Biopathway opportunities for wood-to-liquid transportation fuels in Ontario

Final Report prepared by AFRY Management Consulting, Inc.

31 JULY 2025

Disclaimer

This report has been prepared by AFRY Management Consulting Inc. (“AFRY”) solely for use by CRIBE (the “Recipient”). All other use is strictly prohibited, and no other person or entity is permitted to use this report, unless otherwise agreed in writing by AFRY. **By accepting delivery of this report, the Recipient acknowledges and agrees to the terms of this disclaimer**.

This report was not prepared to be used in connection with the purchase or sale of securities and AFRY shall have no liability for any such use.

NOTHING IN THIS REPORT IS OR SHALL BE RELIED UPON AS A PROMISE OR REPRESENTATION OF FUTURE EVENTS OR RESULTS. AFRY HAS PREPARED THIS REPORT BASED ON INFORMATION AVAILABLE TO IT AT THE TIME OF ITS PREPARATION AND HAS NO DUTY TO UPDATE THIS REPORT.

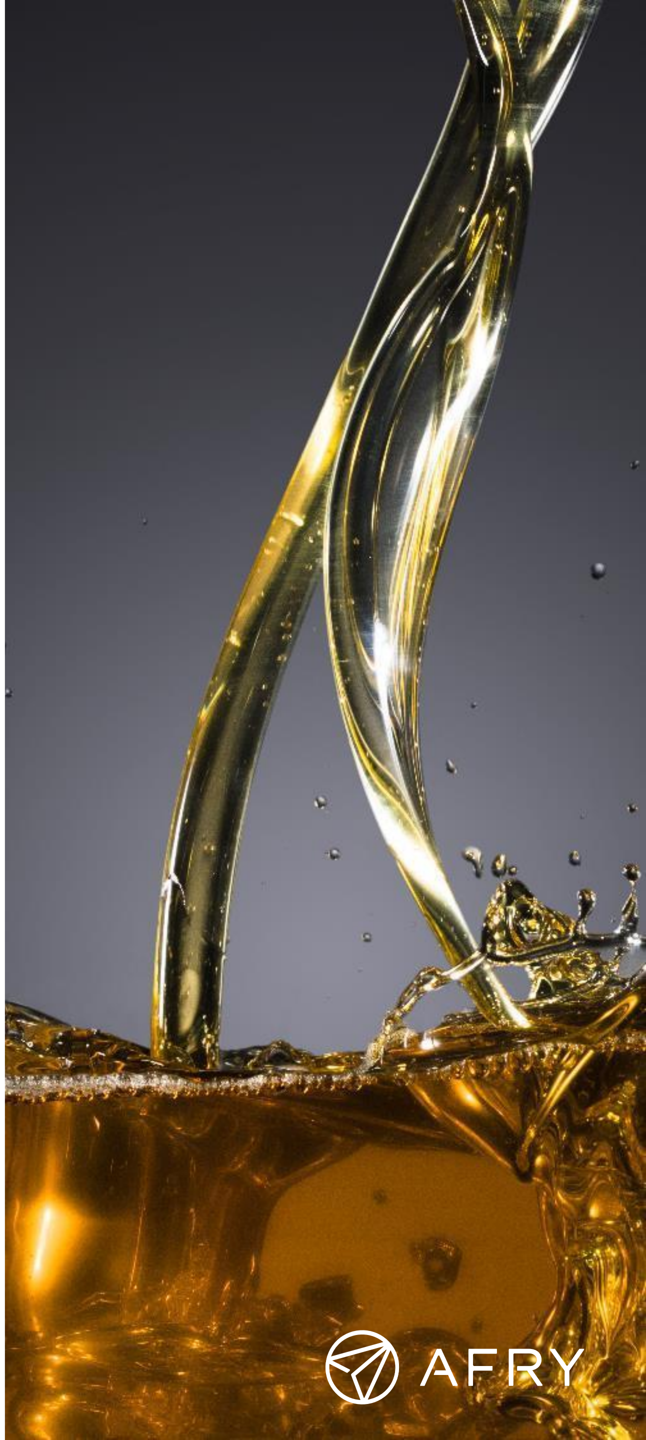
AFRY makes no representation or warranty, expressed or implied, as to the accuracy or completeness of the information provided in this report or any other representation or warranty whatsoever concerning this report. This report is partly based on information that is not within AFRY’s control. Statements in this report involving estimates are subject to change and actual amounts may differ materially from those described in this report depending on a variety of factors. AFRY hereby expressly disclaims any and all liability based, in whole or in part, on any inaccurate or incomplete information given to AFRY or arising out of the negligence, errors or omissions of AFRY or any of its officers, directors, employees or agents. Recipients' use of this report and any of the estimates contained herein shall be at Recipients' sole risk.

AFRY expressly disclaims any and all liability arising out of or relating to the use of this report except to the extent that a court of competent jurisdiction shall have determined by final judgment (not subject to further appeal) that any such liability is the result of the willful misconduct or gross negligence of AFRY. AFRY also hereby disclaims any and all liability for special, economic, incidental, punitive, indirect, or consequential damages. **Under no circumstances shall AFRY have any liability relating to the use of this report in excess of the fees actually received by AFRY for the preparation of this report.**

All information contained in this report is confidential and intended for the exclusive use of the Recipient. The Recipient may transmit the information contained in this report to its directors, officers, employees or professional advisors provided that such individuals are informed by the Recipient of the confidential nature of this report. All other use is strictly prohibited.

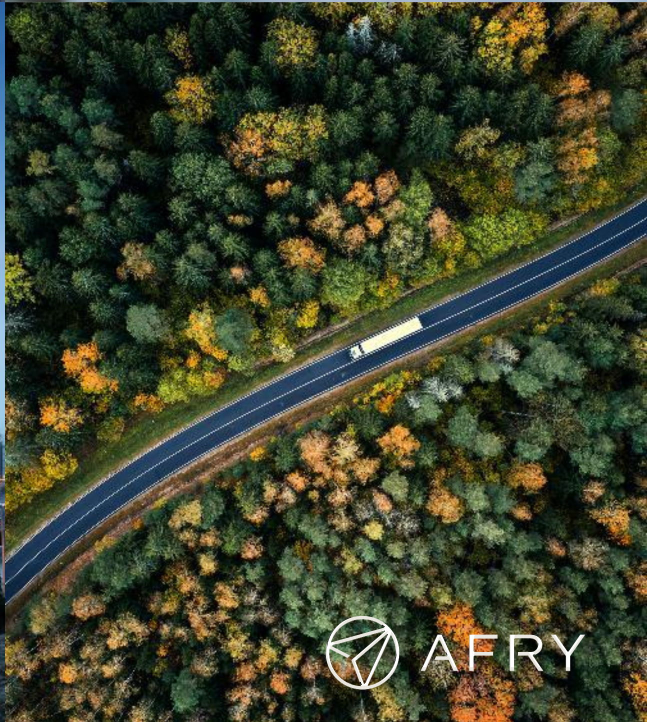
Unlocking Ontario's biofuel potential starts with feedstock, pathways, infrastructure, and smart policy

- What are the available woody biomass feedstocks in Ontario?
- What portion of these would be eligible under Canadian and U.S. biofuel regulations?
- What are the available wood-to-liquid transportation fuel pathways?
- What is their state of technical and commercial readiness?
- What are the associated capital costs for wood-to-liquid fuel biorefineries? What is the demand for bio-fuels in Ontario?
- How could wood-based fuels meet this demand?
- How does biomass supply align with industrial and transportation infrastructure?
- Who are the key stakeholders?
- What policies could be used to attract investment in Ontario?



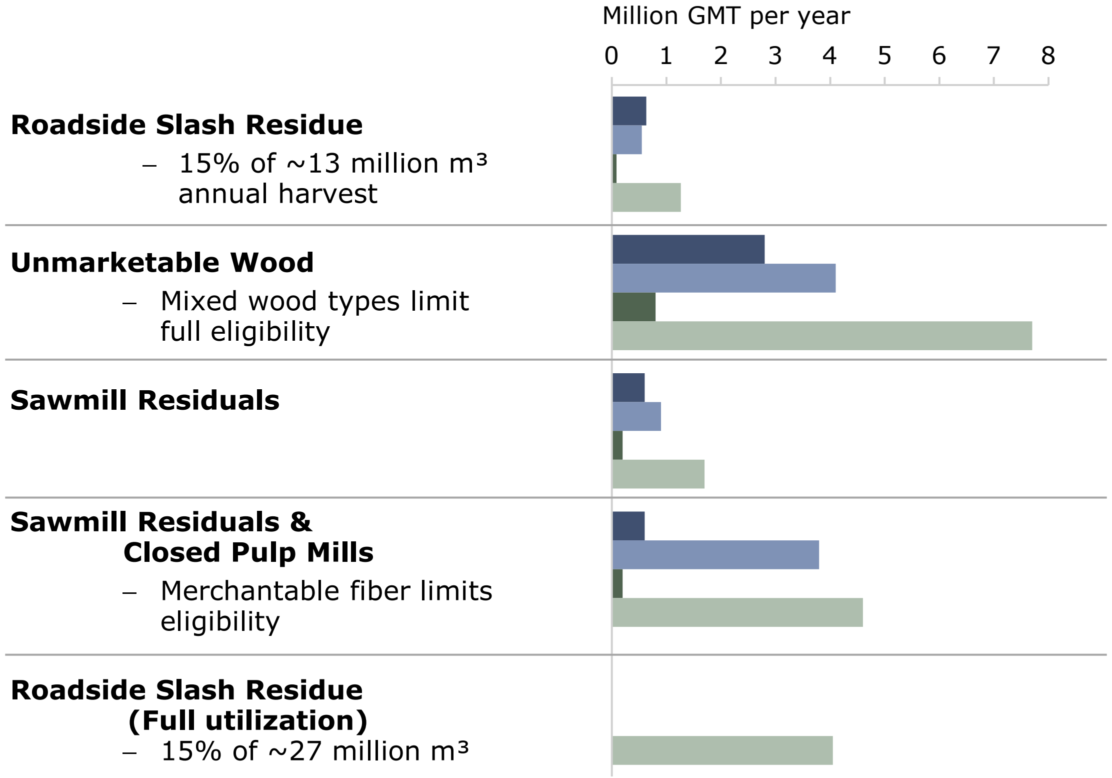
Contents

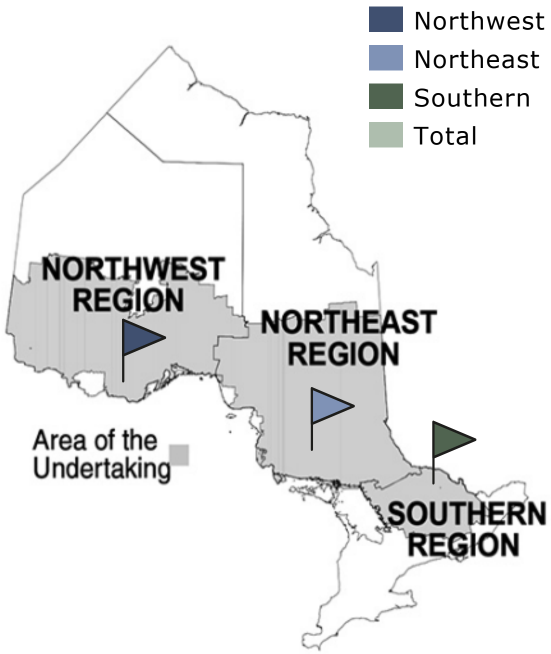
1. **Key Findings**
2. Wood Supply and Eligibility
3. Technology Pathway Assessment
4. Biofuel Supply and Demand
5. Biorefineries and Infrastructure Alignment
6. Next Steps



Ontario forests can supply up to 8 million GMT of underutilized forest biomass to produce biofuels

ONTARIO UNDERUTILIZED BIOMASS SUPPLY BY REGIONS





A significant portion of Ontario's allowable forest harvest represents an immediate, sustainable source of feedstocks that can be used to produce biofuels.

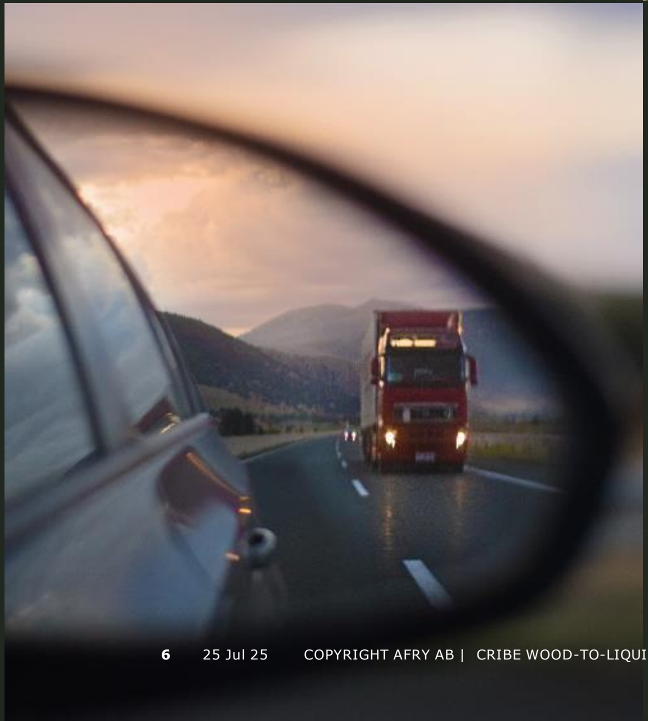
Unmarketable wood, trees or portions of trees that are not economically viable to harvest, represent an untapped resource with huge potential.

