The C-SAF Roadmap

Building a feedstocks-to-fuels SAF supply chain in Canada

in partnership with

C-SAF

The Transition Accelerator L'Accélérateur de transition

energyfutureslab

Authorship team

Bentley Allan
Transition Pathway Principal,
The Transition Accelerator
Lead Author

Jonas Goldman
Senior Research Associate,
Net Zero Industrial Policy Lab

Geoff Tauvette
Executive Director,
C-SAF

Facilitation and Strategy

Pong Leung
Senior Associate,
Energy Futures Lab

Juli Rohl
Lead Animator,
Energy Futures Lab

Cover images:
David Vincent Villavicencio / Unsplash
Dylan McLeod / Unsplash

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About us

The Canadian Council for Sustainable Aviation Fuels (C-SAF) is a not-for-profit organization that aims to accelerate the commercial production and deployment of SAF in Canada by catalyzing the ecosystem and value chains, promoting public policy, strategies and a roadmap, acting as a neutral and balanced technical expert, and serving as the voice of its members to government and non-government stakeholders on SAF issues. C-SAF was created by a consortium of 60 domestic, international and cargo airlines operating in Canada who own and operate aviation fuel storage and distribution facilities at 11 international airports across Canada. C-SAF is comprised of 110 members who represent key industry leaders that are committed to advancing SAF production and use in Canada.

c-saf.ca

The Transition Accelerator exists to support Canada's transition to a net-zero future while solving societal challenges. The Transition Accelerator works with innovative groups to create visions of what a socially and economically desirable net zero future will look like and build out transition pathways that will enable Canada to get there. The Accelerator's role is that of an enabler, facilitator, and force multiplier that forms coalitions to take steps down these pathways and get change moving on the ground.

transitionaccelerator.ca

The Energy Futures Lab was created to address a growing sense of polarization in Canada. Since its inception in 2015, the EFL has brought together stakeholders from across the energy system to collaboratively develop solutions for a low-emissions energy future. This approach has highlighted the importance of drawing on diverse perspectives to address complex, system-level challenges.

energyfutureslab.com

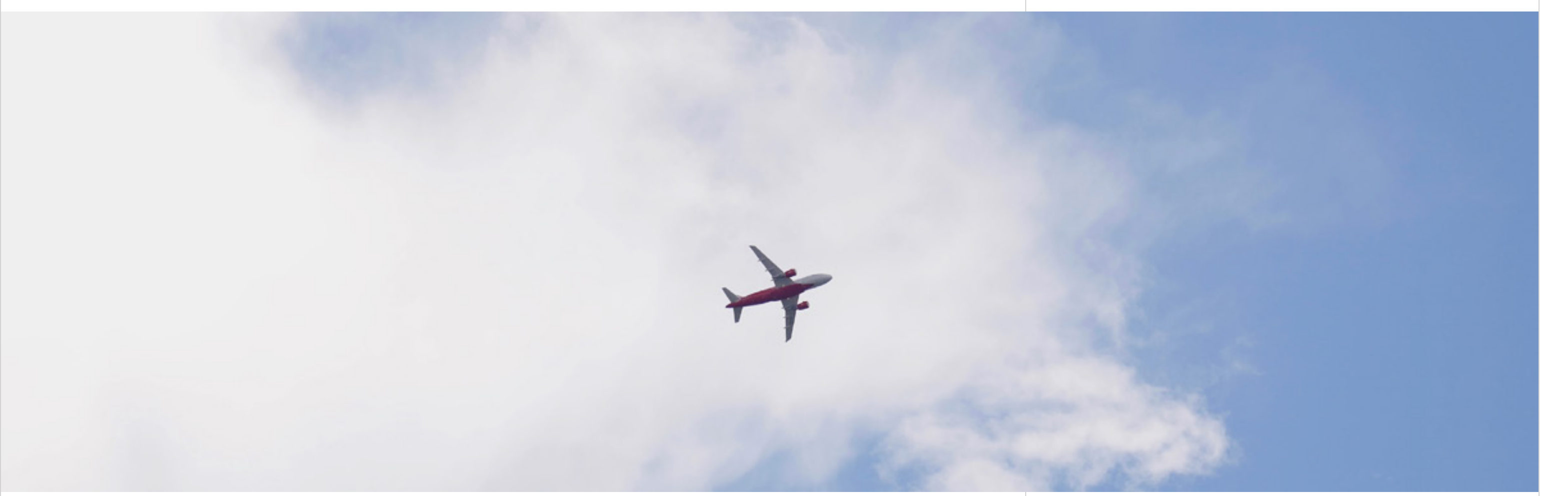
About this report

The Canadian Council for Sustainable Aviation Fuels (C-SAF) was created by leaders from over 60 airlines operating in Canada seeking to bring together key industry stakeholders and government to advance the commercial production and use of Canadian-made low-carbon and sustainable aviation fuels (SAF) in Canada. C-SAF has catalyzed an ecosystem with more than 45 additional stakeholders with insights from across the SAF value chain including refiners, airports, feedstock providers, biofuels companies, aerospace manufacturers, academia, and other related companies.

One of C-SAF's first missions was to develop a Roadmap to create a SAF market in Canada including setting targets and identifying concrete actions, investments, and priorities. To accomplish this, C-SAF collaborated with The Transition Accelerator, and the Energy Futures Lab to plan, design and develop a Roadmap approach. Several workshops were organized to solicit input, active feedback, and recommendations of C-SAF members across the Canadian SAF supply chains with the overarching goal to give C-SAF and its members a clear, concrete set of actions and priorities it could undertake to advance SAF in Canada.

C-SAF collaborated with The Transition Accelerator, and the Energy Futures Lab to plan, design and develop a Roadmap approach.

This work was designed to build on earlier efforts on SAF in Canada. Deloitte's report Reaching Cruising Altitude: A Plan for Scaling Sustainable Aviation Fuel made the case for Canadian SAF and reviewed existing work to date. It also laid out barriers and action plans in four key areas: policy and funding, leadership and accountability, accounting and reporting, and partnerships and collaborations.



These action plans identified a number of critical actions:

1. **Develop and evaluate Canadian policy approach.**
2. **Analyze inter-sectoral feedstock allocation, including data-based analysis of food vs. fuel debate.**
3. **Mobilize partnerships with Indigenous communities and organizations.**
4. **Activate clear federal accountability and coordination across agencies.**
5. **Align Canadian lifecycle methodologies and trading marketplace to global standards.**

In addition to incorporating key insights from the Deloitte work, this roadmap also builds on industry reports and other SAF roadmaps that lay out the feedstock and technology pathways for SAF and policy frameworks that support SAF development and implementation.

This Roadmap explores each of these critical elements in more detail. But this Roadmap goes beyond earlier Canadian studies by taking a deep dive into feedstock availability, technology pathways, and potential supply chains to develop a SAF market in Canada. This will allow C-SAF to build the coalitions necessary to identify project-level opportunities, barriers and risks.

Such a focus is also important because advancing SAF in Canada requires a strategy centered on regional value chains that bring together feedstocks, technologies, refineries and consumers at the project level. Such value chains will deliver the economic benefits necessary to build support for robust climate action in the aviation sector.

We must go beyond an emissions reductions paradigm to think about how we build long-term support for deep decarbonization.

But the broader contribution of this report is to put aviation decarbonization in a new frame: Canada must seize its economic opportunities in the SAF supply chain. We must go beyond an emissions reductions paradigm to think about how we build long-term support for deep decarbonization. That is done by building a broad coalition of citizens and firms that benefit from climate action.

This framing is even more important when considered in light of the rise of net-zero industrial policy across the world.[1] Industrial policy is any set of measures intended to build or shape an industry. Net-zero industrial policy seeks to advance the technologies and firms we'll need to decarbonize the global economy. It is about acting strategically to position Canadian resources and firms in rapidly forming global value chains.

Now is the time to build a whole supply chain that would add value to the Canadian economy.

SAF provides an opportunity to build new net-zero economic prospects and to decarbonize the aviation industry while simultaneously enhancing energy security.

Abbreviations

ASTM	ASTM International
ATAG	Air Transport Action Group
AtJ	Alcohol-to-jet
BC LCFS	British Columbia's Low Carbon Fuel Standard
BC-SMART	The British Columbia Sustainable Marine, Aviation, Rail and Trucking
CAAFI	Commercial Aviation Alternative Fuels Initiative
CAGR	Compound annual growth rate
CCUS	Carbon capture, utilization, and storage
CFR	Clean Fuel Regulations
CI	Carbon Intensity
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
C-SAF	The Canadian Council for Sustainable Aviation Fuels
DAC	Direct air capture
eFuels	Electrofuels
ETC	Energy Transitions Commission
EV	Electric vehicle
FID	Final investment decision
FOAK	First-of-a-kind
FT	Fischer-Tropsch
GREET	The Greenhouse gases, Regulated Emissions, and Energy use in Technologies
GWP	Global warming potential
H_2	Hydrogen
HDRD	Hydrogenation-derived renewable diesel
HEFA	Hydro processed fatty acids
HTL	Hydrothermal liquefaction
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IEA	International Energy Agency
IRA	Inflation Reduction Act
LCA	Life-cycle analysis
LTAG	Long-term global aspirational goal
LUC	Land use change
MSW	Municipal solid waste
NRCAN	Natural Resources Canada
ODT	Oven-Dry Tonnes
OEM	Original Equipment Manufacturer
PtL	Power-to-liquids
R&D	Research and development
RIN	Renewable identification number
RVC	Regional Value Chain
SAF	Sustainable Aviation Fuels
SOC	Soil Organic Compound
TRL	Technology Readiness Level
UCO	Used cooking oil
WWTP	Wastewater treatment plants

Units

g	grams
ML	millions of litres
Mt	millions of tonnes
t	tonnes

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Summary

Sustainable aviation fuel (SAF) is an essential part of decarbonizing aviation.[2] Compared with other sectors which have multiple technology options, SAF is the only viable pathway for long haul aviation (which comprises the majority of sector emissions) in the coming decades. SAF is a critical piece of Canada's Aviation Action Plan, which lays out a 2050 net-zero vision for the industry.[3]

Canada has enormous opportunities in the SAF supply chain: bountiful sustainable feedstock, existing refining capacity, innovative technology providers, and domestic and international airlines seeking to decarbonize.[4] Building the whole supply chain would add value to the Canadian economy. In particular, adding manufacturing capacity to rural communities would create skilled jobs and help to build innovation economies in these important regions.

SAF is a critical piece of Canada's Aviation Action Plan, which lays out a 2050 net-zero vision for the aviation industry.

SAF provides an opportunity to strengthen the Canadian economy by building new future proof economic opportunities and decarbonizing the aviation sector while enhancing energy security. The Russian invasion of Ukraine has illustrated the importance of creating supply chains that are resilient to geopolitical shocks.

How can these opportunities be converted into a large and healthy SAF ecosystem that delivers long-term economic value-added across Canada?

This roadmap charts a pathway and a strategy to produce truly sustainable and affordable SAF in Canada with Canadian feedstock and clean energy, using made-in-Canada solutions that aim to promote Canadian technology.

Targets

Canada's Aviation Action Plan lays out a clear and ambitious goal: by 2030, SAF should be 10% of projected Canadian jet fuel use.[5] Based on this goal and the total market for jet fuel in Canada, C-SAF has established a target of 1 billion litres of SAF production by 2030. This SAF should achieve a minimum 50% reduction in life cycle greenhouse gas emissions compared to conventional jet fuel which would represent a reduction of about 1.6 million tonnes of GHG emissions[6].

There is no SAF being produced today in Canada. The good news is that several companies have announced biofuels facilities that could produce at least 500 million litres of SAF in Canada by 2030.

