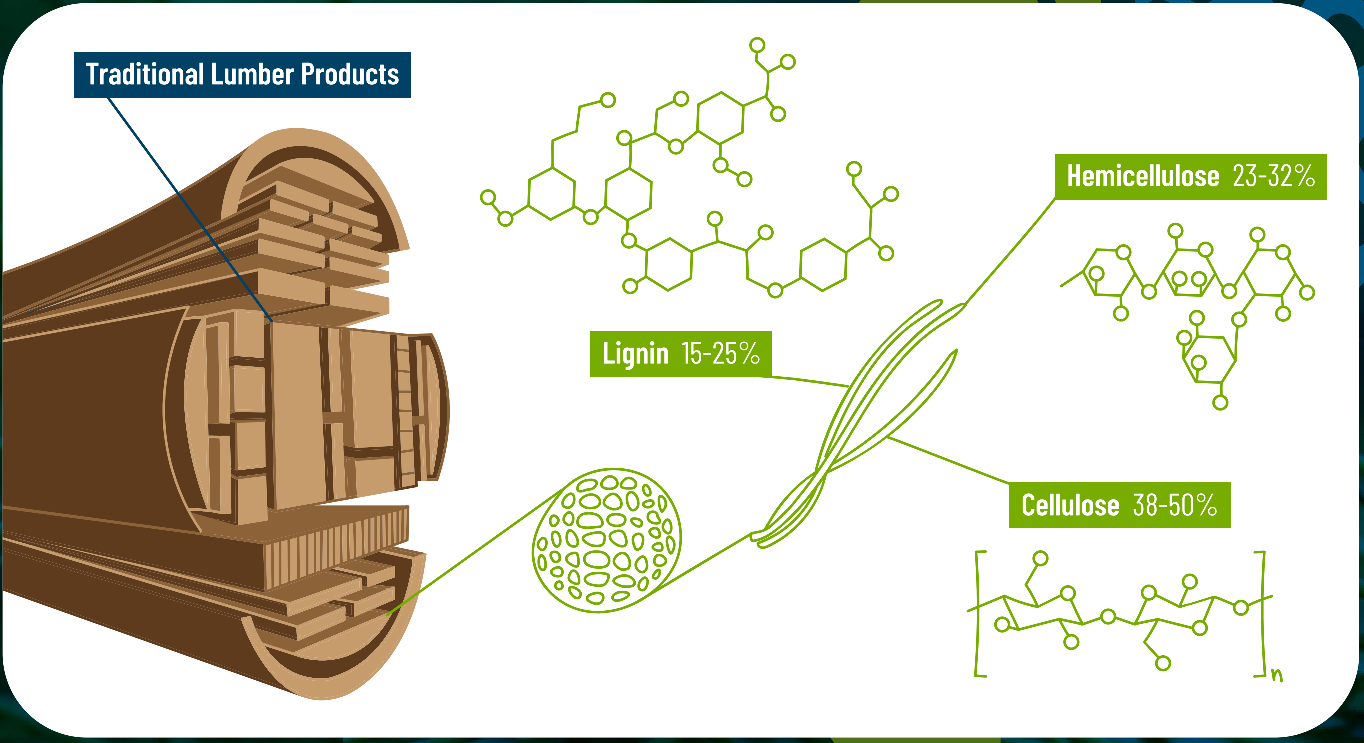
Fibre Utilization Pathways
Northern Ontario

March 31, 2026



CRIBE centre for research & innovation in the bio-economy

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Executive Summary

The province of Ontario has an abundance of available fibre that is currently underutilized. There is an opportunity to put wood to work, with close to 16 million m^3 of merchantable material and an additional 6 million m^3 of unmerchantable available.

This report focuses on advanced pathways not deployed at commercial scale or that lead to world class facilities for pulp and advanced chemical production. There is still the opportunity for traditional solid wood or structural wood products. However, the economics for these products were not evaluated as there is open competition by manufacturers currently operating in Ontario.

With full utilisation of available wood, the province could, in practice, support 2-3 new modern sawmills, 2-4 Engineered Wood Product (EWP) mills, 1-2 new wood fibre insulation facilities, 1-2 new modern kraft mills or advanced biorefineries, and 5-10 energy product mills (bio-coal, bio-carbon, pyrolysis oils). As well, there could be increased generation of heat and power. Other value-added products, where economics are favourable, are also possible given the fibre availability.

The challenge has been cost competitiveness compared to other jurisdictions in North America. Trees naturally take longer to mature in northern conditions and there are some barriers operating within an extensive forest management set of practices. However, recent closures in the pulp and paper sector have led to the potential opportunity to access sawmill residual supply.

To make the full forest work, all products need to be fully utilized to ensure a balanced economy of scale to ensure all consuming mills remain competitive. This includes all species and operating facilities to capacity within a region. In particular, this means that a specific technology option listed here will work at the scale indicated, but there may need to be users identified for either residual materials or for other species, such as hardwoods, that might arise in harvesting.

Key information for specific Best Bets is presented next, and is a key consideration addressed in this report. Prices per tonne of product are compared along with revenues per tonne of feedstock, including feedstock and net of feedstock. (Note that the kraft pulp analysis did not include revenues due to energy generation, which are highly location-specific; actual revenues would be higher than shown.) Not included here, but discussed in detail in the body of the report, is the recapitalisation of existing pulp mills versus building a new mill on a brownfield site.

	Fast, simple		**Large-scale (new pulp, biorefinery)**	
Process	**Torrefaction (Bio-coal)**	**Bio-crude (LCFO)**	**Kraft pulp with lignin**	**Biorefinery Phase 1**
Avg. product sale price, per t	$335	$674	$814	$1,639
Revenues per odt of feedstock	$251	$640	$767	$1,247
Revenues per odt, net of wood	$161	$550	$617	$1,097

Note: kraft pulp does not include value of energy generation.

The simpler, less expensive pathways generate less revenue per tonne of wood consumed than the higher cost plants. This is necessary to cover higher capital and operating costs, and standard metrics such as EBITDA are given in the next table. This table also shows the progression from lower value to higher value products.

More information is included in the following table, which includes the recapitalisation of existing kraft mills in the province.

	Fast, simple		**Recapitalise pulp mills**	**Large-scale (new pulp, biorefinery)**	
Process	**Torrefaction (Bio-coal)**	**Bio-crude (LCFO)**	**1st quartile mills**	**Kraft pulp with lignin**	**Biorefinery Phase 1**
TRL	9				7-8
Complexity	Low		Medium	High	
Time to build	2-3 years		3-5 years	5-10 years	
Wood input	Local to sawmill		Multiple sawmills		
Wood type	HW or SW, chips or bark		SW chips		HW chips

Scale, odt/y	221,400	84,600	Capacity increase needed	1,998,000	289,132
Sales, M$	$56	$54	Capacity dependent	$1,533	$324
Capex M$	$81	$149	$1,500	$2,305	$1,634
Wood costs, $/odt	$90	$90	$150	$150	$150
Total OPEX M$	$38	$19		$826	$120

EBITDA, $M	$18	$35		$707	$237
ROCE	16.2%	18.3%		24.9%	9.4%
Payback, years	8.5	7.7		5.6	15.1
IRR	11.7%	13.0%		18.0%	6.6%

Locations	Scaled to sawmills province-wide		Thunder Bay, Dryden	North East	North West

All options listed are best implemented in collaboration with existing facilities, where utilities such as wood handling, heat and power or effluent treatment can be shared. Partners could include existing forest sector facilities or, as in the UPM biorefinery at Leuna in Germany, an operating petrochemical park. These brownfield installations will be less capital-intensive, even if utilities need to be upgraded, than a stand-alone greenfield mill.

1. Wood supplies across Northern Ontario

1.1. Fibre Overview

The province of Ontario[1] has an available harvest of 28 million m^3 with utilization in 2023 of approximately 12.6 million m^3. Over the last two decades, the utilization has decreased by over 10 million m^3 with the loss of forest products industry producers. The credit crisis in 2006-07 and following years was the last major set of closures. Today, the US market barriers are the latest challenges for forest products producers.

There is an opportunity to put wood to work, with close to16 million m^3 of merchantable material and an additional 6 million m^3 of unmerchantable available.

The average conifer sawmill consumes 600,000 m^3 and an Oriented Strand Board approximately 1 million m^3 annually.

With full utilisation of available wood, the province could, in practice, support 2-3 new modern sawmills, 2-4 Engineered Wood Product (EWP) mills, 1-2 new wood fibre insulation facilities, 1-2 new modern kraft mills or advanced biorefineries, and 5-10 energy product mills (bio-coal, bio-carbon, pyrolysis oils). As well, there could be increased generation of heat and power. Other value-added products, where economics are favourable, are also possible given the fibre availability.

For the context of this report, we have categorized the working area as Northeastern and Northwestern Ontario. The area currently has approximately the following facilities:

- 3 pulp and paper mills
- 21 large scale sawmills
- 14 small-medium scale sawmills
- 3 Veneer plants
- 2 Oriented Strandboard (OSB) mills
- 2 Medium Density Fibreboard (MDF) plants
- 1 Particleboard (PB) mill,
- 1 Laminated Strand Lumber (LSL) mill,
- Various other small mills consuming over 1,000 m^3 of wood,
- 2 idle sawmills,
- Several facilities operating below their rated capacity, and
- 1 potential new OSB specialty product startup.

The focus of this report is to support the current sawmill industry to find new markets or use for residual sawmill material within Ontario and to find product solutions for low grade hardwood fibre.

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[1] https://www.ontario.ca/page/forest-management-facts-and-figures

1.2. Sawmill Residual Supply

Based on discussions with Domtar, Buchanan – Nakina Lumber, Lecours, Hornepayne Lumber, White River Forest Products, GreenFirst and Interfor, there are approximately 2.5 million oven-dry metric tonnes (odmt) of sawmill residuals produced by large scale sawmills. These include chips, sawdust, shavings, and bark. There are additional sawmill residuals from small to medium size producers.

As of January 2026, all material is being sold or marketed. However, shipments are to customers at distances as far as 800 km by truck and 1,200 km by rail. This is a short-term solution as transportation costs will ultimately continue to pressure mill net selling prices which will negatively impact long term financial viability of the sawmills.

As of 2024, permanent closures included the following:

Location	Volumes consumed	Date of shut
Softwood		
AV Terrace Bay	585,000 odmt/y	November 2024
Domtar Espanola	400,000 odmt/y	November 2024
Rayonier Temiscaming	330,000 odmt/y	July 2024
Thunder Bay PM5	250,000 odmt/y	January 2026
Hardwood		
Domtar Espanola	300,000 odmt/y	November 2024
Cascades Trenton	90,000 odmt/y	May 2024

The total impact was over 1.7 million odmt of equivalent chip demand with major impacts affecting large scale sawmills, including:

Interfor – Nairn, Ostrom, Timmins, and Elk Lake

GreenFirst – Chapleau, Cochrane, and a portion of Hearst

White River Forest Products

Hornepayne Lumber

Lecours Lumber

Roskco – Kirkland Lake

Little John Enterprises – Timmins

Midway Lumber – Thessalon

Goulard Lumber – Sturgeon Falls

Boniferro Mill Works – Sault Ste. Marie

Huntsville Forest Products - Huntsville

Lavern Heideman & Sons - Eganville

Ben Hokum & Sons - Killaloe

McRae Mills - Whitney

Murray Brothers - Madawaska

Sawdust and shavings are more balanced in the province with consistent demand. The primary consumers continuing to operate include the following:

Arauco – Sault Ste. Marie – Medium Density Fibreboard (MDF)

Daiken North America Ltd. – Huntsville – Particle Board

Roseburg – Pembrooke – MDF

BioPower Sustainable Energy – Atikokan - Pellets

Resolute – Thunder Bay – Pellets

Various animal bedding companies for shavings.

The pulp mill closures will have a ripple effect to limit sawmill production due to lack of chip customers. This will then directly impact of all other residuals for the current producers of medium density fibre board, particle board, pellets, and energy. As well, it will also impact the production of oriented strand board eventually.

Short term with provincial support and lowering of price expectations, the residuals have been able to be moved from the existing operations to either Thunder Bay, Dryden, or to Quebec pulp and paper consumers (Lebel sur Quevillion, Gatineau, La Tuque, …). However, this is not likely a long term viable economic solution as the delivered cost of chips for the consumer are likely going to exceed a break point or the sawmill will not have enough contribution which may cause curtailment.

Fundamentally, the SPF sawmill producers will be faced with a major barrier to continue to operate long term. They will be faced with the same circumstance as red/white pine and hardwood producers which had to contemplate operating on a single shift or curtailment.

1.3. Low Grade Hardwood Available Supply

In addition, there has been an issue to utilize low grade hardwood in a number of areas within Ontario over the last 10 years. This is now amplified with the current pulp mill closures. The only real customers that continue to exist are as follows:

- West Fraser – Barwick – Oriented Strand Board (OSB)
- Weyerhaeuser – Kenora – Laminated Strand Lumber (LSL)
- Georgia Pacific – Englehart – OSB
- Louisiana Pacific – Wawa – OSB – potential start up
- Roseburg – Pembrooke – minor use of low grade and more residual (MDF)

There has been some use of low-grade hardwood for energy (electricity or heat) generation if it is within an economic hauling distance. These include:

- Thunder Bay Pulp and Paper – Thunder Bay
- Hornepayne Power – Horne Payne
- Kap Paper – Kapuskasing
- Atlantic Power – Calstock
- Confederation College – Thunder Bay – small scale example

The forecast potential hardwood from Crown lands is shown in the table.

MNR Region	**Merchantable (m^3)**	**Unmerchantable (m^3)**
Northwest	1,360,891	1,239,680
Northeast	1,373,839	1,178,141
Southern	331,416	129,185

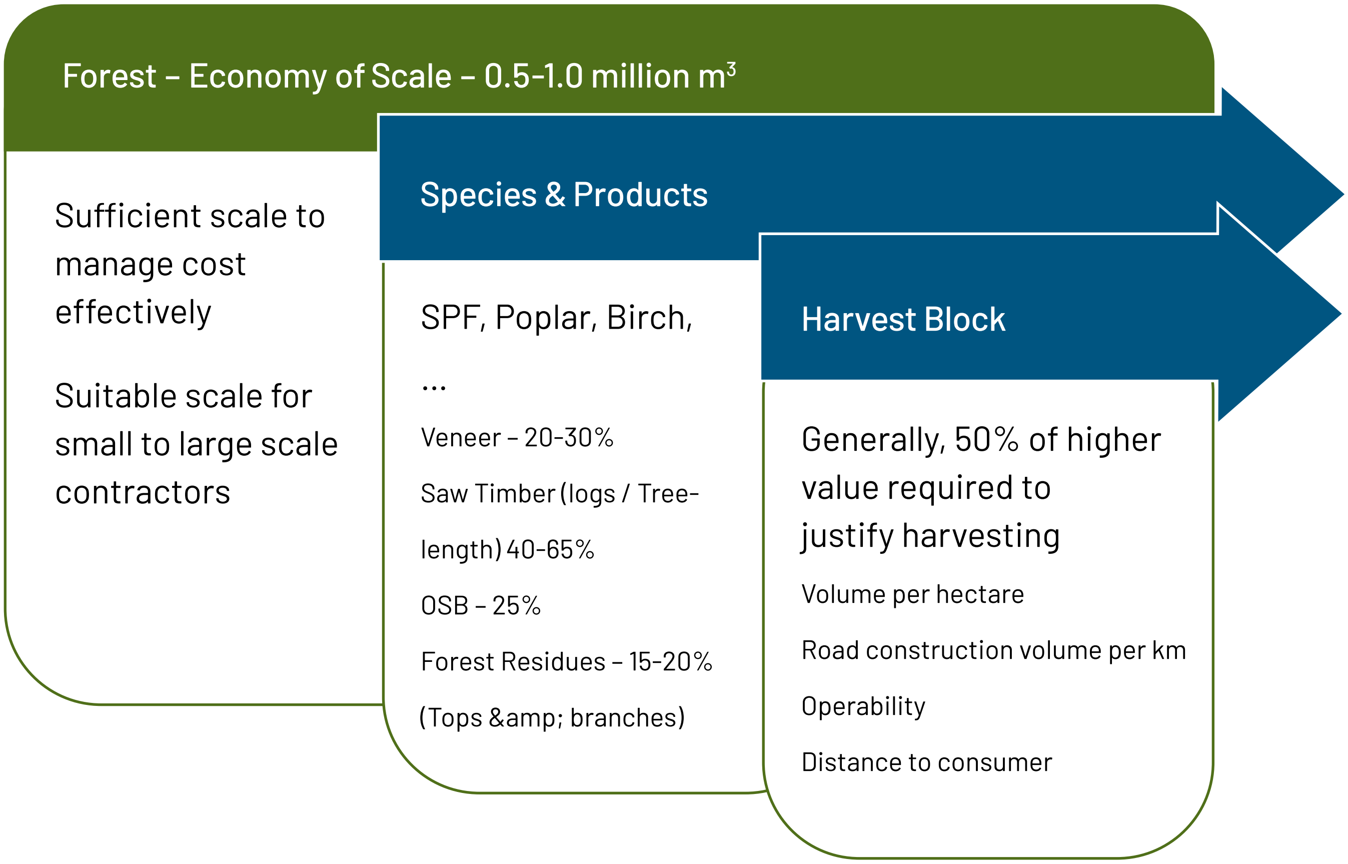
The volume estimate is based on the MNR Available Wood Report, with a further review of the Management Unit reports to review actual commitments. Based on industry changes, the numbers have been adjusted to reflect potential available volume. As well through the CRIBE Case Study – Unlocking Hardwood Potential Investment Opportunities in the Thunder Bay Region – Sept 2025, it was found utilizing only the MNR Available Wood Report is not enough to demonstrate actual volumes that companies may be willing to sell.