GMT = Green Metric Tonnes

AFRY

1.3 million GMT of roadside slash could **fully** meet Ontario’s projected 2030 renewable diesel demand of around **300 million litres**

By 2030, wood-based liquid fuels could meet nearly **15%** of Canada’s annual demand for renewable diesel: around **4 billion litres**



275+ million litre

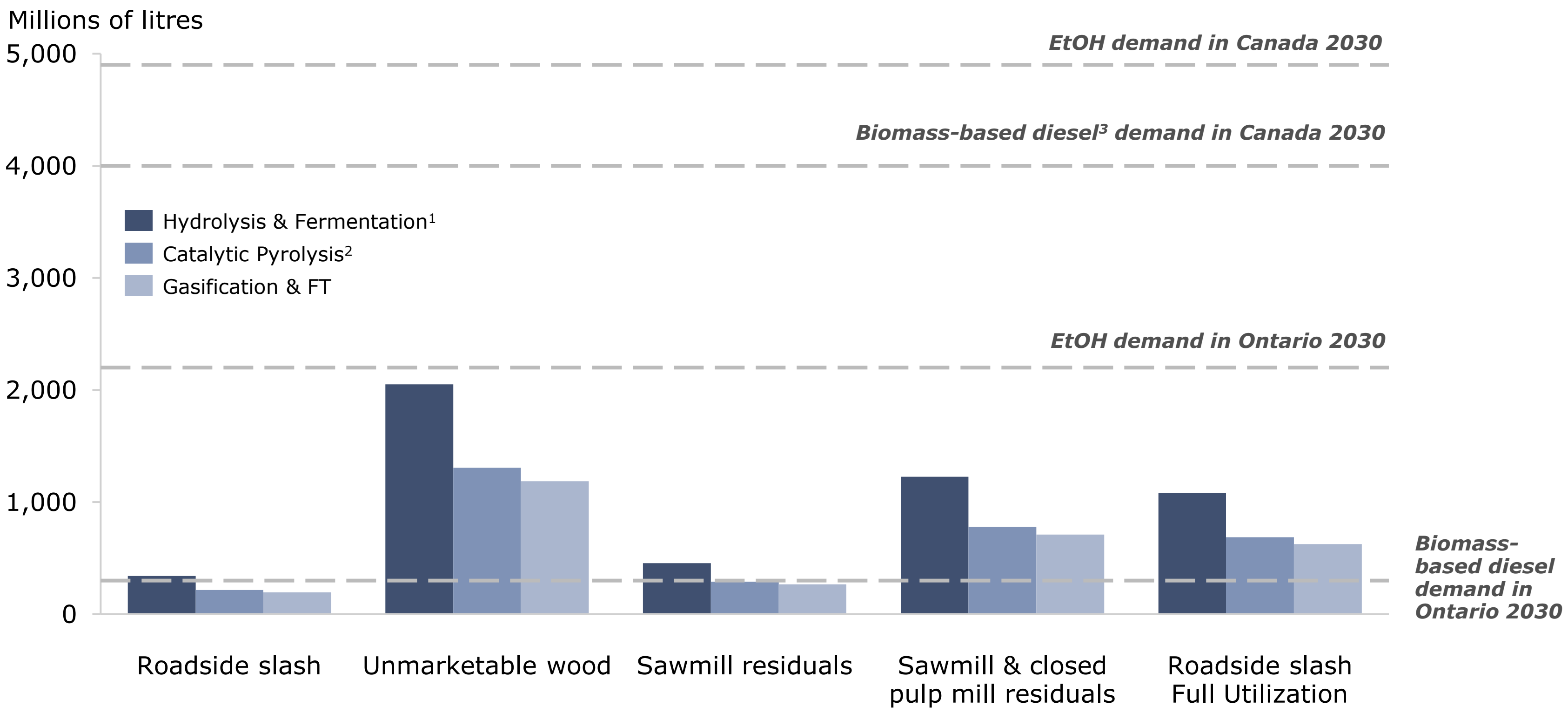
Export potential strengthening Ontario’s position in the national and international biofuels markets

Full utilization of Ontario’s sustainable wood supply could potentially meet as much as **half** of Canada’s biofuel demand

AFRY

Adding unmarketable wood to the biomass feedstock supply could meet 2/3rds of Canada's biofuel demand

WOODY BIOMASS POTENTIAL TO MEET CANADA'S BIOFUEL DEMAND IN 2030



Feedstocks are readily available and could support climate targets, reduces emissions, and strengthens rural economies.

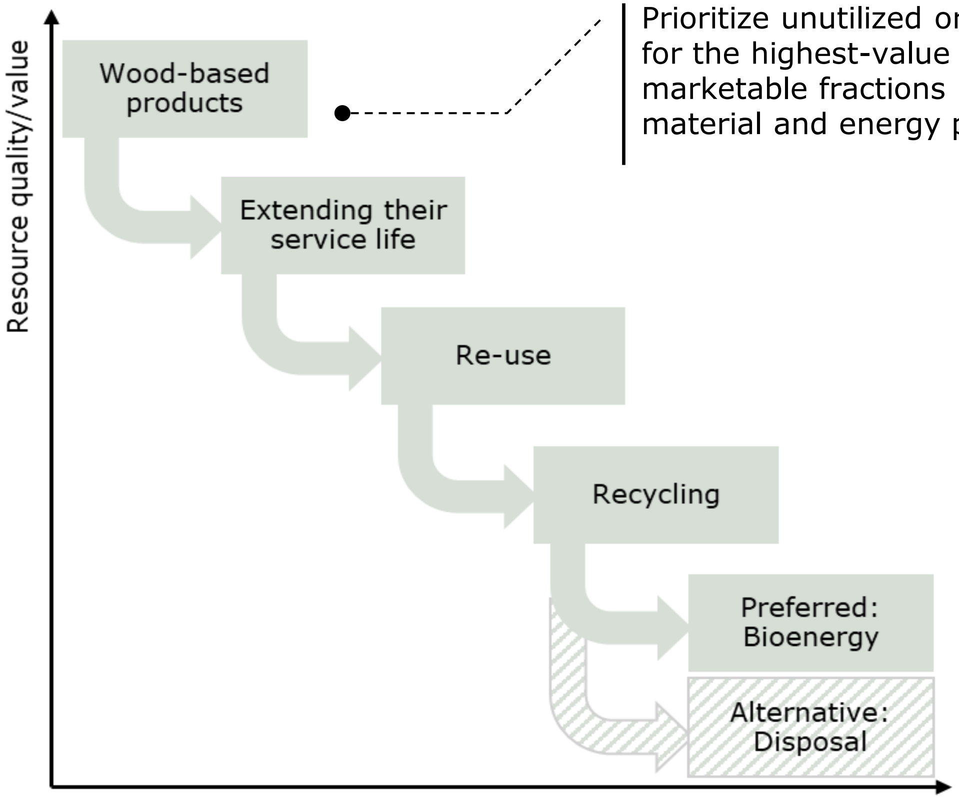
This is a clear opportunity for Ontario to lead in renewable fuels while advancing both environmental and economic priorities

Unlocking this potential requires improved infrastructure and clear eligibility pathways.

1. Potential ethanol yield from woody biomass compared to the full ethanol demand (1G+2G) in Canada 2. Potential drop-in fuels yield from woody biomass compared to the renewable diesel demand in Canada. 3. Includes renewable diesel, biodiesel and co-processing

Ontario should prioritize extracting the full value of its forest resources by applying the Cascading Use principle

CASCADING PRINCIPLE ILLUSTRATED



Prioritize unutilized or low-value wood for the highest-value uses, directing marketable fractions into appropriate material and energy pathways

Policies should prioritize the use of sawmill residuals and harvest residues over roundwood for bioenergy and biofuels

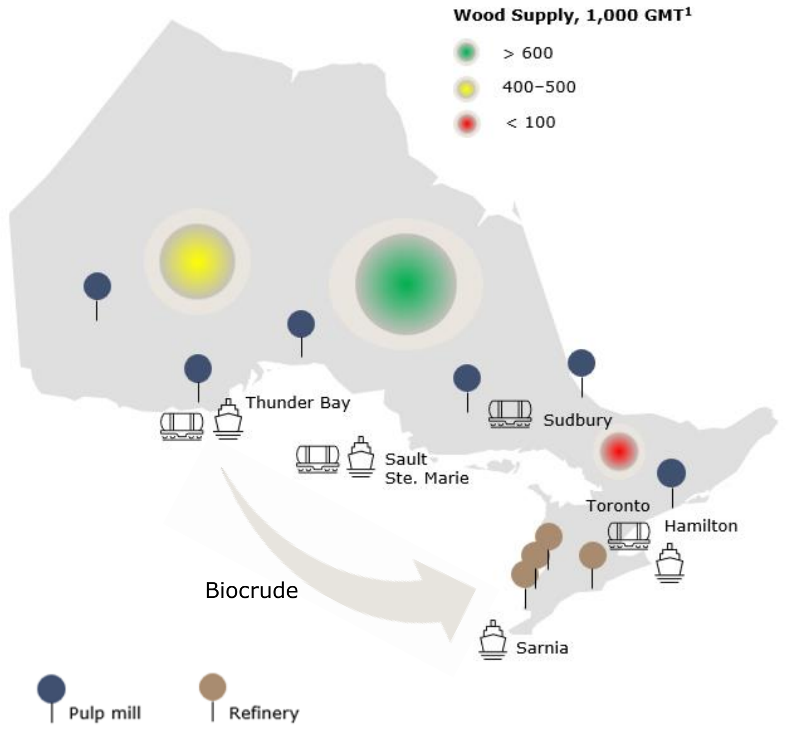
Strengthening forest management improves forest health, addresses climate and insect-related degradation, reduces fire risk, and supports jobs and revenue in rural communities.

This approach also allows for sustainably increasing harvest levels while being fully aligned with Ontario’s ecological regulations.

AFRY

Liquid biofuels supply chain extends from feedstock transport and handling to fuel manufacturing and upgrading, before final blending and distribution

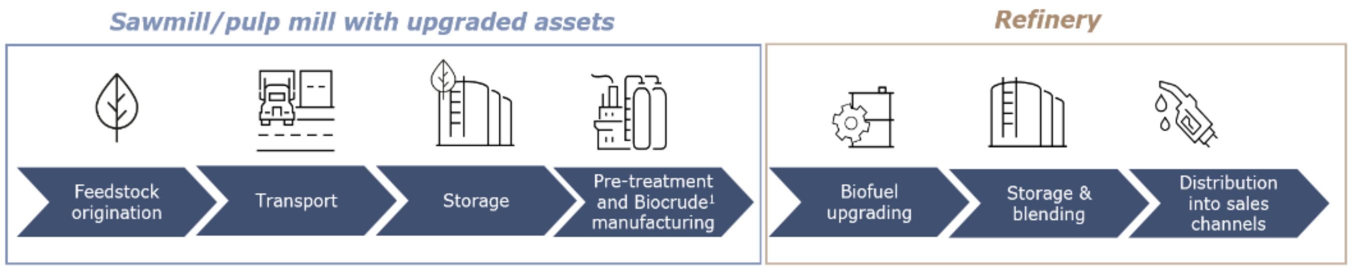
POTENTIAL HOSTING LOCATIONS



ALIGNING WOOD SUPPLY, BIOFUEL PRODUCTION AND REFINERS

- Operating pulp mills are located in northwestern Ontario, close to the province's large wood supply regions. These mills are strategically located in regions with abundant woody biomass and are well-served by rail transport.
- Petroleum refineries on the other hand are concentrated in southern Ontario. However, they benefit from proximity to major markets and logistical advantages provided by water routes and an extensive railway network.
- Additionally, Ontario hosts four major ports at Thunder Bay, Sarnia, Sault St. Marie and Hamilton that support industrial exports and regional trade, representing the potential for strong logistics links between biocrude production and the refineries.