However, it is important to note that most of these announced facilities have not yet reached final investment decision, and there is no guarantee that the facilities would use Canadian feedstocks or that any biofuels they produce end up in the Canadian market. Moreover, many of these facilities are planning to produce renewable diesel and, without proper incentives, may not include any SAF capacity at all. Even if they include SAF capacity, the SAF fraction they produce will depend on the economics and the ability to meet SAF sustainability criteria. So, the 500 million litres we bank on here is an optimistic scenario.

How can we meet the targets and build regional supply chains that benefit all of Canada while decarbonizing aviation?

Canada's opportunity and strategy

We need to seize Canada's opportunities in the SAF supply chain. With the right economic environment, Canada can build resilient, innovative SAF value chains with the goal of meeting demand and emissions reduction requirements for all airlines flying in and out of Canada and generating exports.

An original analysis for this roadmap concludes that **Canada has sustainable biomass for 7–10 billion litres of SAF a year.**[7] This amount, if prioritized for aviation, is about what Canada would need to meet total aviation fuel demand in 2030. But Canada also has the potential to use abundant clean electricity and low carbon hydrogen to produce sustainable jet fuel. So, while in the short-run Canadian SAF should remain available for use in Canada, Canada has the potential to produce additional SAF for export, if the strategy is managed and executed properly.

Canada's opportunity is unique because it has firms that are positioned in all parts of the renewable fuels value chain. Every region of the country can build efficient, homegrown feedstocks-to-fuels value chains that could support the production of SAF and the creation of low-carbon aviation hubs at the airports.

In feedstocks, Canada has opportunities across all SAF pathways. In the short-run, commercial volumes will be dominated by HEFA-based SAF from oilseeds. But to scale SAF to meet the 1 billion litres SAF target in 2030 and beyond, we need technologies and projects that activate Canada's strengths in forest and agriculture residues, municipal solid waste, ethanol, and power-to-liquids. All feedstocks and potential value chains must be activated to meet these targets and realize the potential. Furthermore, Canada must evaluate and demonstrate the environmental and socioeconomic impacts of SAF production in Canada and strive to ensure that life cycle methodologies are standardized for use across jurisdictions including the eligible fuel sustainability requirements under CORSIA[8].

In refining, Canada has world-leading expertise in hydrocarbons and green chemistry. Canadian refiners such as Parkland, Tidewater, Shell, Imperial Oil, Irving Oil and Suncor to name a few are all exploring how they might convert their expertise and facilities to produce SAF.

In technology, Canada has a wide range of technology providers leveraging the country's expertise such as Enerkem, Forge, Steeper, Ensyn, Expander, Carbon Engineering, and SAF+. Positioning these firms as world-leading technology providers would add economic value and create the basis for an innovation ecosystem that produces benefits over the whole energy transition.

However, the key global players are gearing up to produce SAF at scale. The EU has a hard SAF blending mandate that is driving investment in SAF production. *The Inflation Reduction Act* ("IRA") creates incentives that make the US biofuels and SAF production investment climate more attractive than Canada's. This creates a real danger: Canadian feedstocks will be pulled into the US to make SAF and Canada will lose the economic value-added of fuel production. And if the refining and conversion moves to the US, then so too will the innovation ecosystem. The IRA is a serious problem for Canadian competitiveness and threatens to reduce Canada's contribution to a friendly provider of raw feedstock.

Canada has neither clear supply-side production incentives nor a mandate to help build the SAF market—just a nascent voluntary credit market under the Clean Fuels Regulation. From an investor perspective, it is simply impossible to bank a project with completely unknown credit values or uncertain regulations.

In the absence of Canadian-produced SAF supply, most of the SAF required by the aviation sector to meet their decarbonization objectives will need to be imported. But relying solely on imports is unstable and cost uncompetitive given that SAF production is limited even on a global scale and other jurisdictions are adopting positive supply incentives that support production and uptake of SAF production locally.

The strategy underlying this roadmap is to activate all sustainable feedstocks and pathways to build SAF regional value chains that create long-term economic value and innovation capacity.

Canada needs to respond with a clear strategy and concrete action plan. Canada must do three things to compete and capture SAF economic value-add:

- incentivize the production and use of SAF in Canada;
- prioritize sustainable feedstocks for SAF production and ensure demand-pull to develop the supply chains in key areas of competitive strength;
- position its technology providers in global markets with programs that support the scaling of Canadian firms.

Without doing all three, Canada could end up with a thin SAF industry that does not take advantage of Canada's opportunity to strengthen its economy while building an industry that is critical to achieving net-zero aviation.

The strategy underlying this roadmap is to activate all sustainable feedstocks and pathways to build SAF regional value chains that create long-term economic value and innovation capacity. In practical terms, Canada can make the most of Canada's existing HEFA-based renewable diesel capacity to produce SAF now. At the same time, we need to deploy feedstocks and technologies today so that forestry and agricultural residues can produce SAF at scale during the 2030s. We also need to advance power-to-liquids pathways, that produce SAF from low carbon energy and hydrogen, so they can scale in the 2030s.

This strategy depends on two key pieces: a Policy Package and a Flight Plan for SAF outlining a potential project portfolio that balances the goals of producing volumes now while developing innovative pathways for the future.

A Policy Package for SAF

It is beyond the scope of this report to specify a complete policy package, but it is clear that to seize the considerable opportunities for Canada, we must incentivize SAF production with a multi-pronged policy package and explore how federal and provincial measures can be further leveraged to enable and accelerate a SAF market in Canada:

	OBJECTIVE	ACTIONS TO DATE
1	SAF to generate credits in low carbon fuel standards as a voluntary opt-in	Canada Clean Fuel Regulations in force since June 20, 2022, include provisions for SAF to generate credits[9]
2	Provide SAF-specific production incentives (at a higher level than renewable diesel), such as the SAF producers tax credit in the *Inflation Reduction Act*	The federal government has indicated intentions to engage with industry in 2023 to explore opportunities to promote the growth of biofuels in Canada[10]
3	Waive all federal and provincial carbon tax on SAF that meets a certain minimum carbon intensity standard	Draft regulations amending the federal Fuel Charge Regulations[11] to exempt SAF
4	Federal procurement of SAF for federal fleets to support increasing market demand	Treasury Board Canada was awarded $228 million over 8 years to implement a low-carbon fuel procurement program for the federal air and marine fleets[12]

Our feedstock projections rely on fuel production processes that generate high SAF fractions: 40–77% depending on the pathway.[13] That is only going to happen if there is a strong incentive to produce SAF over and above regular renewable diesel.

The key is to kickstart the market now, in order to drive the technology deployments that will bring down costs. A market can be kickstarted by supply-side incentives or by demand-side regulations and mandates.

The key is to kickstart the market now, in order to drive the technology deployments that will bring down the cost of SAF.

A mandate will drive up costs unless supply chains are incented and developed enough to scale with the mandate.

In the absence of a volumetric mandate, supply-side incentives can deliver volumes if they enable the production of SAF at prices on par with regular jet fuel, or a small premium.[14] The US Department of Energy's SAF Grand Challenge makes this bet. It is premised on the idea that existing incentives plus the *Inflation Reduction Act* can drive the production and uptake of SAF.

Canada needs incentives to create a level playing field with the United States. But part of the Canadian package will include credits from the CFR and carbon market. These have uncertain values. But in the 2022 Fall Economic Statement, the Government of Canada announced that the Canada Growth Fund will be able to write contracts for difference at the project level and in Budget 2023, the government will consult on the development of a broad-based approach to carbon contracts for difference that aims to make carbon pricing even more predictable. This means that projects will be able to negotiate contracts that guarantee a certain credit level for the project. If the credit level rises above the agreed strike price, then the government would keep the proceeds. If the credit level goes below the strike price, the government would pay the difference. This could be a key tool to get projects to final investment decision now.

The four-part policy framework must be supported by a robust and science-based sustainability framework. Incentives must be indexed to carbon intensity scores to encourage carbon reductions. But we also have to meet criteria for ecosystem productivity, erosion, biodiversity, and other sustainability standards as considered by CORSIA. This is key to Canada's competitiveness in global markets, which will reward low-carbon and ecologically robust practices up and down the supply chain.

Production Facility For Ethanol Biofuel.

A Flight Plan for SAF: Projects and timelines

This roadmap is premised on a target of 1 billion litres of SAF by 2030 with a minimum 50% reduction in lifecycle GHG emissions compared to conventional fossil-based jet fuel in accordance with an approved lifecycle GHG methodology such as ICAO or equivalent. But this target, which represents 10% of all jet fuel use in Canada is just a waypoint on the way to net-zero. By 2035, Canada should be ready to produce SAF to meet 25%

This roadmap is premised on a target of 1 billion litres of SAF by 2030 with a minimum 50% reduction in lifecycle GHG emissions.

of total jet fuel demand which would reduce emissions by 15–20% for departures from Canada[15].

In order to decarbonize Canadian aviation while seizing the considerable economic opportunities in the supply chain, Canada has to meet that 2030 target by building an ecosystem that is ready to scale. That ecosystem will only be ready to scale if we create demand-pull on nascent supply chains for the Canadian feedstocks that will be critical for long-term goals: oilseeds and waste fats, forest residues, agricultural residues, and the hydrogen and carbon dioxide streams needed for power-to-liquids. Projects in each of these areas are needed to prime supply.

The Flight Plan to 2030 is to produce real SAF volumes while creating the conditions for lift-off after 2030. Moreover, since the global SAF value chain will be highly competitive over a long transition, innovation capacity must be built in from the beginning. That innovation capacity will ensure Canadian production is competitive over time.

There are then three objectives to balance:

1 Decarbonize now

Maximize SAF now from commercial ready pathway

2 Feedstock activation

Establish commercial pathways for all Canada's feedstocks

3 Innovation drive

Launch demonstrations with homegrown technology in multiple pathways

The key is to realize each of these objectives at the project level. We could construct pathways that maximize each individual goal. A strategy emphasizing decarbonization now would focus on the HEFA pathway, because it is an already proven commercial technology, while advancing gasification with Fischer-Tropsch on wood residues, which is a key emerging pathway. To activate feedstocks, commercial scale projects for agricultural residues and power-to-liquids are needed. An innovation drive would involve building multiple demonstrations to advance other feedstocks and pathways such as hydrothermal liquefaction and alcohol-to-jet.

A project pipeline ready for take-off after 2030 needs to do all three. The **SAF take-off portfolio** proposed here points to the concrete projects necessary to achieve all these goals and articulates the priority actions needed to incentivize these projects. In short, Canada must push for as much HEFA-based SAF as possible now, site as many new commercial pathways as possible that use advanced feedstocks, and seed demonstrations in next generation areas with Canadian technology providers where feasible.