Based on the previous CRIBE Case Study, there is a supply equivalent to 1.235 million m^3 in the Thunder Bay area. As well, there are practically more available volumes. To explore further in any diligence exercise, the local forest managers would be engaged to provide more accurate available wood supply.

1.4. Balanced Use of the Forest – Economy of Scale

Forest operations in the eastern boreal forest region need to operate at a certain economy of scale. With a lack of demand for all species and products, the economics of accessing single types of logs or species become unfeasible. Effectively, a low volume per hectare of harvested wood products imposes a higher cost burden on the actual products harvested. The same can be said if the expected price is too low on the lower quality part of the tree. The affordability point to cover overhead costs (roads, forest management, silviculture) cannot just be absorbed only by higher value logs. All volume must carry a proportional share of costs. Ultimately, there is an economic break point which eventually reduces competitiveness and operations.

Over the last 15 years, forestry operations across Northern Ontario have been limited to the utilization of softwood sawlogs and hardwood veneer from certain operating areas as the economics do not work to realize the available volume. If forestry operations do not have high value consumers for about 50% of the available supply, the economics do not favour the use of those areas. Practically, a forest requires a sufficient volume to contribute to the cost to maintain, operate, and access the management unit. This also pertains to a specific harvesting area.



Forest – Economy of Scale – 0.5-1.0 million m^3

Sufficient scale to manage cost effectively

Suitable scale for small to large scale contractors

Species & Products

SPF, Poplar, Birch, …

Veneer – 20-30%

Saw Timber (logs / Tree-length) 40-65%

OSB – 25%

Forest Residues – 15-20%

(Tops & branches)

Harvest Block

Generally, 50% of higher value required to justify harvesting

Volume per hectare

Road construction volume per km

Operability

Distance to consumer

The cost to maintain access to fibre is the long-term forest management planning and compliance obligations of holding a Sustainable Forest Licence. Annually, these costs range from $0.3 to $1.0 million and beyond in some cases.

All operations require supervision of harvesting, hauling, and road construction. This is either a fixed cost or part of the cost embedded in a harvest contract. Either way, if an operating area has a lower volume per hectare the access cost is higher to the point of making the block cost prohibitive.

Road construction is a major driver in ensuring wood costs remain reasonable. As the landowner, the Province of Ontario maintains a program to develop long term access roads for the benefit of the forest industry and the public (recreation, commercial tourism, trapping, mining sector, …). The program does help support long-term access to the forest but there still is branch road construction and in-block road access roads. Both rely heavily on a sufficient volume per hectare to support viable operations. Again, less than 50% value logs or lack of markets for the remainder of the tree drive limitations on the ability to access harvest areas.

A number of companies have had to limit operating capacity to address reductions in economically feasible volumes. As an example, GreenFirst draws supply from the Missinaibi Forest for the majority of their required supply for their Chapleau sawmill operation.

1.4.1. Case study: Missinaibi Forest annual harvest

- Lumber – GreenFirst – Chapleau – 400,000 m^3
- Veneer – Columbia – Hearst – 40,000 m^3
- OSB – LP - Potential Wawa but currently not a reality.
- Forest Residues – No customer

The Missinaibi Forest has been without a potential user of the tops of the trees including what may be utilized as OSB since 2016 when Rentech curtailed pellet mill operations in Wawa. Rentech only purchased fibre from the forest from 2013-2016. Prior to that, Weyerhaeuser operated a full OSB facility up until 2007. Other woody biomass such as treetops and branches have not been utilized beyond small scale fuelwood consumption and pilot projects.

Forest operations under GreenFirst have been very creative to maintain an economically viable long-term supply to ensure their Chapleau sawmill continues to operate competitively.

Accessing specific areas with utilization rates below 50% to draw sawlogs and Veneer, are typically not viable unless they have a shorter average hauling distance. This restricts the full economic use of the forest to less than 80%.

In an ideal world, the Missinaibi Forest would have a consumer for sawlogs, Veneer, OSB, and forest residues.

Currently, hardwood leading stands (over 60% hardwood) are bypassed as they are not cost competitive. With only 40% softwood and no consumer for the lower grade hardwood, the costs to develop and maintain road access are not feasible for just softwood sawlogs.

With a new user for OSB material or alternative products, the yield from the forest improves significantly. This then supports an improved economy of scale which translates into up to a 5% average cost improvement on fixed costs (forest management, overhead, roads). The combined impact could have up to a 5% reduction on delivered cost of fibre to the Chapleau sawmill.

	Current (m^3)	**Potential (m^3)**
GreenFirst - Chapleau	400,000	450,000
Columbia - Hearst	28,000	40,000
LP OSB - Limer		150,000
Energy (Fuel/Electricity)		50,000
Total	**428,000**	**690,000**

1.5. Improved Utilization

There are a host of additional benefits from active forest management and improved utilization.

Enhancing forest utilization offers a range of environmental advantages. By optimizing how resources are used, forests can regenerate more quickly and efficiently, leading to lower costs and more closely mimicking natural systems. Rapid regeneration not only strengthens the forest's resilience, but it also boosts its capacity to absorb carbon from the atmosphere. When surplus fibre is actively used, carbon remains sequestered within products rather than being released back into the environment from decaying material left on the forest floor.

Moreover, improved utilization plays a key role in minimizing wildfire risks. Excess fibre left unmanaged can serve as fuel, increasing both the likelihood and intensity of fires. When a wildfire does occur, these conditions often make it much more difficult to control. By reducing this fuel load, we help protect our forests, maintain their ecological balance, and support healthier, more sustainable landscapes.

This report will not touch on any of the secondary benefits of improved utilization but only focuses to identify merchantable and non-merchantable available.

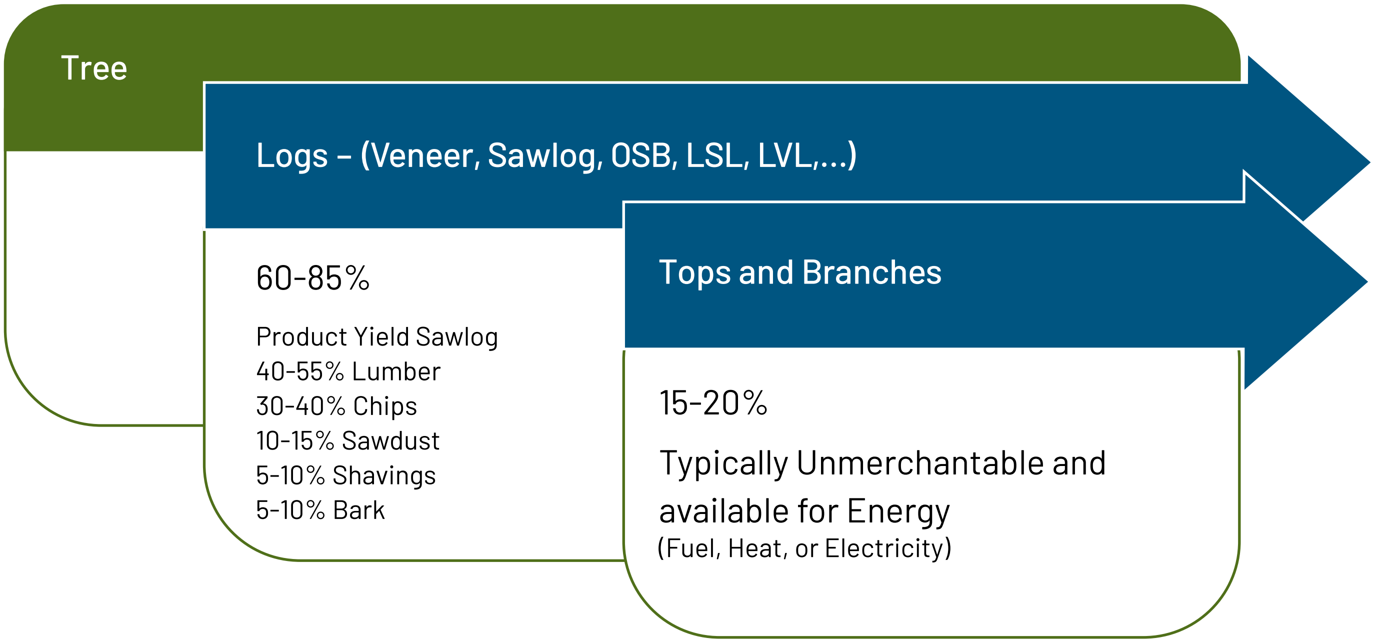
The table lists products a forest generates and uses.

1.6. Sawmill Residual Market Pricing

1.6.1. Spruce Pine Fir (SPF)

The long-term residual SPF chip price in Ontario have historically been $90-110/odmt F.O.B. sawmill. The recent pulp mill closures have impacted expectations but there is a bottom point given the cost of round wood and the percentage of chips produced in sawing lumber.

In the sawing process, a cubic metre of trees yield lumber, chips, sawdust, shavings, and bark. Lumber yields are approximately 40-55% of the inbound fibre volume depending on size, diameter, species, quality, length, and sawing equipment. With that, the remainder of the utilized log or tree length ends up as sawmill residuals (chips, sawdust, shavings, and bark). From those residuals, the majority of the volume is derived from the chips which actually may be as high as 50% of the inbound saw log or tree length fibre.



Therefore, reducing the chip residual selling price too low impacts the financial viability of any operating sawmill. Lumber recovery is a higher driver but too low a chip price will only minimally support a continuous sawmill operation.

The softwood price of chips has adjusted to as low as $55/ odmt F.O.B sawmill. However, there still is influence in Quebec for the need for available supply as there are significantly higher F.O.B. sawmill expectations closer to consumers. In Quebec, SPF F.O.B. sawmill prices continued in excess of $100/odmt or higher for pure spruce. In 2025, the expectations in some regions were as high as $150/odmt F.O.B. sawmill.

1.6.2. Red Pine / White Pine / Hardwood

Current prices for Red & White Pine chips trend at $50-65/odmt F.O.B. sawmill and hardwood generally trends at $60-65/odmt. These have remained unchanged for several years. Sawmill producers have only focused on purchasing available saw logs to be able to operate on a single shift basis.

The trend also remains the same for hardwood residual chips in most cases. Trend prices are from $50-75/odmt depending on the distance to the remaining consumers.

1.6.3. Sawdust and Shavings

For sawdust and shavings, trend in pricing ranges from $30-55/odmt F.O.B. sawmill and is highly dependent on distance to end use, moisture content, and quality.

1.6.4. Bark

Bark is unique as a residual product in Southern Ontario as it actually has a higher price point with higher consumer vs. industrial demand. In denser population areas, mulch is in high demand which offers a higher premium compared to making energy (heat or electricity) for industrial uses. Therefore, bark will have a price range of $5-40 per green metric tonne (gmt), F.O.B. sawmill. Whereas in some cases in Northern jurisdictions, bark has been reduced to only cover the cost of loading as there has been a shift in demand with some energy assets reducing the use of biomass.

A fair market range for bark is from $5-20/odmt depending on the distance to end consumer.

1.7. Hardwood and Top Wood Market Pricing / Cost

Hardwood pricing can be broken down into two main harvesting categories as there are minimal hardwood mill residuals available in Northern Ontario. The first category is the forest residual volume after merchandizing a tree for a primary use like Veneer or OSB and the second category is when the hardwood volume requires a new tree to be harvested.

The first category is the lower cost wood because often the harvester is covering the fixed costs of the operation from the part of the tree with markets. Harvesters normally are looking for a cost of converting the additional product to the form required, loading, and transporting the volume to the customer.

For this category the price varies by the form of the hardwood volume. If the consumer is looking for logs in various lengths with a variety of defects, the log may be purchased at $10/gmt loaded on a truck. If the consumer requires chips with a very low bark content, the product could cost up to $40/gmt roadside.

The second category is the intent is to harvest stands or groups of trees to produce the hardwood volume. In this case, the harvester normally expects the volume being generated to contribute to the fixed cost of the operation. The costs would include tree harvesting, processing or slashing or chipping, and transport to end destination from the stump. The harvester would also expect the consumer to pay a share of the cost of road construction, supervision, and any other general fixed cost of running an operation.

For the second category, the price would also vary by the form of the hardwood volumes. The range roadside would be $20/gmt for tree length wood (minimal contribution to fixed costs) to $50/gmt for clean chips loaded on a truck.

1.8. Market Pricing / Cost Report Assumptions

The assumptions being utilized for this report are as follows:

- SPF Sawmill Residual Net Price - $75/odmt
- SPF Sawmill Residual Sawdust and Shavings - $50/odmt
- SPF Sawmill Residual Bark - $20/odmt
- Hardwood Roadside - $20-50/gmt depending on the form and harvest application

1.9. Potential Volume for Aggregation

The assumptions being utilized for this report are as follows:

Location	Scale (Millions)		Primary Supply	Secondary Supply
	(odmt)	(odmt)		
	Low	High		
Hearst - Kapuskasing	0.75	1.50	Sawmill Residuals, Hardwood Top	Slash (tops, limbs, breakage)
Thunder Bay - Nipigon	0.25	0.50	Hardwood Trees & Top Wood	Slash (tops, limbs, breakage)
Longlac - Nakina	0.25	0.50	Sawmill Residuals, Hwd & Swd Top Wood	Slash (tops, limbs, breakage)
Terrace - Marathon	0.25	0.75	Sawmill Residuals, Hwd & Swd Top Wood	Slash (tops, limbs, breakage)
Chapleau-Timmins	0.50	1.25	Sawmill Residuals, Hwd & Swd Top Wood	Slash (tops, limbs, breakage)
Nairn- Espanola	0.25	0.50	Sawmill Residuals, Hwd & Swd Top Wood	Slash (tops, limbs, breakage)
Central - Eastern Ontario	0.10	0.30	Sawmill Residuals, Hwd & Swd Top Wood	Slash (tops, limbs, breakage)

2. Technology scan: Background

2.1. Need for due diligence

When evaluating the economics of novel technologies, it can be difficult to obtain firm public costing data outside of non-disclosure agreements. Capital costs may turn up in government press releases where there is a significant amount of taxpayer money involved; but the limits of the project may not be well defined. For instance, a site taking advantage of existing wood handling, steam and power generation or effluent treatment services will be a lot less expensive to build than a greenfield plant. Furthermore, actual capital costs at startup (as opposed to when the project was announced) may well include lots of cost overruns if the technology being installed is Serial #001; good estimates for the cost of Serial #002 or indeed the so-called n^{th} plant will not be available.

Finally operating costs are rarely public, except in the form of wood consumption data which is often provided in press releases early in the project development phase. Approximate wood pricing is often well known, and yields of product on wood, based on chemistry, past experience or published target production rates, can serve as a basis for estimating costs. But these remain estimates and subject to error.

The data presented here is meant to provide guidance as to paths worth pursuing. Data is as robust as possible given the constraints. But the results presented here should not be used in any way for investment decisions without an enhanced due diligence step, for example through a study conducted by a consulting engineering firm working under a confidentiality agreement with the technology provider.

2.2. Overview

This section of the report will cover technologies, products and markets, and wood quality requirements, organised roughly as follows.

2.2.1. Fuels

Solid fuels (Biochar, biocarbon, pellets) are low cost, relatively low value energy products that can be shipped across Ontario and beyond. Most processes will run better on white wood chips, either hardwood or softwood, but some can take residues such as bark or roadside slash chipped in-bush. Customers will include industrial operations requiring heat from non-fossil sources and metallurgical plants needing a reductant to substitute for coal and coke. There are also agricultural uses for some of these products.

