactate, etc.) in Brazil. For the most part, production capacities are small.

European lactic acid production capacity is rather small, accounting for only 30 kt per annum (4% of global production capacity). In Western Europe, capacity and production of lactic acid was reduced in 2008 following the decision by Purac (now Corbion) to move European production to facilities in Thailand, Brazil, and the United States. In 2012, domestic capacity and production of lactic acid increased as Jungbunzlauer commenced operations at its new plant in Marckolsheim, Germany.

Figure 13-4: Lactic Acid Supply (2015)



Source: IHS, Neste Engineering Solutions

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Demand

Global lactic acid demand accounts for about 477 kt per annum (2015).

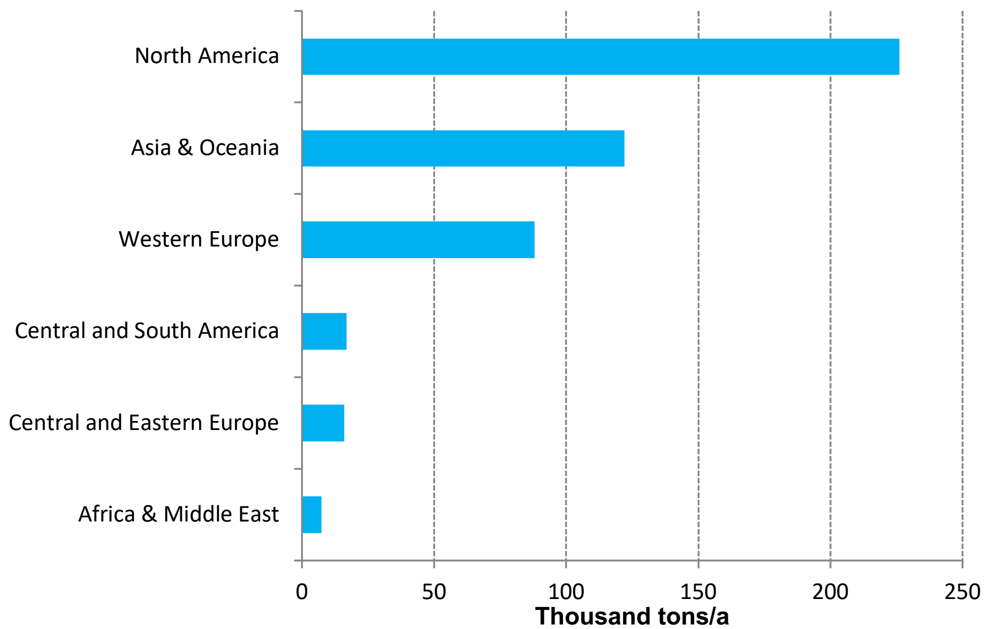
North America is the largest consumer of lactic acid. Polylactic acid production is the major end use for lactic acid, with food and beverage applications second in importance.

In Asia and Oceania (ssecond-largest consuming region) consumption is mostly driven by food and beverage applications. Industrial end uses and polylactic acid manufacture are playing smaller roles.

In Western Europe, food and beverage applications account for the bulk of consumption, followed by industrial end uses.

In other regions, food and beverage applications dominate lactic acid consumption.

Figure 13-5: Lactic Acid Demand (2015)



Source: IHS, Neste Engineering Solutions

13.3 The Competitive Landscape

Competitors

The structure of lactic acid industry is quite concentrated as the four largest lactic acid producers account for almost 80% of world production capacity.

Corbion and Cargill are the leading producers of lactic acid, covering more than 56% of the total capacity.

Corbion is the world's largest producer of lactic acid, with manufacturing facilities in the United States, Brazil, and Thailand. Corbion currently manufactures lactide -a dimer of lactic acid, in Thailand. This polymer is intended for biomedical end uses such as resorbable implants. Lactide may also serve as the starting material for polylactic acid.

Cargill, Inc. is the second largest lactic acid producer. Output from the company's US lactic acid facility primarily supports polylactic acid manufacture at NatureWorks LLC, the world's largest producer. NatureWorks is a joint venture of Cargill and PTT Global Chemical Public Company Limited, Thailand.

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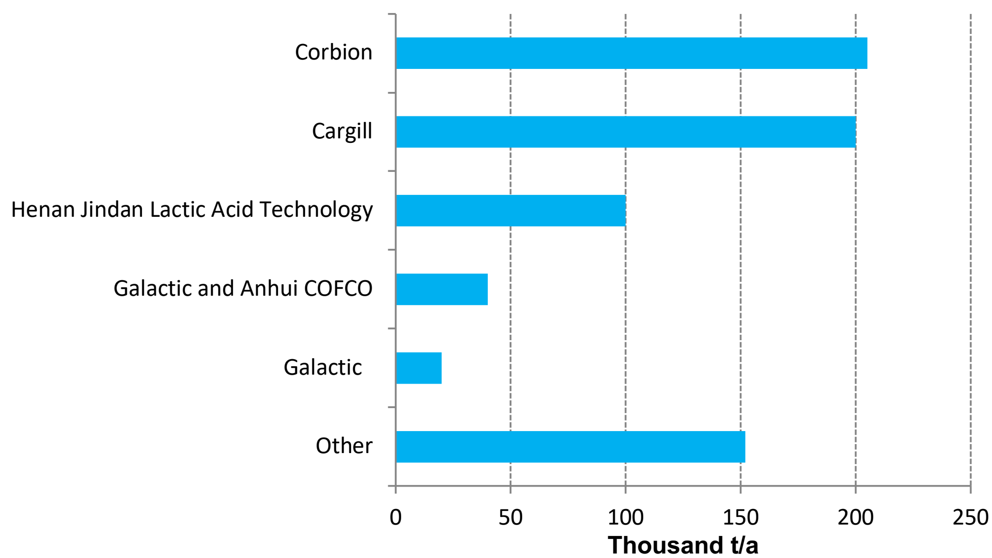
Henan Jindan Lactic Acid Technology Co., Ltd., is the third largest producer; they currently supply lactic acid for food and beverage, pharmaceutical and personal care products, and industrial applications.

Partners Galactic and Anhui COFCO Biochemical Co. are the next largest producers. Their joint venture, **Galactic and Anhui COFCO**, manufactures lactic acid in China. Galactic also produces lactic acid in Belgium.

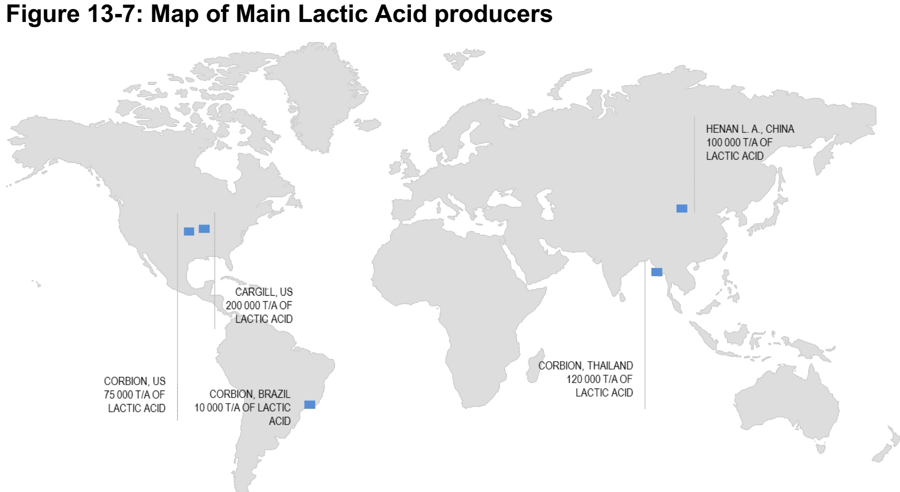
57% of the Lactic Acid production capacity is located in Asia-Pacific (APAC) region, followed by United States with share of 38%.

Figure 13-6: Major Producers of Lactic Acid



Source: IHS, Neste Engineering Solutions

Figure 13-7: Map of Main Lactic Acid producers



Total lactic acid capacity: 717 kt/a in 2015

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Source: IHS, Neste Engineering Solutions

13.4 Barriers to Entry

Lactic acid producers must compete with producers of other fermentation chemicals (such as ethanol, citric acid, and amino acids) for the available feedstocks, which have been in short supply in recent years because of the rapid expansion of the fuel ethanol industry.

Lactic acid consumption for food and beverages may decline due to competition from alternative antimicrobial solutions such as vinegar. For example, such competition is expected to limit growth of lactic acid consumption for food and beverage, especially in the United States.

13.5 Key Drivers for Demand

Lactic acid demand drivers vary from region to region.

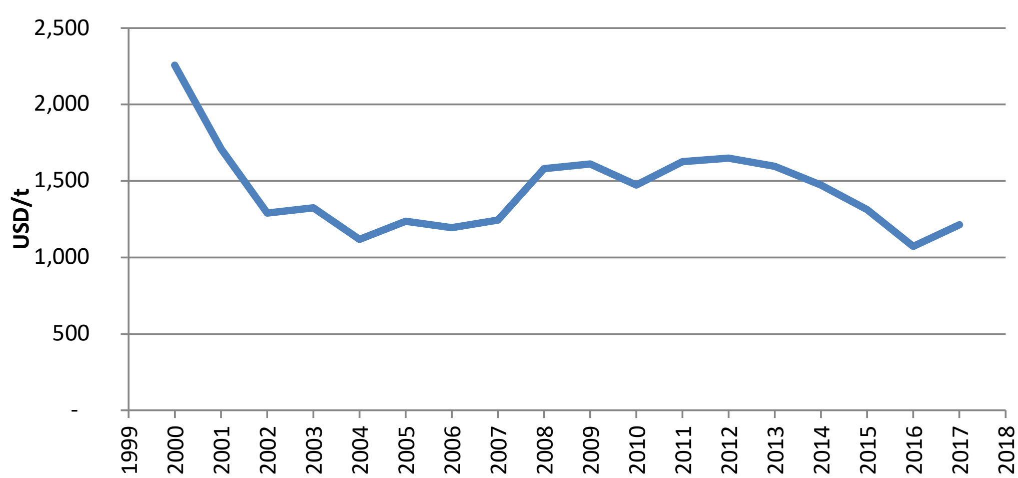
In the United States, the key demand driver for lactic acid is the polylactic acid market. Demand for polylactic acid in food-packaging applications and other established end uses continues to increase, and new applications such as three-dimensional (3D) printing filament are emerging.

In the rest of the world demand is driven mainly by the food and beverage markets where lactic acid is used as an acidulant and preservative.

13.6 Prices and Price Trends

Lactic acid prices are dependent on product purity, quality and packaging (bulk or other). The price of technical grade lactic acid is normally lower than that of food-grade lactic acid. Prices are expected to drop as the market develops and production of lactic acid increases. According to Eurostat, the average lactic acid price in Europe was 1215 USD/t in 2017.

Figure 13-8: Lactic Acid Prices in Europe



Source: Eurostat

13.7 Outlook & Market Growth

Demand for lactic acid is expected to grow by 6.4% per annum globally during the forecast period 2015-2020. The growth will be fastest in the United States, China and other Asia as a result of increased polylactic acid production. In other regions, where demand is driven mainly by food applications, moderate consumption growth is expected. A detailed outlook for selected global markets is presented below:

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United States: lactic acid consumption is expected to grow significantly by 8% per annum as it is driven mainly by the growing polylactic acid market.

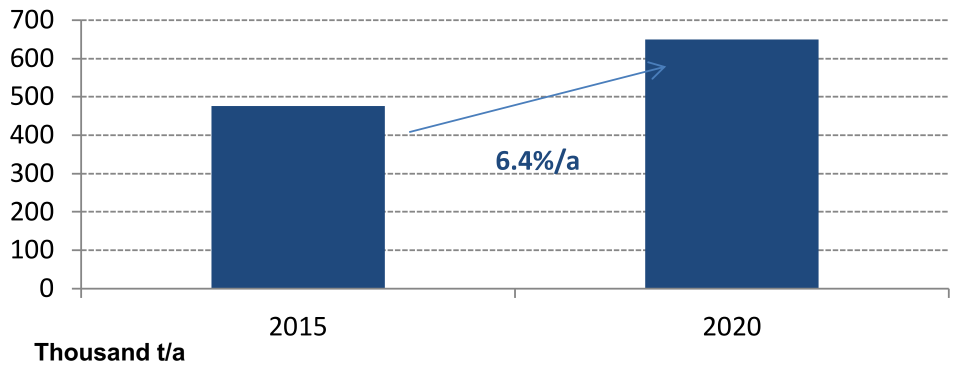
Central and South America: lactic acid consumption for food and beverage applications is expected to grow moderately at 2.5% per annum.

Western Europe: consumption of lactic acid for use in food and beverage applications is expected to grow moderately at 2.5% per annum.

China: consumption of lactic acid for polylactic acid production (a comparatively small-volume end use at present) will increase significantly during the forecast period. Average annual consumption of lactic acid is expected to grow by 8.9% per annum.

Japan: Consumption of lactic acid for polylactic acid production-currently, the smallest end use- is expected to grow by 3.7% per annum.

Figure 13-9: Lactic Acid Global Outlook and Market Growth (2015-2020)



Source: IHS, Neste Engineering Solutions

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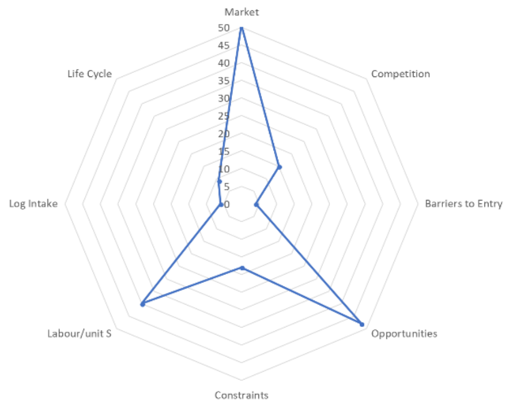
14. SUCCINIC ACID

Succinic acid is among the moderately attractive options for Maine, reaching a total score of 190. Highest scores are obtained for markets (51) and market opportunities (40).

Figure 14-1: Succinic Acid Attractiveness Score



The following section outlines in detail the market opportunity for succinic acid produced in Maine.

14.1 Product Description

14.1.1 The Product

Succinic acid is a C4 building block chemical. Majority of succinic acid production is currently petroleum-based, however, bio-based succinic acid production is expected to gain share as commercial production of bio-based succinic acid has emerged in recent years.

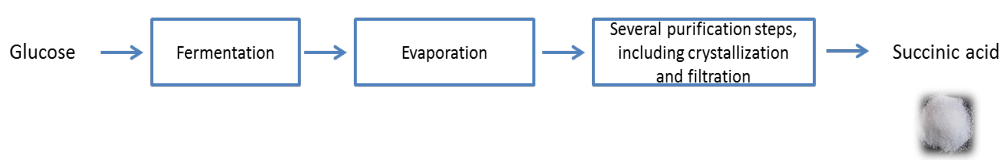
The appearance of succinic acid is colourless to white, crystal or powder and it is soluble in water. It offers broad application potential ranging from industrial markets, such as polyurethanes, resins and coatings to smaller, speciality markets, including personal care, flavours and food, as well as a precursor for other chemicals such as 1,4 butanediol (BDO).

14.1.2 Manufacturing Process

Production of petroleum-based succinic acid is via hydrolysis of maleic anhydride (MA).

Bio-based succinic acid can be produced by bacterial or yeast fermentation of glucose. Using yeast that tolerates low pH is beneficial, because no alkaline needs to be added, and thus no salt is formed. The salts forming in bacterial fermentation need to be converted into acid form with sulphuric acid. The key process steps in succinic acid production are shown below:

Figure 14-2: Key steps in Succinic Acid Production



Source: IHS, Neste Engineering Solutions

Commercial routes are still being optimized. The feedstocks used for production of bio-based succinic acid include wheat, maize, lignocellulosic derived sugar or sorghum grain processed to starch.

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14.1.3 Interesting Facts

Bio-based succinic acid is identical in structure to petrol-based and can be directly substituted into a broad range of processes and applications.

Bio-based succinic acid is cheaper to produce than its petrol-based counterpart.

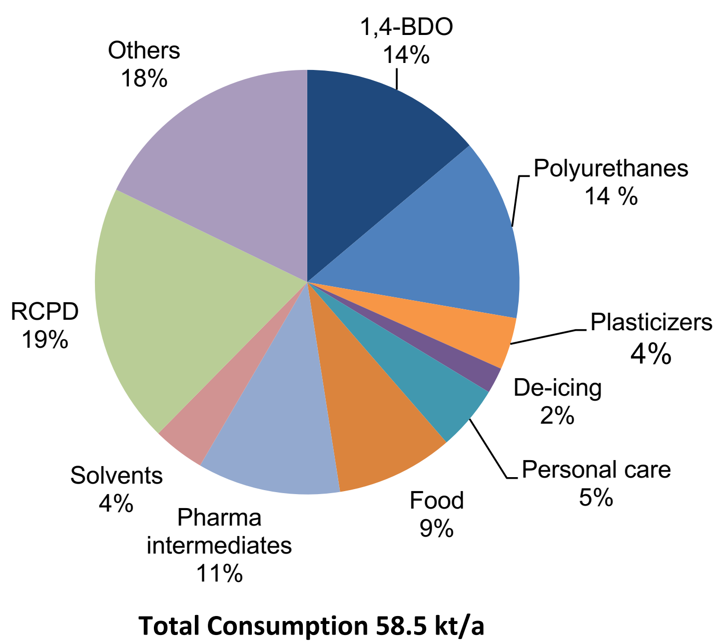
14.2 Market Size and Growth

The global market size for succinic acid is estimated to be at some 59 000 t per annum (2016). Succinic acid is versatile chemical and it offers broad application potential. It can be used in industrial markets, such as polyurethanes, resins and coatings (i.e. replaces mainly adipic acid) and in smaller, speciality markets, including personal care, flavours and food.

There is strong future demand growth potential for succinic acid and its derivatives, which is expected to be driven by BDO and polyurethanes. These two end uses are forecasted to account for over 60% of the total future consumption.

Polybutyle succinate polymers as a new application can be used to replace conventional plastics, such as carrier bags, garbage bags, single-use food catering, packaging film or bottles. The market is currently very small, but it is expected to grow in the near future.

Figure 14-3: Succinic Acid Application Structure (2016)



14.3 The Competitive Landscape

14.3.1 Suppliers

BioAmber is a pioneer in bio-based succinic acid production and is currently the leading producer. BioAmber's bio-based succinic acid plant with annual capacity of 30 000 tons is

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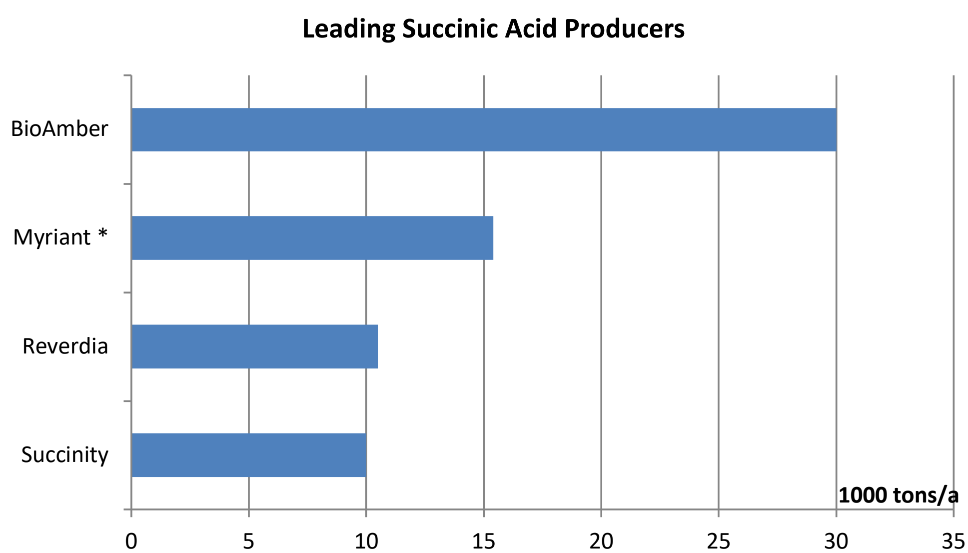
located in Sarnia, Canada. Construction was completed in 2015 and the company is currently focusing on selling out the capacity of the plant. Utilization rates are not confirmed. The company focuses on lowering costs to gain increased market share (target is to reduce variable costs by 25-30%). Technical proof-of-concept still needed for new applications (e.g. PET bottles, polyurethanes).

BioAmber Inc. is also planning to build the second world-scale plant in North America that will produce 1,4-butanediol (BDO), tetrahydrofuran (THF) and succinic acid. Planned capacity is expected to be around 100,000 tons of BDO/THF and 70,000 tons of succinic acid per year.

Succinity is a joint venture between BASF and Corbion with a bio-based succinic acid plant in Spain (annual production capacity of 10 000 tons). The company is testing and validating the succinic acid value chain, one the main drivers being development of complementary product, polybutyle succinate, for polylactic acid. Corbion announced in Nov 2017, that Succinity is minimizing current investment level until production route is optimized (key condition for positive market development).

Reverdia is a joint venture between DSM and Roquette. It operates its bio-based succinic acid plant in Cassano, Italy (annual production capacity of 10 000 tons). The company has announced it is "investing substantially" in market and application development; for example, alkyd paints, microcellular polyurethane foams for footwear and polybutyle succinate.

Figure 14-4: Leading Succinic Acid Producers and their Capacities



Total succinic acid capacity: 65 kt/a in 2015. In 2017, it has announced that Myriant refocuses its activities away from producing bio-based succinic acid and towards R&D.

The largest succinic acid facility is in Canada (BioAmber). Key production facilities are also located in the US (Myriant) and Europe (Succinity and Reverdia).

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Figure 14-5: Main Succinic Acid Producers

* In 2017, Myriant refocused its activities away from producing bio-based succinic acid and towards R&D (non-confirmed information).

14.3.2 Competing and Substituting Products

Succinic acid can be used as a drop-in substitute for fossil-based succinic acid, and as a bio-based building block for a large number of chemicals. Bio-based succinic acid is cheaper to produce than its fossil-based counterpart.

14.4 Key Demand Drivers

Main drivers for succinic acid demand include:

- consumer demand for environmentally friendly products;
- BDO, PBS and polyester polyol markets, which provide the largest market potential for succinic acid;
- several companies have aggressive growth plans; and
- the cost of bio-based succinic acid is in line with that of petrochemical succinic acid.

However, low-price fossil feedstocks create a need for bio-based production process optimization. Also limited access to feedstocks, especially in Europe hinders the development as well as slows down the application development.

14.5 Prices and Price Trends

Current succinic acid price is about 2 000 USD/t in North America (US). The price has been decreasing since 2014 (2 800 USD/t) and price pressures due to market development and production increases are expected to continue.

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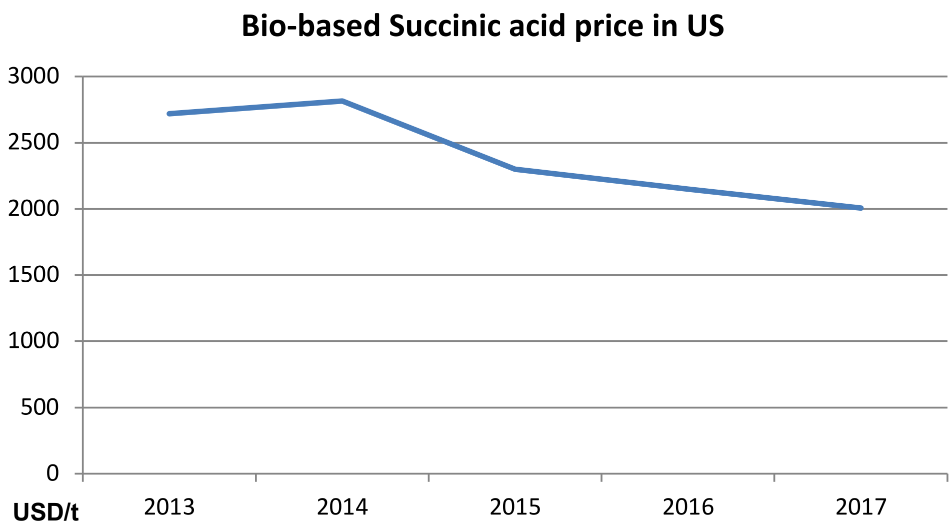
Figure 14-6: Bio-based Succinic Acid (DDP) Price Development in North America (US)



Source: Technon Orbichem

14.6 Outlook

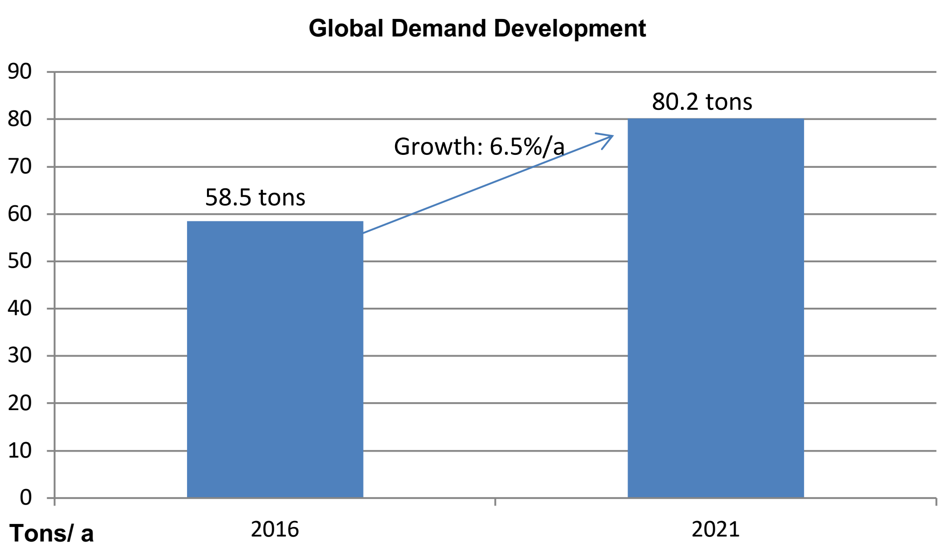
14.6.1 Market Growth

The global market size for succinic acid is estimated at some 58 500 t per annum (2016). The demand is projected to grow annually by some 6.5% per year, resulting in to over 80 000 t per annum by 2021.