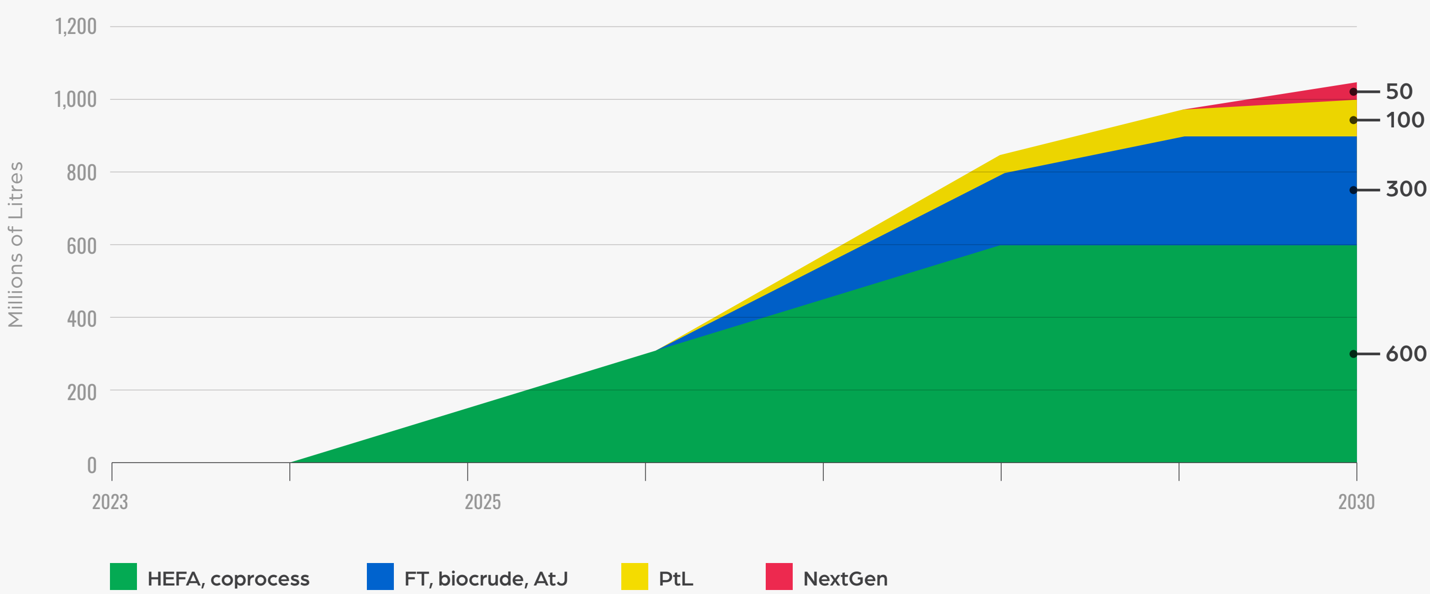
SAF TAKE-OFF PORTFOLIO:	
Advance decarbonization, feedstock, and innovation goals	
HEFA	600 ML
Forestry (FT)	200 ML
Ag residue (FT)	100 ML
PtL	100 ML
Next Gen Demonstrations	50 ML
2030 SAF Production	**1,050 ML**

PRIORITY ACTIONS:

- » Ensure policies and programs support final investment decision and maximum SAF fraction for proposed facilities.
- » Validate the sustainability of Canadian oilseed HEFA to meet CORSIA Eligible Fuel criteria
- » Build upstream collection and delivery logistics for forestry and agricultural residues.
- » Secure demonstration funds.
- » Create long-term industrial and innovation strategy.

Notes: HEFA—SAF from oilseeds, tallow, used cooking oils, fats and greases; Forestry (FT)—wood residues via gasification and Fischer-Tropsch; Ag residue (FT)—agricultural residues (straw and stover) via gasification and Fischer-Tropsch; PtL—power-to-liquids using CO_2 and hydrogen. Next generation demonstrations include: Forestry (HTL)—wood residues via hydrothermal liquefaction; Cellulosic (AtJ)— biomass residues via alcohol-to-jet; and CO_2 (AtJ)—CO_2 via alcohol-to-jet.

FIGURE 1. SAF TAKE-OFF PORTFOLIO – POTENTIAL SAF VOLUMES FROM PATHWAYS



Action Plan and Next Steps

It is time to get to work. With this roadmap, C-SAF and its partners in government, industry, and civil society can build the regional value chains that will activate Canadian feedstocks, incentivize Canadian refining, and boost Canadian technology providers while producing the SAF needed to start decarbonizing aviation now.

In short, Canada must push for as much HEFA-based SAF as possible now, site as many new commercial pathways as possible that use advanced feedstocks, and seed demonstrations in next generation areas with Canadian technology providers where feasible.

This report highlights concrete actions in five SAF Action Areas: feedstock, SAF production, technology and innovation, sustainability, and policy and programs. These actions require collaboration among all members of the ecosystem. The long-term success of the Canadian ecosystem depends on building strategic collaborations that go beyond this roadmap. Best practices from other jurisdictions suggest that public-private partnerships independent from both government and industry are needed to ensure success.[16]

C-SAF is well positioned to bring together the broad coalitions necessary to deliver on these priorities. To do this, C-SAF will create implementation Task Forces that bring together government, industry, indigenous communities, and experts to work together to advance policy and programs, articulate the sustainability case, build SAF supply chains, and advance a long-term industrial strategy for the aviation sector.

The following C-SAF 2 year Action Plan sets out the priorities that each Task Force will focus on to progress the five SAF Action Areas.

C-SAF 2 year Action Plan (from June 2023 to May 2025)	
POLICY AND PROGRAMS	» Advance a policy package that will incentivize the investment needed to meet 2030 and longer-term SAF targets. » Ensure that federal and provincial funding programs take an active role in supporting innovative SAF production here in Canada, including final investment decisions and maximum SAF fractions for proposed facilities. » Build the strategic collaborations necessary to advance a successful long-term industrial policy for SAF and aerospace development in Canada. » Develop a Canadian SAF registry (book and claim SAF accounting system).
SUSTAINABILITY	» Map the GHG emissions footprint from all steps of cultivation, collection and production of biomass and CO_2 derived SAF. » Conduct rigorous analysis of the sustainability of Canadian feedstocks for ecosystem productivity, biodiversity, and other environmental benefits. » Ensure clarity on the differences between Canadian and international sustainability requirements (i.e. CORSIA), lifecycle analysis methodologies, and consumer preferences and work to facilitate and standardize SAF accounting and certification methodologies. » Articulate sustainability case for Canadian feedstocks, including oilseeds.
FEEDSTOCKS	» Build the infrastructure and policy frameworks needed to bring all feedstocks into SAF regional supply chains. » Build upstream collection and delivery logistics for forestry and agriculture residues.
SAF PRODUCTION CAPACITY	» Create an active project pipeline with first commercial, demonstrations, and pilots in critical SAF production pathways. » Ensure proposed HEFA projects reach final investment decision. » Seed projects in emerging commercial pathways such as gasification with Fisher-Tropsch and alcohol-to-jet.
TECHNOLOGY AND INNOVATION	» Canada to establish a national centre of excellence for the future of aviation in a net-zero world to ensure that SAF and aerospace decarbonization priorities are aligned and complimentary. » Canada to create a national industrial and innovation strategy with two clear streams: – Create clear technology development plans for SAF pathways that activate Canadian feedstocks. – Create clear technology development plans for new propulsion technologies. » Secure demonstration funds for SAF. » Coordinate R&D with leading universities and international partners.

Roadmap Overview

Long considered a "hard-to-abate" sector, global aviation is primed for rapid decarbonization in the next two decades. The technological solutions are well known and there is increasing consensus on the pathways which will drive down emissions in this critical sector.[17]

In brief, there are four critical elements of aviation decarbonization:

1. **Sustainable aviation fuel**
   (low-carbon jet fuel from biogenic and synthetic sources)
2. **Operational and fuel efficiency**
   (to reduce fuel demand)
3. **Battery electric aircraft**
4. **Hydrogen combustion**

The aviation industry understands that there is an imperative to reduce emissions and SAF is a critical solution that can be deployed today.

The sector needs all elements to meet long-term decarbonization targets. Electrification is a key technological lever that will capture a high portion of short-haul routes. However, it is unlikely to contribute significant reductions before 2060 (see Figure 2). Hydrogen is also essential to post-2040 aviation, but its role until then, especially on long-haul flights, is unclear. Therefore, the balance of will come from the use of SAF versus traditional jet fuel.[18]

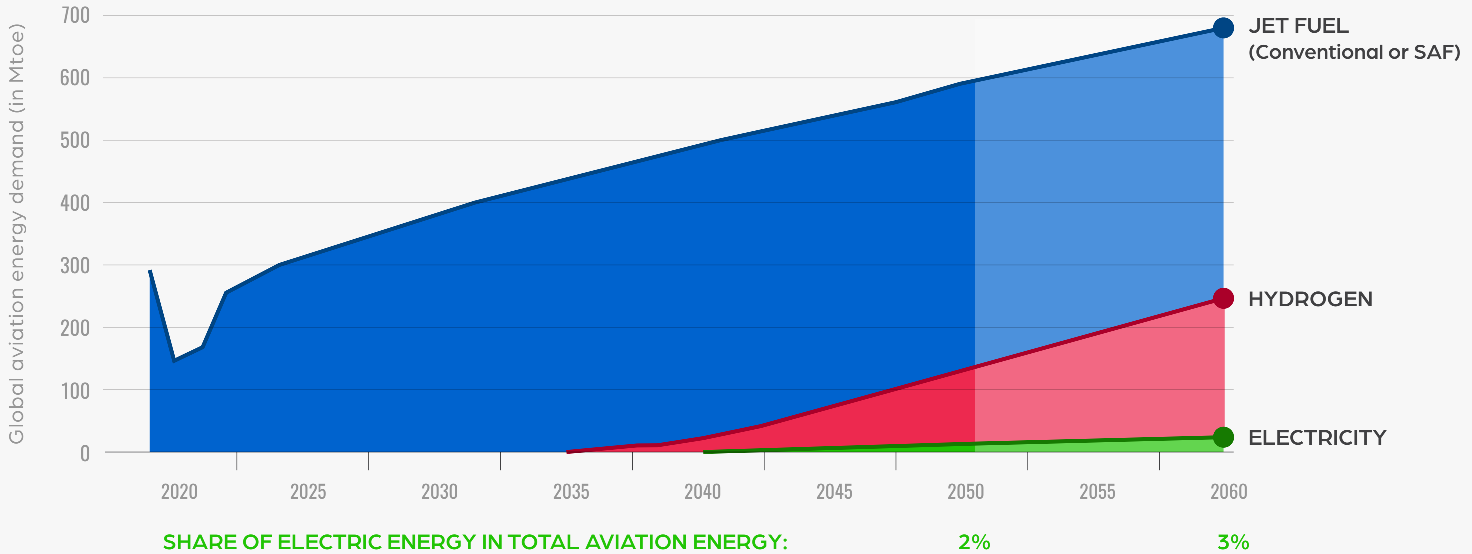
The need for SAF is clear. The aviation industry understands that there is an imperative to reduce emissions and SAF is a critical solution that can be deployed today. There is rising consumer demand and SAF production, driven by incentives in the US and a mandate in Europe, and the development of technologies which can enable zero-emission aviation is on the rise.[20]

Nonetheless, the global market for SAF is still small: 125 million litres were produced in 2021.[21] In a global jet fuel market of 220 billion litres, SAF accounted for only 0.05% of global consumption.

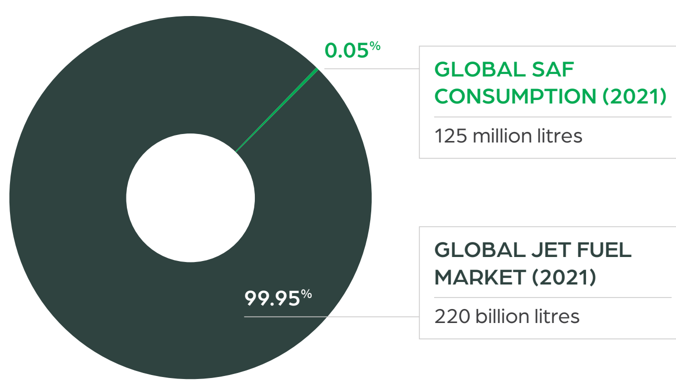
FIG 2 WAYPOINT 2050: SOURCES OF DECARBONIZATION IN AVIATION[19]

AVIATION ENERGY DEMAND EVOLUTION

The global aviation energy demand associated with the T5 scenario, where demand for direct use of electricity from the 51–100 segment starts in 2038 after the entry into service of all-electric aircraft in this segment of the fleet.



At this early stage, SAF is 2–4x more expensive than conventional jet fuel.[22] Conventional jet fuel is one of the cheaper hydrocarbons to produce in a refinery. Nonetheless, fuel is typically the largest operating cost for commercial airlines, accounting for more than 25% of total costs.[23] Since profit margins in the air transport sector are already thin compared to other sectors, absorbing additional costs could be challenging.[24] This creates considerable uncertainty around SAF demand.