WOOD BIOFUEL VALUE CHAIN



1. Biocrude aka pyrolysis oil

KEY FINDINGS – OFF TAKERS

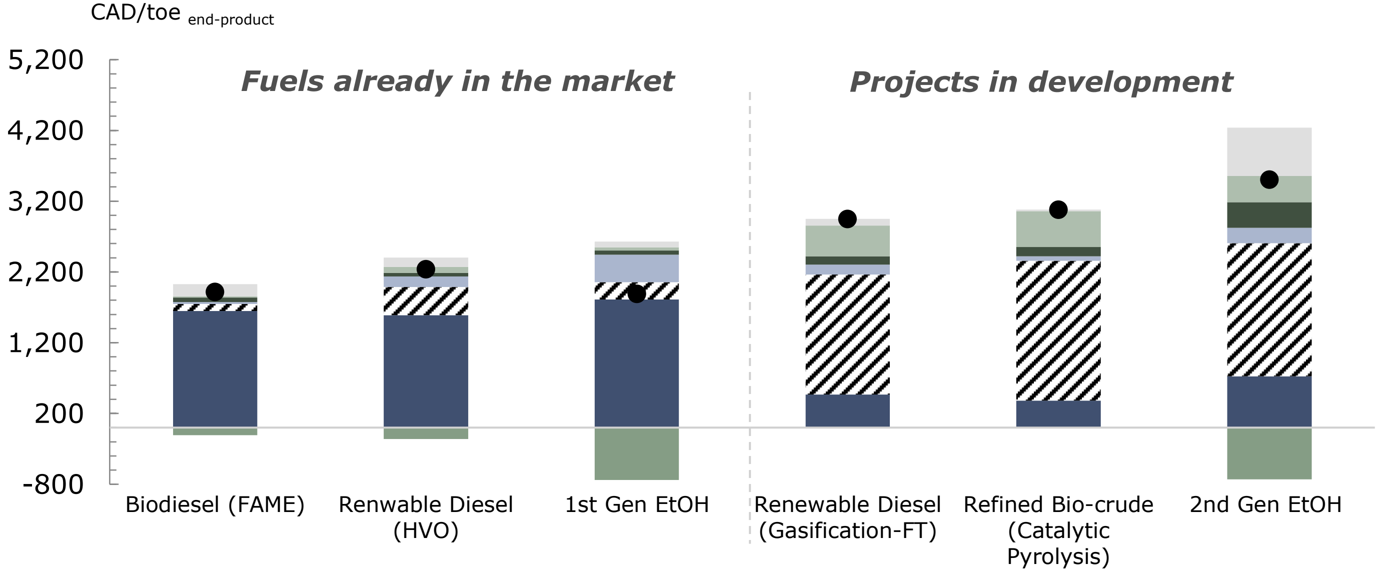
Refiners need scalable, drop-in biofuels to meet clean fuel demand

- Ontario refiners need scalable, low-carbon fuels to meet Ontario Cleaner Transportation Fuel Regulations and market demand
- Wood-derived intermediates like pyrolysis oil offer drop-in compatibility with existing refineries
- Domestic production reduces reliance on imports, de-risks supply chains, and boosts local energy security
- Co-processing requires only modest refinery upgrades

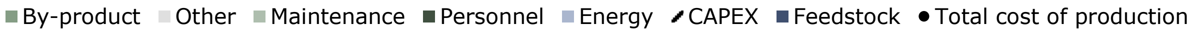
AFRY

Producing biofuels from forest feedstocks involves higher capital and production costs compared to fossil fuels

COST BREAKDOWN COMPARISON OF THE SELECTED BIOREFINERIES [1,2]



Feedstock	Rapeseed oil	UCO	Wheat	Wood residues	Wood residues	Wood residues
Production cost (CAD/toe) ex CAPEX	1820	1850	1645	1255	1110	1630



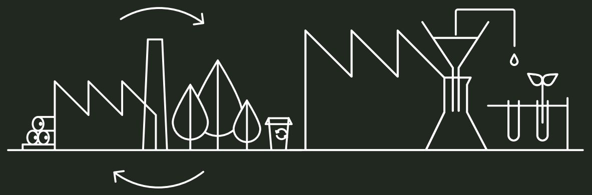
Excluding capital costs, biofuels from wood become a far more competitive option to conventional biofuels.

Biofuels from wood have the potential for lowering carbon emissions relative to competitive options, which adds further value.

1. Cost breakdown calculations are based on 8% interest rate and pay-back time of 20 years. 2. Transportation costs are excluded from the total cost of production.

Unlocking Ontario’s advantage for wood-based biofuels requires strong incentives along with policies that can drive investment and local leadership

1. Bridge incentives are essential to enable early investment
2. Policy tools matching the U.S. IRA to stay competitive
3. Strong tax incentives attract private investment to Ontario
4. Production tax credit to drive local leadership
5. Prioritizing domestic supply strengthens Ontario’s industry
6. Supporting local biofuels creates jobs and boosts rural economies



AFRY

Clearer, faster policy pathways are key to scaling low-carbon wood-based fuels in Ontario

Accelerate approvals: Reduce certification approval process for the new production pathways

Clarify carbon intensity: Set clear, science-based CI benchmarks for wood-based fuels

Support LCA development: Provide support mechanisms for validating LCAs of new low-CI fuel pathways

Focus on volume: Use concrete biofuel output and wood tonnage, not just % targets, to convey real economic impacts

From forest to fuels: *Driving jobs and growth*

Investing in bio-crude facilities in northern Ontario can generate up to $500 million per site, create jobs, and revitalize forest-dependent communities

By optimizing forest use and establishing bioeconomy hubs, the province can strengthen its forestry sector, support rural economies, and meet growing market demands sustainably

AFRY

Contents

1. Key Findings

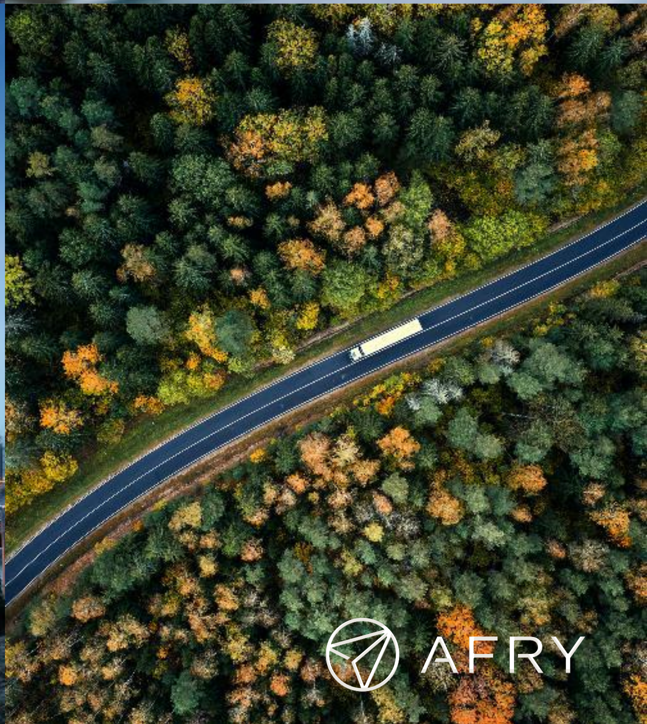
2. Wood Supply and Eligibility

3. Technology Pathway Assessment

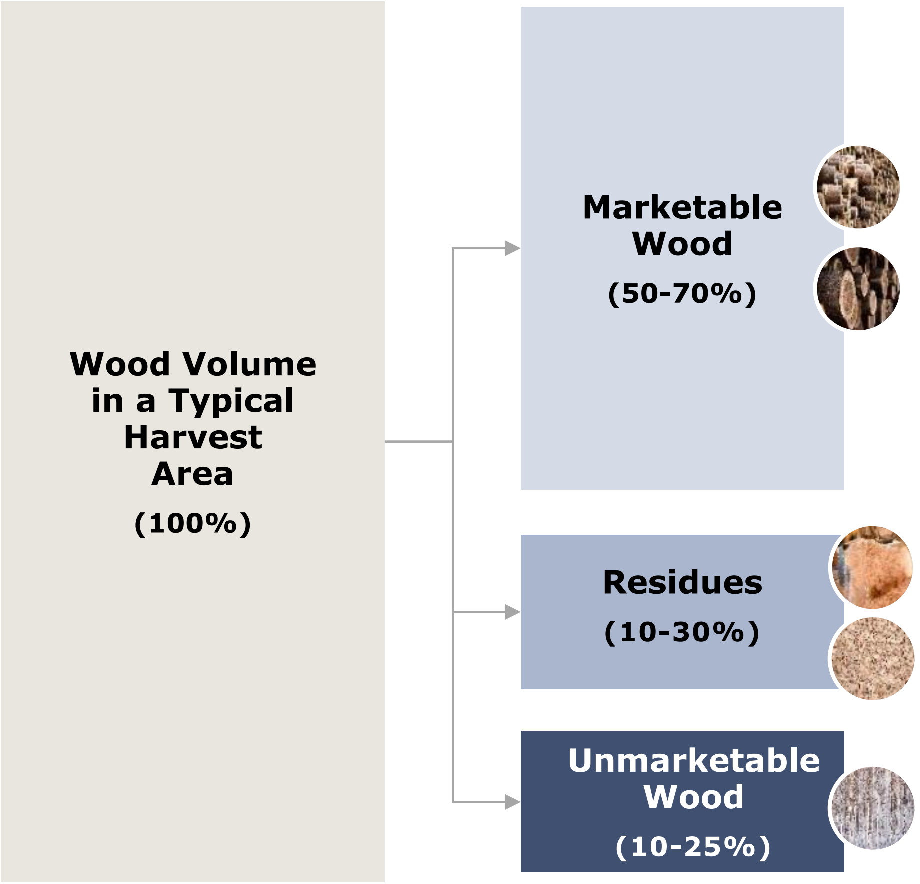
4. Biofuel Supply and Demand

5. Biorefineries and Infrastructure Alignment





Forest harvest composition in a typical Ontario timber harvest area: Marketable wood, unmarketable wood, and residues



COMPONENT	DEFINITION
Marketable wood	The portion of the forest biomass that meets commercial specifications and is harvested for economic use. Includes sawlogs, pulpwood, utility poles, veneer and OSB logs . *Key traits:* – Meets merchantable size limits (e.g., DBH > 10 cm) Free from excessive defects or rot – Belongs to commercially desirable species – Harvested and removed from the site
Residues	Non-stem biomass and leftover wood material generated during harvesting that is typically not removed from the site. Includes branches and tree-tops, **roadside slash**, broken or partially harvested logs, bark and sawdust (if processing on site), and **sawmill residuals**. *Key traits:* – Usually left to decay or burned – Can be collected for bioenergy or mulch – Plays a role in nutrient cycling and soil health
Unmarketable wood	Trees or portions of trees that are not economically viable to harvest, even if technically harvestable. Includes undersized, deformed or decayed trees, non-commercial species, and trees in difficult terrain or inaccessible patches.

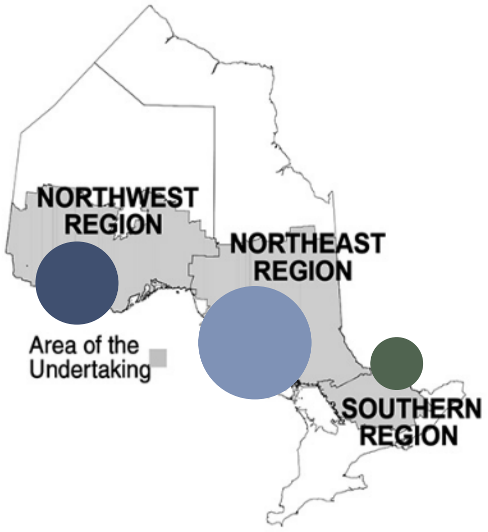
Types, specifications, and characteristics of forest biomass for industrial and biofuel applications

	GENERAL SPECIFICATION	QUALITY CHARACTERISTICS
ROUNDWOOD		
Fuelwood (**Energy wood**)	Trees and logs usually not suitable for industrial usage due to form, diameter or species.	Stem wood with low bark content, relatively low ash content
Pulpwood	Not suitable or in demand for other products like lumber and plywood.	Stem wood with low bark content, relatively low ash content
FOREST RESIDUES		
Branches & tops (**Harvesting residues**)	Branches/tops collected from roundwood harvesting. Collected for energy production or left in the field today.	Stem wood with high bark content, high ash content
Small diameter wood (**Energy wood**)	Smaller diameter roundwood collected during thinnings or tending of the forest. Not suitable for pulp production.	Stem wood with relatively high bark content, higher ash content
Stumps	Stumps of harvested trees. Harvesting stumps presently not a practice in the managed forest. Low quality raw material.	Stem wood with a lot of impurities (soil, stones etc.), lower ash content compared to bark and harvesting residues
INDUSTRY RESIDUES		
Bark	Bark that has been removed during processing of roundwood.	With little stemwood, very high ash content
Sawdust , shaving, etc.	Produced during roundwood processing at primary processing plants. Small fraction.	Stem wood without any bark, low ash content
Chips	Produced during roundwood processing at sawmills. Larger fraction.	Stem wood without any bark, low ash content

AFRY

In the best-case scenario, there is ~ 8 million GMT of residuals available to be used as feedstock for advanced biofuel production

ONTARIO HARVESTING RESIDUES SUPPLY BY REGIONS



– *A significant portion—particularly sawmill residuals and fully utilized slash—offers immediate, usable feedstock. Unlocking this potential requires improved infrastructure and clear eligibility pathways*

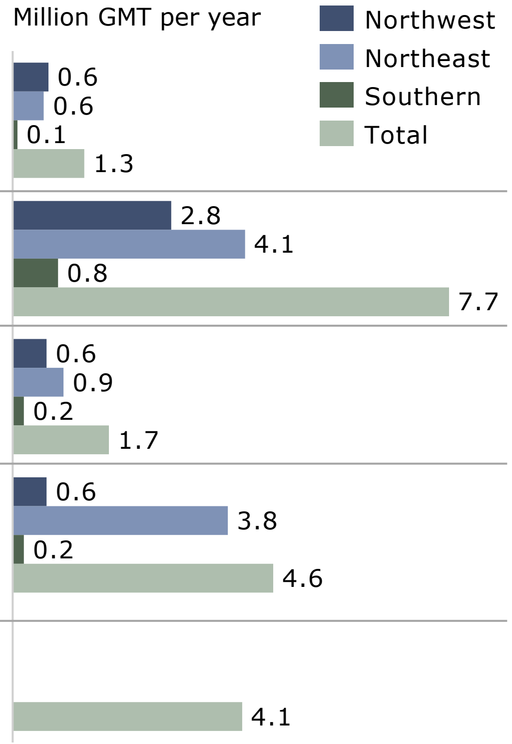
Case 1. **Roadside Slash Residue**
- 15% of ~13 million m³ annual harvest