Liquid fuels (pyrolysis oils, hydrothermally produced oils and Ensyn's so-called Low Carbon Fuel Oils) are low cost, higher value energy products that can substitute for fuel oil in heating plants. They can also substitute for crude oil in petroleum refineries at small substitution levels, or at higher levels where higher oxygen contents are acceptable. In that context, the PREEM refinery in Gothenburg, Sweden, has installed a hydrocracker to remove oxygen from bio-based naphthas prior to refining in conventional petrochemical process equipment. The Parkland refinery in Burnaby, BC, is installing a similar unit, designed to treat canola oil. The suitability of refineries in the Sarnia area or beyond for treating oxygen-bearing liquid fuels would need to be verified.

The processes will run better on white wood chips but can take lower quality material such as bark or slash if a lower quality oil is acceptable, and the product can be shipped across Ontario and beyond.

Gaseous fuels, also known as syngas, arise from gasification processes and can be used as a local substitute for natural gas. Best fits include heat for lumber kilns, dryers used in tissue grades of paper and other heating duties, in particular small-scale off-grid applications. Gasifiers for lime kilns are in use in Europe and elsewhere, but it is unlikely that any pulp mill lime kiln in Ontario is capable of taking a fuel of reduced calorific value without a reduction in pulp production. These processes will run best on white wood chips but can take bark and slash.

Synthetic fuels are hydrocarbons created from biomass feedstocks that mimic the chemical composition of petroleum-based fuels like diesel, gasoline and aviation fuel. Methanol and ethanol may be included in this definition. Many pathways are proposed for production of synthetic fuels, but all start with primary conversion of the biomass to a liquid or gaseous fuel, followed by catalytic cracking, hydrogenation and synthesis to remove oxygen and produce a suitable mix of hydrocarbons. Synthetic fuels produced by these processes are never cost-competitive with petroleum-based equivalents without substantial regulatory support in the form of carbon credits and financial incentives towards plant capital and operating costs. A path to Renewable Natural Gas (RNG) is included to show what is possible. These run best on white wood chips but can take bark and other lower-grade material.

2.2.2. Chemicals and materials

Kraft pulp is well known. Hardwood and softwood feeds make different grades; it is possible for a mill to swing back and forth but this also means shifting from one market to another. The processes require clean, screened white wood chips. Kraft pulp can be exported worldwide. Novel products are being developed from kraft pulps, such as Spinnova's textile fibre or the cellulose filaments and crystalline nano-cellulose products made in Canada today, but these do not need to be on the site of a kraft mill, and so are not immediately relevant to this study.

Bio-chemicals offer a rapidly growing market in Europe and Asia. A variety of processes exist, most running better on hardwoods. All require clean, screened white chips. These rapidly growing markets open the door for export opportunities. A section at the end of this report digs deeper into the EU opportunity.

2.3. Standard input data and analysis approach

Most calculations will be on the basis of oven-dried metric tonnes (odt) of feed. In order to facilitate comparison, a range of standard pricing and conversion factors will be used across all technologies evaluated. (In certain cases, these standard inputs may be altered, with the rationale provided in the text). The Table below lists common assumptions; these were developed in the course of the BioPathways project managed jointly by FPAC, CFS and FPInnovations.

Standard input data and conversion factors (2025 $CAD)				
Biomass or chips, $/odt	$150.00		Construction cost multiplier	2.2
Bark, hog fuel, in-woods chipping, $/odt	$90.00		Total installed cost multiplier	3.2
LP steam, $/t	$16.10		Operating days per year	360
Enthalpy LP steam, GJ/t	2.8		Seconds per day	86400
LP steam, $/GJ	$5.75		Depreciation, years	20
Power, $/kWh	$0.046		Tax rate	30%
Gas, $/GJ	$5.00		Inventory, days	17
Petroleum @ $75/bbl, $/GJ	$16.39		Labour per $ operating costs	$0.09
Kraft yield on wood, t/odt	40%		O&M per $ operating costs	$0.15
Lignin yield on pulp, t/t	14%		Scaleup exponent, n	0.60
Effluent cost per t sewered	$11.75		$US vs. CAD	$0.750
Ash disposal, per kg	$0.10		Euro vs CAD	€ 0.629
			SEK vs CAD	6.77

Other energy conversion factors			https://en.wikipedia.org/wiki/Energy_density	
Bark, GJ/odt	19.0		Gasoline, MJ/L	34.2
Lignin, GJ/odt	25		Diesel, MJ/L	38.6
Power, MW/(odt/d) bark	0.220		Crude, MJ/L	37
Power, (odt bark/d)/MW	4.547		Natural gas, MJ/kg	53.6
Energy, GJ/MWh	3.6		Natural gas, MJ/m^3	36.4
Energy, MWh/GJ	0.278		Power generation efficiency on gas	83%

In many cases, capital cost data for a specific process is publicly available through press releases or conference presentations, but might be several years out of date, and may apply to plants of different scales than what might make sense in a specific location in Northern Ontario. Bearing in mind that many costs increased through the COVID years by factors larger than changes to the Consumer Price Index might imply, inflation data will be applied to bring all information to 2025 Canadian dollars. Conversion rates from $US, Euro and Swedish crowns (SEK) will also be applied.

For scaling purposes, the following rough approximation, based on commonly used engineering approaches, will be used. Where capital costs C_1 are available for a plant of scale M_1, the order of magnitude of the costs C_2 for a second plant, whether larger or smaller, of scale M_2, can be estimated using the exponent *n* as defined in the following equation can be used:

$$C_2 = C_1 \left(\frac{M_2}{M_1}\right)^n$$

where C_1 and C_2 are the costs of plants of scale M_1 and M_2 respectively. This exponent *n* depends on the type of equipment; with *n* = 1, a plant twice as large will cost twice as much as the reference plant. Given economies of scale, this exponent is usually less than 1. A value of *n* = 0.6, which yields costs of 1.5X for a plant of 2X the original scale, is a good starting point and will be used here.

2.4. Triage methodology

This section outlines a triage approach for qualifying a range of constraints on what technology is best in what context, in particular where exact costs are not available. Some triage components will be useful in some contexts but not others; all have been useful at different times. The goal is the best possible estimate, based on the authors' past experience, in order to be able to rank specific technological platforms and market pathways for specific locations in Northern Ontario.

2.4.1. Feedstock supply limits on economies of scale

Some pathways rely on specific feedstocks, such as sawdust to pellets. The upper limit on plant size in this case is available sawdust from the host sawmill; marginal additional tonnes for a slightly larger plant may be very expensive. The marginal cost of additional tonnes of feed will also limit processes depending on harvested wood as these tonnes come from further away and cost more to transport; the value of the end-product will set the limit as to how far you can harvest economically and thus how big your plant can be. This is discussed further under kraft pulping, below.

2.4.2. Volume versus value: market selection and the Sweet Spot

Very high-volume products (such as fuels) are typically low value. Conversely there are lots of specialty products that offer high value, but overall market size is low compared to typical forest industry production rates, and so one small forest industry player may be able to produce enough to upset an existing market. There is a need to focus between these extremes: big enough to consume reasonable amounts of feedstock, but not so big that it overwhelms the target market. As illustrated in the figure below[2], energy pathways are always needed to consume lower-grade wood and residues, but pathways such as phenolics, with world markets in the multi-million tonne range and pricing above the typical kraft pulp market price, need to be prioritised for supplies of high-quality, clean, white wood chips.

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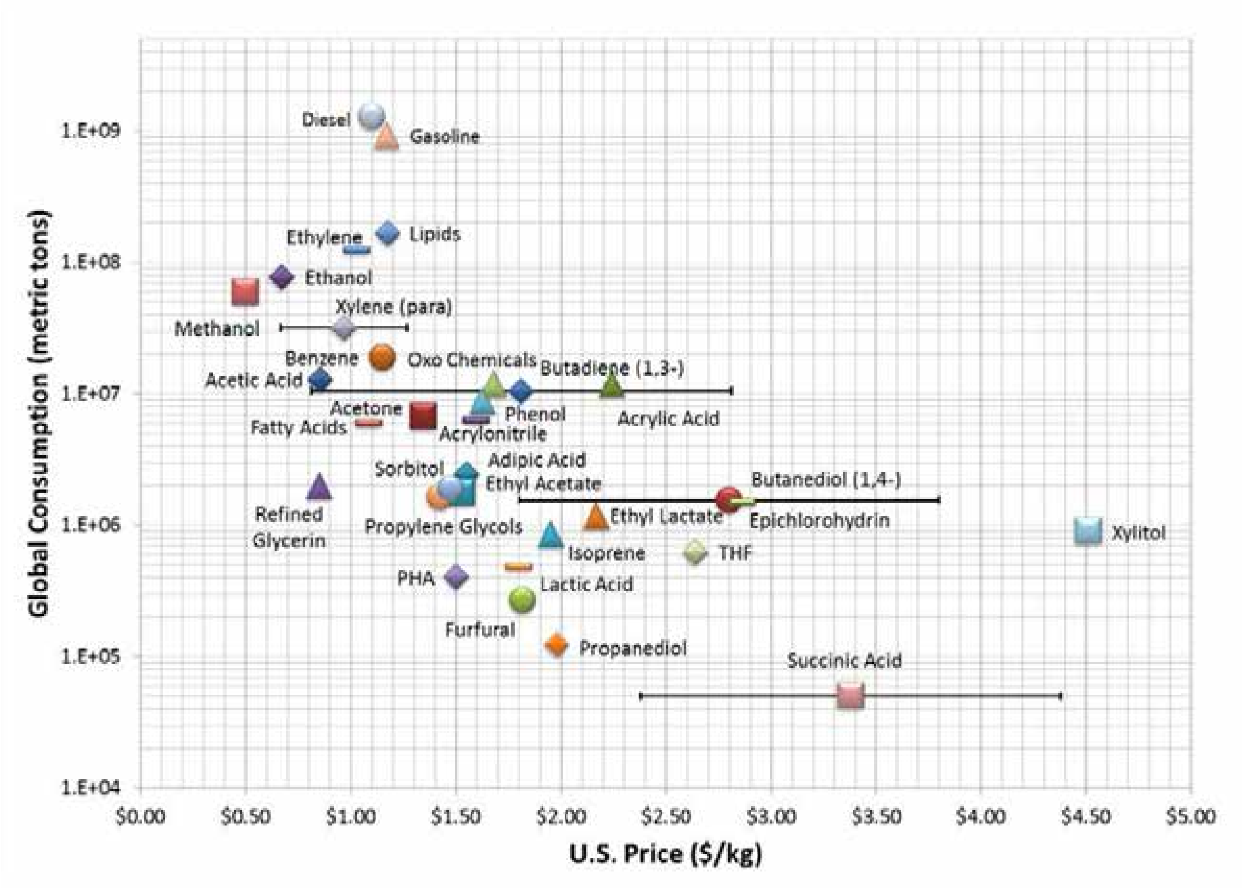
[2] Biddy, M.J., C. Scarlata and C. Kinchin, "Chemicals from Biomass: A Market Assessment of Bioproducts with Near-Term Potential", NREL/TP-5100-65509, March 2016.



2.4.3. Wood quality limitations

What are the process requirements? Will it run exclusively on hardwood, softwood or either one? Does the process require clean white wood chips, or will a mix of hog fuel and chipped harvesting residues be acceptable? Does the wood need to be dried? These are all constraints that may limit the application of a technology to specific areas.

2.4.4. Revenues net of biomass consumed

Revenues remaining after wood has been paid for is a key metric. Simple processes, such as pelletising, can make do with a smaller revenue stream after wood costs than more complex processes such as kraft pulp where additional chemicals and energy inputs are needed. In relatively simple processes wood costs may represent up to 70% of total operating costs; wood costs in more complex processes such as kraft pulping or large-scale gasification may represent 50% or less of the total.

2.4.5. Need for carbon policies

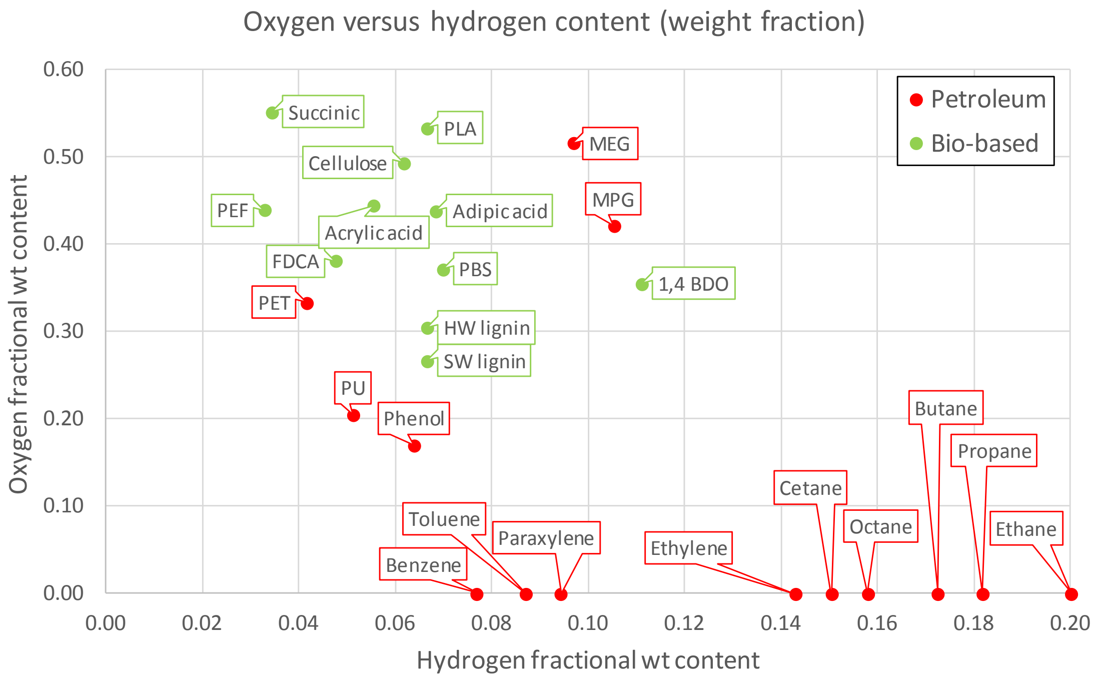
Will the product be competitive with the incumbent in the absence of carbon policies? What carbon policies are needed to incent production of bio-chemicals and materials? Producers of petroleum-based chemicals and materials receive substantial tax breaks and financial incentives along the production chain from exploration through to product manufacture. To compensate, bio-fuel producers receive substantial carbon incentives to make their products competitive with petroleum-based alternatives. While this is a federal responsibility, it is worth pointing out that similar carbon incentives are needed to sustain production of bio-chemicals and biomaterials.

What effective price of oil or of natural gas, after carbon accounting, is needed for bio-based products to be cost-competitive with fossil-based equivalents? If that number is substantially higher than current fossil pricing, then the product will be uncompetitive, the so-called Green Premium notwithstanding. A scoring approach has been developed for cases where hard numbers are not available, where a rating of 1, 4, 7 or 9 is applied to each case as follows:

1	Poor profitability, need for significant carbon accounting policy action
4	Mediocre profitability; High oil price and some carbon accounting is needed
7	Good profitability (competitive with $60 USD per barrel)
9	Very good profitability (competitive with $40 USD per barrel)

2.4.6. Type of molecule produced

This is an indication of process complexity and of fit to specific markets. Oxygenated molecules are generally easier to make from wood than pure hydrocarbon substitutes, since lignin, cellulose and hemicellulose are already oxygenated. Several petrochemical intermediates start off as pure hydrocarbons but are subsequently oxygenated for reasons of product performance, and these are therefore more likely candidates for a bio-chemical pathway. As illustrated in the figure below[3], examples include phenolic resins and intermediates such as monoethylene glycol.



Drop-in, identical replacement molecules have an advantage but can be challenging to make. Novel, functionally similar molecules may be easier to make and may perform as well or better than the pure hydrocarbon version, but may or may not be drop-in, and may require that the customer make significant changes to his processes or how the product is used. For example, ethanol is a drop-in replacement for gasoline up to 10%; beyond that the vehicle fuel system needs to be altered to suit. The early bio-diesel fuels made using the FAME process were limited to 2% substitution in cold climates, but newer hydrogenated renewable diesel products, while molecularly different from a hydrocarbon product, have much higher substitution limits. So these are drop-ins, up to a limit, but are not identical to the petroleum-based molecules. Lignin-based substitutes for phenol-formaldehyde resins are another example where the formula for making the final resin from primary molecules needs to be adjusted when lignin is included.