BioAmber is planning to invest in a second plan with annual succinic acid capacity of 170 000 t with off-take agreements. The plant's planned output will be 70 000 t per annum of succinic acid, 100 000 t per annum of BDO and THF. However, BioAmber announced in November 2017 that it is currently focused on significant reduction in variable costs (25-30%).

Europe is currently estimated to be the largest market in terms of value for succinic acid, while the market growth is the strongest in Asia Pacific.

Figure 14-7: Succininc Acid Demand Development



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14.6.2 Value chain and succinic acid derivatives

Main derivatives of succinic acid are 1,4-butandiol (BDO) and polybutylene succinate (PBS). 1,4-BDO is used in resins, fibres, coating and other downstream chemical products, which are mainly used in manufacturing of engineering plastics and in the application of polyurethane in the leather industry. Some 50% of the global BDO capacity is utilized as an intermediate for production of Tetrahydrofuran, an intermediate in production of Spandex and Lycra fibres. Tetrahydrofuran is also used as solvent in pharmaceuticals. Majority of the BDO production is petrol based, but bio-based BDO is under development and also produced today.

Polybutylene succinate is a key polymer used in production of bioplastics and is an important application for bio-based succinic acid with significant growth potential. It is completely bio-based and bio-degradable. It is mostly used as a blend partner in combination with other bioplastics (such as polylactic acid), and plays an important role in the development of new bioplastics products. Applications include food packaging, food service ware, single-use coffee capsules, agricultural products (mulch films), but also durable applications, e.g. composite materials for automotive.

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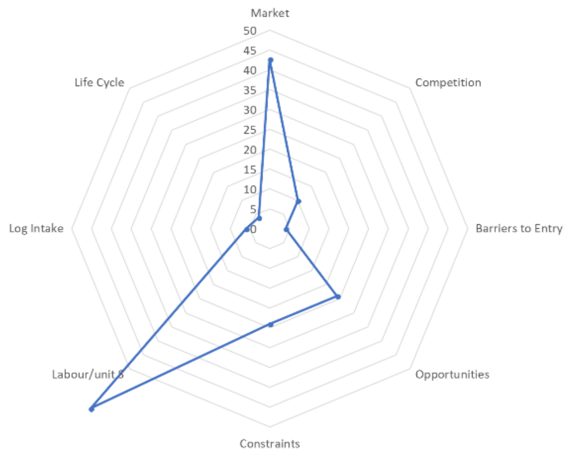
15. FURFURAL & FURFURYL ALCOHOL

Furfural is among the least attractive options for Maine, reaching a total score of 179. Highest scores are obtained for markets (43), and labour intensity (64).

Figure 15-1: Furfural's Acid Attractiveness Score



The following section outlines in detail the market opportunity for Furfural's produced in Maine.

15.1 Product Description

15.1.1 Furfural

Furfural is most commonly produced via hydrolysis of agricultural wastes that contain pentosans (C5 carbohydrates that are major constituent of hemicellulose). Furfural may also be formed as a side product during production of ethanol from wood. The most common raw materials for furfural production include corncobs, cottonseed hulls, bagasse and rice hulls. In addition, by-products from pulp production represent an important feedstock for furfural production.

Furfural is used an extractive solvent for lubricating oils, in butadiene extraction, and in linking foundry sand. Furfural is also used in other minor applications, such as intermediate for the production of herbicides and insecticides, chemicals, pharmaceuticals, and fragrances, among others.

Furfural derivatives include hydroxy furans, furoic acid, 2(5H)-furanone, furfuryl amine, difurfuryl diamines, furanacrylic acid, furylidene ketones, methyl furan, 2-hydroxymethyl-5-vinyl furan, and 2,5-bis(hydroxymethyl) furan.

One important furfural derivative is 2,5-Furandicarboxylic acid (FDCA). FDCA has been suggested by the US Food and Drug Administration as a key renewable building block because it can substitute terephthalic acid (PTA) in the production of polyesters. However, FDCA production is still under development.

Tetrahydrofuran (THF) is another furfural derivative of mostly historical importance. It was produced in large volumes especially in the US during the 1960s to make elastomeric polyurethane fibres like Spandex. Currently no furfural is used in THF production. Tetrahydrofuran is now made mainly with the Reppa/butadienol or propylene oxide/allyl alcohol process.

Future furfural applications might include biopolymers such as polyethylene furanoate (PEF) for use in bio-based bottles, fibres and films (Avantium's YXY process).

15.1.2 Furfuryl Alcohol

Furfural is mainly used for the production of furfuryl alcohol. Furfuryl alcohol is used primarily in the production of furan resins. Furan resins are mostly used for making metal parts by sand casting (furan resins serve as binders for the sand). Other uses for furan resins include corrosion-resistant mortars, grouts and cements for use in chemical manufacturing facilities, and in certain coatings for the automotive industry. Additional resin applications include laminating resins for fabrication of corrosion-resistant fiber-reinforced plastic equipment, such

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as GRP ducts, rigid insulation foams for high-temperature applications, and flame retardant fiberglass equipment. Other uses of furfuryl alcohol include:

a. reactive solvent in epoxy resins, cleaning appliances and biocides;

b. feedstock for tetrahydrofurfuryl alcohol (THFA), which is used as a solvent for active ingredients in pesticide formulations and as a pharmaceutical intermediate; and

c. intermediate in the production of flavour and fragrance chemicals.

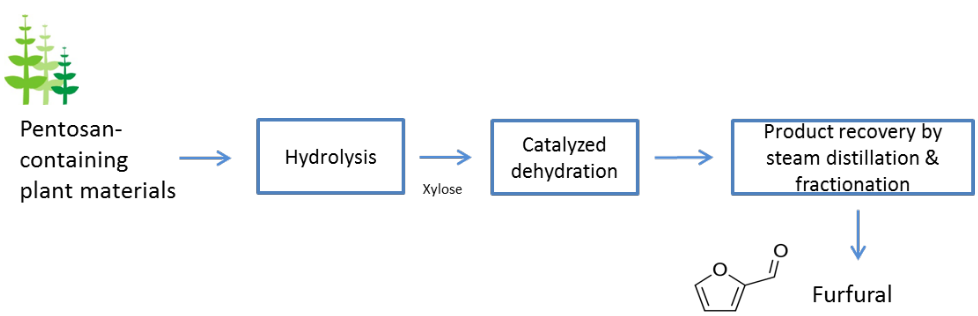
15.2 Manufacturing Process

15.2.1 Furfural

Furfural production processes can be roughly divided into low and high temperature processes. The most commercial units are operated under low temperature (<40°C) conditions to maximize production.

There are two process stages when producing furfural from plant materials. Frst, pentosan is hydrolyzed to pentoses (e.g. xylose), then pentoses are cyclodehydrated to furfural. The reaction is generally heated in a presence of acid catalysts such as dilute sulfuric acid or phosphoric acid, and the furfural is quickly recovered by steam distillation and fractionation, because furfural is a very reactive chemical. Furfural yield based on pentosan content is typically around 30–50%.

Figure 15-2: Furfural Production Scheme



Source: IHS, Neste Engineering Solutions

Some biorefinery concepts use both C5 and C6 carbohydrate fractions in biomass, producing furfural, levulinic acid and ethanol, in parallel streams. However, in the near future, these biorefinery processes are not expected to make a significant impact on the furfural market.

15.2.2 Furfuryl Alcohol and Furan Resins

Furfuryl alcohol is prepared at moderate or high pressures in the presence of a copper chromite catalyst by hydrogenation of furfural. On a theoretical basis, 0.98 kilogram of furfural produces one kilogram of furfuryl alcohol. The reaction can be performed in gas or liquid phase, however, the gas phase is currently most employed in the industry.

Furan resins or furan polymers are condensation products in which furfuryl alcohol (or furfural), and either urea or phenol-formaldehyde are the starting monomers. There are four different types of furan resins: no-bake, cold box, warm box and hot box. By far, the most important are the no-bake resins as they are the preferred materials for casting engine blocks by the automotive industry and parts by the heavy machinery industry.

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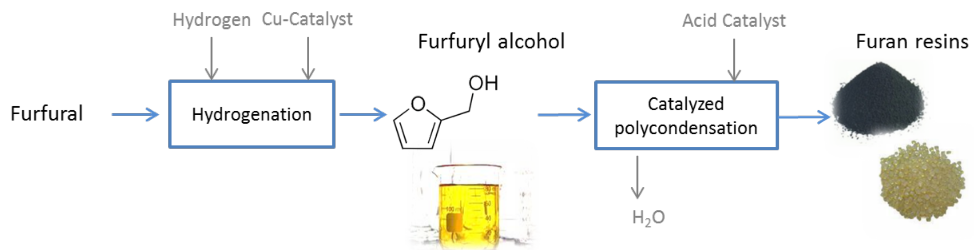
Furan resins compete for use with phenolic urethanes. Production of phenolic urethanes generates small amounts of formaldehyde and phenol, which are objectionable from an environmental standpoint. The furan non-bake systems generate less objectionable by-products, but do not cure as rapidly as the phenolic urethanes.

An overview of the key process steps in furfuryl alcohol and furan resins production is shown below:

Figure 15-3: Key Process Steps in Furfulyl Alcohol and Furan resins



Source: IHS, Neste Engineering Solutions

Tetrahydrofurfuryl alcohol (THFA) can be either produced by the intermediate production of furfuryl alcohol or directly from furfural, both ways by catalytic hydrogenation.

15.3 Issues impacting the economics of furfural production

The economics of producing furfural are highly dependent on the pentosan content of the raw material. It is important to choose a raw material with high pentosan content. The availability and cost of the raw materials as well as the costs of collecting, transporting and handling them, greatly influence the economics. The majority of raw material used in furfural plants today is sugarcane bagasse (Dominican Republic and South Africa) or corncobs (China). Large producers have an advantage if these raw materials are available in large quantities within a limited distance of the furfural plant.

Furfural may be produced as a side stream of wood-based processes, such as during production of ethanol from wood.

15.4 Market Size and Growth

15.4.1 Furfural Market

Global furfural market accounts for 441 kt per annum (2015). Furfuryl alcohol is the dominant end use for furfural, accounting for nearly 90% of total consumption, followed by solvent applications in lubricating oils and butadiene extractions (4%), with the remainder in other applications such as chemical, pharmaceutical, and flavouring intermediates.

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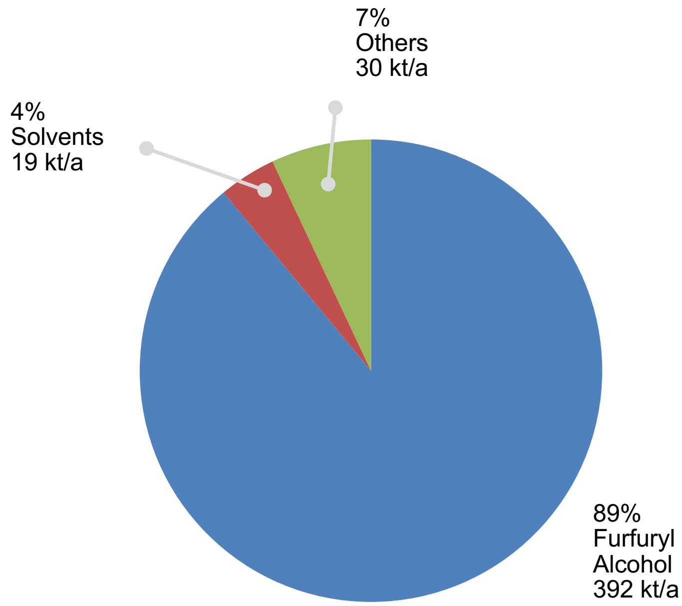
Figure 15-4: Furfural Consumption by Application (2015)



Source: IHS, Neste Engineering Solutions

Notes: 1) Solvents: Mainly in solvent applications in refining of lubricating oils and butadiene extractions 2) Others: Includes chemicals intermediates like THF, THFA, and furan and other solvent uses such as for phenolic resins.

Production Capacity

Global furfural production capacity totals 604 kt per annum (2015).

China accounts for about 85% (511 kt per annum) of the global furfural production capacity. About 200 Chinese companies produce furfural adjacent to agricultural raw material resources.

The second largest furfural producer is the Dominican Republic with a production capacity of 35kt per annum (85% of production capacity in Central and South America). In the Dominican Republic, furfural production serves as the primary method of disposing bagasse waste from sugarcane sugar extraction.

European production capacity accounts for only 1.5% (9 kt per annum) of the global furfural capacity. Lenzing is the only active furfural producer in Europe. The company extracts furfural as a by-product of pulp production.

Currently there is no furfural production in North America (United States, Canada and Mexico).

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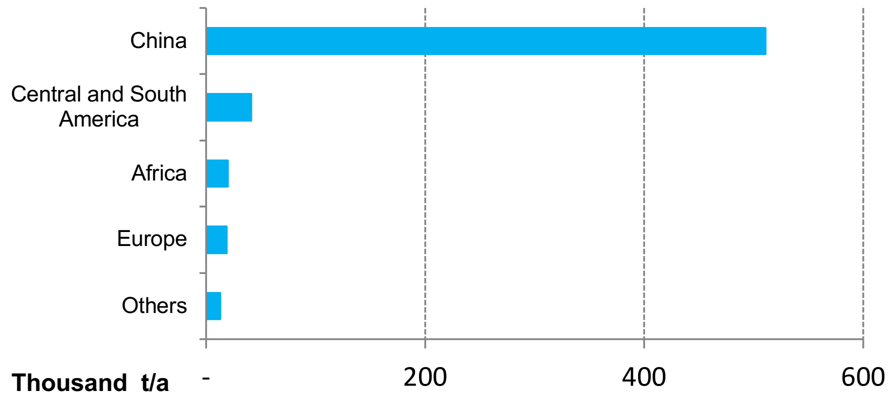
Figure 15-5: Furfural Supply (2015)



Source: IHS, Neste Engineering Solutions

Demand

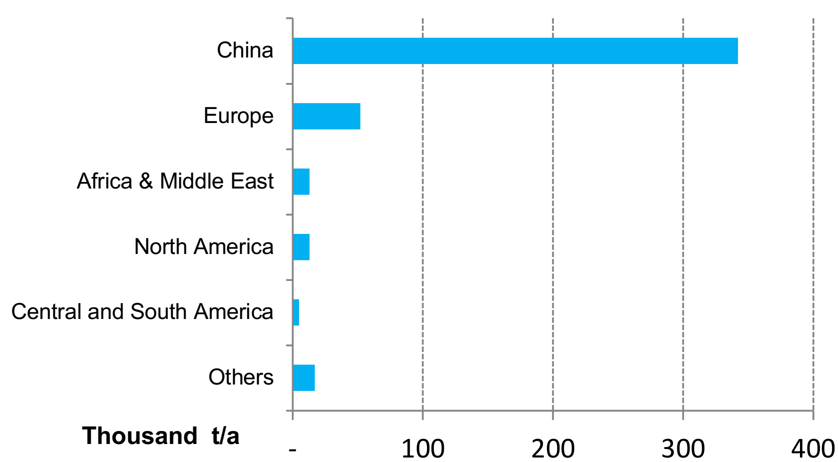
Global furfural production demand accounts for 441 kt per annum (2015).

Outside of China, the demand for furfural is relatively small. No major changes are expected to this trend. Furfuryl alcohol is the major end use. TransFurans Chemicals (TFC), the main furfural consumer in Western Europe, is integrated to its principal supplier Central Romana Corporation (based in Dominican Republic).

Domestic furfural consumption in the United States is 12 kt per annum (92% of furfural demand in North America). Consumption has significantly declined compared to levels in the 2000's, mostly due to the decrease in use of furfural for tetrahydrofuran production which completely stopped in 2004, and a decline in domestic furfuryl alcohol production. Butadiene extraction use has remained essentially constant, while lubricating oil refining applications have continued to decrease.

Demand requirements in the United States are covered mostly by imports from China and Central and South America.

Figure 15-6: Furfural Demand (2015)



Source: IHS, Neste Engineering Solutions

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15.4.2 Furfuryl Alcohol Market

Production Capacity

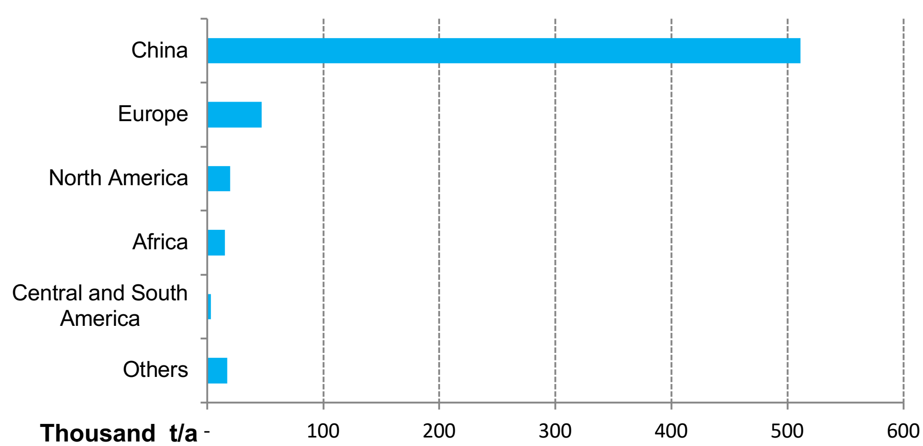
Global furfuryl alcohol production capacity accounts for 612 kt per annum (2015).

China is the leading producer of furfuryl alcohol accounting for 83% of global capacity (about 510 kt per annum). Four additional Chinese furfuryl alcohol plants are being planned with total capacity additions up to 200 kt per annum. However, some of the projects may be delayed or cancelled because of the current overcapacity in China.

Western Europe is the next largest furfuryl alcohol producer with a capacity share of only 7% (40 kt per annum). There is only one furfuryl alcohol producer (TransFuran Chemicals).

North America (United States, Canada and Mexico) is the third largest furfuryl alcohol producer with a total capacity share of only 3% (20 kt per annum). In the US, there is only one producer, PennAKem with a production capacity of 18 kt per annum. PennAKem is a toll producer for International Furan Chemicals (IFC), primarily using imported furfural from the Dominican Republic, South Africa, and China. The company also imports some furfural and furfuryl alcohol from IFC in Europe.

Figure 15-7: Furfuryl Alcohol Production Capacity by Country/Region (2015)



Source: IHS, Neste Engineering Solutions

Demand

Global furfuryl alcohol demand accounts for 391 kt per annum (2015).

It is estimated that about 85-90% of furfuryl alcohol is used in the production of furan resins. The remaining 15% of furfuryl alcohol is used for the production of tetrahydrofurfuryl alcohol (THFA). THFA is used mainly as a speciality solvent or chemical intermediate, with its primary end markets being agricultural chemicals, coatings, and cleaning solutions.

China is the largest consumer of furfuryl alcohol, accounting for some 60% of the global demand (about 228 kt per annum). The Chinese consumption focuses on furan resins (over 90% of the use), which are largely used in the foundry industry as a polymeric binder for foundry sands.

Europe is the second largest furfuryl alcohol consumer, accounting for 17% of the total demand (65 kt per annum). The leading European consumers of furfuryl alcohol for furan resins include Dynea and Ashland.

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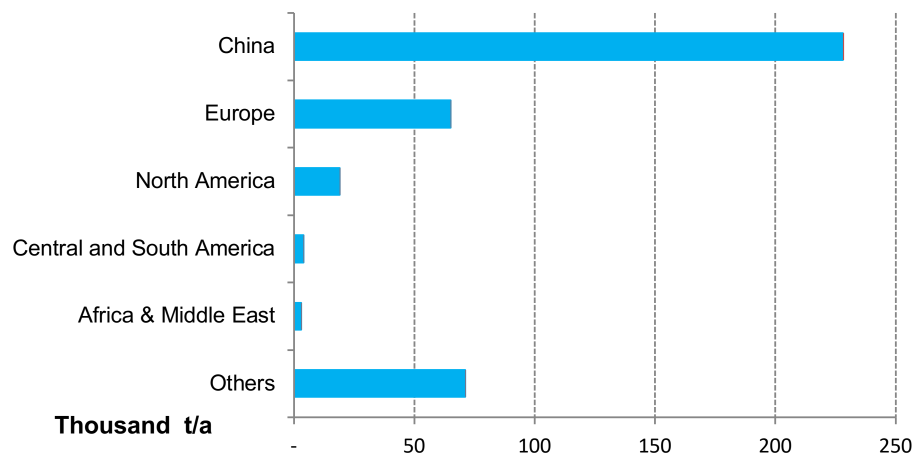
North America (United States, Canada and Mexico) is the third largest furfuryl alcohol consumer, accounting for only 5% of the total demand (20 kt per annum). Furfuryl alcohol consumption in the United States accounts for 13 kt per annum. The leading consumers of furfuryl alcohol for furan resins include ASK Chemicals and HA International (Delta-HA and Hexion joint venture).

Figure 15-8: Furfuryl Alcohol Consumption (2015)



Source: IHS, Neste Engineering Solutions

15.5 The Competitive Landscape

15.5.1 Furfural Competitors

The structure of furfural industry is quite concentrated as the top eight furfural producers account for 57% of the total production capacity.

Among leading furfural producers there are only two producers outside of China; Central Romana (Dominican Republic) and Illova Sugar (South Africa)

Integration among furfural producers is quite typical. For instance, many large Chinese furfural producers are also producing and processing furfuryl alcohol.

An interesting case is the affiliation of Central Romana with furfuryl alcohol producer TransFuran Chemicals. The products are marketed by International Furan Chemicals, which also distributes furfural produced by Illova Sugar.

The world’s largest furfural producer is Jinan Shengquan Group (100 kt per annum). They produce both furfuryl alcohol and furan resins.