Case 2. **Unmarketable Wood**
- Mixed wood types limit full eligibility

Case 3. **Sawmill Residuals**
- ~2 million GMT

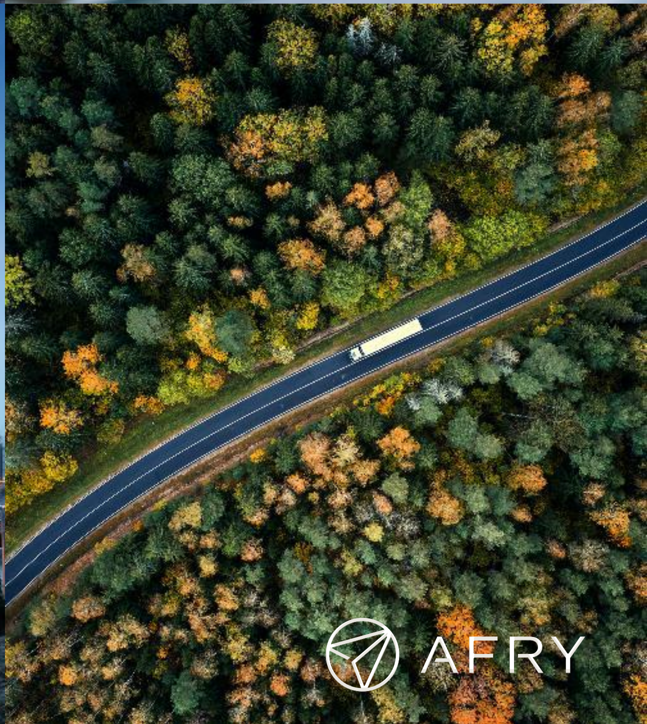
Case 4. **Sawmill Residuals & Closed Pulp Mills**
- Merchantable fiber limits eligibility

Case 5. **Full Wood Utilization (Roadside Slash)**
- 15% of annual harvest
- Up to ~4 million GMT annually



Contents

1. Key Findings
2. Wood Supply and Eligibility
3. **Technology Pathway Assessment**
4. Biofuel Supply and Demand
5. Biorefineries and Infrastructure Alignment



Wood-based biofuels can be used as drop-in fuels in diesel, gasoline and jet fuel or as low blend fuels in gasoline

DIESEL POOL

Low blend fuels

FAME
Fatty Acid Methyl Ester
- Crop-based FAME = methyl esters from e.g. rapeseed oil or soybean oil
- TME, Tallow Methyl Ester
- UCOME, Used Cooking Oil Methyl Ester

FAME is also known as **BIODIESEL**

Drop-in fuels

HVO
Hydrogenated Vegetable Oil

Other drop-in fuels, e.g.
- Biomass-to-Liquid
- Power-to-Liquid

HVO is also known as **RENEWABLE DIESEL**

GASOLINE POOL

Low blend fuels

Ethanol[1]

Methanol[2]

Gasoline additives, e.g.
- ETBE
- MTBE

Drop-in fuels

Renewable naphtha

Other drop-in fuels, e.g.
- Biomass-to-Liquid
- Power-to-Liquid

AVIATION

Drop-in fuels

Other drop-in fuels, e.g.
- Alcohol-to-jet
- Biomass-to-Liquid
- Power-to-Liquid

OTHER TERMINOLOGY

Low blend fuels

Fuels that have a blend wall, e.g.
- Ethanol max. 15% in volume

Drop-in fuels

Fuels can replace 50-100% of the fossil fuel without alterations in the vehicle engine

HVO vs. Biomass-to-Liquid (BtL) fuels

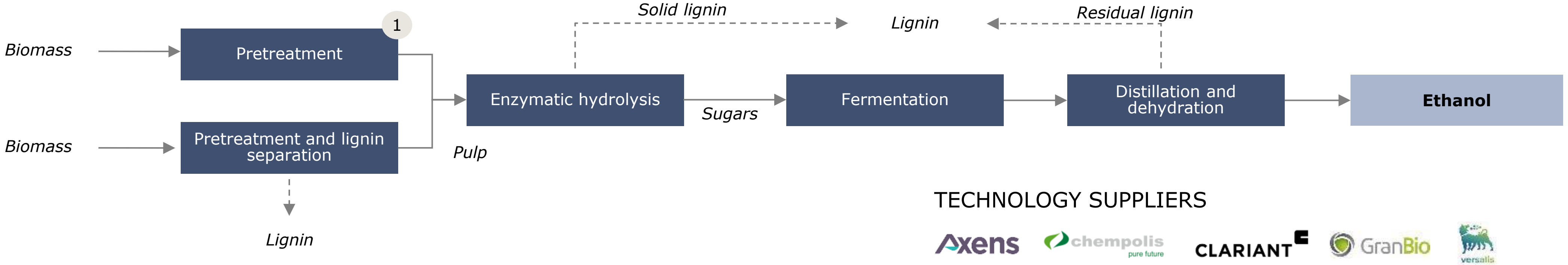
HVO fuels are produced from liquid/oily feedstocks (e.g. vegetable oils), and BtL fuels from solid feedstocks (e.g. forestry residues)

1. Typically blended in gasoline (e.g. E10) or used in higher concentrations in flex fuel-vehicles.
2. Can be blended in small amounts to gasoline, has potential in marine fuel decarbonization.

Ethanol production via hydrolysis and fermentation requires pretreatment of biomass to extract lignin and sugars

HYDROLYSIS & FERMENTATION

TRL **6-8**[1]



TECHNOLOGY SUPPLIERS

Axens, chempolis, CLARIANT, GranBio, versalis
1 Valmet, SixRing

KEY ASSUMPTIONS AND PROCESS CONSIDERATIONS

Ethanol can be produced from wet lignocellulosic biomass by enzymatic hydrolysis and fermentation after the pre-treatment of biomass. Processes can be divided into carbohydrate and lignin dissolving pathways based on the pretreatment technology

Carbohydrate dissolving produces a sugar solution (C5 & C6 sugars) as well as solid and residual lignin, which can be obtained after enzymatic hydrolysis. Carbohydrate dissolving offers five different process options that differs mostly by the pretreatment steps, e.g., steam explosion, dilute acid or ammonia, and hydrothermal pretreatment

Lignin dissolving generates chained carbohydrates and dissolved lignin, which is separated before the enzymatic hydrolysis. Lignin dissolving can be done mainly by two possible routes: SEW organosolv with EtOH, SO_2 and water, or organosolv with formic and acetic acids

KEY STATISTIC

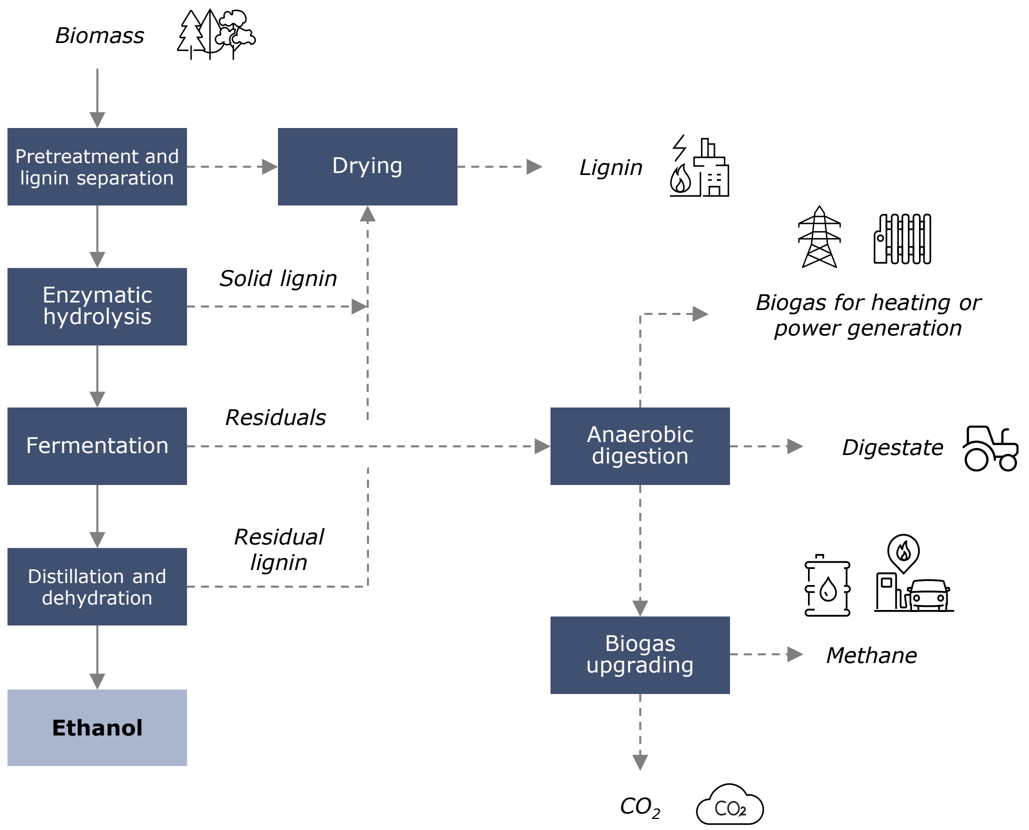
TYPICAL PLANT CAPACITY App. **50-75** ML/year	POTENTIAL YIELD[2] App. **21**% / **32**%
FEEDSTOCK REQUIREMENT App. **250** kADt/a	CAPEX RANGE App. **500–600** MCAD

1. TRL 6–9 with other biomass feedstocks, such as bagasse (Raízen SA). 2. Mass/energy basis. Mass basis calculated from wet biomass while energy basis from biomass energy content (LHV (dry)).

AFRY

Integrating lignin and biogas utilization enhances the process efficiency and circular bioeconomy for production of advanced ethanol

OPPORTUNITIES UTILIZING LIGNIN & BIOGAS AS BY-PRODUCTS



- Lignin is a valuable by-product which can be recovered during pretreatment, enzymatic hydrolysis, and dehydration steps
- Applications for lignin include:
  - Biochemical conversion into biocrude, syngas or valuable biochemicals (aromatic compounds, such as phenols)
  - Material applications include solutions for various bioproducts, such as bioplastics, adhesives, carbon fibre and resins
  - Lignin pellets have great energy-density for industrial or residential heating
- Required post-treatment next to ethanol plant:
  - Biochemical conversion of lignin requires additional gasification or pyrolysis unit which elevates the CAPEX significantly
  - Application for heat generation require drying and palletisation unit

- Biogas, consisting of CH_4 and CO_2, can be generated with anaerobic digestion of fermentation residues
- Applications for biogas include:
  - Biogas upgrading into pure biomethane (>95 wt.-% CH_4)
  - CO_2 fraction can be captured and sold for industrial use
- Required post-treatment next to ethanol plant:
  - Biogas utilization require additional digester and upgrading unit for removing moisture and CO_2

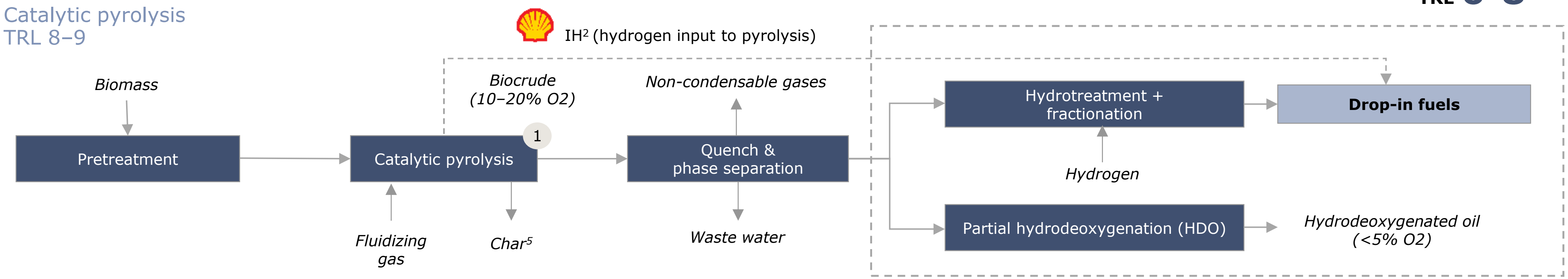
AFRY

Catalytic pyrolysis produces biocrude that can be upgraded further into drop-in fuels via co-processing or dedicated units in standard refineries

CATALYTIC PYROLYSIS & BIOCRUDE UPGRADING

TRL **6-8**

Catalytic pyrolysis
TRL 8–9



TECHNOLOGY SUPPLIERS

1 IH² Valmet

KEY ASSUMPTIONS AND PROCESS CONSIDERATIONS

Catalytic pyrolysis uses catalyst in pyrolysis step to reduce the oxygen content, increasing the stability and heating value of the biocrude product. Lower oxygen content in biocrude enables easier and less hydrogen intensive downstream processing, e.g., in oil refineries. If the catalytic pyrolysis does not include hydrotreatment, downstream processing is required to convert biocrude into drop-in fuels.