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[3] Based on Farmer, T.J. and Mascal, M., Chapter 4: "Platform Molecules", in "Introduction to Chemicals from Biomass", 2nd edition, Wiley, 2014. Cited in Clark, J., "Woody Biomass as a sustainable feedstock for Bio-based chemicals", 8th Nordic Wood Biorefinery Conference, October 23-25, 2018, Helsinki.

2.4.7. Technology complexity level

This is a quick approach for comparing technologies in the absence of hard data. The same scoring approach, with ratings of 1, 4, 7 or 9, is used here:

1	Very simple process. Low Capex and Opex. Wood procurement costs can account for up to 75% of total Opex. Example: wood pellets.
4	Moderately complex process. Wood procurement costs can account for up to 67% of total OPEX. Examples: torrefaction, simple gasification for CO and H_2, pyrolysis.
7	Complex process. Wood supply costs represent 40% to 50% of total OPEX. Examples: kraft pulp, sugar-based biorefinery processes.
9	Very complex process. Wood supply costs account for 25% to 33% of total OPEX. Examples: gasification and catalytic synthesis (e.g. methanation, Fischer Tropsch).

2.4.8. Technology Readiness Level (TRL)

This is a well-known metric. Technologies outlined here will be characterised by TRL levels of at least 7, and ideally higher.

3. Technologies evaluated

3.1. First Quartile NBSK Pulp Mills

3.1.1. Overview

Canadian producers of market pulp are in a precarious position. Even though world demand for kraft pulp continues to increase year-over-year at an estimated CAGR of 3.4%, this growth has largely been satisfied by construction of new large kraft mills in Northern Europe, South America and Asia. At the same time, declining use of paper in business settings has forced existing producers of kraft pulp to find new markets and customers in tissue, packaging and specialty paper markets, a shift that is still on-going. Northern bleached kraft pulp (NBSK) is still valued for its properties as a reinforcing fibre, but large South American producers of bleached eucalyptus kraft (BEK), are innovatively improving the qualities of their fibre to compete in markets where NBSK once held a substantial edge. These producers have such low-cost structures that they are able to offer their grade of pulp at significant discounts - luring customers away on the basis of large cost savings.

Because of these pressures, mills with high cash costs of operation – defined as the costs necessary to keep running day to day, excluding financing and capital – face curtailments or even closure when pulp prices reach cyclic lows. These realities have severely impacted the kraft pulp industry in Canada. Over the past decade, the annual production of wood pulp (not exclusively kraft pulp) in Canada has declined from roughly 7M tonnes in 2015 to under 5M tonnes in 2024. A clear factor is the closure of small, technically obsolete mills whose cash cost of operation was not sustainable. In Ontario, these include recent permanent closures of kraft pulp mills in Espanola and Fort Frances and indefinite idling of the kraft mill in Terrace Bay.

3.1.2. Cash cost curves

Indices have been developed that allow pulp and paper companies to rank the operations of their mills against their peers by the total cost of operations per tonne of product. There is no standard by which cost curves are built, but costs are normally split into contributions to the total by purchased fibre, chemicals, energy, labour, maintenance, and overhead. Financing costs, cost of capital projects and transportation charges from the mill gate to customer are normally excluded.

A standard cost curve presentation is usually a bar chart with mills ranked from lowest to highest total cost of operations. The width of each bar is proportional to the mill's production. First quartile mills are those whose total cash cost of operation fall within the lowest 25% of production in their product categories. Note that the data contained in cost curves produced by industry sources like RISI or Fisher are proprietary and modelled from internal data. They are not built from actual costs. For this reason, the positioning of mills may vary from one analysis to another, and the real cash cost of operations for a mill may be different than suggested by the models.

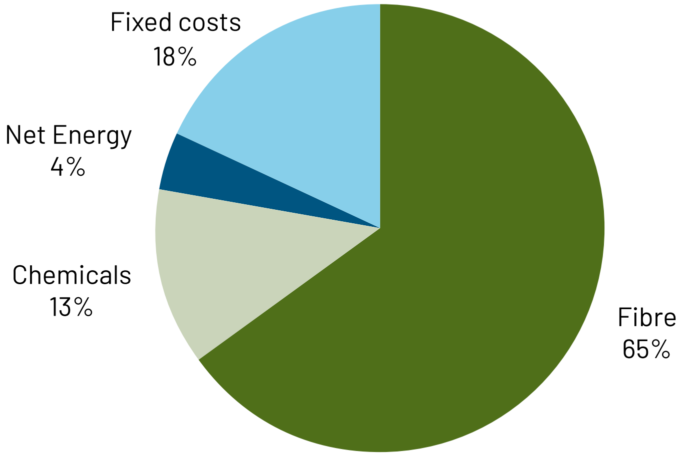
3.1.3. What is a first-quartile mill?

More than 60 kraft mills produce NBSK market pulp in the world. A first quartile mill producing NBSK in 2025 is estimated to have a total cash cost of operation below US$400/air dried tonne (admt) pulp. This excludes financing, capital and shipping charges. To put this number into perspective, Suzano, a large South American manufacturer of BEK, quotes a cash cost of only R 800-859 (US$152-163) /admt pulp.

In general, first quartile pulp mills producing NBSK are characterized by:

- Availability of low-cost fibre
- Large scale of operation (lower fixed costs per tonne)
- Low technical age (more efficient operation)
- Low fixed costs (overhead, labour and maintenance)
- Negative (revenue-generating) net energy costs
- Low chemical costs

Fibre costs are generally the largest contributor to the cost of manufacturing kraft pulp and can account from 50-70% of the total cash cost. Chemicals, fixed costs and energy follow in importance (Figure 1). The importance of each factor to total cash cost can vary by region. In addition, regional changes in cash cost for different factors can occur as a function of time. As one example, Nordic fibre costs have nearly doubled since 2022, primarily a consequence of losing access to cheap Russian fibre but also due to competition for fibre from new large biomass-fired energy plants.



Based on production volume, only a few Canadian kraft mills currently fall into world-wide first quartile performance for NBSK mills. Both remaining Ontario kraft mills currently fall into second quartile performance, but both have a high technical age.

Low GHG emissions are of importance to end-use customers for the pulp, particularly for companies selling into the EU market. Additionally, production and sales of bioproducts like tall oil, turpentine, methanol and lignin are contributing significant revenue to some kraft mills. Kraft mills are also being seen as sources of concentrated biogenic CO_2 that can be captured and sequestered as revenue-generating credits for other more carbon-intensive industries. These developments will certainly affect the ability of mills to remain first quartile in the future.

3.1.4. Fibre costs

Depending on the region and circumstances of individual mills, fibre comes to them in the form of residual chips from sawmills, or direct chipping of pulpwood trees, either on-site or in-woods. Fibre costs are strongly sensitive to transportation distance and mode of transport. The economic fibre basket available to a mill must match the production needs, as the cost of the last few tonnes of fibre delivered to the mill critically affect the overall revenue earned. Due to the large contribution of fibre costs to the overall cost of operations, even small changes in the cost of fibre can dramatically affect the position of a mill on an NBSK cost curve. A mill in the first quartile of fibre costs pays less than US$190/admt pulp.

3.1.5. Fixed costs

Fixed costs are incurred regardless of whether a mill is producing pulp and consequently add significantly to the cost of operations per tonne of pulp. These include general overhead, labour and maintenance. Both labour and maintenance costs correlate strongly to the technical age of the mill. Mills operating older equipment are less automated and require more staff on hand to operate as well as incurring higher maintenance costs. Older mills are particularly prone to unplanned and extended maintenance outages that reduce annual production. A NBSK mill in the first quartile of fixed costs would pay under US$70/admt pulp.

3.1.6. Energy costs

Energy costs are normally reported as net energy. Mills purchase electricity, natural gas and other fuels to support their operations. If they operate a condensing turbine, mills may also sell electricity back to the grid. Some Nordic mills also sell supply heat for district heating purposes. Natural gas is primarily used as a fuel in lime kilns but also provides supplemental heat for bark boilers and recovery boilers. Modern lime kilns can be fueled by bark or sawdust if they have sufficient capacity to handle the needs of the mill when using biomass as a fuel. That isn't the case for most kilns in Canadian mills, and the economics are difficult to justify in Canada with prevailing prices for natural gas.

A state-of-the-art kraft mill produces more than enough steam and electrical power for the needs of the mill just from combustion of black liquor in the recovery boiler. However, for practical reasons, all kraft mills also operate bark boilers. Steam from the bark boiler, along with excess steam from the recovery boiler can produce electricity for sale to the grid. These sales provide substantial revenue. In Canada, with only a few exceptions, some of the steam produced by the bark boiler is required to support mill operations.

Energy costs for Canadian mills are higher than their peers, due to the advanced technical age of our energy islands. Many, but not all mills, have installed condensing turbines and generate excess electricity for sale through power purchase agreements with regional utilities that partially offset their purchased cost of energy. Overall, net energy costs for a first quartile mill should be negative (earn revenue) because their electricity sales exceed purchases of other forms of energy.

3.1.7. Chemical costs

Chemicals are consumed by the pulping and bleaching processes in a mill. Pulping chemicals are largely recycled and reused, but purchases of bleaching chemicals represent significant costs to operation. Cooking and bleaching strategies introduced over past decades have focussed on reducing the consumption of chemicals while retaining the desired properties of the pulp. For this reason, modern mills will have much lower chemical costs than older peers. Chemical costs for a first quartile mill should be less than US$65/admt pulp.

3.1.8. Scale of operation

A modern state-of-the-art kraft mill produces more than 500 kt/y NBSK pulp. The very largest mills being built today produce close to 1,500 kt/y. In contrast, most kraft mills in Canada produce between 300 kt/y and 400 kt/y pulp. Production rates for existing kraft mills in Ontario are estimated to be in the vicinity of 320 kt/y pulp. Relative to modern competitors, the smaller size of Canadian mills puts them at a significant disadvantage in terms of fixed costs contribution to the overall cost of operation. Moreover, chemical costs per tonne of pulp will also be substantially lower for new modern mills. The sheer size of modern mills also provides revenue opportunities unavailable to smaller mills. For example, the operation of a large high pressure recovery boiler enables the new Metsä mill in Kemi, Finland to produce an estimated 2 TWhr/y of electricity. Potential revenues from sales of mill coproducts like tall oil, turpentine, lignin and other chemicals are also enhanced. Operating at a scale much larger than 500 kt/y is likely to be essential for mills that wish to remain in the first quartile of mill operations over the next decade.

3.1.9. Technical age

The technical age of a mill is not its chronological age, but an empirical calculation that considers major upgrades made to the mill over time. A common means of calculating technical age is to break the mill into operating components and then multiplying the years elapsed since the last significant upgrade by the percentage the component contributes to mill operation. The technical age is the sum of the component calculations. Major upgrades, like the addition of a new recovery boiler, will significantly lower the technical age of a kraft mill. Mills with a low technical age are more likely to meet current benchmarks for efficient operation, with significantly lower fixed, energy and chemical costs.

Low technical age mills likely possess most of the following characteristics:

- High pressure recovery boiler operating at > 8 MPa (1200 psi) steam pressure
- Minimal freshwater consumption (< 25 m^3/admt pulp)
- Modern lime kiln with product cooler and specific heat consumption <3.5 GJ/t CaO
- Oxygen delignification prior to bleaching
- Three or four stage bleach sequences such as D-Eop-D or D-Eop-D-D
- New or modernized liquor plant, including energy efficient evaporation systems
- Efficient wood handling and processing with minimal chip rejects
- Enhanced pulp yields from chips with consistent kappa
- Modern pulp screening and washing
- New or renewed forming and drying sections on pulp machine
- Automated baling and warehousing

3.1.10. Capital costs

The kraft pulping industry is capital intensive. Based on the announced cost of recent projects, a completely new greenfield mill can cost more than US$3 billion (~US$1200/admt pulp). Doubling pulp production capacity at a brownfield site cost approximately US$2 billion for the Kemi, Finland mill (~US$1300/admt pulp). Total announced cost for the Irving Saint John NextGen project over the past decade is about US$1.1B.

To give a general sense of the scale of financing needed to replace portions of a NBSK mill, the following estimates (in US$) of equipment costs offer insight. These are exclusive of design, engineering, construction and other associated costs, so final project cost would be substantially higher.

Recovery boiler:	$400M-$600M
Evaporators:	$40M-$120M
Bark boiler:	$40M-$65M
Recaust plant:	$50M-$100M
Lime kiln:	$30M-$90M
Wood yard:	$10M-$30M
Continuous digester:	$30M-$75M
Oxygen delignification:	$24M-$60M
Brownstock washing:	$20M-$40M
Bleach Plant:	$60M-$120M
Pulp machine:	$90M-$250M

3.1.11. Transitioning to first quartile performance

Attaining first quartile performance on the NBSK cost curve provides mills with the resilience needed to handle the cyclic swings of a normal business cycle, as well as ability to weather unpredictable disturbances to kraft pulp markets. The steps needed to transition a mill to first quartile performance are mill-specific and will depend on its technical age and the effort required to sufficiently influence the costs of operation.

A strategic vision is required to achieve this transition. Short of completely rebuilding a mill on a brownfield site or building a new greenfield mill, it requires a deep understanding of current operations and existing process bottlenecks. Sequencing of projects in the right order is essential to maintain production in the interim. The steps taken by Irving Pulp & Paper over the past decade to bring their mill in Saint John to first quartile performance are instructive.

Cost savings alone are usually insufficient to justify large capital investments. All major NBSK mill upgrades undertaken in recent years have come with a concomitant major increase in production. These include the Irving Pulp & Paper Saint John mill, the SCA Östrand mill, and the Metsä Fibre mills in Kemi and Äänekoski. All these mills also assumed additional revenue from sales of electricity to the grid to justify the investment.

Specific steps that might be taken by mills to attain first quartile cost of operations:

- The cost of fibre is such a large component of the overall cost of operation that any improvements in this area will pay major dividends. While many aspects of the fibre costs are outside of the ability of the mill to control, much can usually be done to improve yield on fibre within the mill from storage to chip handling and screening.
- A modern energy island is a prerequisite to sustain first quartile performance into the future. At a minimum, this requires a recovery boiler operating at steam pressures of at least 8.3 MPa (1,200 psi), and preferably at 10-11 MPa (1,500-1,600 psi). Evaporating liquor to greater than 75% solids is necessary. Most bark boilers in Canadian kraft mills were designed and built when energy efficiency was an afterthought and have long outlived their useful life. An energy efficient bark boiler that maximizes steam efficiency is critical to a modern kraft mill energy island.
- Excessive chemical costs can be addressed by upgrading and improving the fibreline from the digester through to the bleach plant. Adding an oxygen delignification stage and use of multiple wash presses significantly decreases cost of bleaching chemicals. Such changes would likely be required to support increased production.
- Pulp machine upgrades or rebuilds can reduce energy consumption and match future production rates.

3.2. Kraft pulp: New world-scale mills

The economic analysis below describes a new, world-class kraft pulp mill. Data comes from press releases by the Finnish forestry company Metsä, which has recently built and started up two modern mills in a northern context at Äänekoski and Kemi.

Metsä: conversions		
Year built	2017	2024
Mill	Äänekoski	Kemi
Production, millions of air-dried tonnes (adt)	1.300	1.500
Capital (millions of euros)	€ 1,200	€ 2,000
Capex (euros) per annual tonne of production	€ 923	€ 1,333
Capital, 2025 $MCAD	$2,558	$3,363
Wood consumption, adt/d	9,028	10,417
Capex ($CAD) per annual tonne of production	$1,968	$2,242
Capital, 2025 $MCAD, scaled to 5,550 odt/d feed	$1,910	$2,305

Both mills were built on the site of existing mills, and so may have had access to different levels of legacy utility equipment (wood or chip handling, heat and power, effluent treatment, etc.). The more expensive of the two is used to model a new mill in Northern Ontario. Wood supply is assumed to be about 2 Modt/y, roughly half the size of Kemi and similar to Canda's current largest pulp mill.

It is worth pointing out that neither of the new Metsä mills were built with a lignin extraction plant. The obvious explanation is that the lignin provides better value through electricity sales when burned for steam; high electricity prices in the Nordic countries would incentivize that approach. In the absence of decent numbers, no estimate is provided here of the financial benefits of power sales to the grid or of heat to district heating systems, but these are likely to be significant.