At the same time, without strong commitments on the demand side, refiners lack the confidence to invest the capital needed to produce SAF. And that scaling is needed to drive down costs – it is learning by doing that creates cost savings in new industries.[25] Government policy can stimulate demand with a mandate, but if there are constraints on supply, prices could rise sharply. This could severely impact the airline industry and also the environment, as airlines could start tankering

Canada has the feedstock, refining expertise, innovation capacity, and domestic airlines to create a world-leading industry that meets its own needs and exports to other jurisdictions. To realize this promise, Canada must mobilize and align the whole SAF ecosystem.

fuel from less costly locations to control costs, or choose to fly to another airport outside of Canada with less costly regulations. More plainly stated, with significantly higher costs, Canada's aviation industry would be at a competitive disadvantage compared to the US aviation industry.

Support is required to ensure that the SAF market can take flight. Fiscal incentives can deliver support in the form of price reductions, but so can supply chain investments in infrastructure and policy changes in adjacent sectors that reduce competition for feedstocks. These, with or without a regulatory mandate requiring airlines to use SAF, will be necessary.

Canada's opportunity: building the whole SAF supply chain

Canada has great opportunities across the supply chain from feedstock to fuels. When we look at supply chains in the global economy, we often see countries with major structural holes in the ecosystem. That is not the case in Canada.

Canada has the feedstock, refining expertise, innovation capacity, and domestic airlines to create a world-leading industry that meets its own needs and exports to other jurisdictions. To realize this promise, Canada must mobilize and align the whole ecosystem.

To gain a better understanding of Canada's opportunities, we need a quick overview of SAF production pathways and supply chains. This report does not provide a thorough introduction to these topics, which are covered in other publications.[26]

There are 7 approved ASTM pathways and 2 routes for co-processing.[27] The 7 approved conversion pathways are:

FT-SPK
Fischer-Tropsch

HEFA
Hydroprocessed Esters and Fatty Acids

SIP
Synthetic Iso-Paraffins from sugars

FT-SKA
Fischer-Tropsch containing aromatics

ATJ
Alcohol-to-Jet which includes isobutanol and ethanol

CHJ
Catalytic Hydrothermolysis Jet fuel

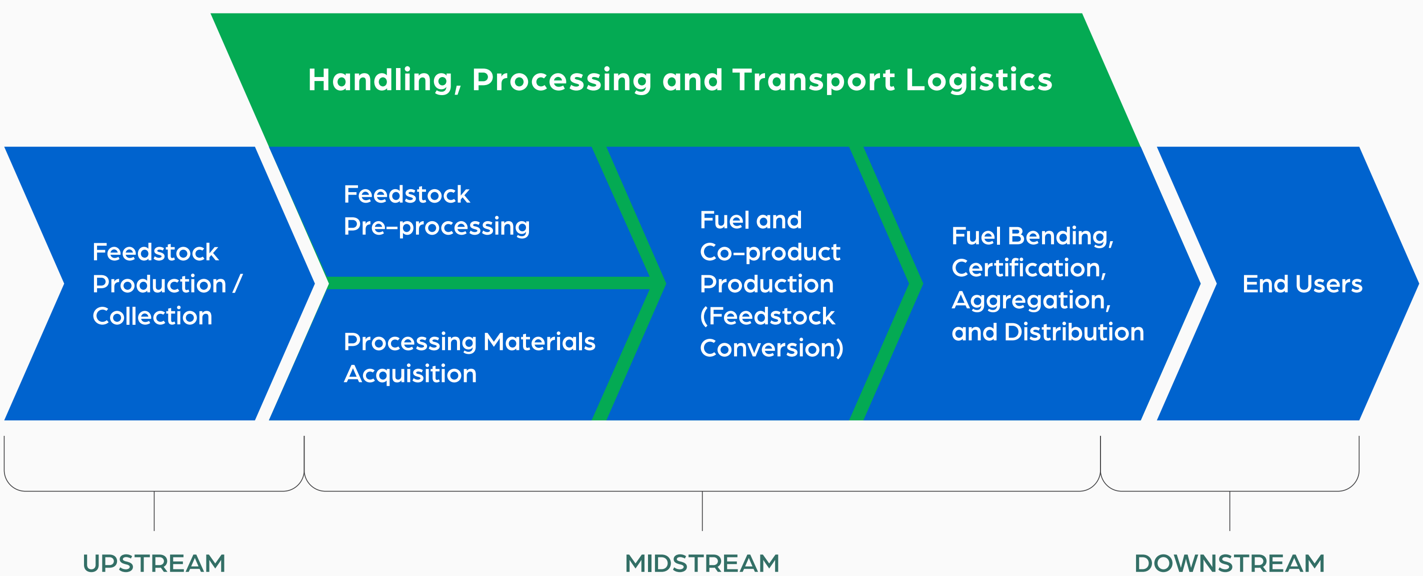
HH-SPK or **HC-HEFA**
Hydroprocessed Hydrocarbons

Co-processing of lipids and Fischer-Tropsch liquids up to 5% is also permitted under ASTM. Five of these processes (FT-SPK, FT-SKA, HEFA, ATJ, and CHJ) are approved for use as a drop-in fuel up to 50% of a jet fuel blend and could potentially be used as a 100% drop-in in the future. The SIP and HC-HEFA process is limited to a 10% blend.

Following van Dyk and Saddler, this roadmap focuses on FT-SPK, HEFA, ATJ, and co-processing (including pyrolysis and hydrothermal liquefaction) as the most viable pathways in Canada.[28] Each of these pathways can use a number of potential feedstocks, so the actual number of possible SAF supply chains exceeds the number of pathways. Additionally, SAF currently requires blending with conventional jet (although industry is working hard to use 100% SAF), so jet supply and blending infrastructure must be part of the supply chain.

Figure 3 outlines the key steps. First, feedstock is produced or collected. Then materials are conditioned and converted to fuel. It is important to note that hydrogen and electricity are also critical inputs to many fuel conversion processes. The SAF is then blended into jet fuel and made available to the aviation industry.

FIG 3 THE SAF SUPPLY CHAIN



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For simplicity's sake, this roadmap refers to feedstocks as the upstream, refining or fuel production and blending as the midstream, and airlines as the downstream.

Wood Pellet Biofuel Mill.

Until recently, firms in the global economy have been incentivized to create fully global supply chains. However, geopolitics and the need to act strategically to build decarbonization industries have changed things. Energy security concerns have moved up the agenda, driving localization, regionalization, and friendshoring. Europe and the United States are centering regional supply chains in their SAF development strategies.[29]

This report explores how to build regional SAF supply chains in Canada. Of course, in reality, supply chains will form across borders. The key is to leverage as much Canadian capacity as we can to produce economic benefits for Canadians and establish supply chains that are resilient to geopolitical shocks.

The strategy advanced throughout this roadmap is to leverage Canada's agricultural and biomass resources, clean energy potential, and expertise in refining and green chemistry to stake out advanced positions in the SAF supply chains of the future. This means investments in pre-commercial or first-of-a-kind production facilities that represent a double play:

- Provide demand-pull on Canadian biomass and energy resources.
- Build up Canadian expertise in new technologies and processes for SAF production.

The strategy advanced throughout this roadmap is to leverage Canada's agricultural and biomass resources, clean energy potential, and expertise in refining and green chemistry to stake out advanced positions in the SAF supply chains of the future.

What is needed are select catalytic investments in the midstream of the SAF supply chain that bring new feedstocks online while driving the technological and logistical cost reductions needed to make SAF competitive. The catalytic investments must be designed with cost reductions in mind, and they must be accompanied by upstream efforts to reduce the costs of feedstock.

A Clean Competitiveness Roadmap and Approach

To begin the work of seizing Canada's economic opportunities, this work takes the approach of a clean competitiveness roadmap. A **clean competitiveness roadmap** articulates the priority actions, policies, and investments necessary to catalyze industrial transformation in key sectors.

A clean competitiveness roadmap is part of a broader strategy to build the industries needed for net-zero targets at home and abroad. Its goal is to produce long-term economic value for industry and the country.

The goal of a roadmap is to align the whole supply chain from upstream resources and capacities to downstream users and markets. By creating clear timelines and action sequences, it hopes to catalyze the investment and action necessary to rapidly build the industry.

To produce this roadmap, C-SAF, the Energy Futures Lab (EFL), and The Transition Accelerator convened a multi-stage process of consultations, workshops, and analysis. The roadmap was actively co-produced by the organizing partners and actors from across the ecosystem.

> *A clean competitiveness roadmap is part of a broader strategy to build the industries needed for net-zero targets at home and abroad.*

The organizers began by forming a technical committee of experts from firms, industry associations, and consultancies. The Transition Accelerator worked with this group to create a straw dog strategy and roadmap.

That straw dog was then the subject of a series of virtual workshops designed and facilitated by the Energy Futures Lab. These sessions brought together firms, government officials, and experts. The workshops were organized into five Action Areas:

Policy and programs

What policy package do we need to incentivize the investment and production necessary to achieve our targets?

Sustainability

How can we keep carbon intensity scores low and ensure the long-term viability of our feedstocks while preserving biodiversity and other ecosystem values?

Feedstock

How do we produce sustainable inputs and bring them into the SAF supply chain?

SAF Production capacity

What capacity is needed to meet the SAF targets?

Technolgy & Innovation

What technological advances do we need to produce volumes and remain competitive?

A key piece of the workshops was to develop a **dashboard** for each action area that addresses three critical questions:

Success

What does success look like in 2030?

Near-term goal

What should C-SAF and partners try to accomplish in the period 2022–2025?

Strategic assessment

What is the state of play in the industry and how can we drive transformation?

Key actions

What actions are needed to advance the near-term goals? Who needs to be at the table?

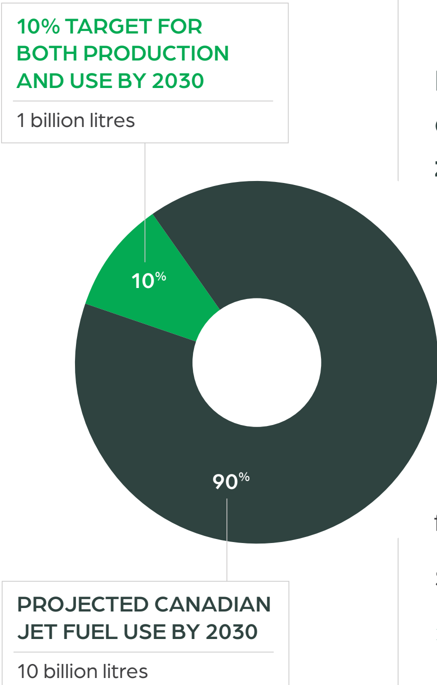
This roadmap is a flight plan—a starting point for action and is meant to flex as new information is produced and science evolves.

The Transition Accelerator offered initial drafts, based on expert input from the technical committee, for each component. Workshop participants then worked collaboratively to refine and build out the insights and priority actions in the straw dog. Further analytical work was done by The Transition Accelerator to develop and prove out these ideas.

The result is a set of **goals, strategic assessments, key actions** and **representative supply chains** that would harness Canadian feedstocks for Canadian fuel production.

This roadmap is a flight plan—a starting point for action and is meant to flex as new information is produced and science evolves. The next step is to widen the group, collaborating actively with governments, Indigenous Peoples, and financial institutions to advance the key actions identified here through a series of task forces outlined in the final section of the roadmap.

Closing the gap:
SAF 2030 targets



Roadmaps and strategies need clear, actionable targets. The approach of the clean competitiveness roadmap is to posit a net-zero competitiveness goal.

The target must be a genuine waypoint to net-zero. Competitiveness means the goals should be economic targets that are benchmarked to Canada's place in the 2030 and 2050 world economy. The goals should be concrete enough to inform the construction of a project pipeline but ambitious enough to catalyze the long-term transformation of the sector.