Oil refineries are expected to require less than 5% oxygen content for bio-oil blends depending on the feed point at the refinery. Oxygen in hydrocrackers, hydrotreatment and FCC tend to corrode the reactor internals, promote coke formation and poison the catalyst. Biobased feedstocks with high oxygen content can be pretreated using a hydrodeoxygenation (HDO) process to reduce oxygen content to acceptable levels.

KEY STATISTIC

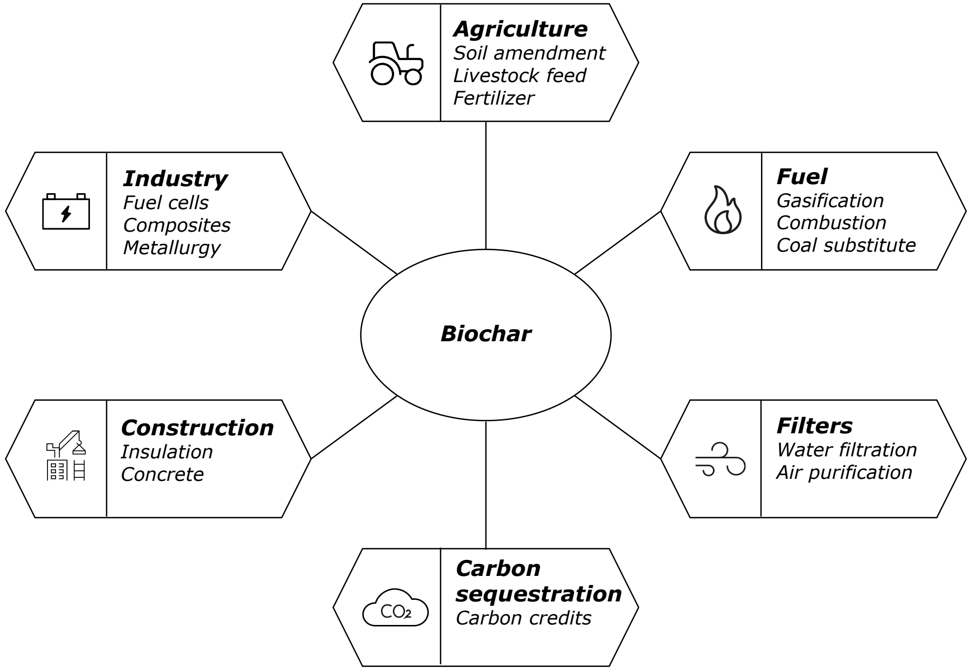
TYPICAL PLANT CAPACITY[1] App. **40-80** ML/year	POTENTIAL YIELD[2,3] App. **24**% / **56**%
FEEDSTOCK REQUIREMENT App. **130–250** kADt/a	CAPEX RANGE[4] App. **800–1 000** MCAD

1. Biocrude capacity range 50–100 ML/year with no upgrading part. 2. Mass/energy basis. Mass basis calculated from dry biomass (bone dry basis) and energy basis from biomass energy content (LVH(dry)). 3. Biocrude mass-based yield 25–32% per ton of dried feedstock. 4. Estimated CAPEX with only pre-treatment and pyrolysis range 350–550 MCAD (not including hydrodeoxygenation). 5. Char yield 10–20% per ton of dried feedstock.

AFRY

Biochar has a range of applications, most of which require activation to enhance specific biochar properties, such as pore size and surface area

OPPORTUNITIES UTILIZING BIOCHAR AS A BY-PRODUCT



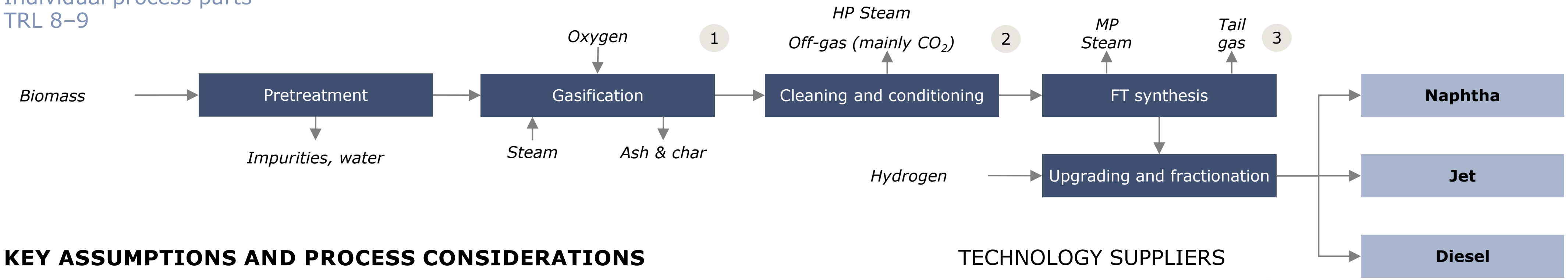
- Biochar is an unavoidable by-product from pyrolysis, which can be utilized for several applications
- Applications for biochar include:
  - Biochar improve soil health and sequester carbon from atmosphere
  - Biochar applications at industry include air/water filters, composites, reduction agents in steel and silicon production, and substitute for concrete
  - Biochar pellets and briquettes have great energy-density for industrial or residential heating, and they can replace the fossil-based coal
  - Biochar can be used as a livestock bedding and food supplement for animals
- Required post-treatment:
  - Refinery grade biochar can be mainly used only for soil improvement and heating applications
  - Specific applications require improved biochar features, such as high porosity and high surface area. These key feature can be improved by activating carbon with oxidizing gases at high temperature

Biomass gasification followed by Fischer-Tropsch synthesis produces drop-in diesel, jet fuel and naphtha

GASIFICATION & FT-SYNTHESIS

TRL **6-8**

Individual process parts
TRL 8–9



KEY ASSUMPTIONS AND PROCESS CONSIDERATIONS

Biomass gasification combined with a Fischer-Tropsch synthesis (FT) is a thermochemical pathway where biomass is first converted into syngas and further transformed into hydrocarbons in a catalytic process

In gasification step, the feedstock is converted into syngas at high temperature (typically >700 °C) without combustion by controlling the amount of oxygen and/or steam present in the reaction

In synthesis step, the cleaned syngas is converted into liquid hydrocarbons through catalytic process typically around 200–300 °C and 20–50 bar

Produced hydrocarbons are finally processed into a range of drop-in fuels in the upgrading and fractionation step

TECHNOLOGY SUPPLIERS

1 Sumitomo SHI FW, thyssenkrupp, Enerkem, GIDARA Energy

2 Linde, Air Products, Air Liquide

3 Velocys, JM Johnson Matthey, Axens, Sasol, Topsoe

KEY STATISTIC

TYPICAL PLANT CAPACITY App. **80-280** ML/year	POTENTIAL YIELD[2] App. **20**% / **44**%
FEEDSTOCK REQUIREMENT App. **800–1 200** kADt/a	CAPEX RANGE App. **1 600–2 700** MCAD

AFRY

We selected ethanol and bio-crude production pathways for analysis due to their promising integration possibilities and/or economics of scale

	HYDROLYSIS & FERMENTATION	CATALYTIC PYROLYSIS	GASIFICATION & FT SYNTHESIS
Assessed product	**Ethanol**	**Bio-crude (aka bio-oil)**	Drop-in fuels
Suitable feedstock	? ✓	✓	✓
Technology readiness	TRL 4-8	TRL 8-9	TRL 7-8
Fuel upgrade possibilities	Alcohol to Jet	Drop-in fuels	Not applicable
Product Yield (Mass/Energy)	21% / 32%	24% / 56%	20%/ 44%
Typical plant size *(biomass input/product output)*	250 kt (dry) / 50–75 ML	130–250 kt (dry) / 50–100 ML	800–1,200 kt (dry) / 80–280 ML
CAPEX, MCAD *(CAPEX for typical plant size)*	500–600	350–550[1]	1,600–2,700
By-products	Lignin, Methane, CO_2	Bio-char	Bio-char
Technology providers	Axens, chempolis, CLARIANT, Valmet, SixRing, versalis, GranBio	ENSYN, Shell, Valmet	Sumitomo SHI FW, thyssenkrupp, Enerkem, GIDARA ENERGY, Linde, AIR PRODUCTS, Air Liquide, TOPSOE, VELOCYS, Johnson Matthey, Axens

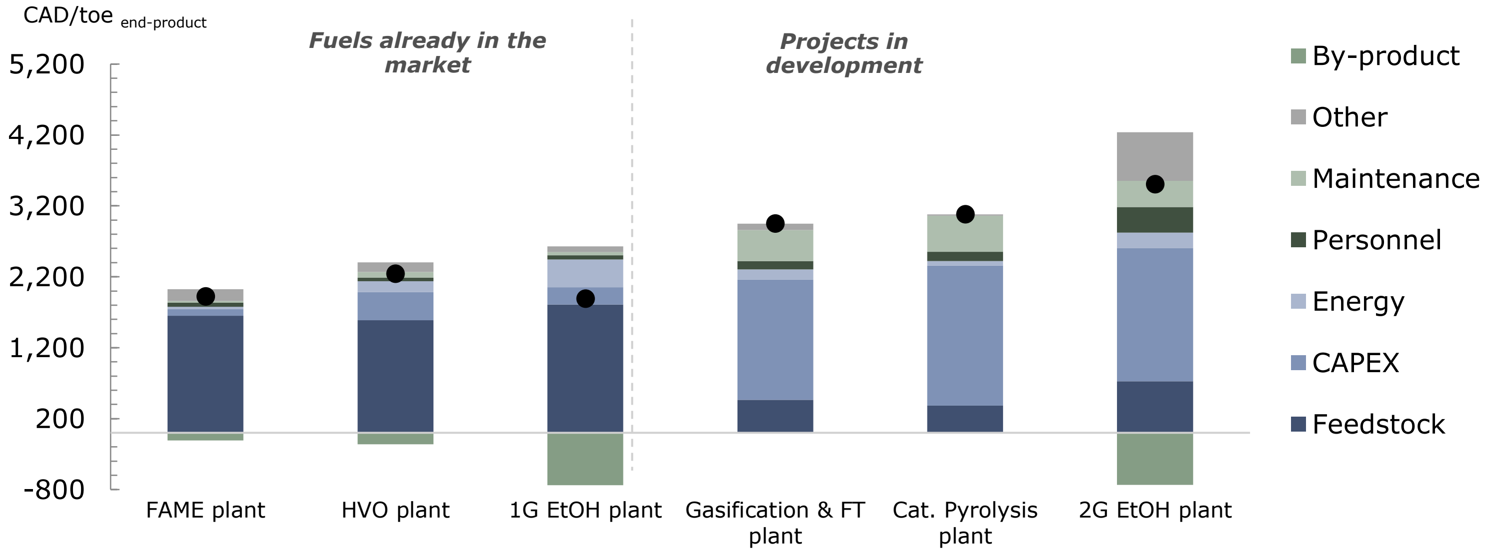
✓ Proven suitability for softwood ✗ Proven unsuitability for softwood ? Theoretically suitable for softwood but lack of operational examples

1. CAPEX corresponding to bio-crude production only; additional CAPEX for up-grading to fuels: 800–1,050 MCAD.

AFRY

High CAPEX cost make advanced biofuel plants unattractive in cost terms when compared to bio-oil plants with a total cost of 1890–2240 CAD/toe

COST BREAKDOWN COMPARISON OF THE SELECTED BIOREFINERIES [1,2,3]



Location						
Scale (million litres)	230	440	205	130	65	65
Feedstock	Rapeseed oil	UCO	Wheat	Wood residues	Wood residues	Wood residues
Production cost (CAD/toe)	1920	2240	1890	2950	3080	3505

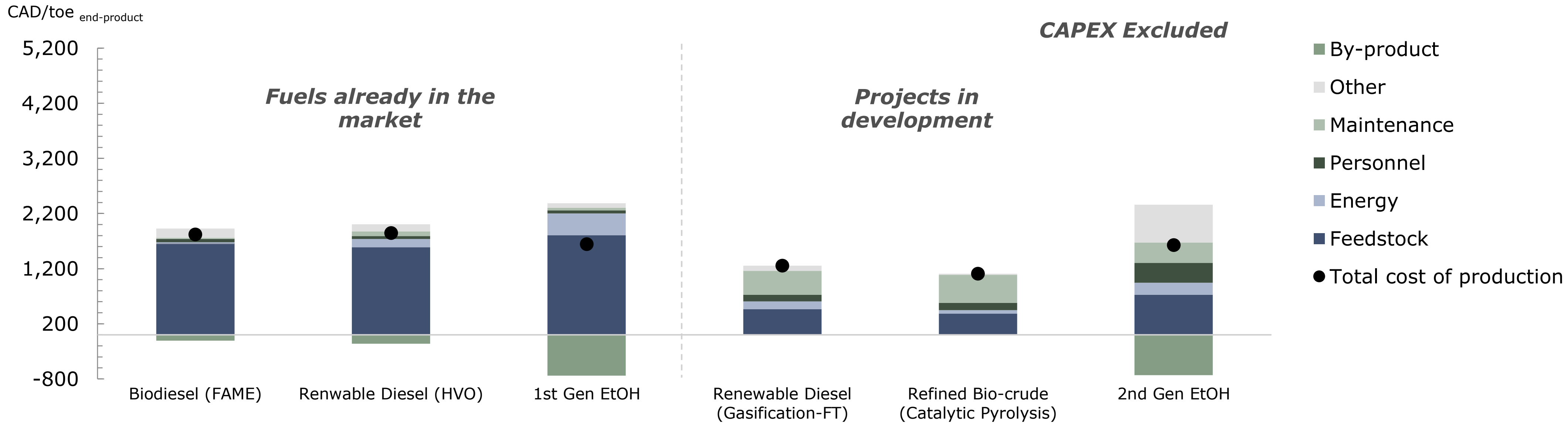
- Advanced biofuels from wood-based feedstocks are currently uncompetitive on a cost-basis mainly due to high CAPEX
- Production cost for FAME, HVO and 1G ethanol plants can be considered lower due to higher maturity in technology, operational excellence and supply chain development for the main process parts
- Total CAPEX cost can be reduced up to 40–50% in catalytic pyrolysis if the upgrading step in downstream is removed from the concept
- Competitiveness of advanced 2G ethanol is hindered due to elevated cost from operating materials, such as enzymes and chemicals, that are required for the process
- Governments are increasingly recognizing the role of advanced biofuels in decarbonizing the road transportation. Grants and tax incentives could help bridge the cost gap as advanced biofuel refineries scale up in the future

1. Cost breakdown calculations are based on 8% interest rate and pay-back time of 20 years. 2. List of by-products in each pathway: glycerol (FAME), naphtha (HVO), stillage (1G EtOH), lignin and biogas (2G EtOH). 3. Transportation costs are excluded from the total cost of production.