Project name	**Kraft pulp with lignin**		
Scale, odt/d (odt/y)	Chips	5550	1,998,000
Revenues			
Product	**Yield on wood**	**Price, $/t of product**	**Annual sales, $**
Kraft pulp	45%	1,600 $	$1,438,560,000
Lignin	6.3%	750 $	$94,405,500
Energy	43%		$-
Sewer losses	5.7%		
Sales			**$1,532,965,500**
Capex and Opex			
Capital	**Equipment**	**Installation**	**Total**
Total capital			**$2,304,883,939**
Opex per odt feed	**Units per odt feed**	**Cost per odt**	**Annual total**
Wood, odt	1	$150.00	$299,700,000
LP steam, GJ/odt	2	$11.50	$22,977,000
Power, kWh/odt	320	$14.72	$29,410,560
Natural gas, GJ/odt	0.6	$3.00	$5,994,000
Sewer costs			$1,338,160
% OPEX due to wood	45%		$306,580,280
Sub-total			**$666,000,000**
Labour			$59,940,000
O&M			$99,900,000
Total opex (annual)			**$825,840,000**

Economics	
Project name	Kraft pulp with lignin
EBITDA	$707,125,500
Depreciation	$115,244,197
EBIT	$591,881,303
Taxes	$177,564,391
Net revenue	$414,316,912
Inventory	$72,390,038
Capital employed	$2,377,273,977
ROCE	**24.90%**
Simple payback, years	**5.6**
IRR	**17.98%**

3.3. Biochar, bio coal, biocarbon and torrefaction

The Canadian Standards Association[4] is working to clarify terminology in this field, as the terms are frequently used interchangeably. Roughly speaking, the difference between these technologies is carbon content, i.e. how much oxygen and hydrogen have been driven off. Bio-coal generally involves a light treatment, leading to low carbon content and high yields on wood. Bio-char involves a more intense treatment, driving off more oxygen and hydrogen, with associated higher carbon content and reduced yield. Bio-carbon has the highest carbon content and the lowest yield on wood.

While CSA standards are under development, the following definitions can be used.

Biochar is defined in the EU as a porous, carbonaceous material that is produced exclusively by pyrolysis of biomass. The carbon remains stored in the material as a long-term carbon sink, for instance in soil remediation, or replaces fossil carbon in industrial manufacturing. It is not intended to be burnt for energy generation. Chars produced by torrefaction, hydrothermal carbonization and coke production are excluded[5].

Biocoal and **biocarbon** are defined in the EU as a low-moisture content solid made from biomass using thermochemical processes. Intended for energy generation, biocarbon, biocoke and charcoal are common synonyms when the material is used as a bio-based alternative to coal for energy, steel and concrete production.

In **torrefaction**, a mild pyrolysis process, woody biomass is transformed to a state intermediate between wood and biocoal. The process operates at low temperatures and at atmospheric pressure. Volatiles are released, which can be burned to drive the process; this represents a loss of mass of about 20%. The resulting powder can be molded into briquettes, which are hydrophobic. Several vendors use the terms “biocoal” and “torrefied biomass” more or less interchangeably.

The Joensuu BioCoal[6] project, based at Savon Voima Oyj’s Joensuu power plant in Finland, will produce biocoal for use in industrial heat and energy production such as steel and cement industries. Given the low capital cost (€20M) provided in the press release, it is assumed that a lot of auxiliary equipment, such as wood handling or heat and power, were already available onsite, as the host is an existing district heating utility. A greenfield plant may cost quite a bit more.

In Canada, several companies offer bio-carbon systems. Among them, Airex Energy[7] offers a similar process and product. Projects have been announced at Nairn, ON, and Port Cartier[8], Québec. Char Technologies[9] is developing projects in Espanola and Lake Nipigon, ON, Thorold, ON and Saint Félicien, Québec. The tables below describe a typical Canadian installation for bio-coal.

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[4] https://publicreview.csa.ca/Home/Details/5895, viewed 2026-01-08.

[5] EBC (2012-2024) ‘European Biochar Certificate - Guidelines for a Sustainable Production of Biochar.’ Carbon Standards International. http://european-biochar.org, viewed 2025-07-01 See specifically Version 10.4E, 2024-12-20, 4000093EN.pdf, https://www.european-biochar.org/en/ct/2-EBC-and-WBC-guidelines-documents, viewed 2025-07-01.

[6] https://www.joensuubiocoal.fi/en, viewed 2025-12-09.

[7] https://airex-energy.com/, viewed 2025-12-09.

[8] https://biomassmagazine.com/articles/airex-energy-celebrates-inauguration-of-canadian-biochar-plant, viewed 2025-12-09.

[9] https://www.chartechnologies.com/post/char-tech-provides-lake-nipigon-and-saint-f%C3%A9licien-project-updates, viewed 2025-12-09.

Project name	**Torrefaction (Bio-coal)**		
Scale, odt/d (odt/y)	Chips and bark	615	221,400

Revenues

Product	Yield on wood	Price, $/t of product	Annual sales, $
Char	75%	335 $	$55,626,750
Sales			**$55,626,750**

Capex and Opex

Capital	Equipment	Installation	Total
Unit ops	$30,000,000	$51,000,000	$81,000,000
Total capital	**$30,000,000**	**$51,000,000**	**$81,000,000**

Opex per odt feed	**Units per odt feed**	**Cost per odt**	**Annual total**
Wood, odt	1	$90.00	$19,926,000
Electricity		$14.85	$3,287,790
Natural gas		$0.41	$90,774
% OPEX due to wood	65%		$7,350,821
Sub-total			**$30,655,385**
Labour			$2,758,985
O&M			$4,598,308
Total opex (annual)			**$38,012,677**

Economics

Project name	Torrefaction (Bio-coal)
EBITDA	$17,614,073
Depreciation	$4,050,000
EBIT	$13,564,073
Taxes	$4,069,222
Net revenue	$9,494,851
Inventory	$2,626,819
Capital employed	$83,626,819
ROCE	**16.22%**
Simple payback, years	**8.5**
IRR	**11.72%**

3.4. Pyrolysis

Pyrolysis[10] involves heating biomass in a reactor in the absence of oxygen. The result is a mixture of solids (biochar), liquids (bio-oil) and syngas. Ratios depend on operating conditions. Energy needed to run the process is typically generated by burning one of the three co-products, usually the gas, in order to maximise production of the more desirable co-products. So-called fast pyrolysis generates typical yields of 50% bio-oil, 20% biochar, and 30% syngas. Slow pyrolysis can produce substantially more biochar (up to 35%) than fast pyrolysis.

Ensyn is the Canadian leader in this field. Their Low Carbon Fuel Oil (LCFO) is a substitute for fossil-based heavy fuel oil in heating, for instance in the heating plants in university campuses. There is also a potential to co-refine LCFO in a petroleum refinery, up to a limit dictated by oxygen content. Through its subsidiary Vyterra, Ensyn supplied a system to Rémabec in Port Cartier, Québec[11] in 2016. The project has seen some setbacks but appears to be on track again[12, 13, 14]. Output has been publicly identified as 40 million litres LCFO per year.

A Canadian government press release[15] listed 2016 capital sources from the federal government ($44.5M), the province ($32M) and industry ($27.4M) for a total of $110M. The feed was identified as 170,000 green tonnes of wood annually. Payback is on the long side but not enough to dismiss this pathway given the approximate nature of the data presented here. Carbon accounting will improve these numbers. More recently Vyterra has announced a new plant in partnership with Ledwidge Lumber in Nova Scotia[16], with Michelin the customer for the fuel oil[17].

Through its US subsidiary Castlerock Biofuels, Ensyn's technology will be implemented in a project in Millinocket, ME. Compared to the Port Cartier project, which used two units, the project will include four modular pyrolysis units to double capacity. End uses will include substituting for heavy fuel oil in college campus heating plants, and potentially for co-processing with crude oil in petroleum refineries. The table below is built on data for the Maine project. Data for sales price and yield are not available and could alter this analysis. Results are no better than for Port Cartier, but it is likely that carbon accounting of various sorts will improve this picture.

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[10] https://en.wikipedia.org/wiki/Biochar, viewed 2025-07-01; https://en.wikipedia.org/wiki/Pyrolysis, viewed 2025-07-09.

[11] https://www.ensyn.com/uploads/6/9/7/8/69787119/press_release_arcelormittal_may_11%5Ej2022.pdf, viewed 2025-11-27.

[12] https://www.ensyn.com/uploads/6/9/7/8/69787119/production_record_for_the_port-cartier_pyrolytic_oil_plant_cbc_radio_canada_may_2024.pdf, viewed 2025-11-27.

[13] https://www.ensyn.com/quebec.html, viewed 2025-06-25.

[14] https://ostrnrcan-dostrncan.canada.ca/entities/publication/97405425-88d1-408a-b7b9-c7eb1efa43cd, viewed 2025-11-27.

[15] https://www.canada.ca/en/natural-resources-canada/news/2016/07/governments-of-canada-and-quebec-support-innovative-renewable-fuel-oil-project.html, viewed 2025-06-25.

[16] https://www.ensyn.com/canada—-vyterra.html, viewed 2025-11-27.

Project name	**Bio-crude (LCFO)**		
Scale, odt/d (odt/y)	Chips and bark	235	84,600
Revenues			
Product	Yield on wood	Price, $/t of product	Annual sales, $
LCFO	60%	933 $	$47,376,,000
Char	20%	400 $	$6,768,000
Gas	15%		$-
Sales			**$54,144,000**
Capex and Opex			
Capital	Equipment	Installation	Total
Total capital	**$-**	**$-**	**$149,301,133**

Opex per odt feed	**Units per odt feed**	**Cost per odt**	**Annual total**
Wood, odt	1	$90.00	$7,614,000
% OPEX due to wood	50%		$7,564,298
Sub-total			**$15,228,000**
Labour			$1,370,520
O&M			$2,284,200
Total opex (annual)			**$18,882,720**

Economics	
Project name	**Bio-crude (LCFO)**
EBITDA	$35,261,280
Depreciation	$7,465,057
EBIT	$27,796,223
Taxes	$8,338,867
Net revenue	$19,457,356
Inventory	$2,556,800
Capital employed	$151,857,933
ROCE	**18.30%**
Simple payback, years	**7.7**
IRR	**13.03%**

3.5. Gasification processes

3.5.1. Gasification for heat

The Canadian company Nexterra[18] produces a small, simple modular gasifier suitable for converting biomass into heat for use onsite. In Canada, industrial units have been installed at Tolko's Heffley Creek sawmill for heating the lumber kiln, and at Kruger Paper's New Westminster tissue mill for steam generation. Units were also sold to universities and other users across North America. Conversations with Tolko employees several years ago revealed that the plant made sense with natural gas prices of $15/GJ, which were current at the time of installation. Apart from the need for some form of carbon accounting, the system makes sense if both biomass supply and heat demand are in close proximity in order to minimise transport costs.

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[18] https://www.nexterra.ca/, viewed 2025-12-09.

Project name	**Gasifier for heat**		
Scale, odt/d (odt/y)	**Chips and bark**	**170**	**61,200**
Feed rate, GJ in biomass/d	3,230	37	MW feed
Production, GJ RNG/j	2,750	32	MW production
Yieldt, GJ/odt	16.18	85%	Yield on wood, GJ/GJ

Revenues			
Product	**Yield on wood**	**Price, $/GJ**	**Annual sales, $**
RNG	75%	15.00 $	$14,850,000
CO_2	10%		$-
Sales			**$14,850,000**

Capex and Opex			
Capital	Equipment	Installation	Total
Modular units		$-	$46,000,000
Total capital	**$-**	**$-**	**$46,000,000**

Opex per odt feed	**Units per odt feed**	**Cost per odt**	**Annual total**
Wood, odt	1	$90.00	$5,508,000
% OPEX due to wood	66%		$2,729,590
Sub-total			$8,345,455
Labour			$751,091
O&M			$1,251,818
Total opex (annual)			$10,348,364

Economics	
Project name	**Gasifier for heat**
EBITDA	$4,501,636
Depreciation	$2,300,000
EBIT	$2,201,636
Taxes	$660,491
Net revenue	$1,541,145
Inventory	$0
Capital employed	$46,000,000
ROCE	**4.79%**
Simple payback, years	**29.8**
IRR	**3.35%**

3.5.2. Gasification for lime kilns

Kraft mill lime kilns remain the only major user of fossil fuels on most pulp mill sites, consuming 1.5 to 2.5 GJ of natural gas per tonne of pulp or paper produced. In the 1980's, a half-dozen EU mills converted their kilns to run on gasified wood wastes, usually sawdust from a local sawmill. The last of these gasifiers, at Södra Cell's plant in Värö, was shut about 5 years ago. Today new kraft mills are again supplied with gasifiers to feed the kiln, and are common in Europe and Asia. Canadian lime kilns, however, tend to be operating well beyond design capacity and are probably not able to take the lower heating value of the syngas without significant capital investment in the kiln and associated ducting. The table below is provided to show what a typical gasifier is capable of producing; it is possible these may find uses in situations other than a pulp mill lime kiln where heat in the form of a gas is required and a solid fuel is available onsite.

Project name	**Lime kiln gas**		
Scale, odt/d (odt/y)	Chips and bark	170	61,200
Feed rate, GJ in biomass/d	3,230	37	MW feed
Production, GJ RNG/j	2,750	32	MW production
Yieldt, GJ/odt	16.18	85%	Yield on wood, GJ/GJ

Revenues

Product	Yield on wood	Price, $/GJ	Annual sales, $
RNG	75%	22.50 $	$22,275,000
Sales			**$22,275,000**

Capex and Opex

Capital	Equipment	Installation	Total
Total capital	**$-**	**$-**	**$54,000,000**
Opex per odt feed	Units per odt feed	Cost per odt	Annual total
Wood, odt	1	$90.00	$5,508,000
Sewer losses			$107,865
% OPEX due to wood	40%		$8,154,135
Sub-total			**$13,770,000**
Labour			$1,239,300
O&M			$2,065,500
Total opex (annual)			**$17,074,800**

Economics

Project name	**Lime kiln gas**
EBITDA	$5,200,200
Depreciation	$2,700,000
EBIT	$2,500,200
Taxes	$750,060
Net revenue	$1,750,140
Inventory	$0
Capital employed	$54,000,000
ROCE	4.63%
Simple payback, years	30.9
IRR	3.24%

3.5.3. Gasification for RNG or methanol

A number of pathways have been proposed for Renewable Natural Gas (RNG), i.e. a methane stream pure enough to be injected directly into a gas pipeline. As well, bio-methane can be reformed to bio-methanol; this can also be obtained directly through catalytic conversion of a syngas. This is a valuable pathway as bio-methanol will have a growing place in decarbonising marine shipping[19] and could be of interest to shipping companies on the Great Lakes. Two public studies provide a significant amount of detail on this pathway.

In 2019, the Gas Technology Institute (GTI)[20] studied the conversion of an existing wood-fired power plant in Stockton, CA to RNG production. Conversion of the existing plant, consuming 860 metric tonnes per day at 17% moisture content, was estimated to cost $US 340M (about $600M in 2025 CAD), with operating costs of $US 39.3M/y. Biomass cost was estimated at $US 30 per short ton at 17% moisture, about $CAD 53/odt. Production of RNG was estimated at 82 MMm^3/y (3.1 PJ/y) with operating costs of about $US 12/GJ. Large portions of the existing plant were to be repurposed, implying capital could be significantly higher in a greenfield situation.

Plant design was provided by Andritz and Haldor Topsøe, supported by engineering firm Black and Veatch. The unit operations and hardware were all said to be commercially available, minimising the technology risk. A Class 30 engineering study was performed, providing detailed estimates of overall process layouts, preliminary equipment specs and operating costs such as power and heat demand. At the time, a gas price of $30/GJ generated a payback period in excess of 50 years. In the table below, the gas price is increased to $35/GJ since revenues at $30/GJ do not cover operating costs once capital and operating costs have been corrected for inflation. This pathway is currently not economically feasible in the context of typical natural gas prices of about $5/GJ in Ontario, with $60/GJ needed for a reasonable return on investment.

The GoBiGas 1 project, which was Göteborg Energi's demonstration facility in Gothenburg, Sweden, yielded similar results from a commercial demonstration plant about six times smaller than the one designed for Stockton. Payback was over 60 years. That plant, which ran on and off over the period 2013 to 2018, has since been dismantled. Two scaleup studies (5X and 10X bigger) showed at best a $25/GJ breakeven price for the gas produced. Two full reports[21,22] were generated and remain useful background information, along with the Stockton report, for anyone considering this path in the future. A full evaluation sheet is not presented here but is available if desired.