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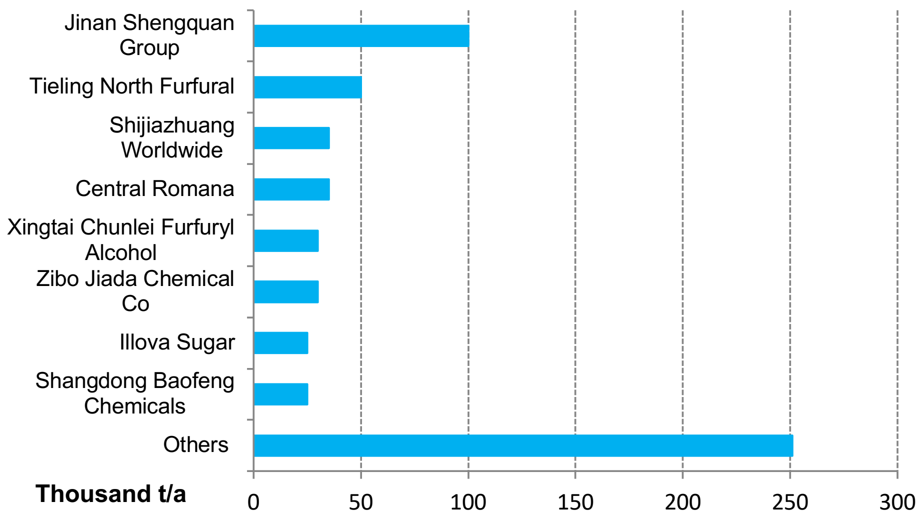
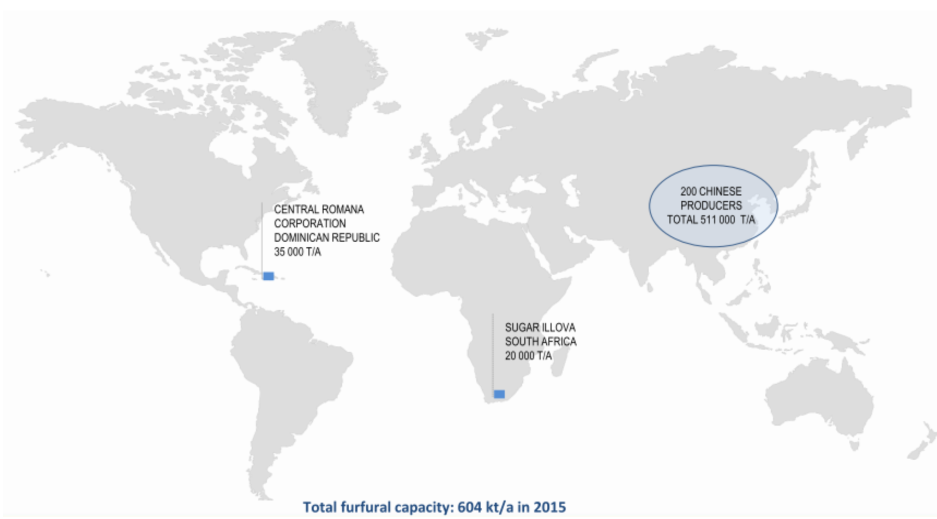
Figure 15-9: Major Producers of Furfural



Source: IHS, Neste Engineering Solutions

Figure 15-10: Map Showing Main Furfural Producers



Source: IHS, Neste Engineering Solutions

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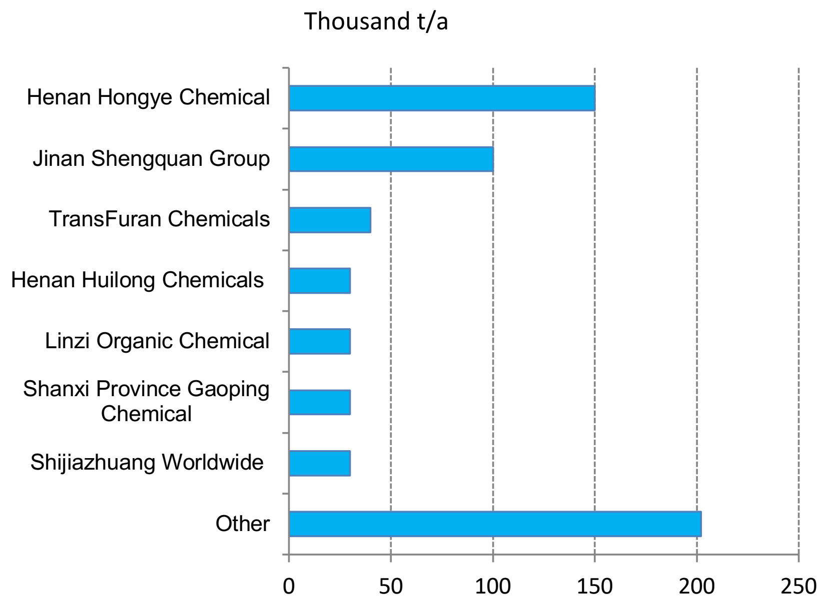
15.5.2 Furfuryl Alcohol Competitors

Integration among furfuryl alcohol producers is quite typical. Most of the larger furfuryl alcohol producers are also producers of furfural and furan resins (19 producers in total as of 1st January 2016).

An interesting case is the affiliation of TransFuran Chemicals with furfural producer Central Romana. The products are marketed by International Furan Chemicals, which also distributes furfural produced by Illova Sugar.

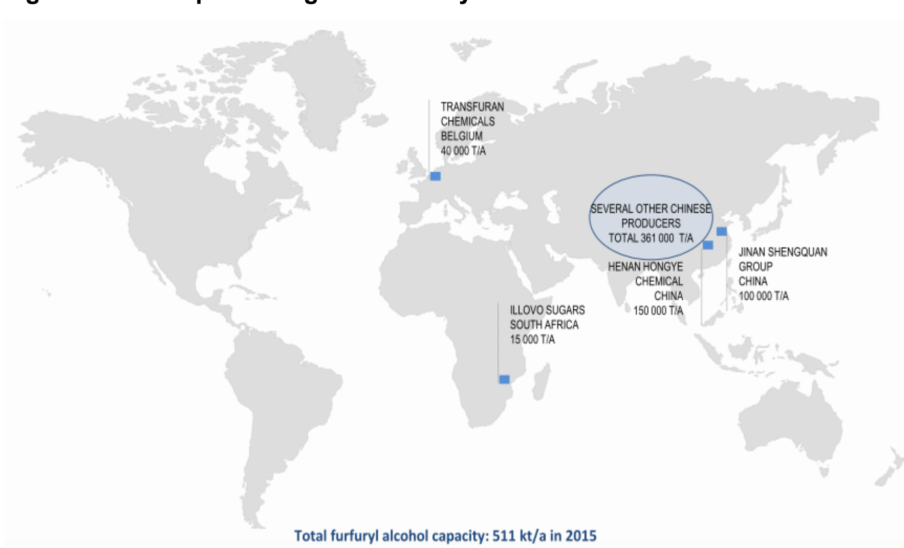
The world's largest furfuryl alcohol producer (150 kt per annum) Henan Hongye Chemicals also produces furfural and second largest (100 kt per annum) Jinan Shengquan Group produces both furfural and furan resin, in addition to furfuryl alcohol.

Figure 15-11: Major Producers of Furfuryl Alcohol



Source: IHS, Neste Engineering Solutions

Figure 15-12: Map Showing Main Furfuryl Alcohol Producers



Source: IHS, Neste Engineering Solutions

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15.6 Barriers to Entry

15.6.1 Furfural

One barrier is the fluctuating availability of the main raw material, corncob. Availability of corncob is highly dependent on Chinese corn yields and is also affected by the competition from xylose and xylitol production, which have been growing fast lately.

This results in a second barrier, which is fluctuating raw material price due to fluctuating availability.

Another barrier is the dependence on Chinese economy. The growth of furfural demand is concentrated on Chinese demand (5.2% p.a. until 2020), whereas demand growth in other regions is significantly lower or even negative.

Lastly, environmental regulation in China serves as a barrier to entry. Furfural production is considered a heavy water-polluting industry. Due to China's Water Ten Plan, some furfural industries with less stringent equipment will face the risk of being closed.

15.6.2 Furfuryl Alcohol

As most of the furfural is used for furfuryl alcohol production, fluctuating availability of furfural's main raw material, corncob, has an impact also on the furfuryl alcohol availability. Corncob availability is highly depending on Chinese corn yields and competitive corncob uses.

Fluctuating price due to fluctuating raw material availability is another barrier.

The Chinese economy serves as a barrier with the growth of furfuryl alcohol demand highest in China, whereas growth of demand in other regions is expected to be significantly lower.

15.7 Key Drivers for Demand

15.7.1 Furfural

Key drivers of demand are global oil, gas and automotive demand. Furfural is mainly used for furfuryl alcohol used to produce furan foundry sand binders. These are used to manufacture high-quality cores and moulds for metal casting.

Demand is also driven by global lubricating oil consumption. Furfural is widely used as selective extractive solvent for lubricant oils.

15.7.2 Furfuryl Alcohol

Demand is driven by the global oil, gas and automotive industries as furfuryl alcohol is mainly used to produce furan resin foundry binders for metal castings.

15.8 Prices and Price Trends

As almost 90% of furfural is used for furfuryl alcohol production, the prices are strongly linked and fluctuating based on corncob availability in China. In 2010 climate conditions in the North Eastern China reduced corn production. The quality of corncobs harvested was very low, resulting in low yield production of furfural. Thus, the Chinese furfural supply situation tightened and both furfural and furfuryl alcohol prices spiked.

It should be noted that in recent years, prices of both furfural and furfuryl alcohol have decreased.

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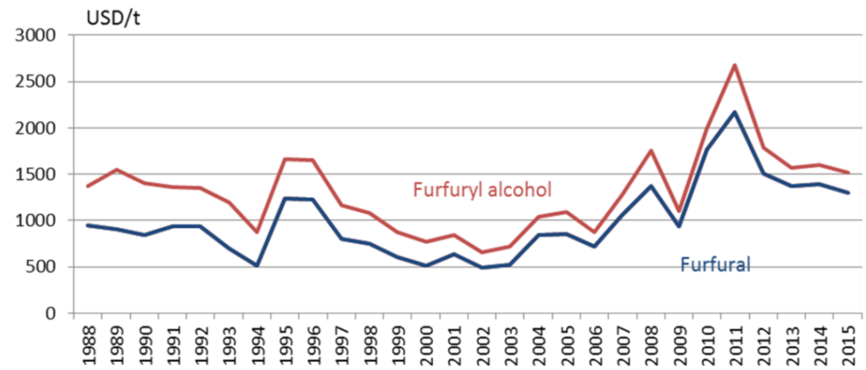
Figure 15-13: China's Average Furfural and Furfuryl Alcohol Export Price, USD/t



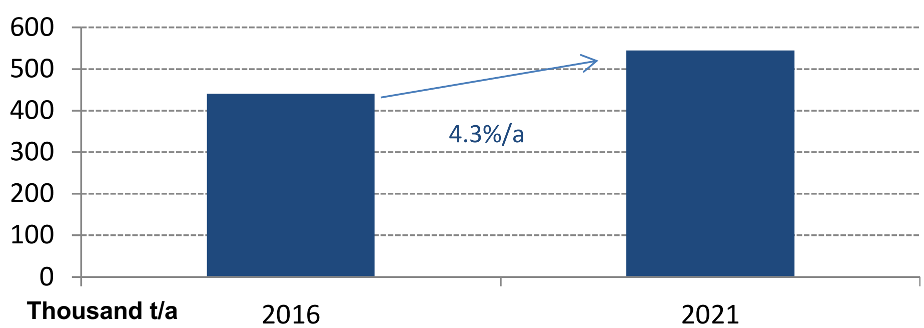
Source: IHS, Neste Engineering Solutions

15.9 Outlook & Market Growth

15.9.1 Furfural

Demand for furfural is expected to grow 4.3% per annum globally. China will continue to drive the overall market with growth projected at 5-6%. The furfural industry has grown rapidly in China for last 20 years forcing out all production in the US and most in the EU. Outside of China, demand for furfural is relatively low, with little change expected. In the US, there has been some downturn in furfuryl alcohol use in castings because of the downturn in the oil and gas business. In Western Europe, demand for furfuryl alcohol is expected to increase only slightly in the near future.

Figure 15-14: Furfural Global Outlook and Market Growth, 2016-2021



Source: IHS, Neste Engineering Solutions

15.9.2 Furfuryl Alcohol

Demand for furfuryl alcohol is expected to grow by 2.5% per annum globally. It is expected that Chinese demand for furfuryl alcohol in the heavy casting industry will grow at a slower rate, at about 3% annually on average. In other Asian countries (not including China and Japan), demand is expected to grow at about 2% annually, mainly in furan resins used in the shipbuilding, automotive, machinery, and electronic industries. In Western Europe, furfuryl alcohol consumption is expected to increase by 1-2% annually, following increasing production of windmill turbine castings in foundries. In the US, consumption of furfuryl alcohol for the foundry industry is expected to grow at about 2-3% annually. Japan imports all its furfuryl alcohol requirements. Little growth is expected.

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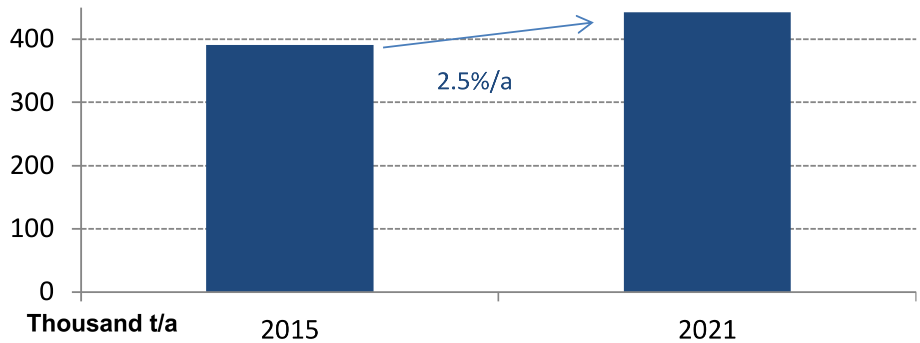
Figure 15-15: Furfuryl Alcohol Global Outlook and Market Growth (2015-2021)



Source: IHS, Neste Engineering Solutions

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16. LEVULINIC ACID

Levulinic acid is among the least attractive options for Maine, reaching a total score of 174.

Figure 16-1: Levulinic Acid Attractiveness Score

The following section outlines in detail the market opportunity for levulinic acid produced in Maine.

16.1 Product Description

16.1.1 The Product

Levulinic acid is a non-toxic organic compound. The bifunctionality of the keto and carboxyic acid groups found in levulinic acid make it a versatile chemical intermediate. It can also be converted into many other useful chemical products such as solvents, pesticides, herbicides, polymer resins, cosmetics, and even gasoline or diesel components.

Figure 16-2: Levulinic Acid Formula

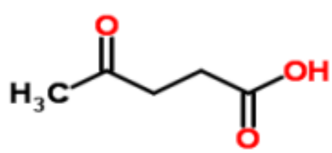

Figure 16-3: Levulinic Acid Platform

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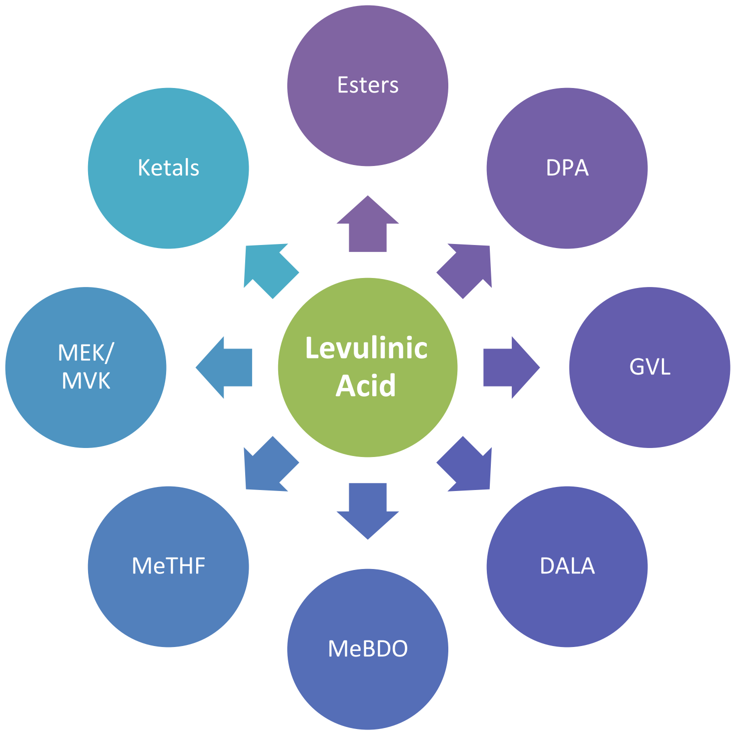

Source: IHS, Neste Engineering Solutions

Glucose has been commonly used for levulinic acid production. However, due to its high cost, use of low-cost biomasses e.g. corncobs or sugar cane bagasse, or even negative-cost materials such as paper mill sludge, have been investigated recently.

16.1.2 Manufacturing Process

A significant amount of research has been conducted over the years to develop processes to manufacture levulinic acid at a cost that is competitive with alternative synthetic materials. These processes typically comprise of the following 5 steps:

1. breaking down biomass into lignin, cellulose and hemicellulose;
2. converting cellulose into glucose;
3. isomerising glucose to fructose;
4. converting fructose to 5-hydroxymethylfurfural (5-HMF); and
5. splitting 5-HMF into levulinic acid and formic acid.

These are chemical steps as they don't involve the use of enzymes. The intermediates are not isolated. Usually two or three of these steps are undertaken in a single process, and indeed in some processes all five steps have been performed in a single reactor. In some trial set-ups steps 1 and 2 have been eliminated and the starting material used is a sugar, which is taken through steps 3, 4 and 5.

The most well-known process for the production of levulinic acid is the Biofine process that claims to convert essentially any lignocellulosic materials such as paper mill sludge, municipal solid waste, paper and wood wastes, and agricultural residues to levulinic acid using high temperature (150-220°C). In the first stage, biomass is converted to soluble sugar monomers, namely hexoses (mainly glucose) and pentoses, with the hexoses immediately being converted to 5-hydroxymethyl-2-furfuraldehyde (5-HMF). In the second stage the 5-HMF is further hydrolysed to levulinic acid. The first stage is rapid, taking only 20 seconds, while the second

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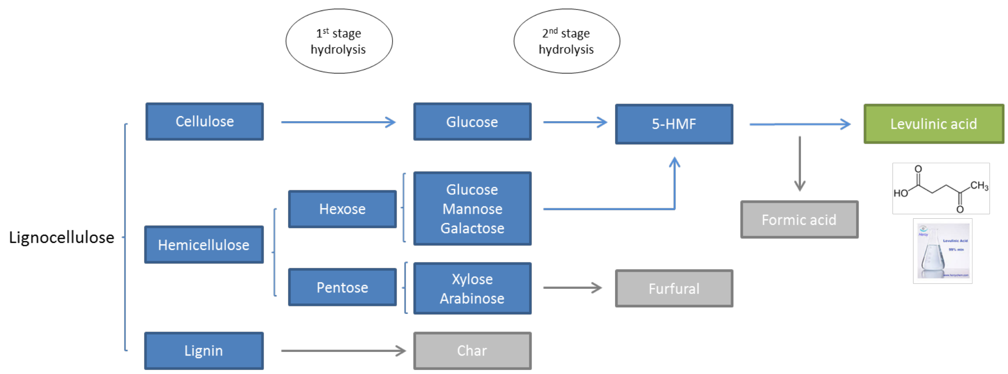
stage takes only about 20 minutes. The conversion rate has been suggested to be about 50% of the mass of 6-C sugars. Co-products include formic acid, furfural (coming from the pentoses), and ligneous char. Formic acid is a valuable co-product and is mainly used as a preservative and antibacterial agent in livestock feed as well as in the production of leather. Furfural is used to make thermosetting resins among other uses. The ligneous char can be used as in-plant fuel.

Figure 16-4: Production of Levulinic Acid from Biomass-Biofine Process (co-products in grey colour, source)



Source: Neste Engineering Solutions

Production of levulinic acid from biomass suffers from yield limitations. Due to conversion chemistry, the maximum theoretical yield from hexoses is 64.5 % wt. In practice, yield is often limited to about 2/3 of theoretical maximum. A major technical problem is the formation of black solids, called humins, which cause clogging of the reactor.

Below are the product yields of the Biofine process per dry tonne of hardwood feedstock:

Levulinic acid: 250 kg

Formic acid: 100 kg

Furfural: 125 kg (but variable according to market demand)

Ligneous char: 525 kg (3% ash)

16.1.3 Interesting Facts

Levulinic acid esters such as ethyl levulinate can be used as additives in biodiesel.

Levulinic acid can be used to produce 'green' solvent gamma-valerolactone (GVL). GVL can be used as solvent for fractionation of biomass and even in manufacture of cosmetic products (nontoxic). GVL can also be converted into adipic acid to produce nylon.

16.2 Market Size and Competitive Landscape

The global levulinic acid production capacity is about 15 kt per annum. Global production in recent years is estimated at around 3 kt per annum.

16.2.1 Supply

Production plants are located mainly in China. Levulinic acid produced in China is mainly used for flavour and fragrance applications. The main Chinese producers are:

- Jiangsu Yancheng China Flavour Chemicals Co.
- Hebei Langfang Triple Well Chemicals Co. Ltd.
- Shijiazhuang Pharmaceutical Group Ouyi Pharmaceutical Co Ltd.
- Hebei Shijiazhuang Worldwide Furfural & Furfuryl Alcohol Funan Resin Co., Ltd
- Tianjin Kailida Chemical

Commercial production in Europe and the United States is very small. Major levulinic acid producers and technology developers include:

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Biofine Technology LLC

Biofine has a 1 ton of dry feedstock per day demonstration plant in Maine, United States. The process is said to be capable of using a wide range of types of biomass. Recently, the company's interest has moved towards making ethyl levulinate as a diesel fuel component, as the quickest route to a commercially viable product. The first commercial plant is planned for New England, with an input capacity of 125 dry tons/day of waste cardboard or forest products, producing 8.1 million gallons/year of levulinate esters and formic acid.

GFBiochemicals Ltd

GFbiochemicals has one demo plant in Caserta, Italy with capacity of 10 kt per annum. The facility started in 2015 operating at 1.2 kt per annum. The company has been active in an EU-funded project called GreenSolRes, which was established in September 2016 to convert lignocellulosic feedstock into chemical building blocks and high-added value products initially focusing on levulinic acid. Future products will include 2-methyltetrahydrofuran (MTHF), gamma valerolactone (GVL) and methyl butanediol with the development of a novel catalyst.

GFBiochemicals has also a pilot plant in Minnesota, US with a capacity of 113 t per annum of levulinic acid. The plant, which previously belonged to US-based Segetis, has been producing ketals-based products from a 1.4 kt per annum demo facility under a toll manufacturer also based in Minnesota. Some industry sources believe these facilities have stopped production.

GFBiochemicals and US-based American Process Inc. (API) have recently entered a joint development agreement to create an integrated cellulosic biorefinery, which they claim will be the largest in the world. The proposed biorefinery to be in the United States is expected to produce 50-200 kt per annum of bio-based products, including levulinic acid.

Innosyn

Innosyn, a management buy-out of DSM, is in the process of establishing levulinic acid production, from pilot and demo-scale up to commercial scale production (biomass via levulinic acid to adipic acid). The demonstration plant after the pilot phase (start-up in 2020) is planned to have capacity of 5-10 kt per annum. The commercial plant is expected to have a capacity of 50-200 kt per annum depending on the market demand.

Bio-on and Sadam Group

Italy-based Bio-on and Sadam Group have announced plans to build pilot and demonstration plants within the next three years to produce levulinic acid using sugar industry by-products as raw materials. The companies have been collaborating on optimising their production technology since early 2015 in order to produce cost-competitive levulinic acid. Bio-on estimates that market demand for levulinic acid will grow 150-200-fold over the next 7-8 years. A pilot plant is expected to be built soon for research and subsequently, the construction of a demo plant with a capacity of 5 ktpa of levulinic acid production at Sadam's Tre Casali agro-industrial site in San Quirico (Parma, Italy). It will also include an industrial plant to produce PHA biopolymers from glycerol also using Bio-on's technology.

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Table 16-1: Companies Involved in Levulinic Acid Production

Company	Location	Status
Langfang Triple Well Chemicals Co. Ltd	China	Producer
Hebei Yanuo Chemical Industry Co. Ltd	China	Producer
Shandong Zibo Shuangyu Chemical Co. Ltd	China	Producer
Zibo Changlin Chemical Co. Ltd	China	Producer
Arzeda	US	R&D
Biofine Technology	US	R&D (demo plant)
Glucan Biorenewables	US	R&D on furfurals
Mercurius Biorefining	US	R&D
Reluceo/XL Terra	US	R&D (levulinic derivatives)
Segetis (owned by GFBiochemicals)	US	Derivatives producer
GFBiochemicals	Italy	Producer
Bio-on SpA/Eridania Sadam SpA	Italy	R&D
DIBANET Project	Ireland	R&D (pilot plant)
LIFE + WALEVA	Spain	R&D (pilot plant)
DSM	Netherlands	R&D on derivative adipic acid
GreenSolRes Project	Europe	R&D

Source: Tecnon OrbiChem

16.2.2 Competing and Substituting Products

Esters from levulinic acid can substitute fossil-based counterparts and be used in various applications in flavours & fragrances, plasticizers, and drop-in chemicals, among others.

Diphenolic acid from levulinic acid is considered as a replacement for bisphenol A (BPA).

Gamma-valerolactone from levulinic acid can substitute conventional solvents used in biomass fractionation.