AFRY

Excluding CAPEX biofuels become an increasingly more attractive option, especially if production costs consider reductions in carbon emissions

COST BREAKDOWN COMPARISON OF THE SELECTED BIOREFINERIES [1,2,3]



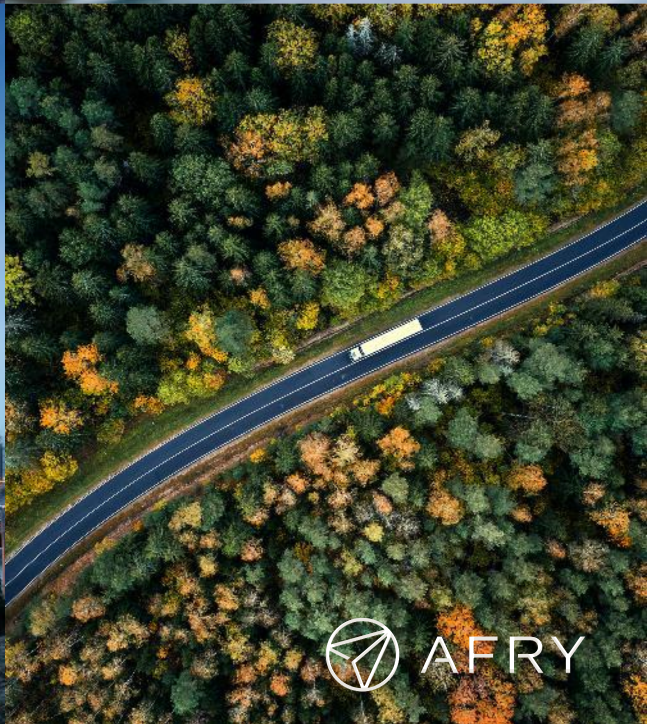
	Biodiesel (FAME)	Renwable Diesel (HVO)	1st Gen EtOH	Renewable Diesel (Gasification-FT)	Refined Bio-crude (Catalytic Pyrolysis)	2nd Gen EtOH
Location						
Scale (million litres)	230	440	205	130	65	65
Feedstock	Rapeseed oil	UCO	Wheat	Wood residues	Wood residues	Wood residues
Production cost (CAD/toe)	1820	1850	1645	1255	1110	1630

Canadian projects in development are theoretical

1. Cost breakdown calculations are based on 8% interest rate and pay-back time of 20 years. 2. List of by-products in each pathway: glycerol (FAME), naphtha (HVO), stillage (1G EtOH), lignin and biogas (2G EtOH). 3. Transportation and CAPEX costs are excluded from the total cost of production.

Contents

1. Key Findings
2. Wood Supply and Eligibility
3. Technology Pathway Assessment
4. **Biofuel Supply and Demand**
5. Biorefineries and Infrastructure Alignment

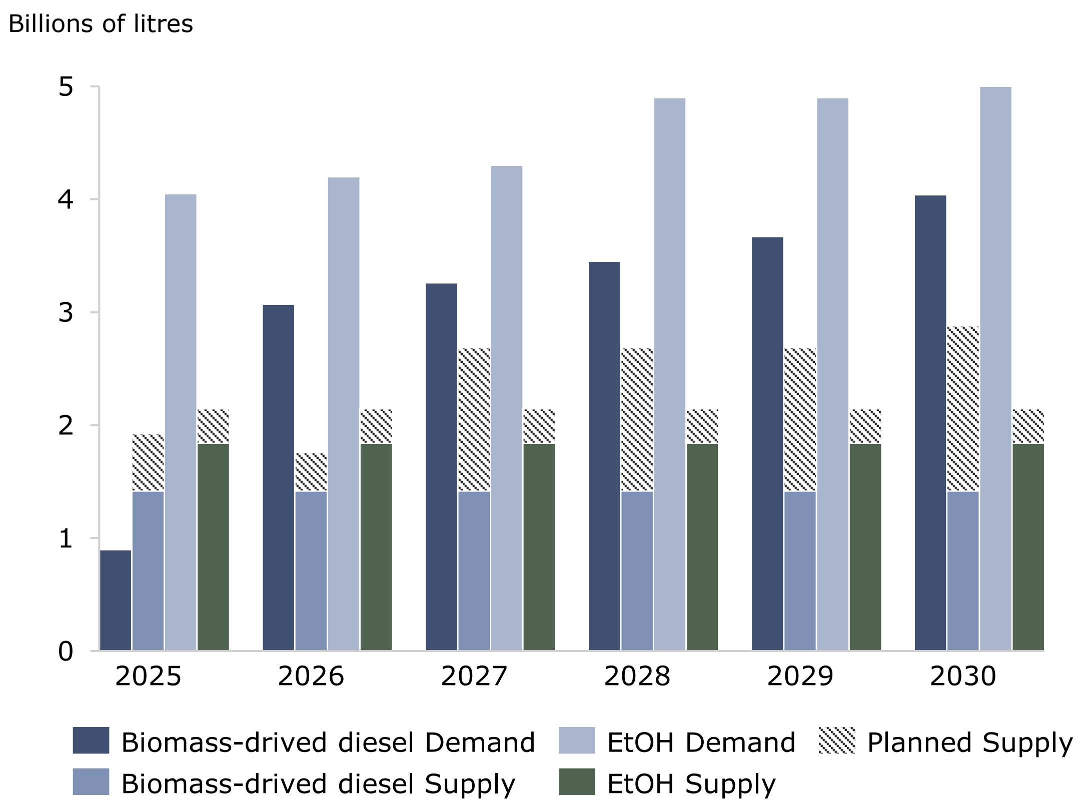


Blending requirements in Canada are driven by both federal and provincial policies, with some province-specific policies being more aggressive

BLENDING REQUIREMENTS IN CANADA

- Clean Fuel Regulation (CFR) in Canada is a federal policy that aims reducing greenhouse gas (GHG) emissions from liquid fuels. It requires fuel suppliers to gradually lower the carbon intensity (CI) of their fuels by blending renewable alternatives in diesel (min. 2%-vol.) and in gasoline (min. 5%-vol.) or using other emission-reducing strategies
- Province-specific low-carbon policies in Canada:
  - **Alberta:** Renewable Fuels Standard (RFS) requires 5% blend of renewable alcohol in gasoline and 2% of renewable content in diesel
  - **Manitoba:** The province requires 10% blend of ethanol in gasoline and 5% blend of renewable content in diesel
  - **Ontario:** Cleaner Transportation Fuels (CTF) regulation requires 11% of renewable content in gasoline and 4% blend of renewable content in diesel (2025)
  - **Saskatchewan:** Renewable Diesel Act (RDA) requires 7.5% blend of ethanol in gasoline and 2% blend of renewable content in diesel
  - **British Columbia:** Low-Carbon Fuel Standard (LCFS) requires 5% blend of renewable content in gasoline and 8% in diesel; Eligibility limited to only Canada-produced biofuels since April 2024 in diesel and since 2026 in gasoline
  - **Quebec:** mandates a minimum of 10% low-carbon fuel content in diesel by 2030, blending ethanol into 15% by 2030

BIOFUELS SUPPLY DEMAND[2] OUTLOOK IN CANADA

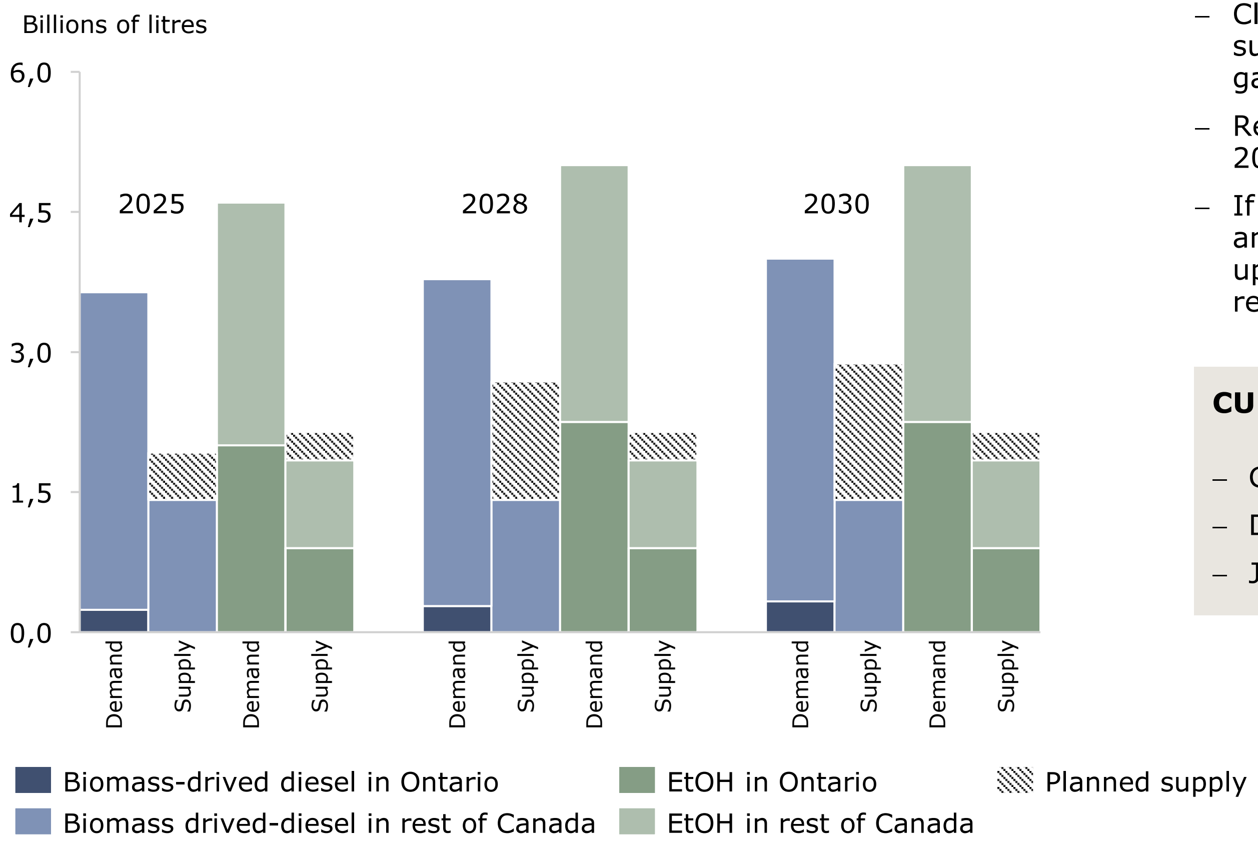


1. Supply presents the total RD and EtOH production in Canada, not considering the volume of biofuels being exported. 2. Demand for renewable diesel is implemented only for LCFS provinces (BC and QC) because the demand for other provinces is estimated negligible.
Source: Government of Canada website (current biofuels supply) and AFRY analysis (planned supply, biofuel demand)

AFRY

Blending requirements in Canada are driven by both federal and provincial policies, Ontario requires the blend 15% of renewable content in gasoline

BIOFUELS SUPPLY & DEMAND OUTLOOK IN ONTARIO



Source: Canadian Fuels Association

BLENDING REQUIREMENTS AND BIOFUEL SUPPLY IN ONTARIO

- Cleaner Transportation Fuels regulation in Ontario requires that fuel suppliers blend 15% of renewable content, such as bioethanol, in gasoline and 4% in diesel by 2030 and onwards
- Renewable content requirement for gasoline has increased to 11% in 2025 and continues increasing further to 13% in 2028
- If the feedstock remains unchanged, ethanol production via hydrolysis and fermentation has the lowest CI, as FT-synthesis and biocrude upgrading require hydrogen, which depends on its source (fossil vs. renewable)

CURRENT FUEL DEMANDS IN ONTARIO

- Gasoline demand: 16 billion litres/year
- Diesel demand: 6 billion litres/year
- Jet fuel demand: 2.5 billion litres/year

There are no publicly released and approved CIs for biofuels produced from wood-based feedstocks – LCA tool is needed for calculating new CI values