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[19] https://cleantechnica.com/2026/01/07/why-shipping-is-quietly-aligning-on-methanol-hybrid-electric-systems/, viewed 2026-01-08.

[20] Gas Technology Institute, "Low carbon renewable natural gas (RNG) from wood wastes". Prepared for CARB, PG&E, SoCalGas, Northwest Natural and SMUD, February 2019.

[21] Larsson, A., Gunnarsson, I, and Tengberg, F., "The GoBiGas Project: Demonstration of the production of biomethane from biomass via gasification", Göteborg Energi.

[22] Thunman, H. (ed.), "GoBiGas demonstration – a vital step for a large-scale transition from fossil fuels to advanced biofuels and electrofuels", ISBN 978-91-88041-15-9.

Project name	**Stockton RNG**		
Scale, odt/d (odt/y)	Chips and bark	650	234,000
Feed rate, GJ in biomass/d	12,350	143	MW feed
Production, GJ RNG/d	8,291	96	MW production
Yieldt, GJ/odt	12.76	67%	Yield on wood, GJ/GJ

Revenues			
Product	Yield, GJ/odt	Price, $/GJ	Annual sales, $
RNG	12.76	35 $	$104,466,600
Sales			**$104,466,600**

Capex and Opex			
Capital	**Equipment**	**Installation**	**Total**
Total capital	$-	$-	$580,968,960
Opex per odt feed	Units per odt feed	Cost per odt	Annual total
Wood, odt	1	$90.00	$21,060,000
Opex other than wood			$35,883,377
Sub-total			**$56,943,377**
Labour			$5,124,904
O&M			$8,541,507
Total opex (annual)			**$70,609,787**

Economics	
Project name	**Stockton RNG**
EBITDA	$33,856,813
Depreciation	$29,048,448
EBIT	$4,808,365
Taxes	$1,442,509
Net revenue	$3,365,855
Inventory	$0
Capital employed	$580,968,960
ROCE	**0.83%**
Simple payback, years	**172.6**
IRR	**0.58%**

3.5.4. Pathways to Sustainable Aviation Fuel

Gasoline and diesel fuel consume ~70% of a barrel of oil. Jet fuel represents 2% of the barrel and is the only transportation fuel for which no electrification option is presently available. Large amounts of so-called Sustainable Aviation Fuels (SAF) will therefore be needed through to 2050.

Multiple pathways to SAF have been approved by ASTM[23, 24], but only the so-called HEFA pathway is commercial. Based on oil-based crops and restaurant residues, HEFA is not relevant to forestry.

Alcohol to jet: Two ASTM-approved fuels start with sugar and are certified for 50% substitution: ASTM D7566, Annexes A3 and A5. Annex A8 fuels are not yet certified.

These pathways start with an alcohol such as ethanol. Large numbers of US-based corn ethanol plants are pivoting to SAF in anticipation of declining demand for fuel ethanol as the vehicle fleet is electrified. Lanzajet[25] inaugurated an alcohol-to-jet plant in Georgia, identified as TRL 8, in 2024[26]. The plant was deemed fully operational[27] in November 2025.

Wood-based pathways to alcohols are very expensive, due to the low yields on wood and the "recalcitrance" of lignin faced with enzymatic breakdown. Hardwood is easier to convert, but economics remain very difficult unless the end-user is particularly concerned about the food-versus-fuel debate and is prepared to pay for a more expensive product. Policy support is essential.

Coprocessing of bio-crudes with petroleum crudes is approved under ASTM D1655, Annex A1, with a blend limit of 5%. This involves supplying a liquid biofuel, such as made by Ensyn or Licella, to a petroleum refinery. This approach may lead to a broader market than the relatively small SAF market, as the 5% dilution rate implies all products from the refinery are 5% bio-based.

Gasification and synthesis pathways: These processes convert almost any carbon-containing material into a synthetic hydrocarbon via the so-called Fischer-Tropsch (FT) synthesis pathway. Two such pathways are certified under ASTM D7566. Annex A1 describes a straight paraffinic jet fuel (so-called SPK), while Annex A4 is a path that includes additional aromatic molecules (SAK). Blend ratio in both cases is limited to 50%.

As shown in the section on the Stockton RNG project, biomass gasification and synthesis is a complex and expensive process. Gasification processes were originally designed to run on coal in the 1920's, but biomass is a more challenging feedstock. Recent activity in the field is described next.

ThyssenKrupp has100 years experience building gasifiers, mainly coal-fired, and its partners IFPEN and AXENS have associated gas cleanup and synthesis technologies such as the Fischer-Tropsch process. The BioTfueL process[28] was a joint project started in 2010 with TotalEnergies[29] and other French firms at the Total refinery in Dunkirk. The scale of this pilot project, which was intended to derisk the technology, has not been disclosed publicly. The pilot gasifier was running in May 2019[30]. Spending reported at that time was of the order of €200M, including €33M in government support.

More recently, Elyse Energy[31] has announced an SAF plant in Lacq, France, based on the BioTfueL platform. Renamed BioTJet, the project aims for commercial operation in 2029. Several of the partners in the earlier phase, including ThyssenKrupp and AXENS, are involved. The project is at the engineering stage.

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[23] https://www.icao.int/environmental-protection/GFAAF/Pages/conversion-processes.aspx, viewed 2025-07-09.

[24] https://www.icao.int/sites/default/files/environmental-protection/Documents/ICAO_EU_II/Session-3-SAF-technical-certification.pdf, viewed 2026-02-28.

[25] https://www.lanzajet.com/freedom-pines, viewed 2026-02-27.

[26] https://www.energy.gov/eere/bioenergy/articles/first-ethanol-alcohol-jet-sustainable-aviation-fuel-production-facility, viewed 2025-08-16.

[27] https://ir.lanzatech.com/news-releases/news-release-details/worlds-first-commercial-ethanol-jet-fuel-plant-operational, viewed 3036-03-02.

[28] Radtke, K., "Syngas Technologies at ThyssenKrupp: from Biomass to Jet fuel to Propane to Acrylonitrile", 2017 Syngas Technologies Conference, Colorado Springs, CO. October 15-18, 2017. https://www.globalsyngas.org/uploads/downloads/S3-1-Thyssenkrupp-%20KarstenRadtke.pdf, viewed 2019-08-07.

[29] https://www.total.com/en/energy-expertise/projects/bioenergies/biotfuel-converting-plant-wastes-into-fuel, viewed 2019-08-07.

[30] https://www.ifpenergiesnouvelles.fr/article/demarrage-gazeification-site-bionext-dunkerque, viewed 2019-08-07.

[31] https://elyse.energy/en/our-projects/biotjet, viewed 2026-03-08.

Various press releases reveal estimated capital costs of €1B (about $1.6B), and wood consumption of 300,000 to 350,000 odmt/y. Classic FT mass balances imply production of 45,000 to 54,000 t/y, but AXENS claims a novel process improvement to boost this to 75,000 t/y. All this requires 32,000 t/y of green hydrogen at a cost of 230 MW green power.

Byproducts include a diesel fraction and some residual naphtha.

There is at the moment insufficient public data on the new process to believe that the economics will be much better than Stockton, although the yield improvement claimed by Axens could improve this picture. Typical pricing of $3500/t for SAF works out to about $65/GJ or $2.50 per litre, showing the level of price per energy unit required.

Many developers are proposing FT-based SAF plants. In the US, Pathway Energy is planning an FT-based SAF plant in Port Arthur, Texas[32]. Pathway Energy is also proposing pairing the Port Arthur plant with a biomass-fired power plant with carbon capture and storage (BECCS). Easy access to an aquifer capable of taking and storing CO_2 is an advantage here. Both pathways, SAF and BECCS, depend on the continuing willingness of the market to pay for carbon credits of one type or another.

3.5.5. Chinese approaches to gasification of biomass

A recent LinkedIn post[33] reported the following:

“CIMC Enric officially launched its 50 kt/y bio-methanol plant in Guangdong today. This is the second industrial-scale bio-methanol facility based on biomass gasification to begin operations in China this year.”

“The start-up of such first-of-a-kind facilities is a crucial step in scaling up the renewable methanol industry and enabling its wider deployment in the maritime, aviation, and chemical sectors. More than 27 million tons of renewable methanol projects are in active development in China, including about 3 Mt under construction, showcasing the scalability of different technological pathways. These include biomass gasification with or without hydrogen boosting, power-to-methanol, and biomethane reforming. This progress also demonstrates the potential for project development in other regions based on locally available feedstocks.”

This can be understood in terms of Chinese policies focused on guaranteeing security of supply over the long term, by using, as the post says, locally available feedstocks. It is not likely that the technologies are any cheaper than those described above; political and security of supply concerns override pure economics.

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[32] https://pathwayenergy.com/project-page/, viewed 2026-02-28.

[33] Protasov, Vitalii, CEO, GENA Solutions Oy (Green Energy Analytics), on LinkedIn. https://www.linkedin.com/feed/update/urn:li:activity:7406701446127169536/, viewed 2025-12-28.

3.5.6. Scenarios for preprocessing biomass

A preprocessing facility collects raw biomass (often at 50% moisture content), dries and concentrates it, and ships the resulting material to a large, centralised processing plant. This could be a gasifier, an existing petroleum refinery for co-processing, etc. Thus, the large central plant receives material from multiple satellite plants located closer to the biomass source.

A pellet mill, which reduces the mass of water to be shipped from about 50% to approximately 5%, is one such approach providing a useful reduction in tonnes-kilometers, at a small cost in yield loss. A second approach involves small-scale pyrolysis or bio-char plants where the yield loss is higher (potentially 30% or more), with a similar reduction in moisture content.

The BioPathways process identified the upper limit on scale for such a facility as the amount of residual material available at a sawmill site, as this eliminates the need to bring in more wet and bulky material from the forest.

Gasifiers and pyrolysis plants can consume oxygenated fuels such as pellets or bio-oil. Petroleum refineries, however, need to be adapted to take any kind of volume of oxygenated feed material. The PREEM refinery in Gothenburg, Sweden, apparently has this ability, and the Parkland refinery in Burnaby, BC, is currently being adapted.

The example of an Ontario petroleum refinery operating at 100,000 bbl/d, with the ability to dilute the crude oil feed with up to 5% liquid oxygenated fuel from scattered pyrolysis plants is instructive. Assuming a conservative feed of 3,000 bbl/d pyrolysis oil feed (3% dilution rate), this requires a total of about 477,000 litres per day (175 million litres per year). Four to five plants of the scale of Port-Cartier's installation (235 odt/d, 40 million litres per year) would meet this demand.

3.6. Lignin: pathways and products

As Nature's only aromatic molecule, lignin provides the only major bio-based opportunity to substitute for the benzene, toluene and xylene trio in the production of a range of intermediate chemicals such as phenols, urethanes and others. Several different types of lignin are available from a range of different processes.

Kraft lignin can be obtained from a kraft mill by precipitation from black liquor. The original patents were obtained by the Tomlinsons, Sr. and Jr., in the 1950's. The process was implemented at the Howard Smith pulp mill (later Domtar) in Cornwall, ON. Removing lignin can lead to increased mill production if the recovery boiler is a bottleneck to production, as it was in Cornwall. Lignin from the Cornwall mill was used as a binder in kitchen countertops made by the Arborite process from about 1955 to 1965, when the installation of a new recovery boiler required all available lignin and eliminated the need for the lignin extraction plant. Several other product pathways were investigated at the time.

The former MeadWestVaco pulp mill in Charleston, S.C. featured a lignin extraction plant in order to debottleneck the mill, with lignin sold on specialty markets. The lignin plant was spun off into a stand-alone specialty chemical company called Ingevity, which is still in business. The pulp mill was shuttered some time ago due to technological age; Ingevity continues to source lignin elsewhere to supply its clients.

A new generation of lignin plants were built in the 2000's, starting with the Domtar installation in Plymouth, N.C. This is still in operation and all product is sold to UPM, who markets a range of lignin-based products such as resins in the EU. The Plymouth lignin plant was provided by Valmet, who also provided a lignin plant to Stora Enso's Sunila mill in Eastern Finland. The Sunila mill, however, was shut when the Russian border with Finland was closed to wood imports.

In Canada, the LignoForce process was developed by FPInnovations and NORAM, partly with funding from CRIBE, and was implemented at the West Fraser mill in Hinton, AB. The plant ran well once fully started up, but was shuttered when the Hinton mill was sold to a buyer with a need for the space where the lignin plant was installed.

Today there is one large-scale kraft lignin plant running, the Domtar unit in Plymouth, N.C. Södra Cell has announced a new lignin plant at its Mönsterås pulp mill in Sweden. Probable capacity will be 110,000 t/y, enough to make up for all the recent shuts. Based on a new process design provided by Andritz, a large portion of the output is presold to Stora Enso and UPM.

Kraft lignins are characterised by low sulfur and ash content, with lignin purity levels exceeding 95% in most extraction processes. Large-scale lignin product development is ongoing in the EU, targeting higher-value products beyond simple substitution for phenolic resins in glues for plywood or other engineered wood products.

Kraft lignin processes are thus commercial at the TRL 9 level. Product sales, while small on the scale of the mill, are more than sufficient to justify the capital and operating costs, and the economics are further enhanced if additional saleable kraft pulp can be made by debottlenecking the recovery boiler.

Sulfonated lignins are generated in sulfite pulp mills. The major producers are Rayonier, Sappi, Domsjö Fabriker and Borregaard; the sulfur content and the fact these are water soluble mean they address a different set of products than kraft lignin. World production is about a million tonnes per year and is not likely to grow due to lack of demand for sulfite pulps. If specific lignosulfonate properties are required, it is possible to sulfonate a kraft lignin.

The **Organosolv pulping process** generates a sulfur-free lignin stream. In Canada the AlCell process was trialed at the Miramichi (NB) pulp mill operated by Repap. The mill was operated at full commercial scale for several years but ultimately was shuttered due to difficulties recovering the ethanol-based solvent, and due to poor quality of the resulting pulp. An Organosolv pathway could potentially be made to work in a biorefinery context if the cellulose is diverted to biorefinery uses rather than trying to compete with kraft pulp; the solvent recovery issues can likely be addressed through the appropriate engineering approaches.

Ionic liquids are a new pulping technology meant to generate a cleaner lignin stream than from the conventional kraft process. Advantages are said to be lignins and cellulose streams with no sulfur; disadvantages are the expense of the solvents and, as with the AlCell process, the challenges in recovering them. These pathways are at a lower TRL than kraft or lignin or lignosulfonates as no commercial plants have been built yet. Companies active in the field include Lixea, which operates a demonstration plant at Bäckhammar, Sweden.

So-called **biorefinery lignins** arise from typical biomass to sugars pathways as in UPM's Leuna installation. Similarly, Fibenol uses a mechanical grinding process followed by enzymatic hydrolysis; the company is approaching the commercial demonstration stage. See the Section on Sugar-based Platforms for Chemicals, below, for more information.

A range of other pathways are being evaluated at scales ranging from laboratory benchtop to pilot level. CH-Bioforce, for example, appears to have developed a hot water extraction process[34]. A full listing would quickly be obsolete.

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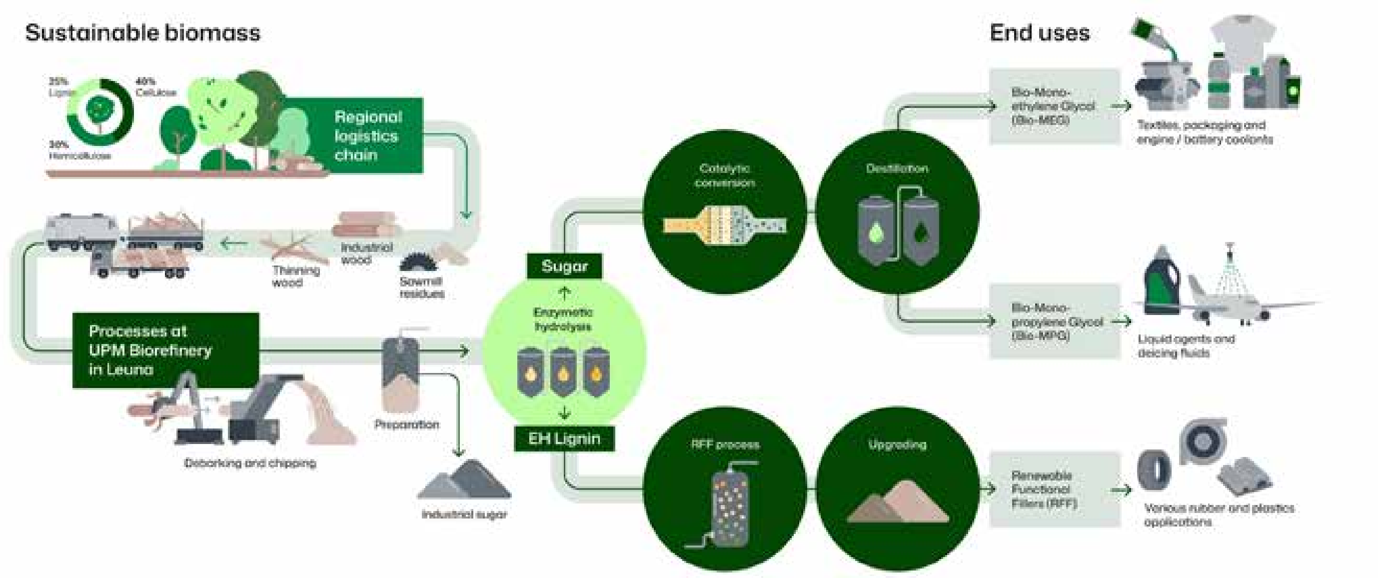
[34] https://patents.google.com/patent/CA2878519A1/en, viewed 2026-02-23.