Aligned with Canada's Aviation Action Plan, this roadmap advances the following goals:

SAF Take-off Goal: 10% target for both production and use.

» By 2030, SAF should be 10% of projected Canadian jet fuel use – **1 billion litres.**[30]

» That SAF should have at least a 50% reduction in lifecycle GHG emissions compared to conventional fossil-based jet fuel by 2030 in accordance with CORSIA or an equivalent approved GHG lifecycle methodology.

» As an initial competitiveness benchmark, Canada should aim to produce 1 billion litres in domestic supply chains.

Current and proposed renewable fuels facilities could produce 500 million litres SAF in 2030 (Table 1).[31]

TABLE 1 Proposed Canadian renewable diesel and sustainable aviation projects (estimated SAF production, millions of litres)[32]

Facility	SAF Fraction (est.)	2023	2024	2025	2026	2027	2028	2029	2030
Braya	15%	122	122	122	313	313	313	313	313
Tidewater	15%	26	26	26	26	26	26	26	26
Covenant	15%	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8
ReFuel	15%		26	26	26	26	26	26	26
Green Energy Transformation	15%					56.6	56.6	56.6	56.6
SAF+	100%					30	30	30	30
RETI	15%						25	25	25
TOTAL		**122**	**197**	**253**	**444**	**500**	**525**	**525**	**525**

These facilities are in the planning stages, but very few have reached final investment decision. That means that there is a lot of work to do to ensure these projects are completed and that they do so with meaningful SAF production. Indeed, strong policy signals could potentially push SAF fractions up. Refiners choose their optimal product slate, trading off renewable diesel for road applications against sustainable aviation fuel, depending on market conditions.[33]

Refiners choose their optimal product slate, trading off renewable diesel for road applications against sustainable aviation fuel, depending on market conditions.

With the exception of SAF+, all these proposed projects will use the HEFA process. While ReFuel proposes to use only used cooking oil, tallow, and non-edible crops, the remainder of the projects are likely to use large volumes of canola. Canola will produce the balance of early volumes.

Table 2 lists other projects with SAF potential. Parkland recently announced that it was cancelling its plans to create a standalone renewable diesel facility.[34] Imperial has paused its plans to include SAF production in its proposed renewable diesel facility.[35] The large Federated Co-operatives Limited (FCL) project could also produce SAF volumes, but public announcements have not indicated an intent to produce SAF.

TABLE 2 Other projects with SAF potential

Facility	SAF Fraction (est.)	2023	2024	2025	2026	2027	2028	2029	2030
~~Parkland*~~	~~15%~~			~~48.8~~	~~48.8~~	~~48.8~~	~~48.8~~	~~48.8~~	~~48.8~~
Imperial	15%			174	174	174	174	174	174
FCL	15%				131	131	131	131	131
TOTAL		**0**	**0**	**223**	**353**	**353**	**353**	**353**	**353**

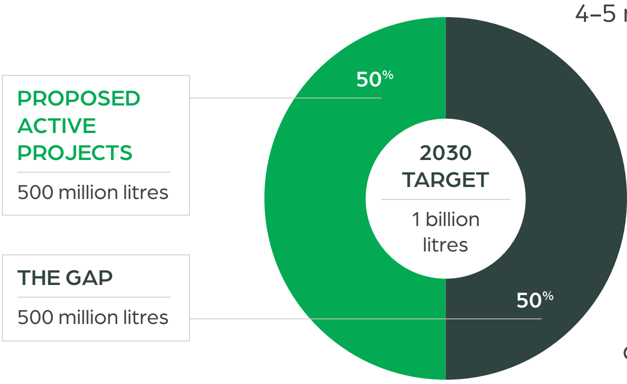
* Parkland recently announced that it was cancelling its plans to create a standalone renewable diesel facility.

TABLE 3 Proposed Canadian co-processing projects

Refinery	SAF Fraction (est.)	2023	2024	2025	2026	2027	2028	2029	2030
Parkland	10%	16	16	16	16	16	16	16	16
Tidewater	10%	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.74
TOTAL		**17.74**	**17.74**	**17.74**	**17.74**	**17.74**	**17.74**	**17.74**	**17.74**

There are also two co-processing projects in Canada (Table 3). These projects co-process tall oil and canola with conventional crude to produce a fuel with 15% renewable content.[36] While industry continues to review how to overcome the constraints of increasing the co-processing biocrude limit to beyond 20% or 30%, even then it is unlikely that co-processing could produce SAF with a 50% reduction in carbon intensity score.[37] Therefore, while valuable in partially lowering GHG emissions in jet fuel, these volumes are not included in the total expected SAF production figures.

In short, even if proposed SAF projects produced 15% SAF fractions, they will fall short of the 2030 target by 500 million litres. This is the equivalent of 4–5 major renewable diesel projects.



The target is achievable, but ambitious.

What must be done in order to close that gap and ensure that Canada seizes its opportunities in the SAF value chain?

The rest of this roadmap explores this question in more detail. The next section breaks down the supply chain into five Action Areas that must advance together. To build a successful ecosystem, Canada must align feedstocks, production pathways, technology development, sustainability criteria, and policy into a dynamic plan that will deliver economic benefits over the long transition.

The last two sections of this report discuss how to build the ecosystem at the project level. We lay out Representative Value Chains that express Canada's opportunities in the form of regional clusters that draw together feedstocks, refining, and end-use. Then, the report charts a Flight Path that advances multiple objectives for the Canadian SAF ecosystem.

Aerial view of Billy Bishop Toronto City Airport.

Action Areas

Photo by Jerry Zhang. Unsplash.com

Policy and Program

Success in 2030

Policies and incentives that differentiate SAF from renewable diesel and provide a credible demand signal to drive investment.

Near-term goals

Advance a policy package that will catalyze SAF production in Canada.

Strategic assessment

- Canada has all the the building blocks of a strong SAF ecosystem. However, the ecosystem for a complete SAF value chain is not yet in place. Canada is still missing facilities and needs technological advancements that will enable SAF to scale.
- To unlock SAF production and use in Canada, we need policies that stimulate demand while keeping costs manageable and are competitive with the policies of other countries, such as the United States.
- One of the biggest challenges for SAF production is competition for feedstocks and refinery capacity with renewable diesel (RD). Currently, low carbon fuel standards and regulations primarily target using RD (and other low-carbon ground transportation fuels) for compliance. Since SAF is more expensive to produce than RD, specific incentives for SAF are needed to stimulate production.
- Much of that RD is going into road transport: but road transport has other decarbonization options that can be deployed sooner than aviation which is limited to SAF for most applications. SAF should be the priority for biofuels over the medium-term.
- Mandates often drive up prices in nascent supply chains but they drive deployment by creating demand.

- In the absence of a mandate, there are two options to build the market:
  - A supply side option: support, such as a carbon contract for difference, that guarantees a credit amount from uncertain markets.
  - An industry option: a mechanism to share costs and price risk across refiners and airlines.

Facilitating SAF accounting methodologies, harmonizing domestic and international sustainability certification frameworks and ensuring certainty and transparency are key to securing long term SAF investments.

All new markets face a chicken-and-egg problem between supply and demand.[38] Without strong demand, upstream producers have no incentive to invest in new production. But supply is needed to clarify price structures and drive down the costs of production through iterative deployments to scale. But before technologies are proven and facilities are built, costs are uncertain, even for producers. Feedstock producers and refiners both take on risk if they act first—what if their products are too expensive and there is no demand?

SAF is harder and more expensive to make than renewable diesel and requires a higher incentive to stimulate production.

A mandate can provide demand side certainty.[39] But with costs expected to be high, this will would impose a cost on downstream users that may be difficult for the aviation industry to bear or pass on given the unique competitive environment in which aviation operates in.[40] Thus, some price controls or supply-side supports would be needed to make a mandate workable and these must also consider aviation's limited decarbonization options.

It is possible that supply-side incentives without a mandate would be enough to drive downstream demand.[41] This is the implicit strategy of the US SAF Grand Challenge and the *Inflation Reduction Act* more broadly. In brief, generous incentives on the supply-side can make the clean options cheaper. Indeed, the Bioport YVR study concluded that existing credits might bring HEFA-based SAF close to parity.[42] Still, credit prices are uncertain and so bankable incentives like the IRA's production tax credit are powerful tools.

SAF faces an additional problem: competition with renewable diesel (see SAF Production Capacity Action Area for more details). As a result, SAF also requires policies that differentiate it from renewable diesel. If SAF is merely offered the same incentive as renewable diesel, there may be insufficient incentives to produce SAF. SAF volumes will remain low and high quality biomass will end up in renewable diesel. That renewable diesel will likely end up in trucks—but trucks have other decarbonization options such as electrification and hydrogen fuel cells[43] could be deployed sooner in the medium-term. SAF should be a priority market for biomass because aviation does not have other viable decarbonization options.

Third, Canada faces competition for SAF production from the United States. The *Inflation Reduction Act* expands the Blenders Tax Credit (BTC) to include a SAF-specific credit of ~$C0.60 per litre. This credit runs from 2023-2025. After 2025, the Clean Fuels Production Credit (45Z) takes effect. This credit provides a full credit value of $US1.75 per gallon to net-zero fuels (discounting others against a 50 kg CO_2e/MMBtu baseline). These credits can be stacked with generous credits from the renewable fuel standard (RINs) and the low-carbon fuel standard markets in California, Oregon, and Washington.

Finally, in nascent markets, government procurement is a key tool to build demand, especially for homegrown goods.[44] The Canadian Greening Government strategy could be used to prioritize purchasing made-in-Canada biofuel.[45]

To address all these issues, the SAF ecosystem needs a policy package with four elements: to generate stable credits in fuel standards markets, exclusion from the carbon tax, a SAF-specific productive incentive, and federal procurement.[46]

Key actions needed to deliver on the near-term goal (target start date)

1. Advance a SAF policy package with 4 key elements (Q2 2023):

i. Allow SAF to generate credits as a voluntary opt-in to grow the SAF market

ii. Provide SAF-specific supply and production incentives (at a higher level than renewable diesel) to stimulate made-in-Canada SAF

iii. Waive all federal and provincial carbon tax on SAF that meets a certain minimum carbon intensity standard

iv. Use federal procurement programs of SAF for federal fleets to support increasing market demand

2. Clarify SAF demand signal (Q2 2023)

» Given the desired outcome to increase the production of SAF in Canada, to drive investment, the go-to policy should incentivize SAF production using:
  - Price certainty: ensuring that bankable incentives stack to create price parity between SAF and regular jet fuel. On this scenario:
    - Carbon contracts for difference must guarantee CFR credit levels.
    - A SAF production credit can then be calibrated to cover the difference between SAF cost and regular jet fuel.
  - Mandates are problematic when not accompanied with positive supply incentives to increase SAF production and availability. Mandates can cause unintended market distortions that could result in higher prices, discouraging innovation or barriers to entry.
  - Aviation's unique competitive environment and limited decarbonization options compared to ground transport modes must be considered when determining SAF policies.

» A joint government-industry task group should be convened immediately to determine which approach is better for all parts of the value chain and economic impact to the industry, to work out the details of the best approach.

3. Align existing public funds within an industrial strategy (Q2 2023)

» With a policy package in place, attention can turn to investment.

» Public and private investments must be strategic: aligned with the ecosystem goals of this roadmap and oriented to creating the kind of regional value chains mapped out in the next section.

» The Strategic Innovation Fund, the Canada Growth Fund, and the Canadian Infrastructure Bank should make SAF investment a priority and hire staff with the domain expertise to support project formation in collaboration with C-SAF and other industry actors.

» C-SAF and the government could then forge an investment strategy to ensure that proposed SAF projects reach final investment decision. The representative value chains and the flight plan of this roadmap could be the basis of this collaborative work.