Delta-amino levulinic acid from levulinic acid is considered as a replacement for traditional herbicides and pesticides.

Levulinic acid based methyl butanediol has good potential as monomer for polyurethanes. Methyl butanediol can also act as an intermediate for butanediol canyethers and polyesters.

Levulinic acid based Methyltetrahydrofuran may be used as gasoline additive and solvent.

16.3 Barriers to Entry

Several technological challenges (low product yields, corrosion and plugging of equipment, presence of contaminants, etc.) and high production costs may limit future growth of the levulinic acid market.

16.4 Key Drivers for Demand

Key demand drivers for levulinic acid include:

- technology developments that will overcome current technical challenges;
- cost effective production-integration of levulinic acid with downstream processes for production of intermediates; and
- growth of market for levulinic acid derivatives e.g. gamma-valerolactone (GVL), ethyl levulinate, and adipic acid, among others.

16.5 Prices and Price Trends

Levulinic acid prices in China in early 2016 were quoted at around 4-5 USD/kg. Industry analysts expect GFBiochemicals to achieve a cost of between 1.1-1.60 USD/kg at full capacity.

16.6 Outlook & Market Growth

Levulinic acid is seen as a promising building block (intermediate) for several chemicals. However, future of levulinic acid remains uncertain as commercial production has not materialized as expected mainly due to several technological challenges.

The focus of development has been placed on bio-based solvents such as gamma-valerolactone for fractionation of biomass. Gamma valerolactone is likely to be produced in large scale, but timing of commercialization is uncertain as low production costs need to be achieved first. Downstream value chain integration is a key aspect for long-term (e.g. by 2030) development of the levulinic acid market. According to estimates by Innosyn, it will take at least 10-12 years before the levulinic acid markets become large.

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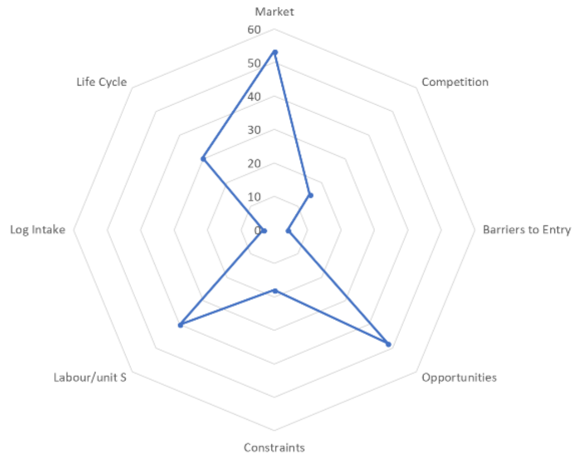
17. LIGNIN

Lignin is among the more attractive options for Maine, with a total score of 212. Highest scores are obtained for markets (53) and market opportunities (48).

Figure 17-1: Lignin Attractiveness Score



The following section outlines in detail the market opportunity for lignin produced in Maine.

17.1 Product Description

17.1.1 The Product

Around 50-70 million tons/year of lignin is produced as a side product of the pulping process, but most is burned for power and it is believed that only one million tons reaches the chemicals market. Lignin can be used in a broad range of applications. Lignosulfonates is the leading product group on the lignin platform. Other lignin-based products such as phenolic resins, composites, binders, sorbents, fuel additives, polyurethanes and other polymer materials are some of the products that have also been developed or are currently being marketed on a commercial scale. Phenolic resins are commonly used to manufacture construction materials such as plywood, oriented strand board, laminated veneer lumber, paper lamination and insulation materials.

There is significant technology development required in order to create higher-value chemicals from lignin given its non-uniform structure, unique chemical reactivity, organic and inorganic impurities, and other depolymerisation challenges.

The most common feedstocks used for lignin production include pulp wood (softwood) and wood chips. Other feedstocks include sawdust and lignocellulose residues.

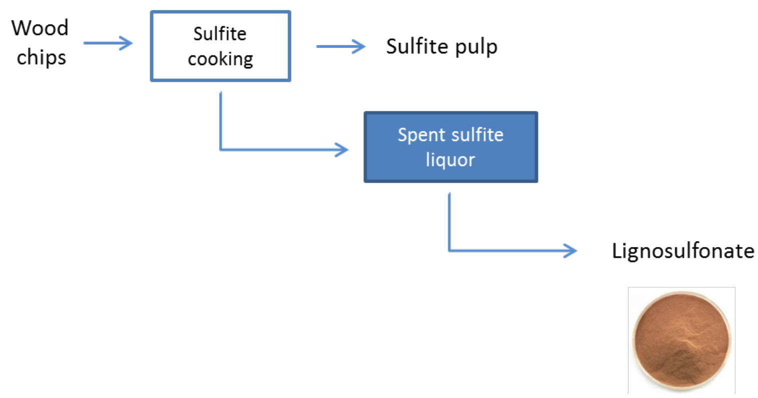
17.1.2 Manufacturing Process

Four major routes are under development to convert lignin into smaller chemical constituents – thermal, chemical, metallic catalytic and biological. Thermal depolymerisation such as pyrolysis is considered the most mature, but most companies that do this process focus on fuel production instead of chemicals. Purely chemical routes are still limited in scale, while the metallic catalytic processes to higher value chemicals have unresolved technical challenges. The biological route lags in commercial development.

Different separation technologies are used to extract lignosulphonates, kraft lignin, soda lignin, organosolv lignin and other hydrolysis lignin.

Lignosulphonates are obtained as a side product from **sulfite** pulping process, in which delignification of wood is performed by means of HSO3- (bisulfites) and SO32- ions (sulfites). In this process, lignin is sulfonated, degraded and solubilized. Due to the sulfonate groups, lignosulfonates are water soluble throughout the entire pH range and cannot be readily isolated by simple pH adjustment. Recovery of the lignin is done from water pulping liquor concentrate after stripping and recovery of the sulfur. Precipitation of the lignin is possible, but none appear to be practised commercially. For example, borregaard uses acidic calcium bisulfite cooking process, which gives high viscosity cellulose with high purity.

Figure 17-2: Lignosulfonate Production

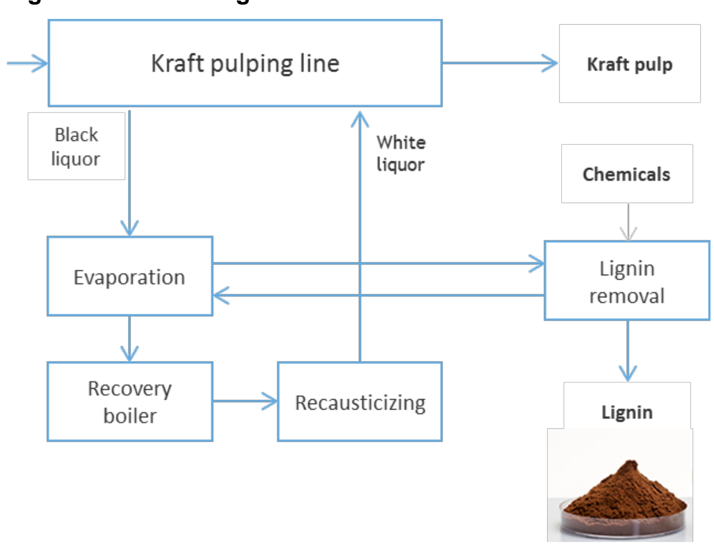


(source: Neste Engineering Solutions)

Kraft lignin is obtained as a side product from **sulfate cooking process** (cooking liquor chemicals are NaOH and Na_2S). The process is conducted at high pH and temperature in the presence of substantial amounts of aqueous sulfide, sulfhydryl and polysulfide. Majority of the solubilized lignin is captured in the spent pulping liquor along with most of the wood's hemicellulose. Prior to the precipitation, the lignin can be degraded into fragments of different molecular weight. Precipitation of lignin can be done with acid and followed by filtration or ultrafiltration. The recovered lignin can be almost free of sugars. Valmet's LignoBoost technology is a commercially available technology for lignin extraction by CO2 precipitation.

A simplified schematic diagram of Kraft lignin production is shown below:

Figure 17-3: Kraft Lignin Production



(Source: Neste Engineering Solutions)

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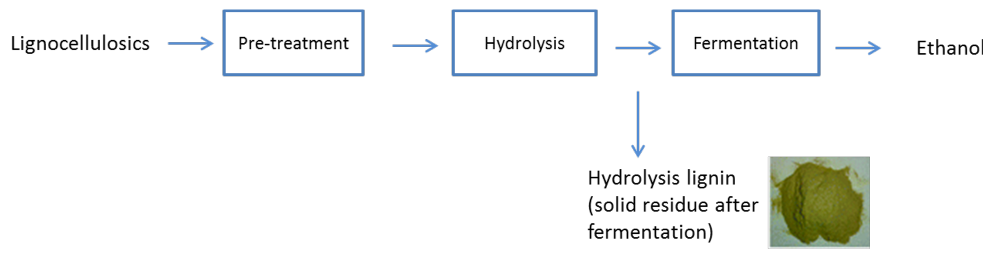
Soda lignin is a side product from soda or soda-anthraquinone pulping. Soda pulping is mainly used for cooking of annual crops. For example, Green Value focuses on production and development of products from lignocellulosic biomass and has patented technology for producing sulfur-free high-purity dry lignin powder from soda pulping process alkaline extract. The main raw material is wheat straw, but also flax, sugarcane bagasse and other annual fibres are used.

Different chemical mixtures are used in **organosolv processes**. Organosolv lignin is a side product of sugar / ethanol production. In the organosolv pulping the cooking liquor is a mixture of organic solvents and water. The process results in separate and easily isolated streams of cellulose, hemicellulose and lignin. Lignin can be separated from the process by solvent removal and recovery, or in combination of precipitation by adjusting the temperature, pH and concentration of the process liquid phase. Lignol, acquired by Fibria in 2015, focuses on developing technology for production of high-performance lignin and bioethanol.

Other hydrolysis lignins vary significantly from each other because of the different fractionation processes prior to lignin recovery. Examples of other hydrolysis methods are ammonia fibre explosion (AFEX) process, steam explosion and dilute acid processes.

Figure 17-4: Hydrolysis Lignin Production Scheme



(Source: Neste Engineering Solutions)

17.1.3 Interesting Facts

Over recent years lignin has evolved from a low value and quality residue that was only useful as a fuel for energy generation in pulp mills into a sustainable raw material for various added value products.

There is great market potential for lignin to replace fossil-based counterparts especially in phenolic resins. However, in most cases extraction of lignin appears to be on more advanced level than application development.

17.2 Market Size and Growth

The global pulp industry generates annually some 50 – 70 million tons of lignin. Roughly 98% of the lignin is combusted, while only a small portion is used for more value-added end-uses.

Lignosulfonates are the leading product group on the lignin platform (with annual production of some 1,3 Mt per annum). The lignosulfonate market is well established.

Other lignin (kraft, organosolv, hydrolysis and soda lignin) market and applications are being developed at the moment by a large number of companies. Much of the research and development work is at an early stage, and many companies have not yet decided which markets and applications to target. Lignin is today commercially available for a variety of end uses ranging from composites and surface active agents to a wide range of resins (kraft lignin production capacity is today 173 500 t per annum). However, the lignin markets are very limited today and the real markets are yet to be established.

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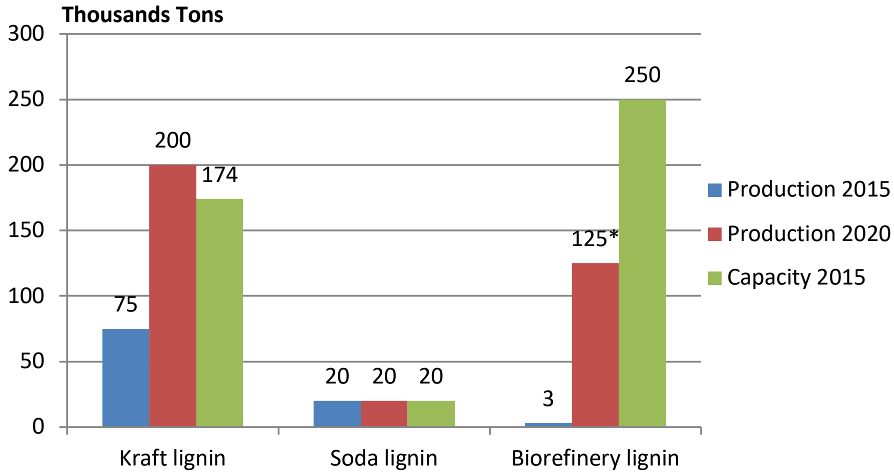
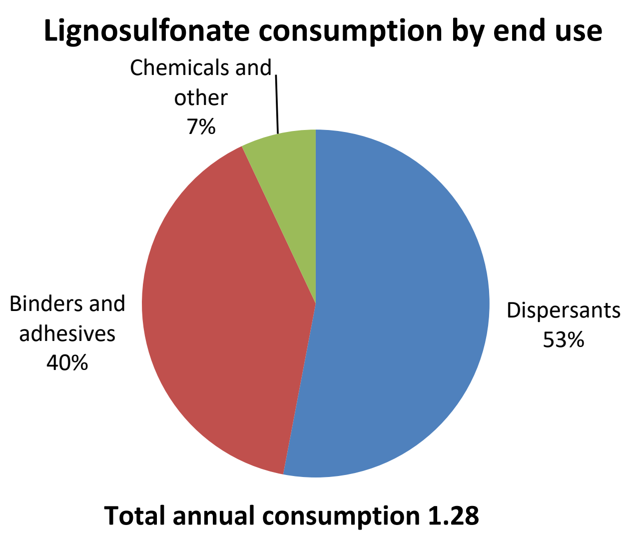
Figure 17-5: Production per Lignin Segment and Outlook*



* Incl. various biorefinery processes; e.g. lignocellulosic-based ethanol or biochemicals production. 250 000 t per annum is the theoretical potential of the 2G ethanol plants e.g. DuPont, Abengoa (sold due to insolvency), POET, GranBio, Beta Renewables being the well known first of a kind plants. However, many of these are not running full capacity and have technical issues to resolve before the nameplate capacity is reached.

Most **lignosulfonates** are obtained from the spent pulping liquor of sulfite pulping operations, although some are also produced by post-sulfonation of lignins. Annual average demand growth rate is projected at 1,2% during the forecast period of 2016-2021. The market is mature and relatively flat, compared to the growing and emerging kraft and biorefinery lignin market, respectively.

Figure 17-6: Lignosulfonate Consumption by End Use (2016)



Lignin-based phenolic resins, composites, binders, sorbents, fuel additives, polyurethanes and other polymer materials are some of the products that have already been developed or even currently being marketed in commercial scale. The demand of phenolic resins for wood adhesives totals some 2.2 million tons per annum. The market is projected to grow at a rate of 4% per annum resulting in 2.9 million tons per annum in 2020.

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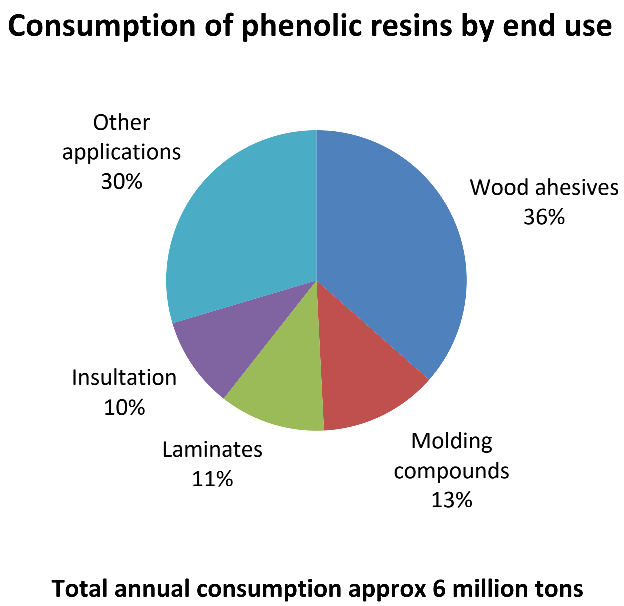
Figure 17-7: World Consumption of Phenolic Resins by End Use (2016)



17.3 The Competitive Landscape

17.3.1 Competitors

Lignin (kraft, organosolv, hydrolysis and soda lignin) market and applications are being developed at the moment by a large number of companies. Much of the research and development work is at an early stage, and many companies have not yet decided which markets and applications to target.

Ingevity, one of the leading kraft lignin producers, operates a plant in North Charleston, S.C., with a capacity of roughly 50,000 metric tons per year.

Stora Enso has been producing lignin at industrial scale using Valmet's process technology, LignoBoost™, since 2015 at its Sunila Mill in Finland, which has a capacity of 50 ktpa. Its lignin is separated during the kraft pulping process of Nordic softwood. The company is also looking for other applications such as carbon fibres aside from replacing phenol. Stora Enso previously noted that 70% of its lignin is still used as a replacement for natural gas in its processing facilities.

UPM, another Finnish forest products manufacturer, has also been developing its own lignin-based resins products and is collaborating with several organisations and chemical companies under the EU-funded ValChem project, which received €13.1m funding from Bio-Based Industries (BBI) consortium. This project has been using SEKAB's CelluApp® technology for wood to sugars, and to crude lignin conversion process. UPM and Technische Universitat Darmstadt in Germany have been jointly developing high-value-added lignin applications such as lignin-based reactive resins and composites. UPM's plywood business recently introduced its WISA BioBond glueing solution using lignin as replacement to phenol. UPM said it can replace 50% of the phenol used in the bonding of plywood and its goal is to increase the amount to close to 100% in the next several years.

In autumn 2017, UPM announced its plans to build an industrial-scale biorefinery in the Chemical Park Frankfurt-Hochst in Germany that would convert wood raw materials into bio-based MEG, MPG and lignin with a capacity of up to 150 ktpa. Production would be based on hardwood from sustainably-managed forests in Central Europe.

Finnish **Metsä Fibre**, pulp and bioproducts manufacturer, joined a new EU-funded project called LigniOx: lignin oxidation technology for versatile lignin dispersants, with the aim to demonstrate the techno-economic viability of alkali-O2 oxidation technology for the conversion of variable lignin-rich side streams into dispersants especially for applications in high-performance concrete and mortar plasticisers.

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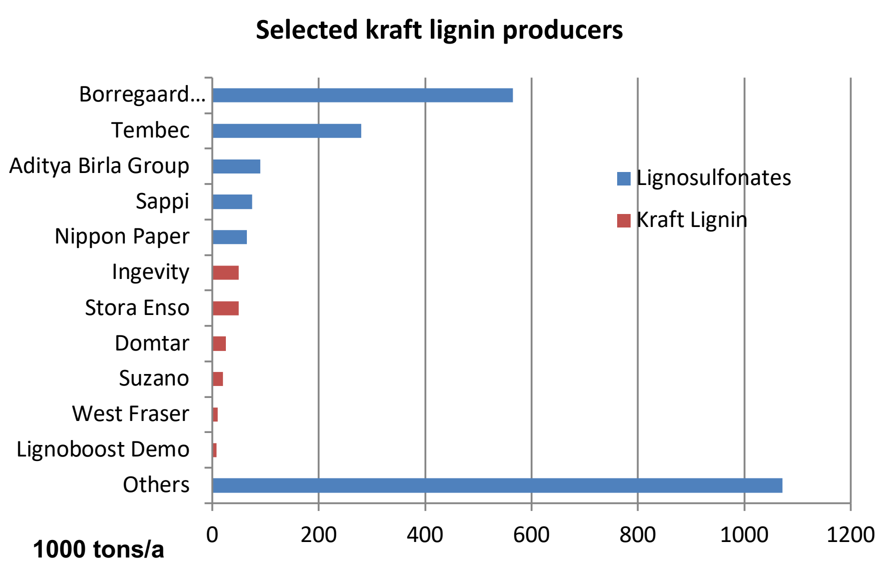
In the US, **Domtar** recently announced that it is exploring more opportunities for its BioChoice™ lignin at its Kingsport Mill in East Tennessee, which will use hardwood and a sulphur-free pulping process. Domtar has been producing its BioChoice™ softwood kraft lignin in a commercial-scale 30 ktpa lignin separation plant at its Plymouth, North Carolina mill since 2013 using Metso's LignoBoost™ processing system that extracts lignin from kraft black liquor.

West Fraser also has a lignin extraction demonstration-scale facility with a capacity of 30 tpd at its pulp mill in Hinton, Alberta, using FPInnovation's LignoForce™ process. The company diverts a portion of the black liquor to extract high-purity lignin. West Fraser has been developing the use of lignin as a natural adhesive in its engineered wood products. The company is also looking at other potential applications that include polyols, plastics, chemicals such as surfactants and dispersants, fine chemicals and biocomposites.

LignoTech Florida, a joint venture between Norwegian pulp and paper company, **Borregaard**, and US-based cellulose products producer, **Rayonier Advanced Materials** (RYAM), is expected to complete the phase one of its high-performance lignosulfonates facility project in late spring 2018, which will be located in Fernandina Beach. The 150 ktpa facility will use RYAM's sulphite pulping process, which is expected to consume around 100 ktpa of lignin. Borregaard currently has a demonstration biorefinery plant in Sarpsborg called BALI™ concept operated by the BBI-funded BIO4EVER project, which started in 2013. The Sarpsborg sulphite mill produces 168 ktpa of lignin, 1,500 tpa of vanillin, 20m litres/year of ethanol and 160 ktpa of cellulose. Borregaard also has sulphite mills outside of Sarpsborg that can produce 300 ktpa of lignin.

Figure 17-8: Selected Kraft Lignin Producers and their Capacities



17.3.2 Competing and Substituting Products

17.3.3 Barriers to Entry

The main barrier to entry is that extraction of lignin appears to be on more advanced level than application development. Other factors hindering the development include:

- consistent quality and specifications for feedstock are challenged by seasonal and processing variations, which need to be mastered to ensure in specs product quality;
- product characteristics limit the use of lignin; e.g. only part of the fossil based product can be substituted by lignin due to differences in reactivity;

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- in the case of phenolic resins in wood products, the real "bio-effect" of lignin is relatively small and the resin production process needs to be adjusted; the products are also typically part of B2B segment where the importance of "bio-effect" is not as critical as in consumer products;
- lignin is not a drop-in material; the whole value chain needs to be adjusted in case petrochemicals are replaced with lignin;
- very long acceptance processes required for food and biomedical end uses; and
- regulations have focused on bioenergy and biofuels instead of innovative bioproducts, materials, and chemicals.

17.4 Key Drivers for Demand

There is significant market potential available for lignin to replace fossil-based counterparts. The actual demand development will be driven by the suppliers and their success in commercializing the processes and technologies currently under development. Other key drivers include:

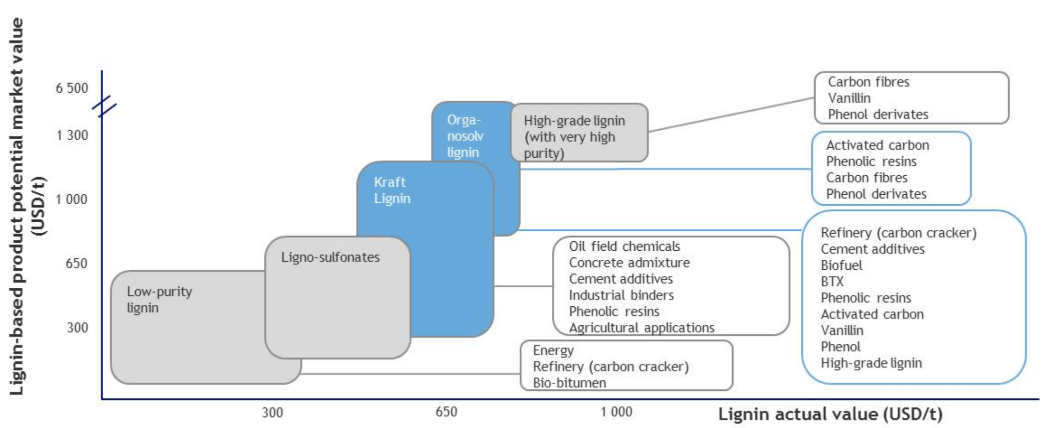
- consumer and brand-owner trends;
- positive consumer attitudes towards bio-based products;
- non-toxic alternatives for petrol-based toxic counterparts;
- sustainability image as a marketing tool for brand owners ;
- opportunities for new product properties and product differentiation (e.g. antioxidative properties and UV coverage);
- search for new lighter materials replacing e.g. steel structures;
- potential ban of phenolic components in resins;
- supply of biomass is independent of the oil and gas; however, lignin prices are projected to decrease in the future as lignin yields increase and technologies mature; and
- as lignin can replace components of petrochemical origin, lignin's value is related to the value of oil.