ACQUIRING CI VALUE FOR A SPECIFIC FUEL PATHWAY

- In Canada, Clean Fuel Regulations require CI values for compliance
  - CI defines the actual amount of biofuel needed for blending. The lower the CI value for a specific fuel type, the less biofuel is needed for blending
- California Air Resource Board (CARB) provides CIs for LCFS certified pathways that includes emissions from feedstock production, transportation, refining and combustion
  - CARB has not yet released approved CI values for any biofuels produced from wood fibre or wood waste. Thus, one must conduct a life cycle analysis (LCA) that would not underestimate the results
- Biofuel suppliers can use a LCA model provided by Environment and Climate Change Canada (ECCC) under the CFR or a third-party consultant to calculate CIs for emerging pathways. The ECCC's LCA model includes feedstocks from forest sector, such as wood fibres, wood chips, and wood pellets
  - The fuel supplier submits the new CI value for ECCC for approval to ensure that it complies with the CFR. Approved CI value for a specific pathway is published as an aggregated or anonymized data in the official list maintained by ECCC
- In RED III Annex V, estimated and typical default values for GHG reduction are presented for future biofuels that are not yet on the market. This list includes some pathways that use wood-based feedstocks

ESTIMATED AND TYPICAL GHG REDUCTION VALUES IN RED III

Biofuel production pathway	Greenhouse gas emissions saving – Typical value	Greenhouse gas emissions saving – Default value
Renewable diesel		
Waste wood FT diesel in free-standing plant	83%	83%
Farmed wood FT diesel in free-standing plant	82%	82%
Renewable petrol		
Waste wood FT petrol in free-standing plant	83%	83%
Farmed wood FT petrol in free-standing plant	82%	82%
Renewable methanol		
Waste wood methanol in free-standing plant	84%	84%
Farmed wood methanol in free-standing plant	83%	83%

Source: Government of Canada web page and RED III, Annex V

Canada has implemented the Clean Fuel Regulations set with a system for reducing the carbon intensity of the diesel and gasoline pools

THE CLEAN FUEL REGULATIONS (CFR)

- The Clean Fuel Regulations (CFR) are requiring gasoline and diesel suppliers to gradually reduce the carbon intensity (CI) of their fuels till 2030
  - The CFR applies from 1 July 2023 onwards on the federal level
  - Fuels that have a lower carbon intensity than the CI target generate credits and fuels with a higher carbon intensity than the CI target generate deficits
  - CI targets for diesel and gasoline pools decrease annually to promote continuous increase in the renewable fuels use
- Compliance credits can be created in three ways:
  - Undertaking projects that reduce the lifecycle carbon intensity of liquid fossil fuel (carbon capture and storage, on-site renewable electricity, co-processing)
  - Supplying low carbon intensity fuels (e.g., ethanol, biodiesel)
  - Supplying fuel or energy to advanced vehicle technology (e.g., electricity or hydrogen in vehicles)

THE CFR MAIN TARGET BY 2030

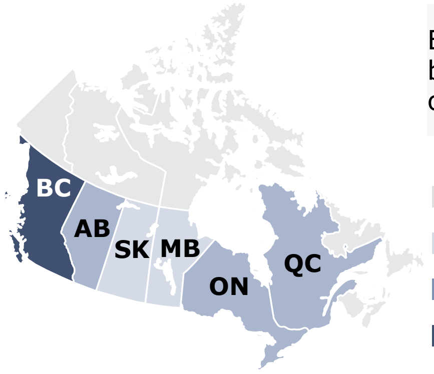
-15% CI basis

Min Vol. Require-ments

5% low CI fuel content in gasoline
2% low CI fuel content in diesel fuel and light fuel oil

PROVINCIAL POLICIES

- In addition to the federal CFR, six provinces have implemented province level renewable fuel policies
  - British Columbia has implemented the Renewable and Low Carbon Fuel Requirement, which mandates a 5% ethanol content in gasoline and 8% in diesel fuel. Similarly to California, the province has an active LCFS program with 30% CI reduction goal by 2030
  - Ontario has implemented the Cleaner Transportation Fuels Regulation (CTFR)
    - The CTFR mandates 11% renewable content in gasoline in 2025. This requirement is set to be increased to 15% by 2030 onwards. The CTFR requires 4% renewable content in diesel
    - The renewable content in gasoline must emit 45% less GHG emissions than fossil gasoline before 2030 and 50% from 2030. The renewable content in diesel must emit 70% less GHG emissions



British Columbia is the largest consumer of biofuels in Canada due to an implementation of the most advanced renewable fuel policies

- CFR
- CFR + Blending mandate
- CFR + Blending mandate + CI requirements
- CFR + Blending mandate + LCFS

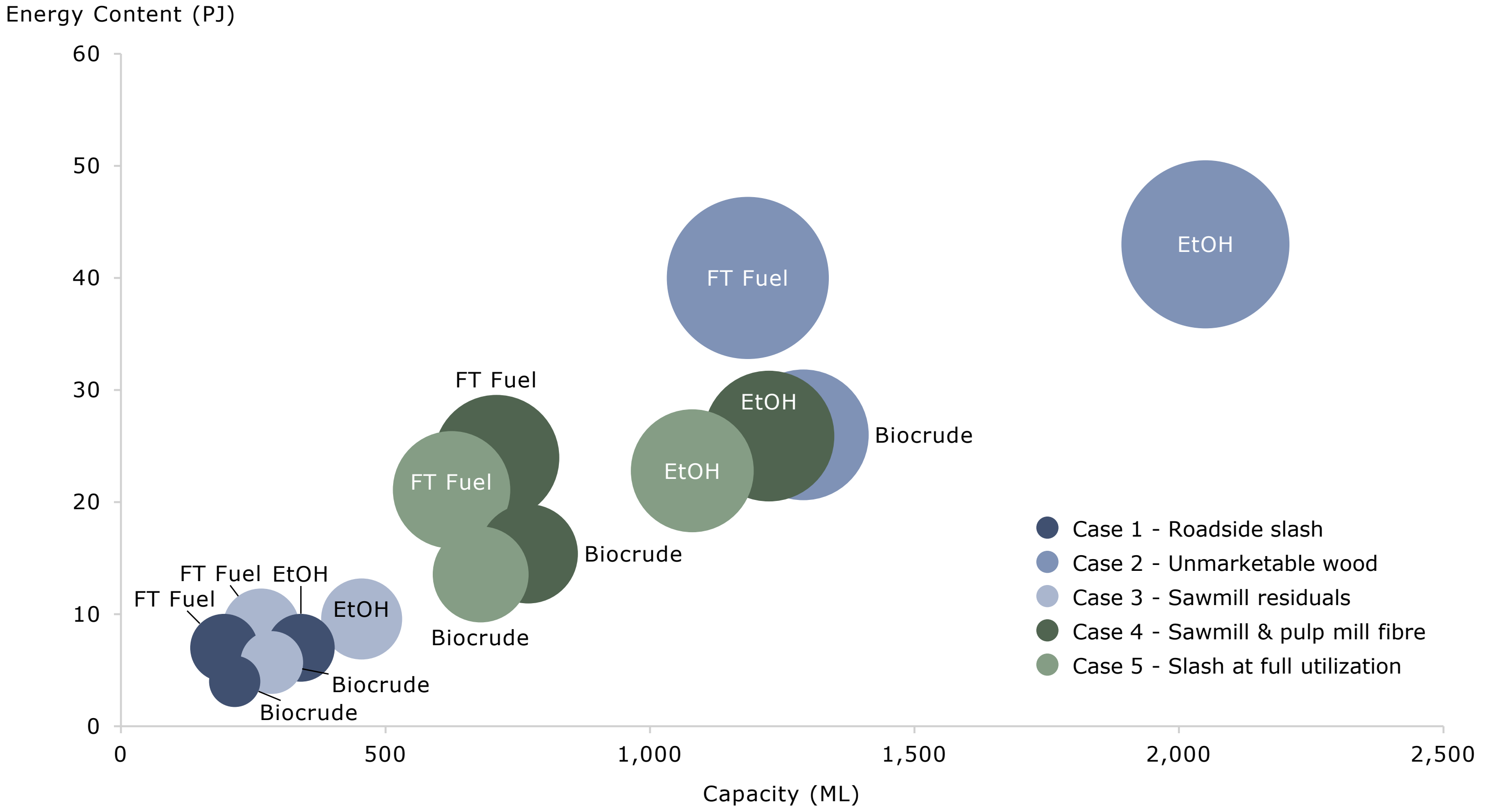
AFRY

Contents

1. Key Findings
2. Wood Supply and Eligibility
3. Technology Pathway Assessment
4. Biofuel Supply and Demand
5. **Biorefineries and Infrastructure Alignment**

The highest biofuel capacity of 2.1 BL can be reached by converting the unmarketable wood into ethanol through hydrolysis & fermentation

POTENTIAL BIOFUEL CAPACITIES FROM AVAILABLE WOOD SUPPLY[1]

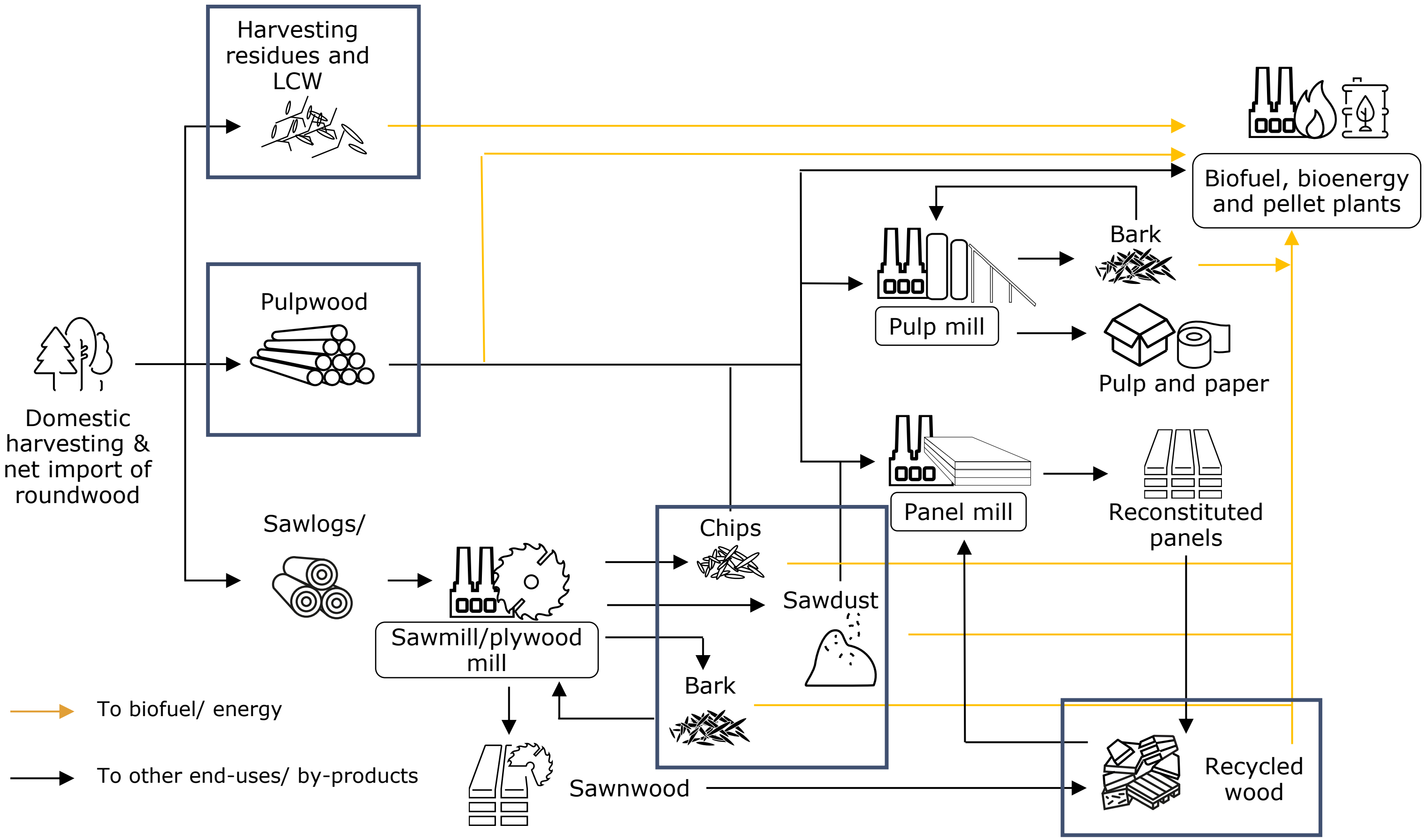


- The best biofuel capacity is obtained in each case by converting the available wood into ethanol through hydrolysis and fermentation, reaching 2.1 BL at the best by utilizing unmarketable wood
- Advantage with the ethanol pathway is that the applied wood-based feedstock do not require drying before processing, thus being able to utilize the full moisture content
- Bubble size on the left side graph is scaled based on the energy content of the potential biofuel volume
- Biocrude, as an intermediate, has the lowest energy content (19 GJ/ton) when comparing to ethanol and FT fuels
- Ethanol has a lower energy content compared to FT fuels, but it has significantly larger biofuel volume

1. Potential biofuel volumes are calculated based on the required feedstock moisture content: 10% for pyrolysis, 20% for gasification, and 100% for hydrolysis and fermentation.