» Look to ensure the economic benefits from SAF development are shared equitably in regional economies, with a particular focus towards enabling economic benefits for marginalized groups.

- Explore the potential to support indigenous owned and operated SAF supply chains or components. Potential for indigenous owned SAF refineries and associated economic self-determination should be weighed against added fuel costs compared to SAF purchase from existing capacity.

4. Create innovative funding programs to fund first-of-a-kind production facilities, including demonstration and early technology projects (Q2 2023).

- This is discussed in more detail in the SAF Production Capacity Action Area but it is an essential piece of the policy conversation.
- To produce SAF volumes after 2030, we need to unlock power-to-liquids and hydrothermal liquefaction pathways. We need investments in these projects now to drive innovation.

5. Establish clean transportation corridors to keep CI scores low (Q3 2023).

- Canada should create a national green corridors forum that brings together all modes, like BC-SMART, to create a comprehensive Canadian transport decarbonization strategy which will deliver benefits for all industries. This will benefit SAF value chains in two ways:
  - Upstream: low transportation emissions will lower the carbon intensity scores of SAF. Since SAF markets are highly likely to be structured by CI score, with the lowest CI scores fetching the highest prices, such a network will benefit SAF producers.
  - A green transportation corridor will increase demand for SAF itself by linking aviation to other green transport modes for net-zero carriers willing to pay a premium for green shipping cost.
- C-SAF should work with partners across transportation to commission a full techno-economic analysis of green transportation corridors. This could be used to secure an advanced market commitment from Canadian OEMs and processors.

The long-term success of the Canadian ecosystem depends on building strategic collaborations that go beyond this roadmap. Best practices from other jurisdictions suggest that public-private partnerships independent from both government and industry are needed to ensure success.

6. Supporting tax credits: ensure electricity and carbon capture, utilization, and storage (CCUS) and hydrogen investment tax credits are stackable with SAF production credits (Q2 2023).

- In the 2023 federal budget, the Government of Canada announced an investment tax credit for clean electricity, hydrogen, manufacturing and CCUS. These are important upstream inputs of the SAF supply chain. Producers should be able to stack the credits to keep costs low.
- Available CO_2 feedstocks will hinge on the creation of carbon trunklines and hydrogen infrastructure.

7. Conduct a comprehensive review of all major Canadian civilian airports to determine what infrastructure limitations must be addressed to enable complete transition to SAF (Q3 2024).

8. Establish a national public-private platform to carry out this roadmap and support a long-term strategic approach to aviation decarbonization (Q2 2023).

- Establish a public-private partnership lab to advance this roadmap.
  - A key lesson from other industrial strategies is that public-private partnerships are essential to creating long-term value.
  - The platform would serve as a collaborative forum where government and industry can meet and work together.
- Manage the project pipeline that comes out of strategic exercises such as this.
- Work closely with firms and economic development organizations to conduct project formation and business development functions.
- Serve as an independent source of analysis that can facilitate the exchange of high-quality information between industry and government.
- Formulate innovation strategies as discussed in Technology & Innovation Action Areas
- Lead strategy setting exercises and ensure alignment among ecosystem actors.
  - Continuously update policy roadmap for SAF in line with the technology frontier and changing availabilities of feedstocks driven by climatic shifts and per-capita changes in waste production.

Sustainability

Success in 2030

Canadian agricultural, municipal waste, forestry and carbon feedstocks are recognized as sustainable throughout the world.

Near-term goals

Support and monitor ongoing evaluations and assessments to ensure Canadian feedstocks are certified using globally recognized sustainability criteria (i.e CORSIA) and work to facilitate and harmonize SAF accounting standards and certification methodologies.

Strategic assessment

- The global aviation industry has committed to using a common framework of international sustainability criteria for CORSIA[47] eligible SAF
- Life cycle and sustainability assessments across domestic and international jurisdictions (i.e. CORSIA) are not standardized but are critical for the development of SAF markets and securing long term investments.
- It is recognized that some sustainability criteria, such as those around land-use, are difficult to quantify in a universal or global manner.[48]
- Oilseed feedstocks have been the subject of controversy with global activist networks arguing that they are associated with high deforestation risk.[49]
- However, canola oilseed can meet sustainability criteria under both CORSIAstandards: the International Sustainability and Carbon Certification (ISCC) and the Roundtable for Sustainable Biofuels (RSB).[50]
- Most Canadian canola is already certified under ISCC.[51]
- The European Parliament recently decided to maintain a role for crop-based biofuels but excluded palm and soy oil due to suspicions around the sustainability of farming practices in developing countries.[52]

CORSIA has adopted a common set of international standards to ensure that all SAF meets the criteria to be considered truly sustainable.

- The carbon intensity of crop-based fuels is dependent on the sustainability of farming practices; better farming practices will improve both the sustainability and profitability of SAF.

The sustainability of biofuels must account for both emissions reductions and the broader ecosystem effects of biomass harvesting. The ETC lists six core principles:[53]

- Dedicated energy crops should be grown on marginal land, and only when the energy crops would use less greenhouse gas emissions than returning the land to nature.[54]
- For woody biomass, only forestry residues should be used, and from forests that use adaptive management practices. Collection must limit biodiversity effects and avoid adverse effects on soil carbon.
- Agricultural residues collection should leave sufficient material on the land to ensure soil and ecosystem health.
- Municipal solid waste pathways should be designed in accordance with circular economy principles (maximize recycling) and utilise CCUS (to reduce emissions).
- Biomass from aquatic sources must have minimal impact on ocean ecosystems.
- For all biomass supply chains, electrification and CCUS should be employed across the supply chain to keep emissions low.

These are critical principles, and they are broadly represented in CORSIA and Canadian Clean Fuel Regulations criteria that govern SAF.[55]

Furthermore, CORSIA has adopted a common set of international standards to ensure that all SAF meets the criteria to be considered truly sustainable. Accordingly, a CORSIA eligible SAF, must demonstrate a net carbon reduction through the full life cycle of the fuel and meet additional sustainability principles, including:

- Lifecycle greenhouse gas emissions
- Direct and induced land use change
- Water supplies
- High conservation value area and biodiversity
- Socio-economic conditions of farmers and local population (particularly in developing countries)
- Improving food security in food insecure regions

Returning to the larger picture we introduced in our discussion of feedstocks above, consider that all SAF is carbon-based. The trick is to harness carbon and combust that carbon without increasing the stock of CO_2 in the atmosphere. Biomass and direct-air-capture both source their carbon from the atmosphere. However, even in the case of biomass and direct-air-capture, the process of capturing and converting the biomass has an impact on the carbon cycle which can increase greenhouse emissions.

What feedstock is sourced (e.g., crops, agricultural/forestry residues), how long it would normally remain out of the atmosphere (in biomass or other forms of storage), and the direct and indirect emissions involved in collection and conversion all have an impact on the CI of SAF.

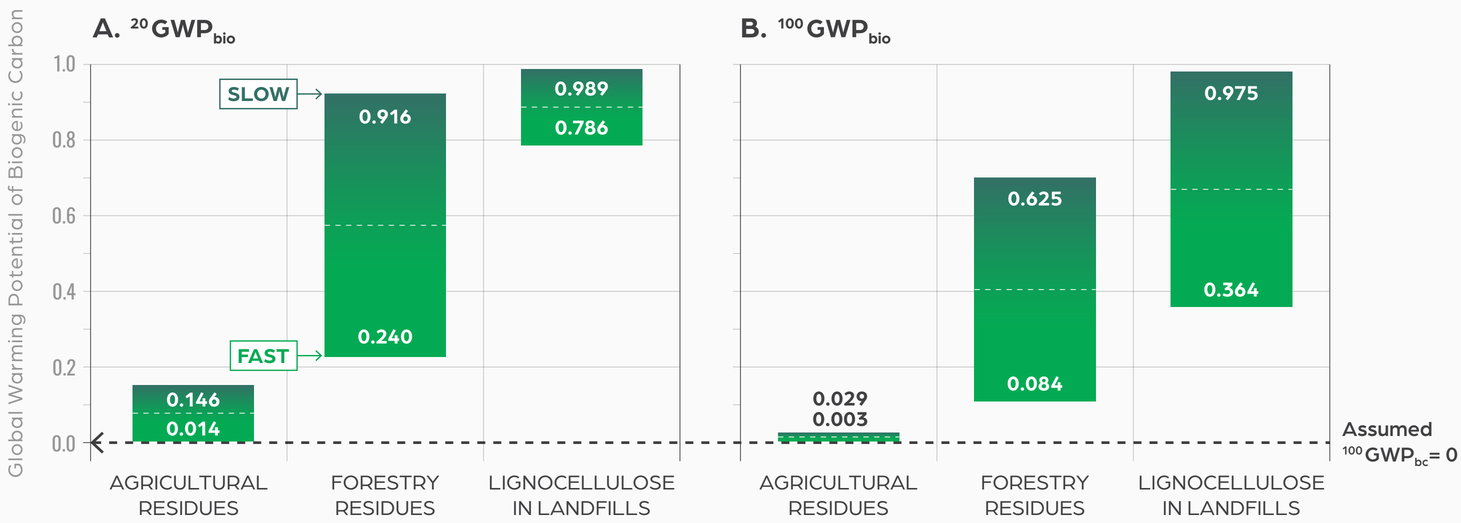
In this section we outline a few opportunities for producers to keep CI scores low. Current emissions from cultivation, collection and refining of feedstocks all present opportunities to reduce the lifecycle emissions of SAF. Building a broad understanding of the latest science is critical to ensuring that firms can get credit for innovative carbon intensity reductions. To incentivize creative ways of reducing emissions, producers need to be confident that real-world low-carbon practices will be reflected in the LCA used to calculate their carbon intensity.

New activities should be incentivized in a dynamic, science-based way to ensure that best practices are clearly represented in sustainability criteria so that low-CI, sustainable SAF will fetch higher prices.

The first thing to consider is that not all waste is made carbon-equivalent. Various forms of waste have different global warming potentials.[56] Consider forest residues that would otherwise rot on the forest floor. Untouched, these residues will gradually respire their CO_2 back into the atmosphere. However, if they are gathered and burned, then that CO_2 is rapidly put back in the atmosphere. This has an effect on global warming.[57] This effect is more pronounced for wood, which decays slowly, than it is for agricultural residues, which return to the atmosphere more quickly. Thus, fuels from agricultural residues should be slightly lower carbon intensity than wood-based fuels.[58]

Agricultural residues

FIG 4 ENERGY CONVERSION RATES AND OPTIMAL SAF FRACTIONS FOR SAF PATHWAYS



Source: (Adetona, A., Layzell, D.) Comparison of the relative emissions footprint of biofuels compared to the warming produced from the combustion of an equivalent amount of fossil fuels over a 20 and 100 year horizon. Note this does not include the emissions footprint from fuel refining, fossil fuel extraction, bio-feedstock collection, or direct/indirect LUC.

Municipal solid waste (MSW) should have a higher baseline carbon intensity then, because carbon locked in landfills, if left undisturbed, can stay out of the atmosphere over a 100-year timespan. If this were considered, then the LCA for MSW may go up. Such effects are not accounted for within the GREET model that underlies CORSIA accounting.[59]

Carbon intensity is highly dependent on circumstances. For example, slash piles (piles of logs left after timber harvest) are frequently burnt or left behind post timber operations.[60] Global warming potential over 100 years could be reduced in woody residue SAF derived from slash piles as opposed to other sources. Further research is required to identify the ideal sources of woody residues for SAF from a CI perspective.

Cultivation techniques for almost all crops in Canada currently carry an emissions footprint. Most of the emissions (as well as the opportunities for their reduction) are from the production and application of fertilizers, and changes in the soil carbon balance.[61] Encouraging uptake of efficient fertilizer practices and technologies presents opportunities to reduce emissions.