17.5 Prices and Price Trends

Bio-based raw materials (such as lignin) requiring multiple process steps may remain more expensive than their alternatives and may not easily be an option for the clients. In several applications, the existing raw materials are more cost competitive than lignin (e.g. in the case of surfactants lignosulfonates have certain cost-benefit).

Lignin's value as fuel is generally below 300 USD/tonne, and low-purity lignin is not worth much more. With low prices for oil, there is a strong incentive to find higher value applications. Lignin application and their potential value are shown in the following picture.

Figure 17-9: Lignin Applications and their Potential Market Value (USD/t)



Source: www.BiofuelsDigest.com, Frost & Sullivan, Neste Jacobs

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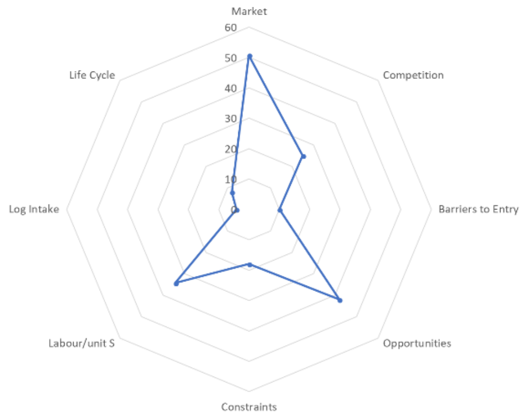
18. PYROLYSIS OIL

Pyrolysis oil is a moderately attractive option for Maine, reaching a total score of 192. Highest scores are obtained for markets (51) and market opportunities (48).

Figure 18-1: Pyrolysis Oil Attractiveness Score



The following section outlines in detail the market opportunity for pyrolysis oil produced in Maine.

18.1 Product Description

Pyrolysis oil is a liquid fuel produced from wood, that can be used in heat and power production to substitute for fossil-based-oil, or further refined as transport fuel. The attributes of pyrolysis oil are close to those of heavy fuel oil. Applicable raw materials are Roundwood, forest residues, forest industry solid by-products (sawdust, wood chips) and black liquor.

In the pyrolysis process, the feedstock is quickly heated to a temperature around 500-600°C without oxygen for a couple of seconds. The biomass is gasified, condensed and can be removed from the process as so-called crude bio-oil or pyrolysis oil. Some of the raw material does not liquefy (mainly lignin) and can be burned in the adjacent boiler plant to produce steam for the process. The best yield of liquid end-product can be about 70-75% of the dry weight of the feedstock. In terms of production costs, pyrolysis oil has proven itself to be the cheapest among liquid biofuels today.

The crude bio-oil from the pyrolysis process contains 10-30% of water, its pH is about 2 and its storage stability is poor. Its heat value is about equal to its raw material, 17-18 MJ/kg. To be able to use it as transportation fuel, it is further refined by hydrogenation to remove oxygen and water. In this refinery process, the heat value increases to the level of a fossil fuel oil, about 40 MJ/kg. This refined bio-oil can be used in similar applications as fossil diesel. Optionally, additives like methanol can be used to improve bio-oil characteristics. The unrefined bio-oil can be used in existing oil-fired power plants, with only minor modifications to the burner required.

18.2 Market Size and Growth

Investigation of fast pyrolysis-based bio-oils started in the 1980s. The first European pilots began in 1994-2000 and the scaling-up stage started in 2004. Currently, there are still only a handful of commercial pyrolysis oil producers – Fortum, BTG BioLiquids/ EMPYRO and Ensyn.

Pyrolysis oil has also been produced at Genting in Malaysia and KiOR (Inaeris Technologies) in the United States, however both plants are currently idle. While the reasons for halting production at the former are unclear, the latter has been struggling with bankruptcy, allegedly due to improper scaling of the project, as well as "*wrong choices during development and commercialization of the technology*".

The pyrolysis oil market is still in its infancy and production at the above-mentioned plants is designated to specific industrial end-users. Fortum Otso pyrolysis oil is currently used at its own plants in Espoo and Joensuu, Finland, as well as by Savon Voima, a Finnish energy producer, in Iisalmi. Some batches from Fortum Otso have also been exported to Sweden for testing at E.ON's Karlshamn power plant**.** Empyro's pyrolysis oil is used for generation of steam in Campina by FrieslandCampina, which has concluded a 12-year supply contract for 80-100% of Empyro's production volumes. Ensyn's pyrolysis oil is supplied to heat producers in the US.

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18.3 The Competitive Landscape

18.3.1 Competitors

Fortum

Fortum started the world's first commercial pyrolysis oil production at its Joensuu CHP plant in 2013 with annual capacity of 50,000 tons (210 GWh). Annual consumption of wood is 250,000 solid m^3 (100,000 dry tonnes). Fortum's sulphur-free pyrolysis oil, branded with the name Fortum Otso, is based on the fast pyrolysis of wooden raw materials (forest residues, wood chips and sawdust). Fortum Otso can be used as a substitute for heavy or light fuel oils at plants producing heat or industrial steam, and in future for production of biochemicals or transport fuels.

BTG-BTL

BTG-BTL initiated bio-oil production in 2015 in Hengelo, the Netherlands with capacity of 25 MWth. The fast pyrolysis bio-oil plant was the result of an EU research project consolidating efforts of a consortium of eight members, including the pyrolysis technology developer, Biomass Technology Group BV (BTG), and the chemical producer, Akzo Nobel Industrial Chemicals B.V. The feedstock for the plant is clean woody biomass, with a feed of five tons per hour. The total investment amounted to EUR 19 million.

Ensyn

Canadian company Ensyn has a pyrolysis oil plant in Renfrew, Ontario. Commissioned in 2006, it initially produced liquids for speciality chemicals and heating fuels, while in 2014 it was subsequently converted to a dedicated pyrolysis oil production facility with capacity of three million GPY.

18.3.2 Competing and Substituting Products

Pyrolysis oil can be used as a substitute for fossil fuels (diesel, heavy fuel oil, and natural gas) for power generation and heating, as well as in medium- or large-scale combustion systems (furnaces, turbines, boilers). Its main advantages are in reduced CO_2 balance, high energy density, applicability in both small and large-scale power systems and a possibility of co-firing with fossil fuels. Complete replacement of fossils with pyrolysis oil is nevertheless challenging due to its high viscosity, coking, corrosiveness and poor volatility. Furthermore, pyrolysis oils have 50% less heating value than fossils. If refined, pyrolysis oils can also serve as a substitute for light fuel oils (transportation fuels). When compared to biomass combustion, pyrolysis oil has a favourable low ash content.

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Table 18.1 Pyrolysis Oil: Physical Properties of Fast Pyrolysis Oils and Mineral Oils

Analysis	Typical bio-oil	HFO 180/420	LFO Motor/heating summer quality
Water, wt%	20-30	~0	~0
Water and sediment, vol%		0.5 max	0.02 max
Solids, wt%	Below 0.5		
Ash, wt%	0.01-0.1[a]	0.08 max	0.01 max
Nitrogen, wt%	Below 0.4	0.4	0.02
Sulphur, wt%	Below 0.05	1.0 max	0.001 max
Stability	Unstable[b]		
Viscosity (40°C), cSt	15-35[c]	180/420 max @50°C	2.0-4.5
Density (15°C), kg/dm³	1.10-1.30[c]	0.99/0.95 max	0.845 max
Flash point, °C	40-110[d]	65 min	60 min
Pour point, °C	-9 – 36	15 max	-5 max
LHV, MJ7kg	13-18[c]	40.6 min	42.6
pH	2-3		
Distillability	Non-distillable	Distillable	Distillable

[a] Note that metals from oxides during ashing and may yield ash values that are larger than the total solids in the liquid.
[b] Polymerizes when heated and for prolonged periods of time.
[c] Depends on water content.
[d] Flash point method unsuitable for pyrolysis oils. Pyrolysis oils do not sustain combustion.

18.3.3 Barriers to Entry

The main challenges for pyrolysis oil are market-based, a pyrolysis oil market still needs to be established. Currently, the main end-use segment of pyrolysis oil is commercial district heating. Unlike biodiesel or bioethanol, without refining, pyrolysis oil cannot be used as a transportation fuel. Its overall technical development is also a challenge and there are some certain unfavourable properties, such as high water and oxygen content, instability, and corrosiveness.

As the progress of commercial pyrolysis oil production has revealed, ensuring availability of biomass and choosing the right scale of production are critical. Feedstock transportation costs have a substantial influence on the overall cost of pyrolysis oil.

Pyrolysis oil is price-competitive in comparison to heating oil, but not when compared to low-priced natural gas in Europe and the US. In some countries, e.g. Brazil, where prices for biomass are low and prices for natural gas high, pyrolysis oil may have a clear cost advantage.

18.4 Key Drivers for Demand

As mentioned above, heating is the main target segment for pyrolysis oil producers. According to the report published by the US Department of Energy, as much as 20% of Number 2 heating oil could be substituted with mixable pyrolysis oil in the Northeast States of the US, the largest consuming region of heating oil in the country (Figure 18-2). Most of this heating oil is currently imported and has been characterised by shortages in supply and price fluctuations. Some of the US North-East states (Maine, Massachusetts, New Jersey, New York, and Vermont) are transitioning to ultra-low sulfur (ULS) heating oil, leading to an increase in fossil fuel oil prices and interest in pyrolysis oil.

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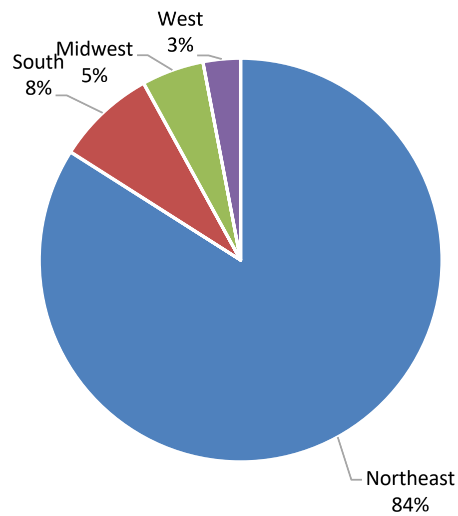
Figure 18-2: Sales of Residential Heating Oil by Census Region



Source: US Energy Information Administration

In Europe, there are currently 122 million heat generator systems for residential use, 90% of them are non-condensing boilers. Most heat energy (80%) is produced from natural gas and to a lesser extent from heating oil. Due to high water content, pyrolysis oil has the most potential to be used in condensing boilers as a sustainable and cost-efficient raw material. Support policies are still the major driver for pyrolysis oil demand in Europe. Especially the EU Renewable Energy Directive seeks to increase production and promotion of renewable energy in the EU member states.

18.5 Prices and Price Trends

The price of a ton of pyrolysis oil produced at the Empyro plant is around EUR 300 (EUR 18-20/GJ, 65-75/MWh) with biomass costs of approximately EUR 80 per dry ton. Biomass feedstock has the highest cost in pyrolysis oil production, accounting for around 43% of the total costs, closely followed by finance costs including equity and depreciation. According to the study by Vasalos *et al*. 2016, the production cost of pyrolysis oil is USD 22/GJ (USD 80/MWh) with the feedstock cost of USD 57 per dry metric ton. The study on the cost of biofuel of the subgroup on advanced biofuels of the European Commission, indicated that for pyrolysis oil co-processing, the production cost ranges between EUR 14-27/GJ (EUR 58-104/MWh), while for stand-alone the range is higher – EUR 23-33/GJ (EUR 83-118/MWh).

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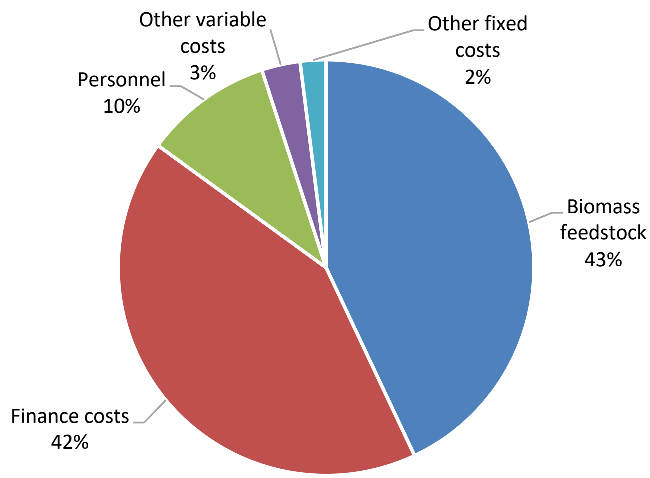
Figure 18-3: Cost Breakdown of Empyro Pyrolysis Oil



Source: TechnipFMC

18.6 Product Certification

In the US, pyrolysis oil is covered by the standard ASTM D7544 - 12(2017) Standard Specification for Pyrolysis Liquid Biofuel. Its scope covers biomass-based pyrolysis oil for fuel-burning equipment and it distinguishes between two grades – G for industrial burners, and D for commercial/industrial burners requiring lower content of solids and ash.

Table 18.2 Pyrolysis oil grades according to ASTM D7544

Property	Grade G	Grade D
Gross heat of combustion, min (MJ/kg)	15	15
Water content, max (mass %)	30	30
Pyrolysis solids content, max (mass %)	2.5	0.25
Kinematic viscosity at 40 °C, max (mm^2/s)	125	125
Density at 20 °C (kg/dm^3)	1.1 - 1.3	1.1 - 1.3
Sulfur content, max (mass %)	0.05	0.05
Ash content, max (mass %)	0.25	0.15
pH	Report	Report
Flash point, min (°C)	45	45
Pour point, max (°C)	-9	-9

Source: VTT

In Europe, a working group of the Technical Committee of the European Committee for Standardization (CEN/TC 19/WG 41) is currently developing standards for fast pyrolysis oils as the result of the EC mandate M/525 (2013). Two standards were published in 2017:

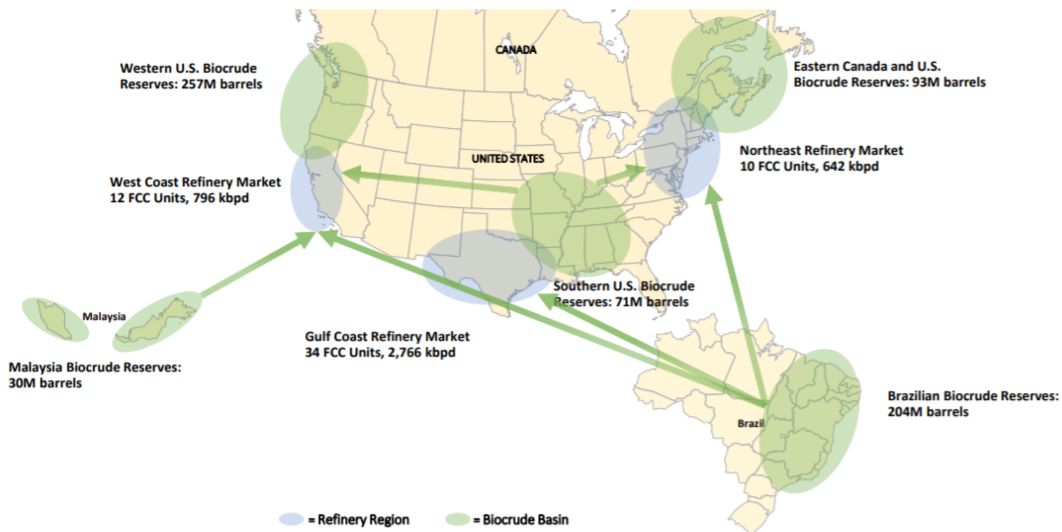
- CEN/TR 17103:2017 Fast pyrolysis bio-oil for stationary internal combustion engines - Quality determination
- EN 16900:2017 Fast pyrolysis bio-oils for industrial boilers - Requirements and test methods.

18.7 Outlook

18.7.1 Market Growth

Fortum and Ensyn have announced plans for commissioning additional pyrolysis oil plants. While Fortum's intentions are rather unclear, stating that Fortum plans to integrate pyrolysis oil production into several other CHP plants both in Finland and abroad, Ensyn is already engaged with several partners in constructing large-scale bio-oil production in Canada, Brazil and the US. Construction of Ensyn's pyrolysis oil production facility in Quebec, Canada with capacity of 10 million GPY was initiated in July 2016 and it is expected to begin operating in Q1 2018. The project has been undertaken as a joint effort between Ensyn, Arbec Forest Products and Groupe Remabec and required USD 78 million of capital investment. Initially, the main customers will be from the heating sector in the US Northeast. In the future, pyrolysis oil will be further refined. In Brazil, Ensyn is developing a 22 million GPY pyrolysis oil project with Fibria Cellulose in Aracruz, Espirito Santos. In the US, Ensyn is planning a 20 million GPY project with Roseburg Forest Products. Both the Brazilian and US facilities are expected to sell pyrolysis oil to major US refineries.

Figure 18-4: Refinery Regions and Bio-oil Basins of Ensyn



Source: Ensyn presentation

In addition to the previously mentioned projects, the Finnish biorefining company "Green Fuel Nordic" has secured financing and is planning to start commissioning of a new pyrolysis oil plant in Lieksa, Finland. Two other pyrolysis projects have received funding from the NER 300 funding program, which seeks to support innovative low-carbon energy demonstration projects. Both are in the Baltic States, the first is a fast pyrolysis project in Estonia (now on hold) and the second, a CHP Biomass pyrolysis project in Latvia. Finland and Sweden are expected to become the main export markets for both facilities.

18.7.2 Opportunities

- Pyrolysis oil reduces GHG emissions by 70-90% and nitrogen oxide compounds by 50% in comparison to heavy fuel oils. In addition, it has a low sulfur content, making it a sustainable alternative to fossil fuels. Environmental awareness is generally rising, triggering more interest towards sustainable biofuels such as pyrolysis oil.
- Only small adjustments are required in infrastructure (pipes, containers and feeding) to switch from the use of heavy heating oils to pyrolysis oils.
- Investment costs of pyrolysis oil production are relatively low, if it is integrated effectively – only some minor additions to an existing boiler plant equipment are required. Fortum's capital investment into pyrolysis oil production was EUR 32 million, of which EUR 8 million were State subsidies.

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- The volume of wood raw material required is at a reasonable scale for the Maine sawmill industry to supply from its by-products (sawdust and chips), being in the range of a few hundred thousand wet tons.
- A wide range of biomass can be transformed into liquid oil and pyrolysis is the cheapest option.
- Storing and transportation of pyrolysis oil is easier in comparison to solid biomass, as it reduces the volume by a factor of 12.

18.7.3 Constraints

- Pyrolysis oil is acidic, thus contacting materials (e.g. steel, plastic) must be acid-proof and stainless. In addition, its high-water content decreases its net heating value and contributes to corrosivity.
- The price for pyrolysis oil is dependent on the prices for oil and natural gas. A low price for oil in 2016 led to the halting of Fortum's subsidiary pyrolysis oil project in Parnu, Estonia.
- There is a lack of internationally accepted and compatible sustainability requirements for pyrolysis oils and undeveloped markets. There is a need for government policies and programs supporting pyrolysis oil production, as well as R&D activities.

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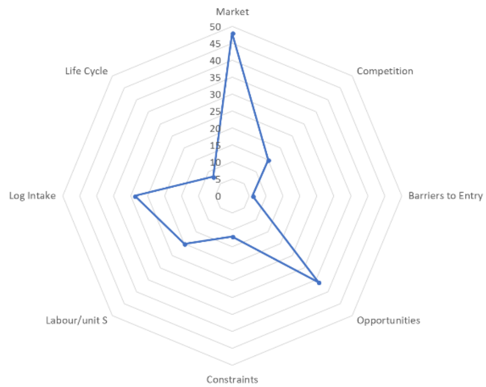
19. 2G ETHANOL

Ethanol is among the less attractive options for Maine, with a total score of 174. Highest scores are obtained for markets (48) and market opportunities (36).

Figure 19-1: Ethanol Attractiveness Score



The following section outlines in detail the market opportunity for ethanol produced in Maine.

19.1 Product Description

19.1.1 The Product

Ethanol is colourless, flammable and antiseptic liquid. Ethanol is mostly used as transport fuel (about 90%).

First generation (1G) ethanol is produced mainly of corn starch, wheat and sugar-containing plants such as sugar beet and sugar cane. Production of 1G ethanol is technologically well established and commercially developed for many years.

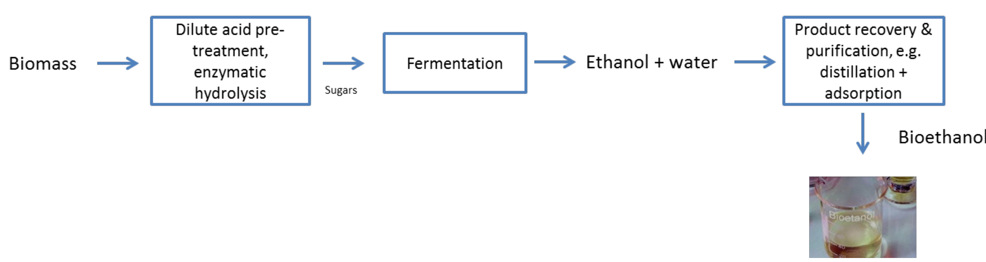
1G ethanol has been criticized for its limited GHG emission savings and for its raw materials that are also used for food production. Over the last years second generation (2G) or so-called lignocellulosic ethanol production has emerged to address these criticisms.

2G ethanol is produced exclusively of non-edible, cellulose and lignocellulose feedstock, such as wood, agricultural residues, straw, grasses and different industrial and even municipal waste streams. 2G ethanol production is not fully commercial yet (early phase of commercialization).

19.1.2 Manufacturing Process

1G ethanol is produced by the fermentation of sugars by yeasts. 2G ethanol is produced by hydrolysis of non-edible, cellulose and lignocellulose feedstocks (e.g. by acid, enzymes) followed by microbial fermentation of released cellulose and hemicellulose sugars to ethanol.

Figure 19-2: Lignocellulosic Ethanol Production Scheme



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(Source: Neste Engineering Solutions)

19.2 Market Size and Growth

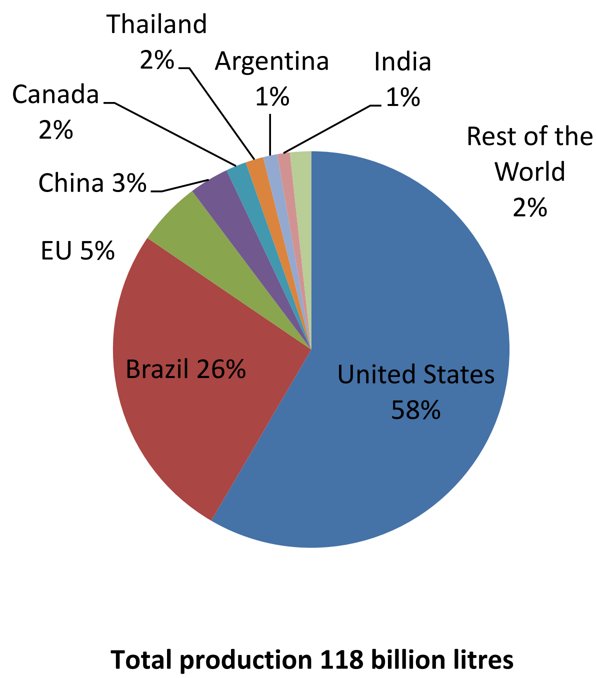
Global ethanol production accounted for 118 billion litres (about 70 billion USD) in 2017. There are three main end use segments for ethanol: fuel, industrial uses, and beverages. Fuel consumption is by far the most important end use at the moment accounting for 80-90% of ethanol consumption. In order to compete price-wise with gasoline, ethanol must be promoted through variety of subsidies.

The United States is the world's largest producer of ethanol with 58% market share. Most of the ethanol produced in the US is sold domestically as the ethanol consumption in the US accounts for almost half of the total global ethanol consumption.

Brazil is the second largest producer with 26% share of global production. The industry is increasingly dominated with foreign capital investing in modern large-scale facilities.

Other producers led by the EU and China account for 16% the global market altogether.

Figure 19-3: Global Ethanol Production (2017)



Future production development is focused on 2G ethanol, such as ethanol from non-food chain products like agricultural waste, wood and even municipal waste. Currently 2G capacity accounts less than 1% of ethanol production (0.8 billion liters in 2017). The production is even lower, only about 25-35% of the capacity (200 - 350 million litres in 2017).

China has the largest 2G ethanol production capacity. Some 75% of the current capacity has been started during 2016 and 2017. Neste Engineering Solutions estimates production to be around 200 million litres in 2017. The first 2G ethanol producer Shangdong Longlive Biotechnology started its production in 2012. Since then two new companies have entered the field as COFCO Biochemical Energy and Henan Tianguan Group started their demo facilities 2016-2017.Currently, there are no new 2G facilities under construction in China.