The biofuel plant could be supplied by residues coming from harvests or other industries. Co-location at pulp mills could lower CAPEX

WOOD FLOWS FROM FOREST TO INDUSTRY PRODUCTS AND ENERGY USE [1)]



- The refinery facility could rely on forest residues coming directly from the forest harvests and industrial residues (such as bark and sawdust)
- It also can also utilize small diameter wood that lacks demand from the pulp industry
- Usually, residues being generated as harvest residues face lower competition but are more fragmented and challenging to mobilise
- On the other hand, industrial residues have higher competition but ready-to-supply chains
- In Ontario, the primary consumer of wood is the pulp and paper industry. However, due to closing of pulp mills there is excess available of pulpwood therefore, there is no balance between pulp wood and residuals available The balance is not there
- Sawmills wood products are a significant user of softwood logs residuals could add to the eligible feedstock portion

AFRY

Liquid biofuels supply chain extends from feedstock transport and handling to fuel manufacturing and upgrading, before final blending and distribution

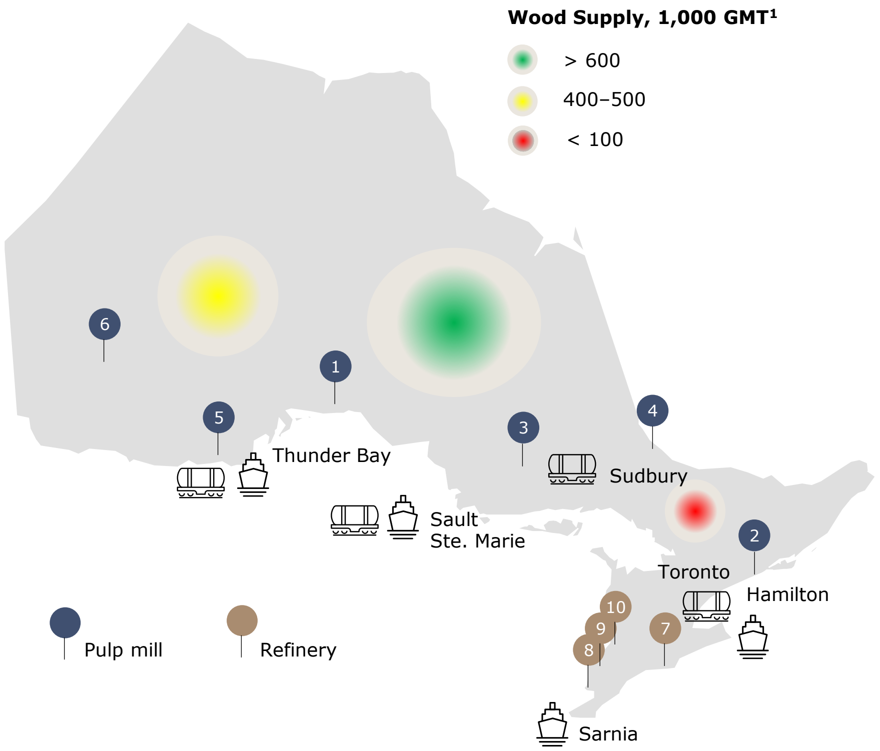
	Steps carried out at a pulp mill with upgraded assets					*Steps carried out at a refinery*		
	Feedstock origination	Transport	Storage	Feedstock pre-treatment	Biofuel manufacturing	Biofuel upgrading	Storage & blending	Distribution into sales channels
Role	– Regular monitoring of production dynamics and volume development – Secure of supply through term contracts	– Transport of demanded feedstocks to the point of use and/or to feedstock hubs	– Storage for import, export, distribution – Bridge of expected operational events	– Specific pre-treatment based on planned final product yields – Operation of pre-treatment facilities	– Ensure asset availability – Safe and reliable asset operation – Management of variable and fixed costs	– Upgrade of intermediates to market specifications – Enhance product quality and value	– Storage for import/export – Blending operation – Bridge of expected operational events	– Optimize sales and distribution across sales channels – Optimize cargo lots and transportation mode
Value generation	– Sourcing approach – Outside conditions (weather, water, soil, …)	– Logistics capabilities – Freight markets know-how	– Location – Accessibility – Capacity	– Technical set-up and capacities – Availability and reliability	– Technical set-up and capacities – Availability and reliability – Operation capabilities	– Technical configuration – Availability and reliability	– Location – Accessibility – Capacity – Blending	– Market know-how and assessment – Access to B2B and B2C channels

AFRY

Wood resources and pulp mills still in operation are distant from major petroleum refineries, impacting supply chain and logistics

WOOD SUPPLY HEATMAP IN ONTARIO

#	Company / Facility name	Status	Capacity kt/a
1	Aditya Birla / Terrace Bay	Shut/idle	940
2	Cascades / Trenton	Shut/idle	295
3	Domtar / Espanola	Shut/idle	625
4	Rayonier / Temiskaming	Shut/idle	320
5	First Quality Enterprises / Dryden	Operating	660
6	Atlas Holdings / Thunder Bay	Operating	1 350
7	Imperial oil / Nanticoke	Operating	4 935
8	Shell / Corunna	Operating	3 305
9	Imperial Oil / Sarnia	Operating	5 330
10	Suncor Energy / Sarnia	Operating	3 745



KEY TAKEAWAYS

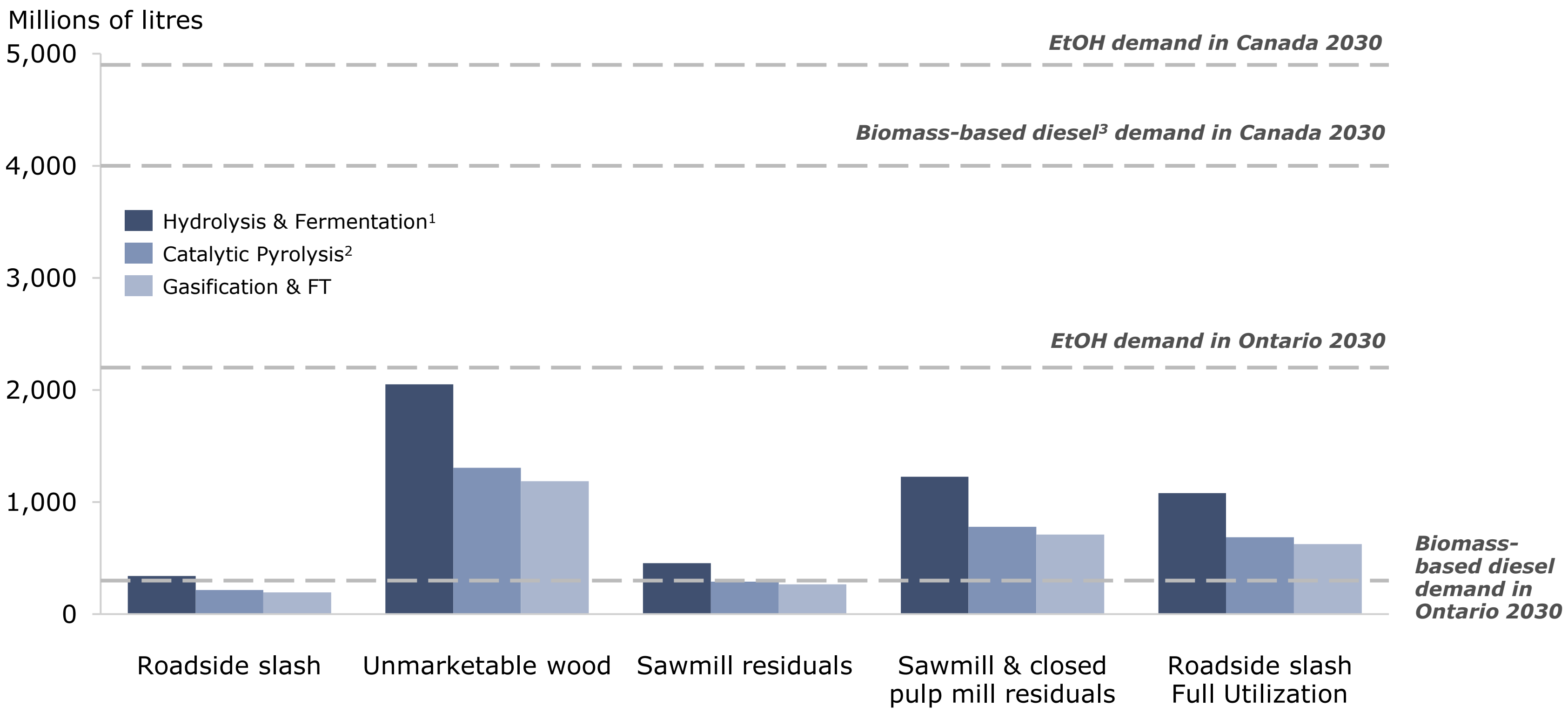
- AFRY has identified 6 pulp mills and 4 petroleum refineries in Ontario that are either in operation or shut/idled. Small demonstration projects are not included
- Current operating pulp industry is located northwestern Ontario near the largest supply volumes for wood
- Petroleum refineries are located in southern Ontario due to proximity of markets and logistical advantage from water routes and railway network. In addition, the main utilities, such as water and energy, are more accessible
- Railway is available to pulp mills throughout the north if they are on a main line from Toronto to Thunder Bay via Sudbury. However, the railway capacity is already stretched in Ontario and reaching its capacity limits
- Ontario has 4 main ports located in Thunder Bay, Sault Ste. Marie, Sarnia and Hamilton. All these ports are connected by the Great Lakes – St. Lawrence Seaway system (GLSLS)

1. Case 1 – Available roadside slash.

AFRY

Adding unmarketable wood to the biomass feedstock supply could meet 2/3rds of Canada's biofuel demand

WOODY BIOMASS POTENTIAL TO MEET CANADA'S BIOFUEL DEMAND IN 2030



Feedstocks are readily available and could support climate targets, reduces emissions, and strengthens rural economies.

This is a clear opportunity for Ontario to lead in renewable fuels while advancing both environmental and economic priorities

Unlocking this potential requires improved infrastructure and clear eligibility pathways.

1. Potential ethanol yield from woody biomass compared to the full ethanol demand (1G+2G) in Canada 2. Potential drop-in fuels yield from woody biomass compared to the renewable diesel demand in Canada. 3. includes renewable diesel, biodiesel and co-processing

Woody biomass could supply up to 50% of Canada’s renewable fuel demand

From the analyzed production technologies, catalytic **pyrolysis to biocrude would be the most attractive conversion pathway.** Co-location at a pulp mill opens opportunity for process integration and lower capital costs.

Advanced ethanol pathway requires hardwood feedstock and investment in a green field facility.

Integration of biorefineries with legacy pulp mill assets in Ontario presents a strategic opportunity to leverage existing infrastructure, skilled labor, and supply chains for cost-effective biofuel production

OPPORTUNITIES

- Under the most conservative scenario, biomass could supply approximately 10% of Canada’s renewable liquid fuel demand.
- In a more favorable scenario, biomass could support up to **50%** of the country’s renewable liquid fuel needs.
- In the best-case scenario, developing new advanced biorefineries to convert the available wood supply into renewable fuels could create more than **2,000 new jobs**[1] — not including additional employment in forestry and harvesting sectors.

RISKS

- Insufficient sources of funding and regulatory support could limit the financial viability of these capital-intensive production pathways.
- Uncertainty in the biomass supply chain stability could impact consistent feedstock availability and pricing.
- Complex regulations around feedstock eligibility could further delay project development.
- Delayed engagement with potential project partners could hinder collaboration opportunities and project momentum.

1. Job creation estimate is derived from a high-level technical analysis of renewable diesel production via gasification–Fischer-Tropsch (FT) technology, assuming a facility configuration that processes "unmarketable wood" as the primary feedstock.

Clearer, faster policy pathways are key to scaling low-carbon wood-based fuels in Ontario

Accelerate approvals: Reduce certification approval process for the new production pathways

Clarify carbon intensity: Set clear, science-based CI benchmarks for wood-based fuels

Support LCA development: Provide support mechanisms for validating LCAs of new low-CI fuel pathways

Focus on volume: Use concrete biofuel output and wood tonnage, not just % targets, to convey real economic impacts

From forest to fuels: *Driving jobs and growth*

Investing in bio-crude facilities in northern Ontario can generate up to $500 million per site, create jobs, and revitalize forest-dependent communities

By optimizing forest use and establishing bioeconomy hubs, the province can strengthen its forestry sector, support rural economies, and meet growing market demands sustainably

AFRY

Contents

1. Key Findings
2. Wood Supply and Eligibility
3. Technology Pathway Assessment
4. Biofuel Supply and Demand
5. Biorefineries and Infrastructure Alignment

Definitions of technology readiness levels

TRL	DEFINITION
9	Actual system proven in operational environment, commercial scale manufacturing
8	System complete and qualified
7	System prototype demonstration in operational environment
6	Technology demonstrated in industrially relevant environment
5	Technology validated in industrially relevant environment
4	Technology validated in laboratory
3	Experimental proof of concept
2	Technology concept formulated
1	Basic principles observed

TRL = Technology readiness level

AFRY

Contact Information

ALEXANDER KOUKOULAS, Ph.D.
Director

Savannah, GA | USA
E-mail: alexander.koukoulas@afry.com
Phone: +1 617 407 4266

MARYAM AREFMANESH, Ph.D.
Senior Consultant

Toronto, ON | Canada
E-mail: maryam.arefmanesh@afry.com
Phone: +1 438 862 7815

AFRY

AFRY