Gevo has recently argued that using no-till or zone-tilling techniques can reduce carbon intensity scores for energy crops by as much as 35% through increased soil carbon uptake.[62] Zone-tilling preserves soil structures that hold carbon and can ensure that crop production sequesters more carbon in the soil than released during combustion.[63] Producing some biochar and sequestering that would also increase soil carbon uptake.[64]

Canadian farmers are already leaders in adoption of minimal-till and no-till practices. In the prairies, no-till agriculture has been routine since the 1980s.[65] These practices have had a demonstrable effect on soil carbon that increases over time.[66] Ensuring that the full benefits of these practices are credited in fuel markets is crucial. The practices should be maintained and incentivized to support Canadian advantages in SAF markets.

Regarding refining emissions, as ETC highlights, there are opportunities to electrify and capture carbon up and down the value chain. For example, installing carbon capture on industrial refining operations with geological storage can reduce production emissions and lower CI scores. New tax credits for carbon capture, clean energy, and clean hydrogen create additional benefits for those looking to create deep carbon reductions in the value chain.

Key actions needed to deliver on the near-term goal (target start date)

1. Canada needs a broad public-private partnership to incorporate the best scientific knowledge on the carbon intensity of low-carbon fuels into its regulatory frameworks (Q3 2024).

- Ensure clarity on the differences between Canadian and international sustainability requirements (i.e. CORSIA), lifecycle analysis methodologies, and consumer preferences and work to facilitate and standardize SAF accounting and certification methodologies
- The potential for innovative relationships between agriculture, chemicals production, and fuel production means that we need a systemic approach to measuring and monetizing carbon. This approach is reflected in the Clean Fuels Regulation and Low Carbon Fuel Standards.
- C-SAF should maintain an active platform that brings together government and industry to deploy experiments and incorporate the best science so that the CFR and other policy platforms incentivize the most sustainable practices possible
- Advise the federal Finance department on the importance of carrying this approach into tax credits or other policies designed to incentivize SAF production. Done right, carbon intensity scoring in fuel production can support decarbonization throughout the economy by pulling on clean power, low-carbon hydrogen, and green transportation corridors.

2. Engage in detailed mapping of the GHG emissions footprint from all steps of cultivation, collection, and refining of biomass derived SAF (Q3 2024).

» Conduct rigorous analysis of the sustainability of Canadian feedstocks for ecosystem productivity, biodiversity, and other environmental benefits.

» Ensure that certifications for biocrops recognize the true carbon intensity of Canadian cultivation, collection, and refining practices.

» Validate the sustainability of Canadian oilseed HEFA to meet CORSIA Eligible Fuel criteria

» For wastes and residues, C-SAF should initiate extensive data collection on the source of feedstocks to achieve a more accurate carbon intensity scoring, with greater granularity within streams i.e. (the type of MSW used, what forest residues were harvested (slash piles vs others, the crop source of agricultural residues).

New activities should be incentivized in a dynamic, science-based way to ensure that best practices are clearly represented in sustainability criteria so that low-CI, sustainable SAF will fetch higher prices.

3. Support research on the environmental impact from scaling up feedstock collection among various regional SAF pathways.

» To ensure the long-term sustainability and resilience of feedstocks, research should be supported to continuously monitor the broader ecosystems impact of feedstock scaling.

» Such work might include scientific analyses of soil carbon after forest and agricultural residues are removed, or the carbon impacts of land-use change in so-called marginal lands.

4. Commission studies to determine the carbon intensity and sustainability of various forms of Power-to-liquids processes (CCUS and DAC) (Q1 2024).

» CO_2 can be used to make SAF through both PtL and AtJ pathways.

» Studies should be commissioned on the CI of DAC-to-jet on Canada's electricity supply and on potential ways to drive down the CI of CCUS-to-jet.

5. Explore pathways for using Municipal Solid Waste while keeping carbon intensity scores low (Q2 2023). (CCUS and DAC) (Q1 2024).

» Studies should be commissioned on the optimization of MSW as a feedstock, including the potential for CCUS.

» The LCA for MSW is complex. On the one hand, it can prevent the release of methane from the anaerobic digestion of organic waste. On the other, much of the energy from municipal solid waste can come from plastic. Plastic is sequestering fossil CO_2, so burning it produces carbon emissions.

» An optimization framework has been used by select companies for sorting that allows trade-offs between energy output and carbon emissions. Canadian companies could pursue a similar approach with the right policy and LCA supports.

Low carbon hydrogen is a key input in producing more SAF.

6. Identify agricultural practices that drive down carbon intensity scores and work with farmers and regulators to test and develop these practices (Q2 2024).

» Explore further potential for no-till and zone-tilling practices that preserve carbon structures in soil and lower CI scores of agricultural feedstock. These are already widespread in Canada, but more can be done to ensure upstream SAF emissions are as low as possible.

» Work with partners to reduce the emissions from fertilizer. This is another high impact agricultural practice. While there has been controversy around the Government of Canada's fertilizer emissions targets, replacing grey hydrogen with low-carbon hydrogen and electrifying the Haber-Bosch process for ammonia will have a high impact.

» Create policy incentive frameworks to support the cultivation of soil building energy-crops cultivation systems in areas of low soil organic carbon (SOC). Especially where biofuel cultivation may expand into undeveloped (wild acreage).

» Support agricultural best practices that as part of cultivation will actually increase soil organic carbon as part of feedstock cultivation and collection.

7. Work with international partners to ensure that carbon intensity scores recognize all forms of hydrogen based on their carbon intensity (Q3 2024).

» Canada has outlined a strategy for widely available low-carbon hydrogen.[67] But some international frameworks may exclude blue hydrogen. Canada must ensure that international standards focus on hydrogen carbon intensity, not on colours.

Feedstock

Success in 2030

Efficient and growing supply chains for all types of feedstock.

» Sustainable lipids, agricultural residue, wood residue, and municipal solid waste (MSW) feedstocks provide 80–90% of Canada's SAF needs.

» Low carbon intensity H_2 and atmospheric CO_2, the feedstocks needed for power-to-liquids, are poised to provide 10–20% of Canada's SAF needs.

» To ensure sustainability, there is a robust, science-based system to appropriately reward the carbon intensity of feedstocks in place.

» Continuously improving feedstock logistics.

Near-term goals

» Clarify and build demand signal to unlock feedstocks for 2030;

» Organize collection for agricultural residues, forest residues, and municipal waste.

Strategic assessment

» Canada has available feedstock for 7–10 billion litres of SAF per year.

» The key to building a sustainable and competitive supply chain is clarifying downstream demand while properly incentivizing carbon reduction practices at the feedstock stage.

» Agricultural and forestry waste is a big opportunity for Canada—if we can get collection and pre-processing right, these feedstocks could ensure that there will be SAF volumes available for export.

» It is important to ensure that CFR-driven demand for low-carbon ground transportation fuels does not monopolize available energy-crop supply.

Canola agriculture. Alberta, Canada.

The feedstock picture for SAF is complex but can be summarized simply as, where does the carbon come from? What matters, for the climate and for long-term competitiveness, is the emissions profile of the carbon source. Put differently, how can we harness carbon without increasing the amount of carbon in the atmosphere?

But from a broader environmental and social perspective, SAF must also harness carbon without disrupting ecosystems and harming social systems. We discuss the importance of broader sustainability criteria in **Sustainability Action Area**.

The feedstock analysis for this roadmap suggests that Canada could produce between 7 and 10 billion litres of SAF from biogenic and waste sources.

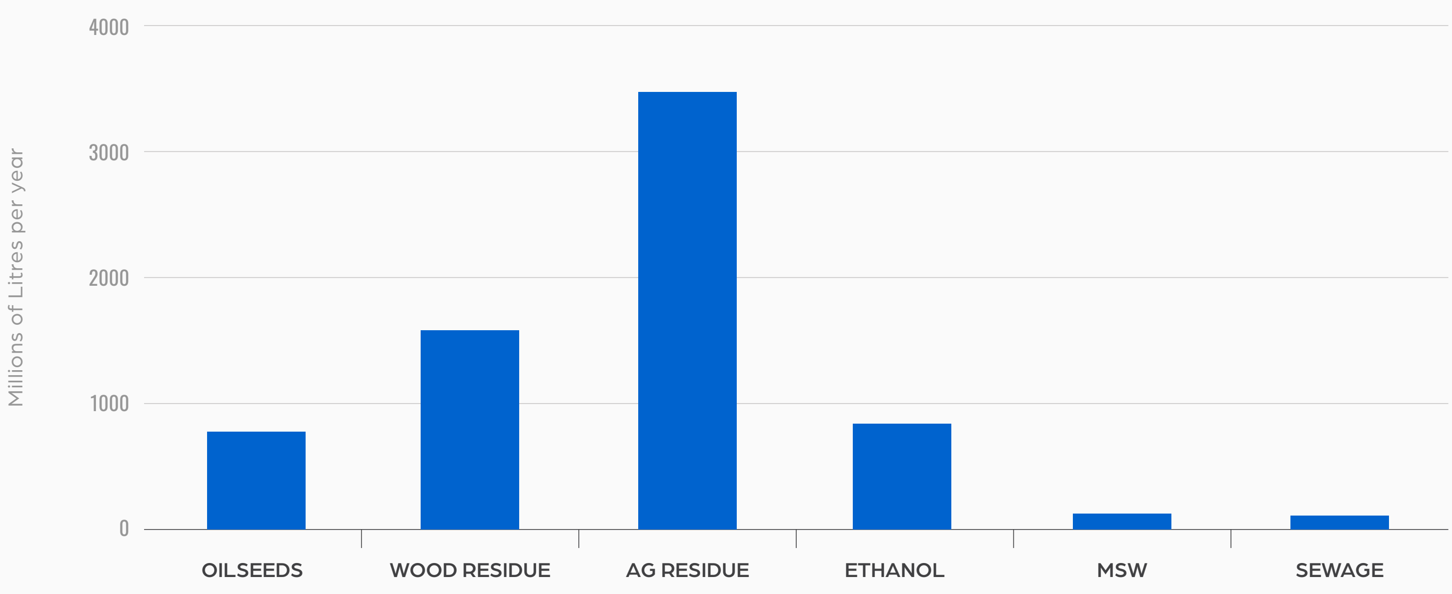
HEFA-based SAF from oilseeds, tallow, and used cooking oil has powered 95% of SAF flights thus far.[68] The gasification with Fischer Tropsch pathway will be the next to scale.[69] USA Bioenergy has reached final investment decision on its biorefinery which will use forestry residues from southern white pine plantations to make SAF.[70] Canada has significant available biomass in agricultural and forest residues that can be utilized by this pathway. Fulcrum has begun producing commercial volumes from municipal solid waste (household garbage).[71] Alcohol-to-jet from corn and sugarcane ethanol has secured large offtakes, with commercial production slated for 2025.[72] In the long-run, scalable volumes of SAF will be available from power-to-liquids, or efuels, or as termed in Europe, Renewable Fuels of Non-Biological Origin (RFNBO). But that pathway is still about 10 years from commercial viability.[73]

In Canada, HEFA utilising lipids is best positioned to meet most of the near-term demand.[74] The flurry of renewable diesel facility announcements suggest that volumes of lipids are available and most canola in Canada is already certified as sustainable under ISCC.[75] But in order to scale supply, agricultural residues, forestry residues, and municipal solid waste will need to be developed. We will need all feedstocks and multiple technology pathways to meet the targets.[76]

The feedstock analysis for this roadmap suggests that Canada could produce between 7 and 10 billion litres of SAF from biogenic and waste sources. Figure 5 shows 2022 volumes for six leading feedstocks, totaling over 6.8 billion litres. If we allow for modest improvements in technology and low rates of annual growth in some feedstocks, these six sources could produce 9.5 billion litres. Add to this the likelihood of plentiful CO_2 and hydrogen feedstocks for power-to-liquids fuels, and Canada has the potential to produce 100% of jet fuel demand in 2030 and beyond (10.6 billion litres, according to Deloitte[77]).