The US has the second largest production capacity (about 200 million litres in 2017). The production remains well below the capacity.

The Renewable Fuel Standard was amended in 2007 to include requirements for 2G bioethanol. As the industry moved towards the next generation of biofuels, many demonstration plants were built. The first wave of commercial-scale 2G bioethanol projects started production around 2014, including Abengoa's Kansas project and POET-DSM Advanced Biofuels' Iowa project.

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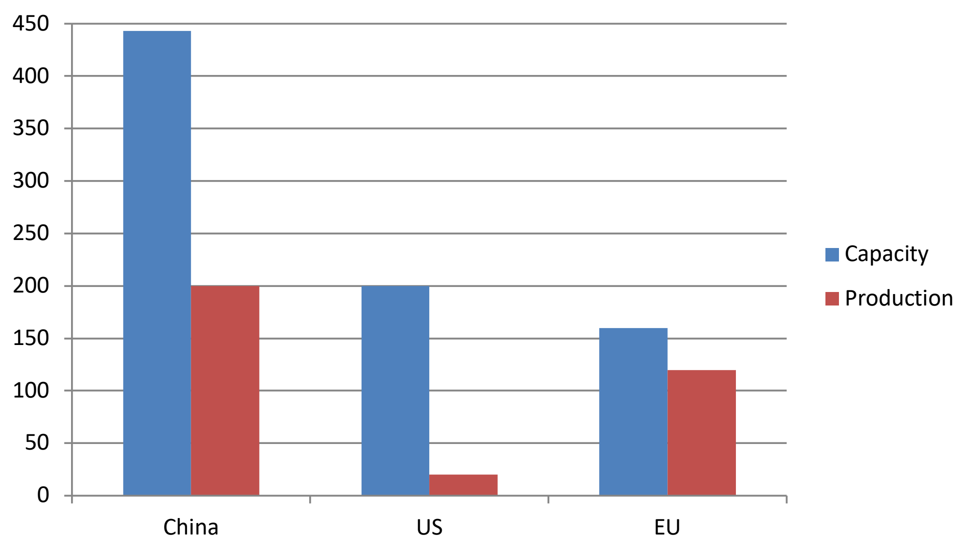
As of 2014, there were 18 active 2G ethanol projects in the US. However, announcements of new 2G projects, changes in project plans, project delays and cancellations occurred. The oil price slump in the second half of 2014 hurt especially the large-scale projects resulting to BPs announcement that it would no longer invest in 2G ethanol production and it would down their existing projects. In addition, in March 2016, Abengoa filed bankruptcy and sold its 2G ethanol plant to Synata Bio. In November 2017, Dow DuPont announced plans to sell it's 2G biofuel business and its Nevada Iowa plant.

Currently, there are seven players. In the US small-scale 2G plants make better progress towards commercial production than their large-scale competitors. The reason for this is that most of the plants are located next to conventional ethanol plants and this way can reduce their operating costs, capital cost and in some case also secure their raw material supply.

In Europe the ethanol market is rather young, but has grown steadily since 2004. The 2G ethanol capacity accounts for 160 million litres and 2G ethanol production accounted for 120 million litres in 2017.

Large-scale 2G ethanol investments have been constrained by political and price uncertainties. In 2013, Beta Renewables completed the world's first commercial-scale 2G ethanol plant in Crescentino, Italy. However, in October 2017 a plan to sell the Crescento plant was announced. Due to financial difficulties, the plant was shut down. A large commercial project was shut down in Holstebro, Denmark. Still in Finland there are three to four 2G ethanol plants based on wood raw materials announced. All in all, there are more than 300 million litres of additional 2G ethanol capacity scheduled to come on-stream within next two years. Currently, there are more than 10 small-scale second generation plants operating in Europe with capacities between 1-30 million litres with high production levels.

Figure 19-4: Global 2G Ethanol Capacity and Estimated Production in Main Producing Regions



Global ethanol demand accounted for 118 billion litres in 2017. The US is the leading ethanol consumer with 48% share of global consumption. In 2017, 96% of ethanol consumed was used for fuels. Gasoline sold in the US contains 10% of ethanol on average. The growing gasoline demand since 2012 together with growing share of ethanol in gasoline have boosted the ethanol demand. Ethanol mandate of the Federal Renewable Fuel act together with ethanol subsidies have helped in this process.

Brazil accounts for 23% share of global consumption. In 2017, 95% of ethanol consumed was used for fuels. Brazil has a long tradition of supporting ethanol fuel. Proalcool programme launched in 1975, resulted that by 1985, 85% of the cars in Brazil ran with 100% ethanol. However, the programme ran into difficulties as supplies of ethanol decreased due to

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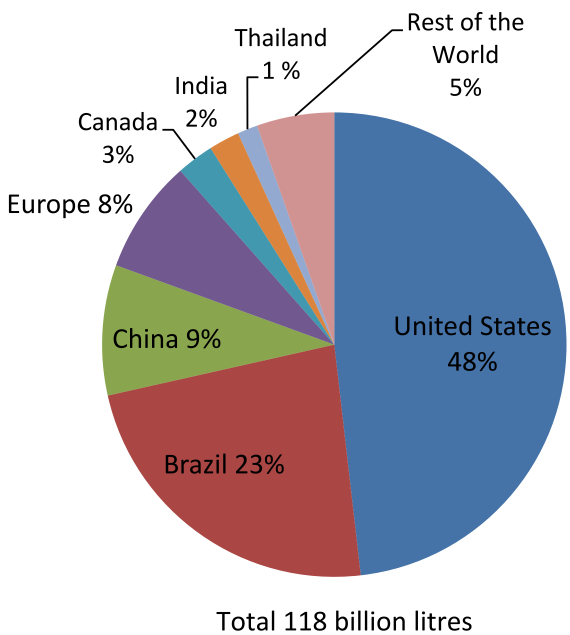
liberalization of sugar market. Currently, 72% of car fleet are flex-fuel vehicles and the government regulates ethanol blending level to gasoline that has varied between 20-27%.

China accounts for 9% of the global demand. In 2017, only 37% of ethanol consumed in China was used in fuels. Other major end-use segment was alcohol with 35% share.

As Chinese Government has promoted E-10 in limited provinces in 2017 and announced plans to expand the use of ethanol fuel in transportation. The ethanol consumption for fuels is expected to more than double in during next five years. At the same time, no significant growth is expected in other segments.

Europe accounts for 8% of global consumption. 76% of ethanol is used for fuel. The ethanol fuel consumption is driven by EU's 2020 targets and fuel blending requirements.

Figure 19-5: Global Ethanol Consumption



The 2G ethanol is entirely used for fuels and driven by incentives to produce non-food based ethanol. Most important of these incentives are the US's Federal Renewable Fuel Acts' mandates for cellulosic ethanol and EU's latest proposal to amend the Renewable Energy Directive for 2021-2030. Due to these incentives 2G ethanol is expected to be consumed mainly in the EU and the US in the future.

19.3 The Competitive Landscape

The development of technology of producing 2G ethanol economically has been slow. Many large-scale facilities have announced commercial production, but output volumes have been low.

Currently, there are only a handful of companies with large-scale 2G ethanol facilities. It seems that small-scale plants have succeeded better in the current industry environment, but this will probably change along with advanced ethanol production technology development.

Shangdong Longlive Biotechnology currently wold's largest 2G ethanol producer, started its ethanol production based on corncob in 2012. The plant has since been expanded and two new straw based production lines started in 2016. The plants current capacity is 190 million litres of 2G ethanol. Henan Tianguan Group started their straw based 2G ethanol 190 million litre capacity demo facility in 2016-2017.

Dow DuPont's cellulosic ethanol plant in Nevada, Iowa was the first commercial scale cellulosic ethanol plant in the US with 113 million litre capacity. In November 2017, the company announced its plans to sell their ethanol business and their production facility in Iowa, Nevada.

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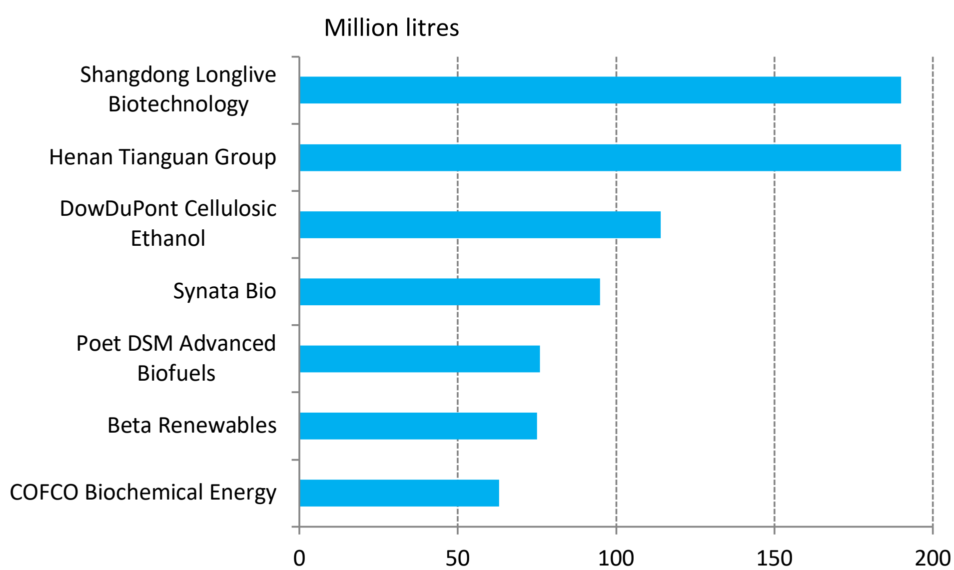
Synata Bio bought Abengoa's Hugoton, Kansas plant, after Abengoa's financial difficulties that almost led to bankruptcy in 2016. The plant is one of the first 2G ethanol facilities in the US and has the capacity of 95 million litres.

Poet is second largest ethanol producer in the US with 25-30 ethanol facilities and 6.3 billion litre production capacity. Poet has 2G ethanol joint venture with DSM in Iowa, with capacity of 76 million litres.

Beta Renewables is a joint venture between Gruppo Mossi & Ghisolfi and US private equity company Texas Pacific Group. The company completed the world's first cellulosic ethanol plant to Crescentino, Italy in 2013. The plant has capacity of 75 million litres. In October 2017, Gruppo Mossi & Ghisolfi announced its plans to sell their biofuel business due to financial difficulties. During the same month Crescentino plant was shut down.

COFCO Biochemical Energy is one of the largest ethanol producers in China with four conventional ethanol plants and one 2G ethanol demonstration plant in Zhaodong, Heilongjiang. The plant was started in 2016 and has a capacity of 63 million litres.

Figure 19-6: Major 2G Ethanol Producers Based on Capacity



Source: IHS, Neste Engineering Solutions

19.4 Key Demand Drivers

As 2G ethanol is almost entirely used to produce transportation fuels, the key driver is the development of transportation fuel consumption. Within fuel sector the 2G ethanol demand is on the other hand driven by the incentives to boost biofuel demand and on the other hand need to separate the feedstocks used from the food chain. As the 2G production capacity is still developing different tax incentives, subsidies and government mandates have an important role. Currently, the US 2G ethanol mandate and EU's REDII directive are clearest efforts to increase 2G ethanol demand.

19.5 Prices and Price Trends

The profitability of the ethanol industry can be volatile since it is subject to fluctuation of two major commodities, corn prices and gasoline prices. The price of ethanol historically moved in relation to gasoline prices, but since 2007 the price of ethanol has been largely driven by demand/supply fundamentals and price of corn.

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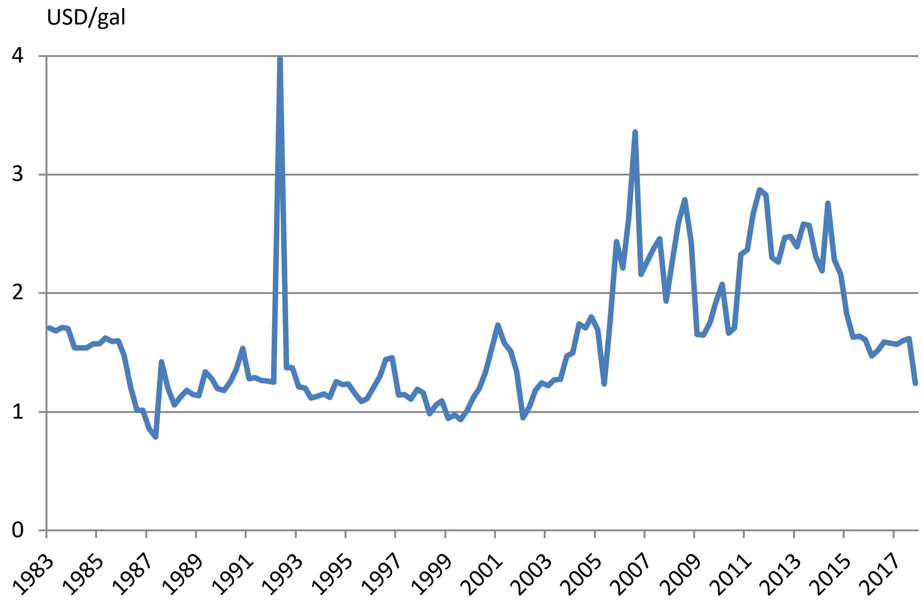
Figure 19-7: Ethanol Price in the United States



Source: IHS, Neste Engineering Solutions

19.6 Outlook

Global ethanol market is expected to grow with moderate rate of 2.1% till 2022. The strongest growth is expected to emerge from the fuel use as other end-use segments are mature (e.g. solvents and alcoholic beverages) are growing at a slower pace (industrial alcohols). In the fuel segment, growth rates could be significantly higher, but would require a commitment from governments, industry and consumers towards the increased use of biofuels through mandates and incentives.

The 2G ethanol market will grow faster than the global ethanol market in general due to the switch away from food chain to second-generation feedstocks. There are many 2G projects in the pipeline, but in the end, the level of regulation and incentives will determine the pace of 2G ethanol market growth. If proper incentive levels are set 2G ethanol production can be easily doubled during next five years.

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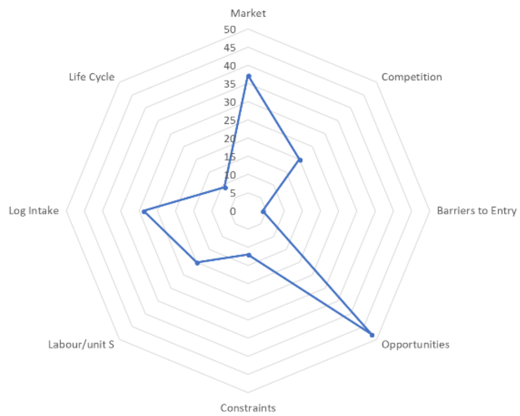
20. LIGNOCELLULOSIC BIOBUTANOL

Lignocellulosic biobutanol is among the less attractive options for Maine, reaching a total score of 179. Highest scores are obtained for markets (37) and market opportunities (48).

Figure 20-1: Lignocellulosic Biobutanol Attractiveness Score



The following section outlines in detail the market opportunity lignocellulosic biobutanol produced in Maine.

20.1 Product Description

Lignocellulosic biobutanol is a bio-based alcohol produced from similar feedstock to 2G ethanol, such as corn, sugar beet and different types of biomass (softwoods, hardwoods, sawdust, pulp, agricultural residues). It has been studied mostly for use as drop-in fuel in mixtures with gasoline. Biobutanol is an interesting biofuel as it has superior properties vs. bioethanol:

- higher energy density
- lower volatility
- less corrosive

Biobutanol also shows promise as an industrial solvent. Other possible applications may include use in paints/coatings, resins, plasticizers, pharmaceuticals, food grade extractants, chemical intermediates and herbicides.

Butanol has four different isomers, two of which are commercially dominant: *n*-butanol and isobutanol (Figure 20-2). The butanol isomers have different properties, such as density, viscosity and boiling/flash-points.

Figure 20-2: *n*-Butanol and Isobutanol Molecular Structures

n-butanol isobutanol

20.1.1 Manufacturing Process

Biobutanol is traditionally produced using ABE (acetone-butanol-ethanol) fermentation by *Clostridium acetobutylicum* (Figure 20-3). A major technological bottleneck of the ABE fermentation is its low butanol yield. Due to the toxicity of butanol to the production organism, the product needs to be continually recovered from the fermentation broth. Alternatives to the energy-intensive distillation are e.g. adsorption, pervaporation and membrane separation.

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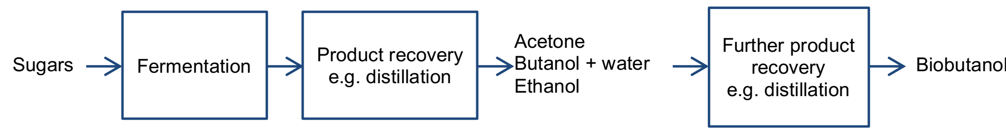
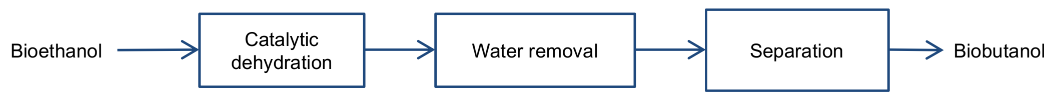
Figure 20-3: Biobutanol Production via ABE Fermentation



There are several players developing modifications to the original ABE fermentation process to optimize the yields and selectivity. Gevo and Butamax Advanced Biofuels have developed their own proprietary yeasts for bio-based isobutanol production process.

Biobased *n*-butanol can also be produced from bioethanol using catalytic conversion, where the ethanol passes through a catalytic bed producing *n*-butanol and co-products. Butanol and co-products are separated and butanol further purified (Figure 20-4). Abengoa has been working on this production route.

Figure 20-4: Biobutanol Production from Bioethanol



20.2 Market Size and Growth

Butanol has a global market of 3.7 million tonnes annually, with a market value of over 6 billion USD (Source: Research and Markets). Currently, the bio-based butanol production is almost non-existing, due to the low profitability of the renewable process routes. In 2016, bio-based butanol was produced only 1.3 ktonnes by Gevo.

Several analysts forecast bio-based butanol market an annual growth rate of over 9 % for the coming years. (Sources: Mordor Intelligence, Research and Markets, Technavio)

20.2.1 Production

Biobutanol production has suffered from low profitability due to high raw material price and low fermentation yields. Hence, there is practically close to none commercial production to date. Plans and development are still in place for future commercialization. Fermentation process improvements and lower-priced raw materials (2G sugars, steel-mill off gases) could help biobutanol compete with fossil-derived butanol in production costs.

Bio-based Isobutanol Production

Currently Gevo is the only commercial producer of biobutanol with its bio-based isobutanol plant in Luverne Minnesota. The current capacity of the plant is some 6-9 ktons per annum (2-3 million gal per annum) and Gevo has announced its plans for increasing the capacity of Luverne facility to 40-50 ktons per annum (12-16 million gal per annum). The production of bio-based isobutanol was, however, only 1.3 ktons per annum (440 000 gal per annum) in 2016. (Figure 20-5).

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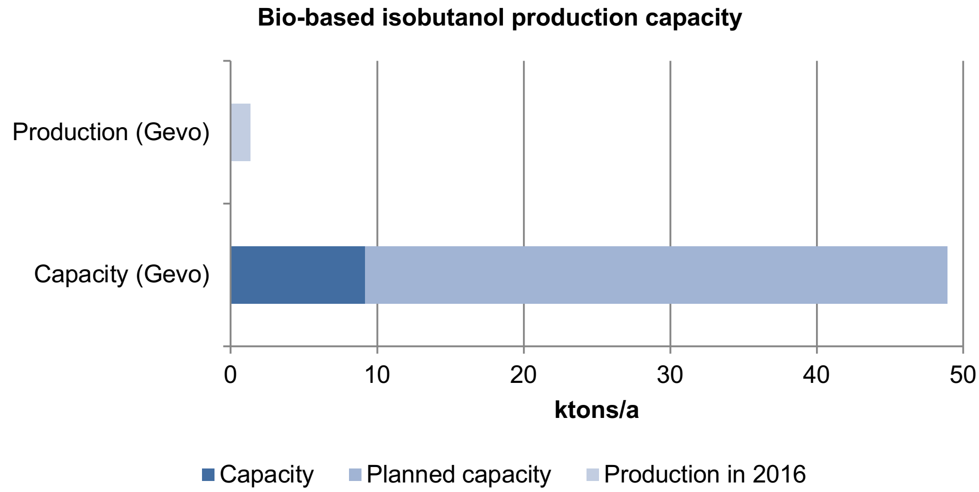
Figure 20-5: Bio-based Isobutanol Production Capacity



Butamax Advanced Biofuels has also announced its plans for starting bio-based isobutanol production at two existing ethanol plants in US. The capacity of these plans is, however, unknown and there is no production currently.

Bio-based *n*-Butanol Production

There have been several initiatives for the production of bio-based *n*-butanol, but few of them have progressed. Green Biologics has retrofitted an ethanol plant in Minnesota, US, and announced first shipments of bio-based *n*-butanol in 2016. Their *n*-butanol production volume and plant operation status is, however, unknown.

20.2.2 Demand

Currently butanol is used mainly in the production of butyl acrylate, butyl acetate, glycol ether and plasticizers as well as a direct solvent in the production of other chemicals (Figure 20-6).

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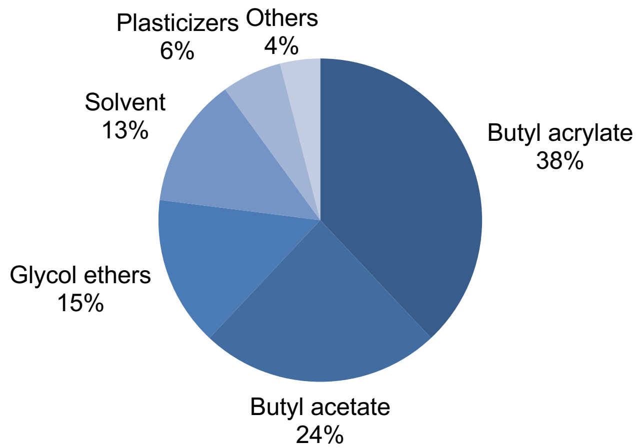
Figure 20-6: Butanol Applications



Total: 3.7 million tons

Source: Informa Economics

The global butanol market was estimated to be some 3.7 million tons in 2016. Biobutanol is considered as an attractive alternative, as it has superior fuel properties to ethanol. Ethanol is consumed globally some 85 million tons per annum as a fuel. Thus, biobutanol has a huge potential market, if it were to substitute fuel bioethanol but also if it would gain foothold in fossil-derived butanol applications.

20.3 The Competitive Landscape

The biobutanol market is fragmented. Several key players are developing new technologies and forming strategic alliances. The leading bio-based isobutanol players in the market are Gevo and Butamax Advanced Biofuels and bio-based *n*-butanol player Green Biologics for bio-based *n*-butanol.

Bio-based Isobutanol Players

- **GEVO Inc.** is a Colorado-based U.S. renewable technology, chemical products and advanced biofuels company. It is currently the only producer of bio-based isobutanol. Gevo has been producing renewable isobutanol at its fermentation plant in Luverne, Minnesota US since 2014. The Luverne plant has a production capacity of 6-9 ktons per annum (2-3 million gal per annum), and planned additional capacity to 40-50 ktons per annum (12-16 million gal per annum). Gevo uses corn as raw material for the isobutanol production, but has also been able to convert wood waste -derived cellulosic sugars into isobutanol

  Gevo has partnered with Musket Corporation for introducing bio-based isobutanol to the fuel markets and blending it with gasoline. Gevo is also developing isobutanol-based paraxylene with Coca-Cola
- **Butamax Advanced Biofuels** is a joint venture between BP and DuPont. Butamax has developed a bio-based isobutanol production technology for converting of sugars from various biomass feedstocks, such as corn and sugarcane, into bio-based isobutanol via fermentation. The Butamax technology uses existing bioethanol facilities and retrofits them for bio-based isobutanol production

  In 2013, Butamax started to retrofit Highwater Ethanol LLC's ethanol plant in Lamberton Minnesota. However, there is no production of bio-based isobutanol currently at the Highwater plant. In April 2017, Butamax announced the acquisition of Nesika Energy, LLC ethanol facility in Scandia, Kansas and starting of detail engineering work for adding bio-isobutanol capacity to the facility, while continuing to produce bioethanol prior and after the revamp
- Gevo and Butamax have had a dispute over the proprietary rights of their bio-based isobutanol technologies, but in 2015 they entered into global cross-license and settlement agreements. Gevo will lead the development of jet fuel market and Butamax focus on the on-road gasoline blendstocks

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Bio-based *n*-Butanol Players

- **Green Biologics** is a UK-based industrial biotechnology and renewable chemicals company with bio-based *n*-butanol production utilizing corncobs and corn stover as feedstock. In 2014 Green Biologics acquired a 63 ktons per annum (21 million gal per annum) ethanol plant in Little Falls, Minnesota, which Green Biologics retrofitted for the production of *n*-butanol and acetone. Green Biologics has announced that the retrofitted plant was started-up in late 2016 and that first commercial shipments of Little Falls bio-based *n*-butanol were made in December 2016. Current status of the plant operation is unknown
- **Abengoa Bioenergy** is a unit of Spanish bioenergy company Abengoa SA, who has been developing catalyst and process for catalytic synthesis of *n*-butanol from bioethanol. Abengoa has piloted the process, but it has not proceeded into commercial scale. Abengoa Bioenergy has been close to bankruptcy, but was able to avoid it and settle with its creditors in 2017.