3.7. Sugar-based platforms for chemicals

Since the release of the US DOE report of 2004[35], a large number of paths to products from cellulose (via glucose) or hemicellulose (via xylose) have been described[36, 37, 38, 39, 40, 41]. Products include substitutes for a wide range of petrochemicals, both molecularly identical and novel, functionally similar molecules. Many pathways are in development and approaching commercialisation at large scales, many involving fermentation or catalytic processes. This section will describe the facility under construction by Finnish company UPM at the petrochemical park in Leuna, Germany, based on publicly available information.



Overview of the UPM Biorefinery in Leuna[42]

This facility is located on the site of a petrochemical park in Leuna, Germany. Among the advantages are easy access to green hydrogen from a local supplier, heat and power generated from burning bark and other sawmill residues, and proximity to clients in the petrochemical space. The Bio-Amber facility in Sarnia's Lanxess Bio-industrial Park, now operated by LCY Biosciences, was built on this premise[43].

The Leuna project, illustrated above, likely consists of an acid hydrolysis process to remove hemicellulose (labelled "Industrial Sugars" in the image), followed by an enzymatic process to separate cellulose and convert it to glucose. Glucose is then converted to monoethylene glycol (MEG) and monopropylene glycol (MPG) in a catalytic step followed by distillation. MEG and MPG are petroleum-based platform chemicals. The conversion of glucose to glycols requires additional hydrogen, obtained from a green hydrogen facility adjacent to the Leuna petrochemical park. The lignin will be used as a functional filler for tires, with Nokian identified as a buyer[44]. Revenues from the industrial sugars arising

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[35] Werpy, T. et al., "Top Value Added Chemicals From Biomass, Volume I: Results of Screening for Potential Candidates from Sugars and Synthesis Gas", PNNL, August 2004. http://www.nrel.gov/docs/fy04osti/35523.pdf

[36] Bozell, J.J and G.R. Petersen, "Technology development for the production of biobased products from biorefinery carbohydrates—the US Department of Energy's "Top 10" revisited", GreenChem 12:539, 2009. doi:10.1039/b922014c

[37] E4Tech, RE-CORD and WUR, "From the Sugar Platform to biofuels and biochemicals: Final report for the European Commission Directorate-General Energy", ENER/C2/423-2012/SI2.673791, April 2015.

[38] Biddy, M.J., C. Scarlata C. Kinchin, "Chemicals from Biomass: A Market Assessment of Bioproducts with Near-Term Potential", NREL/TP-5100-65509, March 2016.

[39] Alam, M.I. et al, "Biological Routes for the Synthesis of Platform Chemicals from Biomass Feedstocks", In V.C. Kalia (ed.), Microbial Applications Vol.2, 2017. DOI 10.1007/978-3-319-52669-0_8.

[40] De Jong, E. et al., "Bio-Based Chemicals A 2020 Update". IEA, February 2020. ISBN 978-1-910154-69-4. https://www.ieabioenergy.com/wp-content/uploads/2020/02/Bio-based-chemicals-a-2020-update-final-200213.pdf

[41] Skoczinski, P. et al., "Bio-based Building Blocks and Polymers – Global Capacities, Production and Trends 2024–2029. nova-Institut GmbH (Ed.), Hürth, Germany. https://doi.org/10.52548/UMTR4695, March 2025. ($)

[42] https://www.upmbiochemicals.com/siteassets/images/infographics/upm-1920x1080_en_210728-2.pdf, viewed 2026-04-01.

[43] LCY Biosciences announced in 2023 that they were pivoting away from succinic acid, a plastics precursor, to animal feed and human nutrition. https://www.theobserver.ca/news/local-news/sarnia-bio-chemical-plant-lays-off-30-workers-and-switches-production, viewed 2026-03-30.

[44] https://www.upmbiochemicals.com/about-upm-biochemicals/news-and-stories/2024/06/upm-and-nokian-tyres-partner-to-revolutionize-the-tire-in-

from hemicellulose extraction at the beginning of the process are not mentioned. Feed is beech wood from local forests; it is unlikely that this will run well on softwood.

A recent press release documents the start up of the acid, and possibly also the enzymatic hydrolysis stage[45]. As of writing, production is said to have started, with full production by mid-2026.

Unlike many projects described here, cost overruns and delays were described in a number of press releases. The Tables below outline results using the latest capital estimates.

A key part of this estimate is the yields of MEG, MPG, lignin substitute for carbon black and industrial sugars. A range of references were used to build a basic mass balance for the components of beech wood as they are processed via autohydrolysis (for removal of hemicellulose), enzymatic hydrolysis (for conversion of cellulose to glucose and lignin separation)[46], catalytic conversion of glucose to MEG and MPG[47], and hydrothermal carbonisation of the lignin-carbohydrate complex (consisting of all lignin plus residual cellulose and hemicellulose) to a carbon black substitute[48]. No losses are assumed in the distillation process separating MEG from MPG. The actual numbers may be somewhat different, but the estimates here are probably not unreasonable; most references provide a range of yields and the values used in the mass balance were roughly the middle of those ranges. Higher yields would, of course, require less wood for a production rate of 220,000 t/y and would improve the economic analysis.

UPM 2025: conversions		
Production, t/y	220,000	Press release
Capital (millions euro 2024)	€ 1,335	Press release
Capital (millions euro 2025)	€ 1,371	
Yield on wood (estimated)	76%	Estimated
Capital, 2025 $MCAD	$2,181	Calculated
Wood consumption, odt/y	289,137	Estimated

Yield losses are estimated to be due partly to extractives (about 3% on wood), hydrolysis losses (4%), catalytic process losses (10%) and losses in the thermal carbonisation process meant to increase the carbon content of lignin by reducing oxygen content (8%). So a 76% yield on wood, while low compared to kraft pulp, is probably a conservative estimate; more optimistic numbers can be found which imply overall yields could approach 80%.

A hypothetical installation in Ontario, with typical Canadian wood costs, is presented next.

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dustry-by-introducing-the-first-concept-tire-with-upm-biomotion-renewable-functional-fillers/, viewed 2025-11-27.

[45] https://www.upmbiochemicals.com/about-upm-biochemicals/news-and-stories/2025/12/upm-unlocks-new-bio-based-markets-as-leuna-biorefinery-produces-its-first-commercial-product/, viewed 2025-12-30.

[46] Himmel, M. E. et al., (2007). Biomass recalcitrance: Engineering plants and enzymes for biofuels production. Science, 315(5813), 804–807. https://doi.org/10.1126/science.1137016. https://pubmed.ncbi.nlm.nih.gov/17289988/, viewed 2026-01-27.

[47] Ji, N., et al. (2008). “Direct catalytic conversion of cellulose into ethylene glycol using nickel-promoted tungsten carbide catalysts.” Angewandte Chemie International Edition.

[48] Lahtinen, M. et al., “A tyre comprising hydrothermally carbonised lignin”, EU Patent Application EP 3 243 877 A1, published 2017-11-15. https://patents.google.com/patent/EP3243877A1/en, viewed 2026-01-12.

Project name	**Leuna 2025 Actual**		
Scale, odt/d (odt/y)	**HW roundwood or chips**	**803**	**289,137**

Revenues			
Product	**Estimated production, t/y**	**Price, $/t of product**	**Annual sales, $**
MEG	81,772	$1,071	$87,574,276
MPG	15,096	$1,881	$28,394,451
Lignin for Carbon black	68,485	$2,341	$160,355,512
Industrial sugars	54,647	$749	$40,948,507
Sewer and other losses	24%		
Sales			**$317,272,745**

Capex and Opex			
Capital	**Equipment**	**Installation**	**Total**
Total capital	**$-**	**$-**	**$2,181,455,847**

Opex per odt feed	**Units per odt feed**	**Cost per odt**	**Annual total**
Wood, odt	1	$120.00	$34,696,440
% OPEX due to wood	40%		$51,232,301
Sub-total			**$86,741,100**
Labour			$7,806,699
O&M			$13,011,165
Total opex (annual)			**$107,558,964**

Economics	
Project name	**Leuna 2025 Actual**
EBITDA	$209,713,781
Depreciation	$109,072,792
EBIT	$100,640,989
Taxes	$30,192,297
Net revenue	$70,448,692
Inventory	$14,982,324
Capital employed	$2,196,438,171
ROCE	**4.58%**
Simple payback, years	**31.0**
IRR	**3.23%**

Profitability at a capital cost of $2.2B is poor. UPM took an impairment of close to €400M on this project in a recent Annual Report; the impairment plus the original estimate of €550M works out to about 1 billion euros, probably a reasonable estimate (in 2024 currency) of the capital the company expects for capex for plant Serial #002. Assuming capital of €1B ($1,634M in 2025) for the next plant serial #002, assuming operating costs other than wood can also be reduced by 20%, and assuming overall yield on wood improves to 79%, payback decreases to 20 years with a ROCE of 7%.

The company's stated target is a ROCE of 14%; it is possible that the numbers presented here, in particular sales prices, are excessively pessimistic. Average price per tonne of product on spot markets is $1440/t. In a world where phenolic resins can retail for $1500 or $2000 per tonne, this may indeed be low. Anecdotal "Green Premium" pricing available from EU customers in long-term contracts for some of these products can easily lead to a ROCE approaching 14% and an average product price over $1600/t, not an unreasonable price for typical intermediate petrochemicals in 1 to 10 million tonne per year markets.

Revenues per tonne of feedstock work out to $1097/t, $1250/t in the Green Premium scenario.

Economics

Project name	**Leuna Serial #2**
EBITDA	$197,762,785
Depreciation	$81,702,466
EBIT	$116,060,319
Taxes	$34,818,096
Net revenue	$81,242,223
Inventory	$14,982,324
Capital employed	$1,649,031,648
ROCE	**7.04%**
Simple payback, years	**20.1**
IRR	**4.97%**

3.8. Hydrothermal Liquefaction (HTL) and Carbonisation (HTC)

Australian company Licella, a proponent of HTL technologies, has recently bought out its share in the Arbios JV with Canfor Pulp in Prince George, BC. No immediate reasons for the split are available. But recent press releases describe the takeover of Canfor Pulp by the solid wood company Canfor, with one of the reasons given being the financial challenges Canfor Pulp is facing; it is possible that Canfor Pulp was no longer willing or able to meet its commitments to the JV.

Advantages of these technologies include the ability to use wet wood, where pyrolysis and gasification processes require a dryer. The output of HTL is an oil that can be co-refined in a petrochemical refinery or converted to sustainable aviation fuel. Capital costs are likely large.

3.9. Carbon Capture

Carbon capture, use and/or sequestration (CCUS) has recently attracted a lot of attention.

Regulatory opportunities for generating and selling carbon credits are growing, and a number of large high-tech companies are considering CCS plants to recover and sequester biogenic CO_2 associated with pulp mill operations. Canadian firm CO280 claims paybacks of the order of two years, even for multi-billion-dollar capital investments, due to sales of credits. While not a novel "product", this has the opportunity of converting a pulp mill into a CO_2 producer, with kraft pulp a side-product. Issues will be how to sequester the CO_2; proximity to the right geology and/or an existing CO_2 pipeline would be critical, and it is possible these applications won't work easily in Northern Ontario.

The following table illustrates the challenges in building a biomass-fired power plant, with a CCS plant on the stack, in North-Western Ontario. As the carbon comes from biomass, it is more valuable than carbon sequestered from a fossil combustion source. The numbers are as optimistic as possible, given the fact that the compressed CO_2 needs to be sent by rail car to Brandon, MB, which is the nearest geological formation compatible with underground storage. Operating and especially shipping costs for about 550 km would need to be evaluated very carefully; shipping here is given as $50 per tonne but much larger numbers have been presented publicly elsewhere[49].

Biogenic carbon captured from pulp mill boiler flues and, especially, line kilns, has some potential to generate future large revenues even if the CO_2 is not sequestered. The EU envisages captured CO_2 serving as a feedstock for the petrochemical industry, as petroleum-based naphtha and natural gas liquids become harder to source. As with the example above, if the flue gasses are biogenic, there is an added benefit. See the section below on the EU policy landscape.

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[49] Roberts, D., "Carbon Capture & Storage on Pulp, Paper & Biopower Platforms: What are investors looking for in these projects?", BioFor 2026, Montreal, February 10-13, 2026.

Project name	**BECCS, carbon shipped to Brandon**		
Scale, odt/d (odt/y)	**Chips or bark**	**250**	**262,000**

Revenues

Product	**MWh or t CDR**	**Price, $/MWh or $/t CDR**	**Annual sales, $**
Power 36 MWe	311,040	180 $	$55,987,200
CDR credits	425,000	170 $	$72,250,000
Sales			**$128,237,200**

Capex and Opex

Capital	Equipment	Installation	Total
Total capital			**$350,000,000**

Opex per odt feed	Units per odt feed	Cost per odt	Annual total
Wood, odt	1	$60.00	$15,720,000
Non-wood opex		$-	$20,000,000
Rail N.W. ON to Brandon		$50.00	$21,250,000
Sub-total			**$56,970,000**
Labour			$5,127,300
O&M			$8,545,500
Total opex (annual)			**$70,642,800**

Economics

Project name	**BECCS, carbon shipped to Brandon**
EBITDA	$57,594,400
Depreciation	$17,500,000
EBIT	$40,094,400
Taxes	$12,028,320
Net revenue	$28,066,080
Inventory	$6,055,646
Capital employed	$356,055,646
ROCE	**11.26%**
Simple payback, years	**12.5**
IRR	**8.02%**

3.10. Other novel technologies

There are always startup firms offering novel pathways, but most tend, on closer inspection, to fall back into one or another of the basic pathways outlined above. A few exceptions follow.

3.10.1. Expander Energy

Calgary-based Expander Energy is an active player in synthetic fuels for some time and is proposing a "bio-synfuel facility that uses technology developed in tandem by Canadian Nuclear Laboratories and Expander known as biomass electrolysis to liquids, or BETL."[50]. An agreement has been signed with East Fraser Fibre for 84,000 odt/y of forestry wood waste, which is claimed to make 30 million litres of renewable diesel, renewable naphtha, and bio-wax. The yield and product mix is reminiscent of Fischer-Tropsch synthesis pathways. No other information is available at this time.

3.10.2. Small-scale heat and power

The pulp and paper industry operates boiler-based cogeneration systems, providing heat to the mill and power to both the mill and the grid. But these systems are large, complex and require licensed steam plant operators in attendance 24/7. This expertise is costly; and in the absence of a pulp mill as host, the amount of heat generated quickly exceeds the needs of small-scale local users.

Cities in the Nordic countries of Europe are frequently heated via a centralised district heating plant, which often supplies electricity to the grid as well. While often operated on woody biomass and frequently located on the site of a pulp mill, this utility is often a separate corporate entity from the pulp mill, and sells heat and power to the mill as well as the town. While Canadian mills frequently sell power into the grid, the rare cases of heat sales involve a small number of large-scale heat users such as institutional or light industrial clients.

Organic Rankine Cycle systems, which do not require the presence of a full-time steam plant operator, are in use in Canada at small scales. West Fraser installed two such units, of 6.5 MW each, at each of their sawmills in Chetwynd and Fraser Lake[51, 52] for a total of 4 units and 26 MW. Waste wood is used to make power for the grid under a long-term power purchase agreement. A range of companies offer smaller units, with or without the ORC component, frequently designed to fit inside a standard shipping container, for off-grid heat and power projects such as in First Nations townsites or mining camps.