There are also other companies exploring the biobutanol markets, such as Swiss start-up technology developer **Butalco**, acquired by **Leaf Technologies/Lesaffre** in 2014. Butalco has been developing yeast-based isobutanol from lignocellulose. Also **GranBio** and **Rhodia** announced their partnership in renewable chemicals in 2013 with an objective to build a bio-based *n*-butanol plant in Brazil. The current status of these initiatives is unannounced. A number of other companies have been active in biobutanol production, but many have discontinued their development work. Some Asian companies, such as Korean refining company GS Caltex, have also shown activities, but the current status of these projects is unknown.

20.4 Key Demand Drivers

The main driver boosting the biobutanol market is growing requirements for cleaner alternatives. Biobutanol is an attractive alternative to bioethanol as a transportation fuel and the increasing demand of biobutanol from the automobile industry is a key driver for the market.

Butanol is used as raw material or solvent in the production of chemicals used in various applications, such as paints, plastics, textiles, coatings, polymer composites and ceramics. The demand for bio-alternatives in the production of consumer products is also a biobutanol market driver.

20.5 Prices and Price Trends

Since 2010 *n*-Butanol price range has typically been about 1000-1500 USD/ton. The price was even lower in 2016, due to crash in crude oil price in 2015-2016. (Figure 20-7).

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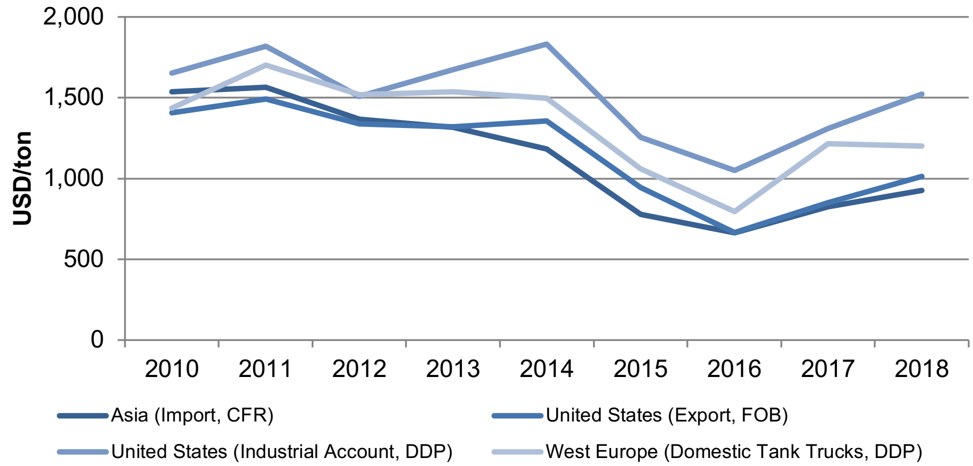
Figure 20-7: *n*-Butanol Price Trends



Source: Technon OrbiChem

n-Butanol is more valuable product than its isomer isobutanol. In Europe, the price of fossil-derived isobutanol has been typically some 60-125 USD/ton (50-100 EUR/ton) below the *n*-butanol prices. The price difference has been, however, higher recently with reported isobutanol prices of 945-985 USD/ton (770-800 EUR/ton) ddp and *n*-butanol prices of 1290-1475 USD/ton (1050-1200 EUR/ton) ddp in Europe, March 2017. (Source: Technon Orbichem)

The cost competitiveness of bio-based versus fossil-derived butanol is a major obstacle in the development of biobutanol industry. The average selling price of Gevo's bio-based isobutanol is estimated between 1150-1500 USD/ton (Source: Technon Orbichem, 2017), which is some 25 % higher than the fossil-derived isobutanol prices reported in March 2017.

20.6 Product Certification

In the US, bio-based isobutanol is qualified as an advanced biofuel. Environmental Protective Agency (EPA) also rewards bio-based isobutanol with renewable energy credits.

20.6.1 Opportunities

One of the key opportunities of biobutanol is its potential to replace fuel ethanol. Biobutanol has higher energy content than ethanol making it preferable as fuel. It also prevents moisture absorption and reduces engine corrosion. Butanol is an attractive fuel alternative, as it is a drop in product and does not require modifications to the engines. Biobutanol as a fuel has also lower carbon emissions. Biobutanol is also a sustainable alternative to fossil-derived butanol in its applications.

20.6.2 Constraints

The relatively high costs of biobutanol have restrained biobutanol from break through to the market. The availability and increasing price of biobutanol raw materials as well as challenges with yield and selectivity in the production processes are inhibiting demand growth of bio-based butanol. In addition, the on-going debate over food versus fuel and uncertainty of regulations may hamper producers when making business plans.

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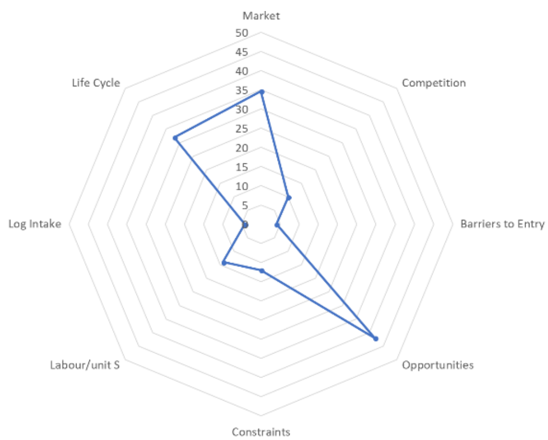
21. XYLITOL

Xylitol is among the moderately attractive options for Maine, reaching a total score of 153. Highest scores are obtained for markets (35) and market opportunities (42).

Figure 21-1: Xylitol Attractiveness Score



The following section outlines in detail the market opportunity for xylitol produced in Maine.

21.1 Product Description

Xylitol is a sugar alcohol used as an alternative sweetener to traditional sugar. Xylitol is a natural occurring sugar, that was first was discovered by German Chemist Emil Fisher and French Chemist M.G. Bertrand in 1890.

During the second world war, sugar shortages in Finland resulted in local manufacture using birch bark. Since the 1970's the University of Turku in Finland focused serious research on the manufacture of Xylitol resulting in commercial production from approx. 1975 onwards.

Xylitol's is an ideal sweetener for diabetic patients because its metabolism is independent of insulin. It may also prevent dental decay.

It is principally used in certain sweetened products such as confectionery, in personal health products such as mouthwash and toothpaste, and in the pharmaceutical industry such as a sweetener or coating agent for pharmaceutical products.

Photo 21-1: Xylitol

Hemicellulose extracted from either hardwoods or corncobs is the traditional source to produce xylitol. Alternative production uses a fermentation process.

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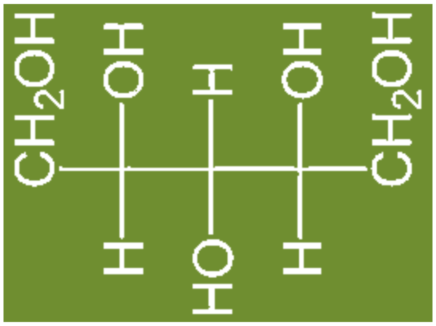
Equation 20-1: Chemical Structure of Xylitol



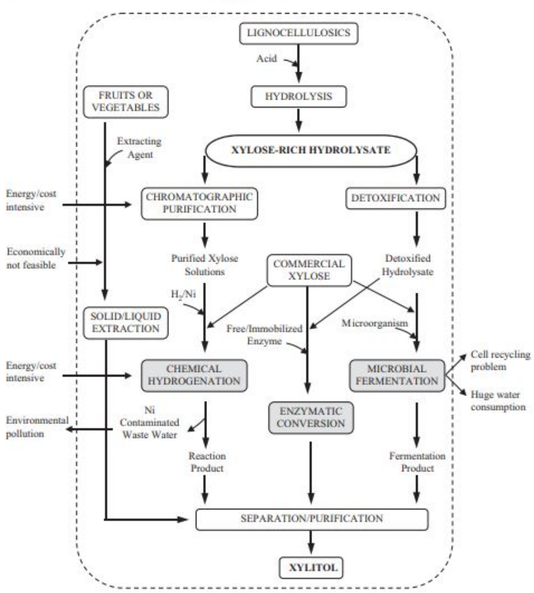
There is strong global and local demand. US demand for xylitol has been estimated as some 60 000 tons in 2017. Xylitol production from corncobs is currently more competitive compared to wood-based xylitol, although wood-based xylitol is regarded as a superior product.

The fast majority of xylitol is current produced from corncobs through the catalytic reduction of pure D-xylose. Alternative raw material includes various biomass types including agricultural and woody biomass. Currently, the world's largest producer is China.

21.1.1 Manufacturing Process

Xylitol is industrially produced by catalytic reduction of pure D-xylose but can also be produced by biotechnological approaches. The hemicellulosic sugar xylose is extracted from lignocellulosic material mainly by acidic orenzymatic hydrolysis. Industrially, xylitol is currently manufactured by chemical hydrogenation of pure D-xylose in the presence of a nickel catalyst at elevated temperature and pressure.

Figure 21-2: Xylitol Manufacturing Process



The chemical method of xylitol manufacturing is energy and cost-intensive. It involves intensive refining treatments needed to produce pure xylose. Alternatives to the conventional method, two biotechnological approaches seem promising: the microbial process and the enzymatic approach. These biotechnological processes seem to be highly attractive alternatives that might be able to produce a high-quality and cost-effective product.

The process of xylitol production methods is presented in Figure 21-2 above.

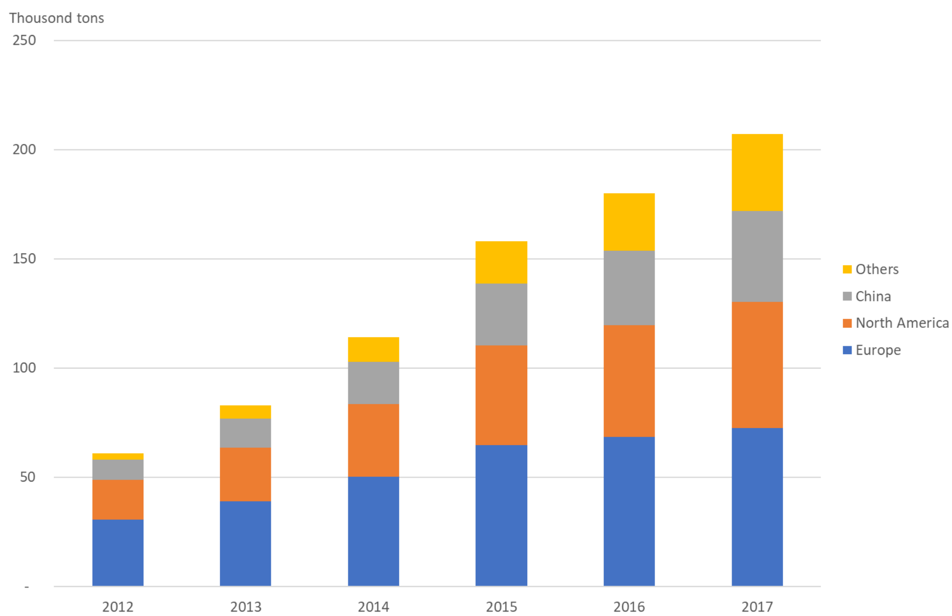
Currently, the fast majority of xylitol produced is produced from corncobs using the hydrolysis process. The production of wood-based xylitol is by Danisco, a Du Pont company which produces xylitol in Europe and the US uses the DuPont Wood Based integration concept (DWP). This process uses pulp and paper side streams as feedstock. This process reduces energy requirements in manufacture and extracts a high-value product from an otherwise lower value product.

Currently all wood-based xylitol production is based on hardwood Kraft black liqueur, as this provides for better recovery of xylitol compared to softwood based materials.

21.2 Market Size and Growth

The global market for xylitol has been estimated at some 200 000 tons in 2017, and the market has been growing at 15% over the past years. Global demand is expected to continue to develop at this rate over the coming years as xylitol becomes better known in the marketplace. Total demand is expected to have reached some 200K tons in 2017. Europe, North America and China are the largest consumption regions.

Figure 21-3: Global Xylitol Demand by Region



Source: Indufor Research

21.2.1 Production

Xylitol production is concentrated in China, where most (60 to 70%) of global production capacity is based. Total xylitol capacity in China according to market commentators is likely to have reached some 140Ktons in 2017. All of the Chinese capacity is based on corncob or bagasse. Corncob is by far the most desired raw material, due to its availability and low cost.

Outside of China, only Dupont has manufacturing facilities in Europe (Finland and Austria) and the US. In addition, DuPont also produces xylitol within China. Although total production capacity is not published, Indufor estimates that the combined DuPont capacity is in the 60 to 80Ktons per annum.

21.2.2 Demand

Demand for xylitol is driven by its unique properties as an alternative sweeter, with several beneficiary health benefits. The product has been approved for consumption as well as pharmaceutical use in Europe, the US, Japan and other jurisdictions.

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Industry commentators are forecasting global demand to develop at 10 to 15% per annum over the coming years. Actual demand will ultimately be a function of availability, price levels and uptake by the confectionary and pharmaceutical industries.

The rapid growth of Type 2 diabetes worldwide is expected to become a major driver for increased uptake of xylitol in various sweetened products.

21.3 The Competitive Landscape

Xylitol manufacturing is split between the two types of manufacture, the Chinese high energy intensity manufacture of xylitol from corncobs and the DuPont method. The Dupont method of manufacturing is requiring significantly less energy. From DuPont life cycle analysis, the indication is that this process requires 15% of the energy compared to the traditional BHP process. This is likely to provide the product with significantly lower production costs. However, as the full process is proprietary, the exact cost structures are not know.

Increased production from corncob in China is likely to be restricted due to availability and cost of the corncob, as well as increasing energy costs. Bagasse based production of xylitol has the ability to expand globally. However, it is anticipated that this will remain a high cost material for the production of xylitol.

Wood based xylitol has been identified as the most likely type to provide the opportunity for further production expansion.

As such, in the future it is likely that production increases will be limited within China, and greater expansion is expected at location where suitable raw material (in the form of black liquor from pulping operations) will be available.

Currently the dominant global producers and marketers of Xylitol are:

- Danisco - Global
- Roquette - Global
- Futaste - China
- Huakang - China
- Shandong LuJian Biological - China
- Shandong Longlive Bio-Technology - China

21.4 Key Demand Drivers

The main driver boosting the xylitol market is growing demand for alternative sweeteners, especially sweeteners which are suitable for use by diabetics. In addition, xylitol has a range of other known and potential health benefits, which are likely to result in an increasing demand for the product. Product knowledge is still limited in many markets. As product understanding develops, consumer demand is forecasted to become a major driver for increased used in a ever wider range of products.

Demand growth has been increasing as product price has reduced. Future reduction in price is expected to continue to increase demand.

21.5 Prices and Price Trends

Xylitol prices (FOB China) have declined over the past years from a high of 3.5 USD/kg in early 2014, to below 2.0USD/kg in 2017.

The future price of xylitol is expected to continue to reduce and follow global sugar prices over time, as global supply and demand increases.

21.6 Product Certification

Xylitol is used extensively in a range of food and pharmaceutical products globally. The product has been approved by the various countries for use in these applications.

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21.6.1 Opportunities

The key opportunity for xylitol is the increased demand for alternative sweeteners, and especially sweeteners that have beneficial health benefits.

The attractiveness to diabetic patients, because its metabolism is independent of insulin is key to this. In addition, the recorded benefits of xylitol in oral health are likely to see its use promoted for a range of sweets and gums. Increasing production of xylitol is likely result in a lowering of the product costs, further assisting it's use.

The opportunity to utilise side stream products from the pulping process provides the product with additional positive impetus as it can improve economics of the pulp mill and provide for an environmentally attractive product.

21.6.2 Constraints

The key constraints to the market development of xylitol is the strong competition in the alternative sweetener markets from a wide range of other products.

Many of the alternative products are price competitive compared to xylitol.

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Appendix II

Long List
Selected Products Data

Structural Sawn Timber	
The Product Structural sawn timber is a key wood product used in the construction of dwellings and low-rise buildings. The product is produced in a standard range of sizes, and is typically machine or visually graded for strength.	**Manufacturing Process** Structural sawn timber is produced in a sawmill. As the products produced are relatively standard, mills have developed into highly specialised, mechanised processing logs at high speed into sawn timber. The timber is typically dried in kilns before it is either sold as rough sawn or surfaced.
Raw material Requirement Softwood structural sawn timber requires a softwood sawlog of a species suitable to produce structural lumber. Specific strength properties of the wood are essential. Economies of scale are important, and a competitive sawmill would have a log intake of 500 000 m^3 or more.	**Market – Domestic and Export** The United States of America is the world's single largest global market for structural softwood products. Other key markets include Canada, Northern Europe and Japan. The global structural softwood market is estimated to exceed 300 million m^3, while the US structural softwood market accounts for approximately 60 million m^3. Products such as laminated timber and CLT are becoming increasingly important, as are end uses for structural sawn timber.
Life Cycle Although structural sawn timber is regarded as a mature product, advances in engineering technologies and building standards, have resulted in an expansion of the use of structural sawn timber in low rise multi-storey developments.	**Value Add** Structural sawn timber is used in wood frame construction. Increasingly wood frames and trusses are built off-site. Increasingly, there is a focus on pre-fabricating house components and entire homes within a controlled factory environment.
Fit Structural lumber fits in well within the Maine forest industry cluster. There are sufficient resources available. Sawmill residue demand is limited at present, and new outlets for this product would assist the existing and any new sawmill industries.	**Scale and Investment Costs** Today's structural sawmills have grown significantly in scale, and it's likely that a greenfield mill would have a log intake capacity of well over 500 0000 m^3. A mill of that size, including all required infrastructure, buildings, kilns etc., would cost in excess of US$50 million.
Product Outlook The market for structural sawn timber is strongly linked to activity within the construction sector, particularly in the residential construction sector. Within the US, residential construction activity has been expanding over the past years, and all forecasts expect this to continue over the coming years. As such, structural sawn timber demand is expected to rise in line with this.	

Laminated Timber	
The Product Laminated timber allows for the development of long span timber beams. Laminated beams provide known performance and greater stability. Custom made large-scale timber and beams are used in structures and generally form a portion of visible architecture. In addition to the traditional beams, developments in the manufacture of end glued exterior products (i.e. decking and cladding) have broadened potential market.	**Manufacturing Process** Graded sawn timber is laminated into more substantial and longer beams. A range of resins are used depending on building code requirements, the environment in which the product will be used, and customer preferences.
Raw material Requirement Laminated timber requires a graded sawn timber product. This can be sourced from third party sawmills or produced by the same company	**Market – Domestic and Export** It is estimated that the total global demand for LT exceeds 6 million m^3/a. Most LT manufacturers focus on selected segments of their target markets. Within North America, key markets included commodity grade LT beams and architectural LT structures.
Life Cycle LT has been available for many years, but demand for LT has been expanding over the past decade as there is an increasing demand for larger dimension beams in modern construction applications.	**Value Add** LT is a value-add product for sawn timber. The level of value-add is dependent upon the actual LT product targeted, with architectural LT having a significant value add due to the engineering and specialised manufacturing required for these products.
Fit LT fits well within the Maine forest industry cluster. With readily available sawn timber and a tradition of using timber in construction, an expansion of LT production would be logical.	**Scale and Investment Costs** The scale of production of LT depends greatly on the products produced, and the markets serviced. Commodity grades of LT require operations of size to be competitive, while the more specialised architectural manufacture is less affected by the size of the operation. Commodity grade manufacture would require to have output levels in access of some 100 000 m3/a to be competitive.
Product Outlook Strong demand outlook for engineered wood products, as quality guarantees improve, they are increasingly used over traditional products	

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Cross Laminated Timber (CLT)	
The Product CLT is a product developed in Europe as a mass timber product to produce large construction elements. CLT is used for structural wall, floor and ceiling components. CLT panels come in various sizes, up to 4 by 20 meters, in a wide range of thicknesses	**Manufacturing Process** CLT is a structural panel produced by glueing layers of solid sawn timber together. Each layer is orientated perpendicular to the adjacent level. The panels and layers are glued and clamped together to create a large structural panel.
Raw material Requirement CLT requires a graded sawn timber product.	**Market – Domestic and Export** Estimates for the 2017 global market for CLT are over 2 million m^3/a.
Life Cycle CLT is a relatively new product. In Europe, it has been in production for over ten years—but within the US, production has only developed in recent years.	**Value Add** CLT is a significant value-add product as it is the initial component in the production of larger building components.
Fit CLT would fit well within the Maine Forest Industry Cluster, by either drawing on existing sawn timber producers or by developing new sawmilling capacity. Maine is well located to supply CLT products into the US East coast markets.	**Scale and Investment Costs** Newer and larger CLT manufacturing set-ups today are increasing in scale and sophistication. This has increased capital requirements and scale considerably, and a large scale (using over 50 000 m^3/a of sawn timber) operation would require an investment in excess of 35 to 40 US$ Million.
Product Outlook The market outlook for CLT is very positive with significant interest due to developments in the mass timber building construction market. Also, CLT is a very attractive building material for multi-unit developments, providing a cost-effective, rapid building solution.	

Laminated Veneer Lumber (LVL)	
The Product An engineered wood product made of many layers of veneer, oriented in the same direction and glued together to form large dimension and thick panels.	**Manufacturing Process** LVL can and (in Asia) is often made in a conventional plywood mill. In Europe, North America, Japan, and Oceania it is more common for LVL to be made in dedicated inline processing facilities. The process is similar to plywood production, except veneers are all oriented in the same direction. In-line facilities can produce long length LVL sheets.
Raw material Requirement Saw/peeler grade logs (preferably larger diameter with small diameter knots). Smaller diameter trees are better utilised in this process.	**Market – Domestic and Export** The global market is approximately 3.0-3.3 million m^3. Key consumption areas are North America and China (1.0 and 0.8 million m^3 respectively), Europe (0.7 million m^3) and New Zeland (0.3 million m^3). Most LVL is consumed locally, except in Japan and Australia, where a significant portion of the produced LVL is exported.
Life Cycle LVL is in the growth stage. Typical market growth on average has been around 10% per annum.	**Value Add** High. Range (ex-mill) can be between USD 500 and USD 750/m^3. Structural LVL attracts a significantly higher price than non-structural LVL.
Fit Good fit as 70% of the resource by area is inventoried as large and medium diameter logs.	**Scale and Investment Costs** 100 000 m^3/a is a standard world scale size for an LVL facility. Typical "all in" facility costs are around USD 50 million.
Product Outlook Global LVL demand is expected to continue growing at rates (2-5% per annum) over the coming years. In real terms this could potentially amount to global demand reaching 3.8-4.0 million m^3 by 2025. US demand is likely to increase at a slower rate.	

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Orientated Strand Board (OSB)	
The Product An engineered wood panel formed by adding adhesives to wood flakes that are then generally oriented in a specific direction and pressed into a board. A board typically has 3 to 5 layers, with each layer generally oriented at right angles to each other.	**Manufacturing Process** Logs are first 'flaked', dried then coated with resin before being laid upon a forming mat in several layers, each layer is cross-oriented with the layer below. The mat is then pressed, while the resins are melted, and bonded to the flakes to form a panel.
Raw material Requirement Typically, only pulp grade logs are used in the manufacturing process.	**Market – Domestic and Export** The global demand for OSB is currently around 30 million m^3/a most of which (24 million m^3/a) is consumed in the North American market.
Life Cycle Mature. Current demand growth rate globally is around 3%. The North American market is rebounding from a low, following the crash in housing starts in 2007-2009. Markets are now returning to pre-crash levels.	**Value Add** Moderate value-added product. Prices can range from USD 250/m^3 to USD 400/m^3 ex-mill.
Fit Good fit as a substantial portion of the Maine harvest is of pulp grade log quality.	**Scale and Investment Costs** Existing mill capacity can range from as little as 100 000 m^3/a to over 700 000 m^3/a. Typically European mills are smaller than North American mills. A typical mill size in the US is 500 000 m^3/a and up. A mill of 500 000 m^3/a capacity will require an investment between USD 200 to 280 million.
Product Outlook Globally OSB demand is expected to continue growing at a moderate pace (1-3% per annum). Global demand could reach 35-38 million m^3/a, with North American demand approaching 25-26 million m^3/a. Markets in Europe are projected to grow faster than in the US.	