Nonetheless small-scale bio-based heat and power projects have been proposed for Northern Ontario. The following tables describe one such proposal, where the plant comprises a fluidised bed boiler and condensing turbine[53]. The exact heat to power ratio will vary with the season; the example shown may not be applicable on a yearly average basis.

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[50] https://www.gasworld.com/story/expander-energy-secures-feedstock-and-land-for-canada-biofuel-project/2169254.article/, viewed 2025-12-09.

[51] https://www.cleanenergyconsulting.ca/uploads/files/brochures/CEC-ProjectProfile_ORC-w.pdf, viewed 2026-01-08.

[52] https://www.turboden.com/case-histories/1449/west-fraser-mills, viewed 2026-01-08.

[53] Browne, T.C. (tech. ed.), "Energy cost reduction in the pulp and paper industry", Montreal, Paprican, 1999. See specifically Figures 9.3 and 9.4.

Project name	Small-scale CHP for DES		
Scale, odt/d (odt/y)	Chips and bark	417	150,000
Revenues (condensing, some steam)			
Product	**Yield on wood, MW**	**Price, $/MWh or $/GJ**	**Annual sales, $**
Power, MWe ($/MWh)	22.91	250 $	$49,479,167
			$-
Sewer losses			
Sales			**$60,879,167**
Capex and Opex			
Capital	**Equipment**	**Installation**	**Total**
Boiler and power genset			$200,000,000
Total capital	$200,000,000	$-	$200,000,000
Opex per odt feed	Units per odt feed	Cost per odt	Annual total
Wood, odt	1	$150.00	$7,500,000
% OPEX due to wood	70%		$3,214,286
Sub-total			**$10,714,286**
Labour			$964,286
O&M			$1,607,143
Total opex (annual)			**$13,285,714**

Economics	
Project name	**Small-scale CHP for DES**
EBITDA	$47,593,452
Depreciation	$10,000,000
EBIT	$37,593,452
Taxes	$11,278,036
Net revenue	$26,315,417
Inventory	
Capital employed	$200,000,000
ROCE	**18.80%**
Simple payback, years	**7.6**
IRR	**13.16%**

3.10.3. Wood insulation

Wood fibre insulation is a building product that can be made from a variety of residual material such as chips, sawdust and shavings. One report states[54] that "using representative building typologies, the study estimates that if wood fibre insulation were adopted in 30% of new housing construction, annual demand in Ontario could reach approximately 230,000 metric tonnes of insulation products, requiring roughly 415,000 metric tonnes of green raw wood fibre each year. This level of demand could support two to three mid-sized manufacturing plants and generate hundreds of millions of dollars in annual product value and industrial investment."

A single family home of 1800 square feet could use up to 3.6 tonnes of wood fibre insulation. A multi-unit residential building, consisting of 60 units totalling 63,000 square feet, would need 93 tonnes of insulation. The demand for this is driven by existing housing shortages and could amount to demand of about 230,000 odt/y if 30% of the projected new housing demand in Ontario used this technology.

More information is provided in the report referenced, which will not be repeated here.

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[54] "Wood Fibre Insulation in Ontario: A Roadmap for Market Growth and Adoption", Studio VMA, March 2026.

4. World markets for bio-chemicals

One constant refrain in Canada is finding new export markets for our products. The traditional approach would be to increase lumber and pulp exports, but these markets are well known and already well supplied by others, and new Canadian products will face stiff competition from current players, not to mention new regulatory hurdles and new market requirements for product specifications and performance. But the world market for bio-chemicals and biomaterials, driven by billions of euros in EU government and industrial investments, is predicted to grow rapidly in the coming decades, leaving lots of room for a newcomer who gets in early and signs up some customers.

In that context, one of the authors of this report attended the Third edition of Nova Institute's Renewable Materials Conference, held September 22-24 in Siegburg, Germany. The conference attracted over 400 people from around the world. Large petrochemical firms and brand owners such as Lego were well represented along with the usual R&D and start-up communities, giving the presentations a real-world industrial slant. With a few notable exceptions, the forest sector was not well represented.

4.1. EU policy landscape: impact on biochemicals

Much EU policy centers around the concept of circularity. EU political and business leaders agree that petroleum as a raw material for plastics and chemicals will need to be replaced. For governments, the driver is emissions; for industry it is security of supply. If gasoline and diesel demand disappear due to increasing adoption of EVs, the availability of naphtha, representing about 5% of the barrel, becomes uncertain; the same may eventually be true of natural gas liquids. (Closures of two refineries in California[55], due to declining gasoline demand, are instructive. Note also that these both run on heavy crudes, possibly from a mix of Venezuelan[56] and Canadian sources.)

"Sustainable" or "Renewable" carbon is defined as carbon that avoids or replaces the need to extract additional fossil-based carbon, i.e. renewable carbon is carbon that is already on hand. Three pathways have been identified to 2050:

- Recycling of existing plastics (replacing 70% of demand by 2050, 750 Mt/y);
- CO_2 capture and use for new chemicals (20%, 300 Mt/y); and
- Bio-based products (10%, 150 Mt/y), serving as makeup for recycling losses.

In order to attract investment, comments made by presenters and other attendees in informal conversation all pointed to the need for well-designed international standards for ensuring and reporting renewable content in plastics and materials, in a trustworthy and transparent way. An LCA-based method, using a mass-balance and allocation approach for tracking chain of custody, will be needed for tracking sustainable carbon separately from fossil-based carbon. In effect, it will be necessary to incent low-carbon intensity chemicals and materials, just as low-carbon intensity fuels are incented today.

Most importantly, policy needs to be focused, stable and in place for extended time frames, accompanied by focused, stable and long-term funding commitments shared by government and industry to support innovation and scaleup. Incentives need to be devised to encourage both producers and users of renewable materials. A new EU strategy on the coming bioeconomy is in preparation for release in November 2025, and new sustainability criteria for bioplastics by 2027. To attract international investment, or for Canadian firms to sell into international markets, Canada's policy landscape may need to change or adapt in order to be consistent with the EU approach.

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[55] https://www.nytimes.com/2025/09/16/business/energy-environment/california-gas-prices-oil-refineries.html, viewed 2025-09-24). Further reporting (2025-11-20): Valerio Benicia will shut in April 2026 (https://www.eenews.net/articles/valero-exec-nothing-has-materialized-to-stave-off-calif-refinery-closure/); Phillips 66 L.A. refinery to shut (https://www.reuters.com/business/energy/california-refinery-closures-spark-pipeline-race-west-coast-2025-11-18/)

[56] Note this section was written prior to recent US actions in Venezuela.

4.2. EU Markets for biochemicals

In a presentation at the NOVA conference[57], Doris de Guzman of Green D Analytics outlined Renewable Chemicals Markets. The key driver is uncertainty of supply of petroleum and natural gas byproducts currently used in the manufacture of plastics and other petrochemicals. This extends beyond the EU to Japan, Korea and elsewhere in Asia. Additionally, policy drivers beyond the EU are in place or coming in China, India, Thailand, Vietnam and the Middle East[58].

In the EU, consortiums of industries and governments are investing heavily and moving beyond the pilot/demo "Valley of Death" to commercial demonstration levels. Renewable hydrocarbons (such as for sustainable aviation fuel) and monomers (the BTX family and a range of sugar-based substitutes for ethylene, propylene and butylene pathways) are all moving ahead rapidly. Much of this is currently driven by an increased push on recycling, but it is worth keeping in mind that the 10% bio-based target adds up to a market size of 150 Mt/y, closing in on the scale of world markets for cellulosic fibres (300 to 400 Mt/y) and synthetic fibres (124 Mt/y in 2023). As the current rate of substitution by biomass-based molecules is well under 1%, and the potential CAGR is 20%, there is lots of room to grow.

In a conference presentation, UPM, which also had a booth, described the biorefinery at Leuna, Germany. This process was described earlier in this report. In conversation over coffee, the Managing Director at Leuna asked about the potential of a plant at Sarnia with shipping to Asia via Prince Rupert; this would be cheaper, he felt, than Leuna to Asia via Rotterdam. This comment was unprompted and shows they have been thinking about locations for Plant Serial #002 in the face of substantial wood shortages in the Nordic countries.

Separately a presentation by personnel from Södra Cell discussed their plan to build "the world's biggest lignin plant", but provided little information beyond what is already known: that UPM and Stora Enso have contracted to buy large amounts of the anticipated production, and that Södra does not intend to develop its own lignin-based products. Capacity is rumored to be 110 kt/y from the 750 kT/y pulp mill at Mönsterås, Sweden; equivalent scale for a typical 1000 t/d (360 kT/y) Canadian pulp mill would be closer to 50 kT/y. Startup is predicted for 2027. The implications are that both Stora Enso and UPM see a rapidly growing market for kraft lignin, especially in light of recent closures of lignin plants at Charleston (SC), Hinton (AB) and Sunila (FIN).

4.3. Implications for the Ontario forest sector

Ontario's current excess wood supply neatly offsets the current shortage of wood in the Nordic countries. The coming demand, for 150 Mt/y of biochemicals by 2050, is one that should be carefully evaluated in light of the potential benefits over the medium to long term. At a yield of 75% on wood, this represents 200 Modt/y of biomass, or of the order of 400 million cubic metres; this market significantly more wood than is available in Ontario. But time is of the essence, as getting the first plant built will take 5 to 10 years. Delaying until 2035 before getting on the bandwagon will not be productive. Given access to the resource and the right policy landscape, Ontario has the potential to be a world leader in this field and to stake out a strong position on which to build.

4.4. Barriers to biochemicals implementation

At least one EU-based company seems to have identified shipping made-in-Canada products via Prince Rupert as a quicker route to China than shipping the same product from an EU plant via Rotterdam. But a lack of containerisation in Thunder Bay, along with congested rail traffic, will be logistics issues. A biorefinery in Sarnia may be better served by rail to Montreal, but wood is not as available in the Sarnia area as in Thunder Bay and the North, and the same containerisation issues arise. Decongesting Canada's western rail network, and the availability of an intermodal yard in Thunder Bay, may well be critical.

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[57] De Guzman, D., "Renewable Chemicals Market: Navigating Shifting Dynamics". Renewable Materials Conference 2025, Siegburg/Cologne, Germany, September 22, 2025.

[58] Current events is the Persian Gulf demonstrate the wisdom of planning for supply disruptions.

5. Best bets

The technologies described above can be divided into four categories, based on complexity and TRL level of the technology, order of magnitude of capital costs, and time to implement.

5.1. Easy, fast, cheap: Energy products

- Bio-energy products or energy carriers such as bio-oil, biochar, pellets (torrefied or conventional), bio-coal, etc.
- For use on-site (gas) or for sale (solid, liquid)
- Scaled to sawmill residues already onsite – additional tonnes of feed are expensive
- Processes are relatively insensitive to bark content and run on either HW or SW
- Capex up to $150M depending on scale and site-specific conditions
- TRL 9, 2-3 years to implement

Customers can include mill energy users such as a lumber kiln, district heating system, bio-crude for a petroleum refinery, bio-coal for a steel mill, pellets for coal firing generation in AB or abroad, etc. These should move forward as fast as possible to ensure the survival, indeed the growth of the sawmilling industry. These energy products are typically low cost, with relatively low revenues per tonne of wood consumed.

5.2. Well-understood, capital intensive: Recapitalise existing pulp mills

- Bring existing kraft pulp mills to first quartile
- Increase pulp production to help offset capital costs
- Will continue to require sawmill chips (ideally SW) from multiple sawmills
- Capex exceeds $1B per site; upgrades can be staggered to keep the mill running as each new process step is implemented (recovery boiler, O_2 delignification, etc.).
- TRL 9, well understood processes (TRL 9), complex processes, 3-5 years to implement

The example here is the process Irving has embarked on in Saint John, NB.

5.3. Complex, capital intensive: New pulp mills or biorefineries

- New pulp mills: TRL 9, 5 years, $2 to $4B
- Biorefineries: TRL 7-8, 5+ years, $2 to $4B
    - Probable scale 300,000 odt/y HW initially, 600,000 odt/y HW as markets mature
    - HW only at this stage
    - Phased approach best as markets grow
    - Fastest approach will be to attract investment from existing players such as UPM – builds on learnings from Leuna
- Both will pull chips from multiple sawmills
- Both require 5-10 years depending on permitting and engineering requirements.

The pulp mill examples are the two new mills built by Metsä in Finland. The biorefinery case is the UPM facility in startup in Leuna, Germany. Both pathways are chemically complex and require expensive equipment such as pressure vessels with metallurgy suited for demanding conditions, but generate high returns per tonne of wood consumed.

In the biorefinery case, technological know-how and market understanding are critical and not available in Canada. These large wood consumers will cost of the order of $1B to $5B. Each will require of the order of one to two million odt/y of fresh white wood chips, along with the associated bark for heat and power. This implies sourcing from a large number of sawmills within reasonable transport distance of the mill site, as has been the case with pulp mills in the past. Furthermore, these projects will take time, at least 5 years once all the necessary permits and wood supplies have been secured. Ensuring enough wood is available in a specific locale in the period 2030-2050 will involve ensuring that all available wood is not carved off piecemeal in a large number of small-scale energy projects and locked up in long term contracts, perhaps leaving tonnes stranded in multiple small pockets across the North.

5.4. Wildcards

At least two potential surprises could work if the right conditions arise, such as an oil price or supply shock. Geopolitical events have led to oil price shocks worldwide, and to supply shocks in economic zones which are net importers of fossil fuels. While North America is not likely to experience a supply shock in the short term, price shocks have been seen to be possible. Coordinated decision by governments to price carbon emissions aggressively would also drive adoption of wildcards, including the following.

- Pathways to SAF look challenging from wood, just as pathways to ethanol were challenging. The competition remains the HEFA pathway from oil seeds, and the alcohol-to-jet pathways based on converted corn ethanol plants. Feedstocks for both are cheap. Other pathways include:
    - Via liquefaction/pyrolysis to dilute refinery crude supply: Expensive.
    - Via gasification to synthesis: Very expensive.
- Carbon capture associated with stack emissions from a bio-energy plant such as a boiler (BECCS) is challenging as NW Ontario is a long way from the necessary aquifer geology.

5.5. Summary of best bets

Key information for specific Best Bets is presented next. Prices per tonne of product are compared along with revenues per tonne of feedstock, including feedstock and net of feedstock. (Note that the kraft pulp analysis did not include revenues due to energy generation, which are highly location-specific; actual revenues would be higher than shown.)

Best Bets also include other sawmill-scaled, relatively fast and easy processes such as wood fibre insulation.

All of these approaches work better in a partnership scenario with an existing industrial facility, where utilities and transportation links can be shared. The host or partner facility can be an existing sawmill or pulp mill, but could also be a petrochemical facility where the integration opportunities made sense.

	Fast, simple		**Large-scale (new pulp, biorefinery)**	
Process	**Torrefaction (Bio-coal)**	**Bio-crude (LCFO)**	**Kraft pulp with lignin**	**Biorefinery Phase 1**
Avg. product sale price, per t	$335	$674	$814	$1,639
Revenues per odt of feedstock	$251	$640	$767	$1,247
Revenues per odt, net of wood	$161	$550	$617	$1,097

Note: kraft pulp does not include value of energy generation.

The simpler, less expensive pathways generate less revenue per tonne of wood consumed than the higher cost plants. This is necessary to cover higher capital and operating costs, and standard metrics such as EBITDA are given in the next table. This table also shows the progression from lower value to higher value products. More information is included in the following table, which includes the recapitalisation of existing kraft mills in the province.

	Fast, simple		**Recapitalise pulp mills**	**Large-scale (new pulp, biorefinery)**	
Process	**Torrefaction (Bio-coal)**	**Bio-crude (LCFO)**	**1st quartile mills**	**Kraft pulp with lignin**	**Biorefinery Phase 1**
TRL	9				7-8
Complexity	Low		Medium	High	
Time to build	2-3 years		3-5 years	5-10 years	
Wood input	Local to sawmill		Multiple sawmills		
Wood type	HW or SW, chips or bark		SW chips		HW chips

Scale, odt/y	221,400	84,600	Capacity increase needed	1,998,000	265,000
Sales, M$	$56	$54	Capacity dependent	$1,533	$324
Capex M$	$81	$149	$1,500	$2,305	$1,634
Wood costs, $/odt	$90	$90	$150	$150	$120
Total OPEX M$	$38	$19		$826	$88

EBITDA, $M	$18	$35		$707	$237
ROCE	16.2%	18.3%		24.9%	9.4%
Payback, years	8.5	7.7		5.6	15.1
IRR	11.7%	13.0%		18.0%	6.6%

Locations	Scaled to sawmills province-wide		Thunder Bay, Dryden	North East	North West

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