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Medium Density Fibreboard (MDF)	
The Product An engineered wood panel made from fiberised wood.	**Manufacturing Process** Wood is first mechanically fiberised and dried. The fibres are then coated in resin, laid upon a mat then pressed through heat and pressure. Resins bind fibres together to form a panel.
Raw material Requirement Typically, only pulp grade logs and some forms of wood processing residues are used in the manufacturing process.	**Market – Domestic and Export** Current global consumption for MDF is 100–105 million m^3/a. The North American market is estimated to be around 6 million m^3/a.
Life Cycle Mature. The global market for MDF continues to grow, and over the last ten years has ranged between 5 and 10% per annum. The North American market has expanded, but at a much slower rate over the past decade, and is only now returning to pre GFC levels	**Value Add** Moderate. Ex-mill panel prices can range from USD 250/m^3 to USD 300/m^3.
Fit Good fit as a substantial portion of the Maine harvest is of pulp grade log quality.	**Scale and Investment Costs** Like many other reconstituted panels, MDF production capacity has steadily risen over time. In the US, mill capacity is between 200 000 m^3/a to 300 000 m^3/a. A 300 000 m^3/a capacity mill requires an investment of USD 200-300 million.
Product Outlook Although MDF is a mature product, growth rates are expected to remain positive overall, including the North American market. Global demand may reach 120 to 125 million m^3/a. Over this period, the North American market could expand by an additional 1-1.5 million m^3/a.	

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Wood Plastic Composites (WPC)	
The Product A hardened composite of ground wood particles and heated thermoplastic resin.	**Manufacturing Process** WPC's are produced by thoroughly mixing wood particles or sawdust and heated thermoplastic resin (recycled or virgin plastics). Products are commonly made by extruding the material to the desired shape. Injection molding is used to a lesser degree.
Raw material Requirement Pulpwood, nonmerchantable log residues, harvest residues and wood processing residues. Recycled fibre (from paper and board products) can also be used.	**Market – Domestic and Export** The Global WPC market is estimated to be in the order of USD 4-5 billion. North America and Europe are the major markets.
Life Cycle Growth phase. WPC products are mostly used in traditional sawn wood applications, indoor and outdoor. Growth rates vary by country but typically are between 8 and 12% in primary markets.	**Value Add** High. Prices for WPC's are product specific. In the US, the price for WPC decking, for example, ranges from USD 60 to 100 per m^2.
Fit Close fit due to the abundant supply of key raw materials (pulp grade logs), and potential to use residues from harvest activities and wood processing. WPC can serve as a value add product for waste wood and paper.	**Scale and Investment Costs** Highly dependent on the intended product for manufacture.
Product Outlook Strong growth is expected in the industry as WPC based products are forecasted to replace the end use markets for plastic and wood products. Asia is viewed as a critical growth region for both products, by 2025 global markets are projected to reach USD 5-5.5 billion.	

Bioplastic Composites (BPC)

The Product

Bioplastic composites are bio-based plastic resins (biopolymers) reinforced by natural fibres. The term biodegradable bio-composites refers to products that have a biodegradable polymeric matrix.

Some commonly used natural biopolymers include lignocellulose, cellulose, starch, lignin, hemicelluloses, chitin, pectin, and proteins. Bio-based plastics include PLA, PHA, and cellulose esters.

Manufacturing Process

Bioplastic composites are manufactured in a manner similar to other composite materials. The specific process is dependent on the type of product required, fibre used, and form of polymer. Twin-screw extrusion is the main production method for compounding biocomposites. The process blends fibres with polymer, which are then extruded and pelletized. These pellets can then be used as the feedstock for another process, such as injection moulding.

Raw material Requirement

Pulpwood, nonmerchantable log residues, harvest residues and wood processing residues. Recycled fibre (from paper and board products) can also be used

Market – Domestic and Export

Bioplastic composites with cellulosic reinforcement are used in automotive parts, electronics, and household appliances. Biocomposite filaments are used in 3D printing.

Life Cycle

Early stage. Bioplastic composites compete with oil-based polymers. Interest in biocomposite materials and their use in various applications has grown steadily over the past decade. Increasing environmental awareness and lower material costs are the main driving forces for renewable materials, such as wood and cellulose fibres, as reinforcement in polymer composites. Innovations in material science continues to reveal materials and expanded uses for emergingin products.

Value Add

Very high.

Actual prices for BPC range widely depending on the exact makeup of the BPC product. Low-end BPC prices start at around USD1 000/ton.

Fit

Close fit due to the abundant supply of key raw materials (pulp grade logs), and potential to use residues from harvest activities and wood processing. WPC can serve as a value add product for waste wood and paper.

Scale and Investment Costs

Wood or natural fibre filled and reinforced biocomposite granules mill scale can range from <500 ton/a to 50 000 ton/a, though the typical size varies between 1 000-5 000 ton/a. A mill of 15 000 ton/a could cost as much as USD 15-20 million.

Product Outlook

Green bioplastic composites can be sustainable and economical materials that can serve as an alternative to synthetic fibre reinforced polymer composites or plastic materials available in markets today. Currently, green biocomposites are already available in markets for various applications such as automotive, construction, and buildings components. Barriers to development include inconsistencies in natural fibre properties and high moisture sensitivity.

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Biochar	
The Product Biochar is a charcoal produced typically from a woody product via pyrolysis. Biochar is stable, high in carbon and can assist in enhancing soil fertility. In addition, it can assist in carbon sequestration by storing carbon within the soil.	**Manufacturing Process** Biochar is produced as a by product of pyrolysis oil and bio-crude.
Raw material Requirement Biomass – Pulpwood, wood chips, sawdust.	**Market – Domestic and Export** The global market is projected to be significant, due to biochar's capabilities as a soil enhancer or fertiliser. Biochar is also seen as a valuable tool for carbon sequestration, which is likely to further increase demand.
Life Cycle Early stage.	**Value Add** Serves as a value add for the by-products in bio-crude and pyrolysis production.
Fit This fits well in Maine as pulpwood and sawdust availability is high.	**Scale and Investment Costs** Biochar is predominantly a by-product from other processes.
Product Outlook Increasing demand as a soil enhancer and for carbon sequestration.	

Activated Carbon

The Product	Manufacturing Process
Activated carbon is used for adsorption (the adhesion of atoms/ions/molecules from a gas, liquid or dissolved solid to a surface). Primary uses are in water and wastewater treatment, food and beverages, motor vehicles, and the pharmaceutical industry. New area: flue gas Hg cleaning Removes contaminants	Activated carbon is produced from coal and biomass. One of the highest value biomass sources is coconut shell. Biomass is first carbonised (1000 – 2000 °C) and then activated with 850 – 950 °C steam (or air and carbon dixoide.
Raw material Requirement	**Market – Domestic and Export**
Pulpwood, nonmerchantable log residues, harvest residues and wood processing residues.	Global market 1.7 Mtonnes per year, of which 15-20% renewable from coconut shells. Market grows by 10% per year and global activated carbon market was estimated to be worth USD5 billion in 2017.
Life Cycle	**Value Add**
Growth – Activated carbon demand is expanding rapidly, as its use in various filter applications continues to grow.	High. End-use products utilising activated carbon are typically higher priced.
Fit	**Scale and Investment Costs**
Close fit due to the abundant supply of key raw materials (pulp grade logs), and potential to use residues from harvest activities and wood processing.	Depending on target markets there are a wide range of scale and investment requirements.
Product Outlook	
Strong growth is expected to continue. Broadly speaking, many industries have witnessed a shift from coal-based activated carbon to biomass activated carbon, for environmental reasons.	

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Dissolving Pulp	
The Product Dissolving pulp is a raw material for various products, the largest volumetric market of which is for textiles (60%).	**Manufacturing Process** Dissolving pulp can be produced in a kraft pulp mill (example Enocell), but there are other alternate processes, for example Organocell (ethanol) and Chempolis (formic acid). The raw material is lignocellulosic materials.
Raw material Requirement Typically, only pulp grade logs and wood processing residues are used in the manufacturing process.	**Market – Domestic and Export** The global dissolving pulp market is about 5 million tonnes/a, and it is growing 4-5%/a. This can be compared to the total market for cotton- and oil-based textiles, which is approximately 70 million tonnes—and is grown mainly in Asia. Additionally, the use of dissolving pulp in several other higher value-added products such as plastics (i.e. acetate) presents a strong opportunitiy to replace oil-based products.
Life Cycle Growth - Dissolving pulp was for many years regarded as being at the end of its life cycle. In the past decade, however, total usage and the number of end uses has undergone substantial development.	**Value Add** High - Ex-mill prices can range from USD 1 300/ton to USD 2 000/ton.
Fit Good fit as a substantial portion of the Maine harvest is of pulp grade log quality.	**Scale and Investment Costs** The scale is moderate, and investment costs are high. Regarding scale, dissolving pulp mills are likely to require a log intake of some 600 000m3/a or more. Capital cost for such a mill would be from US$600 million and up.
Product Outlook Global demand growth is expected to continue, with increasing pressures on supply.	

Nanocellulose	
The Product Nanocelluloses are a group of materials that are defined as having at least one of its fibrous dimensions in nanoscale. The three major groups are: Nanofibrillar cellulose (NFC), nanocrystalline cellulose (CNC) and bacterial cellulose (BC). The most common feedstocks utilized for nanocellulose production include different forms of pulp (dissolving, bleached or unbleached Kraft pulp).	**Manufacturing Process** NFC: Mechanical sheering of fibres. Various enzymatic/chemical treatments are also applied. CNC: Acid hydrolysis of cellulose. BC: Cellulose biosynthesis by bacteria. BC is obtained in the form of gel.
Raw material Requirement Dissolving pulp, bleached or unbleached Kraft pulp, non-wood, annual plants.	**Market – Domestic and Export** NFC and CNC markets are small as they have only just reached early commercialisation stages. Production scale is in the order of hundreds of kg/day. Several producers exist in North America, Europe (esp. Scandinavia) and Japan. BC has not reached commercial production status yet.
Life Cycle Nanocellulose production is in the early phases of commercialization.	**Value Add** Nanocellulose products have versatile applications, but mostly serve as additives that function as property enhancers (e.g. in cement). High value adds from nanocellulose products are used in cosmetics, pharmaceuticals and the food industry.
Fit Close fit due to the abundant supply of key raw materials (pulp grade logs), and potential to use residues from harvest activities and wood processing. The University of Maine is producing NFC, which may present public-private partnerships in the future.	**Scale and Investment Costs** The investment cost for nanocellulose production is currently unknown as the base technology is still under development.
Product Outlook Nanocellulose is in its early phase of commercialization. Significant technological improvements and thus capacity increases are expected in the coming years.	

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PLA	
The Product Polymerization of fermented lactic acid produces PLA	**Manufacturing Process** Fermented lactic acid is polymerized into PLA. The polymerization is completed either in one step as direct polymerization or in two stages via lactic acid dimer (lactide) and ring opening polymerization.
Raw material Requirement Lactic acid	**Market – Domestic and Export** The market is consolidated, as the two leading producers of lactic acid cover more than 80% of the total capacity. PLA production is concentrated mainly in the US, followed by China.
Life Cycle Both polymerization methods are well established. Two-step polymerization (formation of lactic acid dimer followed by ring opening polymerization) is the prevailing commercial practice.	**Value Add** PLA production is an excellent way to utilise biomass to produce a high value product (current market price is high at 2070 USD/t).
Fit PLA fits well in Maine as pulpwood and sawdust availability is high as required for the production of sugars for lactic acid—which subsequently is polymerised to PLA.	**Scale and Investment Costs** The investment cost for a lignocellulosic glucose plant using 300 000 dwt of raw wood is approximately 500 million USD. The investment cost for conversion of glucose to LA and polymerization of LA to PLA, is currently unknown.
Product Outlook The global PLA market is growing rapidly at a rate of 15% per annum. The share of bio-based plastics is forecasted to increase, dominated by rigid packaging (including food service ware). Currently, PLA is the only economically viable fully bio-degradable and bio-based polymer.	

Lactic Acid	
The Product Lactic acid belongs to the C3 chemical building block. Microbial fermentation of sugars from biomass produces lactic acid.	**Manufacturing Process** Lactic acid is produced by fermentation of glucose or sucrose originating from 1st generation biomass feedstocks such as corn starch, sugar cane, sugar beet and cassava. Second generation biomass fractions (e.g. bagasse, corn stover, wheat straw and wood chips) are currently under development.
Raw material Requirement Starch from corn, sugar cane, sugar beet, cassava, bagasse, corn stover, wheat straw, wood chips, sawdust.	**Market – Domestic and Export** The global market for lactic acid is 477 kt/a. The market is consolidated, as the two leading producers of lactic acid cover more than 56% of the total capacity. Lactic acid production is concentrated mainly in APAC region, followed by US.
Life Cycle First generation feedstock-based fermentation is well established. Second generation feedstock-based fermentation is under development.	**Value Add** Along with succinic acid, this is one of the most promising platform chemicals.
Fit This fits well in Maine as pulpwood and sawdust availability is high for the production of sugars for Lactic acid via fermentation.	**Scale and Investment Costs** The investment cost for a lignocellulosic glucose plant using 300 000 dwt of raw wood is approximately 500 million USD. The investment converting glucose to Lactic Acid is currently unknown.
Product Outlook Global demand for lactic acid is expected to grow 6.4% per annum. Growth will be fastest in the US, China and other Asian states as a result of increased PLA production. In other regions, where demand is driven mainly by food applications, moderate consumption growth is expected.	

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Succinic Acid	
The Product Succinic acid belongs to the C4 chemical building block. Succinic acid has long been derived from petroleum. Conventional succinic acid is produced from maleic anhydride (MA) through hydrolysis. A majority of the succinic acid production is petrol-based (close to 100 %).	**Manufacturing Process** Fermentation of glucose can produce Bio-based succinic acid Bio-based succinic acid is identical in structure to petrol-based and can be directly substituted into a broad range of processes and applications. The feedstocks used for the production of the bio-based succinic acid include wheat, maize, lignocellulosic derived sugar or sorghum grain processed to starch
Raw material Requirement Pulpwood, wood chips, sawdust	**Market – Domestic and Export** The global market for succinic acid is about 60 kt/a. Only 4 pilot scale mills exist.
Life Cycle Pilot-scale. Near commercial breakthrough.	**Value Add** Along lactid acid, this is one of the most promising platform chemicals.
Fit This fits well in Maine as pulpwood and sawdust availability is high.	**Scale and Investment Costs** The investment cost for a lignocellulosic glucose plant using 300 000 dwt of raw wood is approximately 500 million USD. The investment required to establish facilities to convert glucose to Succinic Acid is currently unknown.
Product Outlook Annual growth figures are expected to surpass 10% as bio-based succinic acid is cheaper to produce than its petrol-based counterpart. Significant capacity increases are expected in bio-based succinic acid production during the coming years. Commercial processes are still in the final stages of development, and are currently being optimized.	

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Furfurals	
The Product Furfural is produced from agricultural waste that contain pentosans (a major constituent of hemicelluloses). The most common feedstocks used for furfural production include corncobs, cottonseed hulls, bagasse and rice hulls. By-products from pulp production represent an essential feedstock for furfural production.	**Manufacturing Process** Furfural is produced from xylose by dehydration. From wood biomass, furfural is generated as a side stream of pulping and ethanol processes.
Raw material Requirement Pulpwood, wood chips, sawdust	**Market – Domestic and Export** The global market for furfural is about 400 kt/a. Production and consumption is centred primarily in China.
Life Cycle Mature. The required technology has been available for several decades. The market size is moderate, with high growth rates.	**Value Add** Furfural production is an excellent way to convert agricultural biomass or pulping or ethanol process waste streams to a higher value product (current market price 700 USD/t).
Fit Because furfural is a side product from cellulose or ethanol production, market fit is dictated by these primary products.	**Scale and Investment Costs** The scale and investment requirements are largely dependent on the primary products (cellulose or ethanol production).
Product Outlook Furfural is mainly used to produce furfuryl alcohol that is used primarily to produce furan resin sand moulds that are used in iron castings for oil, gas, and in the automotive industry. The furfural demand is growing about 5% annually, with particularly rapid growth in China.	

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Levulinic acid	
The Product Levulinic acid belongs to the C4 chemical building block. Levulinic acid is typically derived from hexoses.	**Manufacturing Process** Levulinic acid produced from biomass is relatively new. Globally there are two pilot plants in operation with a combined capacity of 15 000 tons per annum. Both plants are encountering a range of manufacturing issues, that have yet to be resolved.
Raw material Requirement Biomass - Pulpwood, wood chips, sawdust	**Market – Domestic and Export** The global market is projected to be significant as levulinic acid has a wide range of end uses: cosmetics, pharmaceuticals, resins, and coatings.
Life Cycle Pilot-scale. Near commercial breakthrough.	**Value Add** Levulinic acid once produced commercially is a highly promising platform chemical.
Fit This fits well in Maine as pulpwood and sawdust availability is high.	**Scale and Investment Costs** Currently only at pilot scale. Large-scale plants are expected to be costly.
Product Outlook Once available, at a competitive price, demand is projected to be high.	

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Lignin	
The Product Lignin is mainly generated as a by-product of pulp mills (e.g. during wood fractionation when C6 and C5 sugars are separated from wood). The most common feedstocks utilized for lignin production are pulp wood (softwood) and wood chips.	**Manufacturing Process** There are several forms of wood fractionation processes, each producing a different form of lignin residue stream. The most common industrial lignins are Kraft lignins (based on Kraft pulping of softwood). Other lignins include lignosulfonates produced in sulphite mills and sulfur-free Organosolv lignins which are generated as part of Organolv biorefineries.
Raw material Requirement Pulpwood, wood chips, sawdust, lignocellulose residues	**Market – Domestic and Export** The global market for lignosulfonates is about 1 Mt/a. Kraft lignin market is much smaller at about 145 000 t/a. Lignin production is mostly concentrated in Northern Europe and North America.
Life Cycle Technology for lignin recovery has existed for a number of years (e.g. the LignoBoost process for Kraft lignin extraction from black liquor). The market size for lignin products is large, and continues to grow due to an ever-increasing number of added value end uses.	**Value Add** Lignin is a promising raw material for high value products. Low-purity lignin has an approximate base price of 650 USD/t.
Fit Close fit due to the abundant supply of key raw materials (pulp grade logs), and potential to use residues from harvest activities and wood processing.	**Scale and Investment Costs** The scale and investment requirements are largely dependent on the primary products (cellulose or ethanol production).
Product Outlook Lignin has developed from a low-quality residue that was only useful as a fuel for energy generation in pulp mills into a sustainable alternative for various added value products, ranging from composites and carbon fibres to multiple resins. There is significant market potential for lignin to replace fossil fuel-based counterparts, especially in phenolic resins (the phenolic resins market is projected to grow at a rate of approximately 4% annually).	

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Bio Crude/Pyrolysis Oil	
The Product Oil produced by recovering the condensate of pyrolysis	**Manufacturing Process** Biomass is heated in the absence of oxygen. The resulting gasses are condensed to their purest form to generate bio-crude. Various processes can be applied to refine the bio-crude depending on the method used and desired outcomes.
Raw material Requirement A wide range of biomass can be used including wood chips, sawdust etc.	**Market – Domestic and Export** There is potential for a large market, as many of the products can be used as a substitute for traditional oil-based products. Production costs are currently hidering growth, but regulations and subsidies will likely play a large role in future demand.
Life Cycle Early stage	**Value Add** There is potential for high value-add with low-value raw material inputs.
Fit Fits well with Maine's forest sector, as the state has an ample supply of biomass.	**Scale and Investment Costs** Various models are developing. While bio-crude production can be relatively low scale and capital intensive, next stage refining is even more capital intensive.
Product Outlook Due to expected increases in renewable requirements, the outlook for bio-crude and pyrolysis oil is good. Their production processes produce developing market by-products such as biochar.	

Lignocellulosic Ethanol and Butanol	
The Product Ethanol/butanol is colourless, flammable, antiseptic liquid. First generation ethanol is ethanol produced mainly from starch and sugar-containing plants. First generation ethanol has been criticised for limited GHG emission savings and taxes to the food production sector. Second generation ethanol is produced exclusively from non-food items, cellulose and lignocellulose feedstocks such as wood and agricultural residues. Second generation ethanol does not compete with food crop agriculture for raw materials, and its production processes are less costly than ethanol.	**Manufacturing Process** The fermentation of sugars naturally produces first generation ethanol by yeasts. Hydrolysis of wood-based and waste-based materials produces second generation ethanol (e.g. by strong acid or enzymes). This is followed by microbial fermentation of released cellulose and hemicellulose sugars to ethanol. Ethanol can also be synthesized through the thermochemical processing of biomass. The resulting synthesis gas is either fermented or catalytically converted to ethanol (e.g., via Fischer-Tropsch synthesis) Biobutanol is produced from yeast. Isobutal has the advantage of being a suitable jet fuel.
Raw material Requirement First generation ethanol: corn starch, sugar beet, sugar cane, wheat Second generation ethanol: Roundwood, chips and sawdust, lignocellulose residues, straws and grasses	**Market – Domestic and Export** The global ethanol market currently accounts for 90 million t/a. About 90% of ethanol is used as transport fuel. The United States and Brazil produce 85% of the world's traffic fuel ethanol. The share of lignocellulosic and other second generation ethanol/butanol is small, accounting for about 3% of the total ethanol market
Life Cycle First generation ethanol production is technologically well established but competes with food production. Second generation ethanol production is in its early phase of commercialization.	**Value Add** Ethanol production is an excellent way to use biomass to produce a higher value product. The price of ethanol varies widely in regions. Because companies in the US have the lowest production costs, they largely dictate the base price.
Fit Close fit due to Maine's available pulpwood, wood chips, and sawdust.	**Scale and Investment Costs** The investment cost for a lignocellulosic glucose plant using 300 000 dwt of raw wood is approximately 500 million USD. The investment costs for conversion of glucose to ethanol are case specific.
Product Outlook Global ethanol consumption is expected to grow 2.4% per annum. This growth is mainly due to its increasing, regulatory-driven, use as a transport fuel (especially second generation lignocellulosic ethanol). The growth of second generation ethanol can be significantly higher if the use of first generation faces increased regulatory restrictions (e.g. REDDII in EU, second generation quota in the US.	

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Xylitol	
The Product Xylitol is a sugar alcohol used as an alternative sweetener to traditional sugar.	**Manufacturing Process** Hemicellulose extracted from either hardwoods or corn cobs is the traditional production source for xylitol. The alternative production process uses fermentation.
Raw material Requirement Hardwood, Corn cobs or hemicellulose as a by-product of kraft pulping. Various hardwoods have proven suitable, including aspen, birch and beach.	**Market – Domestic and Export** Strong global and local demand. US demand for Xylitol has been estimated at some 60 000 tons in 2017. Xylitol production from corn cobs is currently more competitive compared to wood-based xylitol, although wood-based xylitol is regarded as a superior product.
Life Cycle Early stage/growth.	**Value Add** Xylitol is a significant value-add product in a hardwood kraft process.
Fit Potential fit with the existing hardwood pulping industry.	**Scale and Investment Costs** High cost (US$200 million+) for large-scale production.
Product Outlook Very strong outlook for the product. A key hurdle in demand growth has been the availability and cost of xylitol currently on the market.	

Indufor Oy
Esterinportti 2
FI-00240 Helsinki
FINLAND
Tel. +358 50 331 8217
http://www.induforgroup.com

Indufor North America LLC
1875 Connecticut Avenue Northwest
10th Floor
Washington, DC 20009
USA
http://www.induforgroup.com

Indufor Asia Pacific
7th Floor, 55 Shortland St, PO Box 105 039
Auckland City 1143
NEW ZEALAND
Tel. +64 9 281 4750
http://www.induforgroup.com

Indufor Asia Pacific (Australia) Pty Ltd
Level 8, 276 Flinders Street
PO Box 425
Flinders Lane VIC 8009
Melbourne
AUSTRALIA