For this study, we made estimates of available feedstock by drawing on government data and leading scientific papers. To calculate the SAF potential, we used energy conversion rates and SAF fractions from *Clean Skies for Tomorrow.*[78]

FIG 5 SAF POTENTIAL FROM AVAILABLE CANADIAN FEEDSTOCKS (2022 VOLUMES)[79]



To ensure that the forestry and agricultural residues are used sustainably, we relied only on estimates of available feedstock that left sufficient material behind to maintain soil carbon and ecosystem health. For canola, it is difficult to estimate how much of current production would be available.[80] Our calculations include only canola seed and oil that is currently exported[81], on the grounds that Canada could keep this material at home and add economic value to it by putting it in the SAF supply chain. For MSW, we assumed that half the plastics were removed to lower carbon intensity scores.[82] This reduces the energy yield, but lowers the carbon intensity.

Biomass facility.

In the end, these are potential numbers. Regional-scale work is needed to verify the availability of feedstocks in the range of specific sites. Moreover, incentives and logistical work are necessary to mobilize these feedstocks and ensure they end up in the SAF supply chain.

The key actions in this section are intended to catalyze the creation of regional SAF supply chains that bring together feedstocks, refiners, transportation networks, and end-users.

The central problem is that a number of these feedstocks have other potential markets. There must be incentives in place to draw these feedstocks into SAF markets.

- Agriculture products like canola, soy, and corn are staples in food markets. Canola, strictly speaking, is mostly used as cooking oil, but is also included in processed foods. The meal left over after making oil is an important animal feed.[83]
- Even when oils make it into the fuel market, they predominantly end up in the strong renewable diesel markets.
- Wood biomass is an all-purpose fuel. In BC, forest residuals are turned into pellets for export and used in former coal-fired power plants in Asia and Europe or used for self-power by pulp and paper facilities.
- Hydrogen, a key input into advanced biofuels conversions processes and most importantly power-to-liquids, has many potential downstream markets in the power sector, transportation sector, and heavy industry. There will be competition for the lowest carbon hydrogen, which SAF producers will need to keep CI scores low.

Given this competition from adjacent sectors, there is a risk that feedstocks will end up in renewable diesel to reduce emissions in road transport. However, road transport has other decarbonization options that can be deployed sooner than the aviation sector.[84] For this reason both the Energy Transitions Commission and the International Energy Agency argue that biomass should be prioritized for SAF.[85]

The key to building a sustainable and competitive supply chain is clarifying downstream demand while properly incentivizing carbon reduction practices at the feedstock stage.

Key actions needed to deliver on the near-term goal (target start date)

1. Create a performance-based policy approach that appropriately rewards the carbon intensity (CI) of feedstocks (Q2 2023).

- Align and deploy Canada's lifecycle accounting (LCA) frameworks. Canada maintains its own lifecycle analysis accounting frameworks. GHGenius is currently used in the BC Low-Carbon Fuel Standard[86] and the federal government maintains its own Fuel Life Cycle Assessment Model.[87]
  - To ensure competitiveness and alignment, C-SAF should work with the government and outside experts to compare Canadian accounting standards to Argonne National Laboratory's GREET model—the industry standard LCA used in the US and ICAO-CORSIA. Canadian researchers should be integrated into Argonne's activities to ensure cutting-edge information is being transferred to Canada.
  - This work should seek to identify areas where changes to the LCA could incentivize activities that would increase the competitiveness of Canadian firms.
- Ensure that production incentives (see Policy & Program Action Area) are indexed to the CI of the feedstock.
- Develop partnerships between fuel producers and farmers to conduct demonstrations for practices that can reduce carbon intensity at the feedstock production stage (e.g. no-till, zone-till, no burning, smart/precision farming, and innovative fertilizer practices).
- Work with Carbon Capture, Utilization and Storage (CCUS) firms to explore how CCUS could be used to keep CI scores low and enable low-CI process plant inputs such as hydrogen or low carbon power.

2. Advance regional supply chains and supply chain logistics (Q1 2024)

- Build on the Representative Value Chains in this roadmap to design regional supply chains.
  - This is a key recommendation in the US SAF Grand Challenge: "Model and demonstrate sustainable regional supply chains for critical pathways by 2035 to promote commercialization of SAF supply chains through process validation and risk reduction via access to critical data and tools that empower rapid, informed decision-making when evaluating SAF supply chain options."[88] Canada needs a similar approach.

- To ensure systems can scale, C-SAF must conduct ongoing work on supply chain logistics including but not limiting to feedstock supply logistics improvement, increased reliability of feedstock handling systems etc.
- C-SAF should convene a government-industry workshop on supply chain logistics to identify barriers to collection and distribution of next generation feedstocks.
- Oilseed and waste fat supply chains are mature, but work is needed to ensure that agricultural and forestry residues can make it to market via green transportation corridors that will keep CI scores low.

3. **Agriculture and used cooking oil (UCO):** Build the infrastructure and policy frameworks needed to bring more agricultural goods into regional supply chains (Q3 2023).

- Oilseeds: the infrastructure for canola, tallow, and UCO is mature. Adequate incentives are needed to ensure that these feedstocks make it into the SAF supply chain.
  - This roadmap assumes that volumes of canola seed and oil which are currently exported could be brought into the SAF supply chain. To make this possible, additional crushing capacity would be needed in Canada.
- Validate the sustainability of Canadian oilseed HEFA to meet CORSIA Eligible Fuel criteria Ethanol: begin advance planning to steer ethanol into the SAF supply chain as gasoline demand declines over the course of the electric vehicle revolution.
- Ethanol is a key feedstock for alcohol-to-jet. Lanzajet and Gevo have demonstrations and are targeting large volumes of production as early as 2025.

Soybean farm field. Ontario.

Ethanol Plant. Adobe Stock

Incentives and logistical work are necessary to mobilize these feedstocks and ensure they end up in the SAF supply chain.

- Volumes of ethanol should begin to be available as soon as 2030. Locating SAF production near ethanol facilities may leverage existing infrastructure.
- Explore the potential of CCS alongside ethanol facilities in Canada for further fuel CI reduction.
- Agricultural residues: Pull together partners for a demonstration of agricultural residue collection to study the logistical and technological challenges to bring more Canadian residues into the SAF supply chain.
- Innovative crops: Explore the potential for camelina, miscanthus, and carinata on marginal lands in Canada.[89]
- Double cropping: Examine potential of double cropping systems to increase feedstock availability while addressing agrosystem impacts (soil mining excessive utilization of nitrogen fertilizers).
- Fertilizer innovation: Explore the potential for reducing fertilizer emissions to lower carbon intensity scores.

4. **Wood:** Build the supply chain for wood feedstocks (Q3 2023)

- Co-locate SAF facilities with forestry operations. Explore the availability of fibre at a regional level to inform site selection.
- Create an efficient hub-and-spoke system for wood residue collection and processing.
- Explore mechanical bundling of forestry residues, learning from efficient collection practices in the Nordic countries.
- Prioritize the collection of wood slash that would otherwise stunt regeneration post-harvest due to combustion or deadwood crowding out of new growth.[90]

- Work with the Forestry Products Association of Canada and others to explore changes to forestry practices that would make more wood waste available.

5. **Municipal Solid Waste:** Work with municipalities to collect carbon-rich waste and deliver it to the biofuels pipeline (Q4 2023)

- Connect with provincial and territorial unions of municipalities to see which municipalities might be looking at this; prioritize locations for biofuels hubs.
- Reach out to large municipal waste collection firms to explore opportunities to increase the efficiency of collection, sorting, and treatment.

Slash piles and clear cut Douglas fir forest.

6. **Sewage sludge and biosolids:** Explore potential with pilots and demonstrations (Q2 2024)

- Conduct rigorous study of the SAF potential from sewage sludge.
- Advocate for a federal fund to support and share costs with municipalities who have a population greater than 500,000 to install methane capture infrastructure at wastewater treatment facilities.

7. **Develop hydrogen feedstock:** Source low-carbon hydrogen for power-to-liquids (PtL) and upgrading (Q4 2023).

- Low-carbon hydrogen can reduce the direct GHG emissions of fuel conversion by 20%.[91]
- Build regional supply chains to include low-carbon intensity hydrogen.[92]

Ashbridges Bay Wastewater Treatment Plant, Ontario.

- Co-location of hydrogen and SAF production will benefit both industries. In Canada, work has begun on a hydrogen corridor from Winnipeg to Calgary, up to Edmonton, and on to Vancouver. With available biomass along this route, C-SAF should work with both industries to explore co-location.
- Request that the Ministry of Finance make tax credits for clean energy, CCUS, and hydrogen stackable to lower the cost of low carbon hydrogen.

8. Develop CO_2 feedstock for power-to-liquids (Q4 2024).

- Leverage industrial hubs like the Alberta Heartland and Becancour as suppliers of SAF feedstock carbon.
- Identify high potential areas for CCUS and direct-air-capture of sustainable carbon sources, as the availability of clean electricity and the local climate impacts the efficiency and economic viability of the technology.

9. Clarify and communicate the amount clean electricity needed to meet SAF production targets (Q3 2023).

- Advise Natural Resources Canada (NRCan) on the benefits of power purchase agreements (PPA) for SAF.
- US projects can secure net-zero power that is heavily subsidized by the production tax credits in the IRA. Canadian projects should have this option. Only Alberta has reliable behind the fence power (which is rapidly being built).[93]

We will need all feedstocks and multiple technology pathways to meet the targets.

- Provide an estimate of projected electricity demand from SAF projects to the Pan-Canadian Grid Council and the Regional Energy and Resource Tables.
- SAF production, like all processing, requires a lot of energy. Adding processing value-added to the Canadian supply chain will increase demand on the grid (with the partial exception of Alberta, which allows for power to be purchase behind the fence).
- This increased demand, including the energy needed for green hydrogen, direct-air-capture, and should be modelled and incorporated into Canada's electricity planning projects, such as NRCan's Pan-Canadian Grid Council and Regional Energy and Resource Tables. This will help ensure that clean energy assets can support SAF projects on the timelines needed.

SAF Production Capacity

Success in 2030

Canada SAF production projects that will meet the 10% target – 1 billion litres of made-in-Canada SAF. There is a strong project pipeline that will expand SAF capacity in multiple pathways over the 2030s.

Near-term goals

Close the production gap—secure the investments in the facilities needed for 2030 targets.

Strategic assessment

- We have the midstream capabilities and ecosystem to create a leading SAF industry in Canada.
- Publicly announced SAF facility proposals could deliver about 500 million litres of HEFA-based SAF. However, these projects have not reached final investment decision so additional incentives and policies are needed to secure SAF production.
- Another key question is what feedstocks and pathways will produce the additional SAF we need. This action area must advance projects that will accelerate learning and investment.
- To do this, funds for first-of-a-kind and other plants at earlier technology readiness plants are needed. Existing funding instruments are not a good fit for these. But to be a market leader and secure a place in global supply chains, quick action is needed to catalyze learning through deployment.

Canada has world-leading refining capacity, including a number of refiners taking innovative approaches to co-processing and renewable diesel production.[94] This strength in the midstream of the supply chain can pay dividends over the course of the transition.

However, SAF is a new product. That means that both new and existing producers must grapple with technological uncertainty and outlay significant capital. Existing bio-refiners will have to modify their facilities to produce SAF. New entrants need capital for first-of-a-kind and early technological readiness plants to produce renewable diesel and SAF from new feedstocks.

The low-carbon fuel standards in BC and California are priming the renewable diesel market and demand is strong. However, SAF is distinct from renewable diesel and requires new standalone facilities or additional refining equipment, depending on the pathway. There is also a yield loss for a refinery to produce SAF versus renewable diesel, using the same amount of feedstock. In order to ensure that SAF is even produced, refiners need additional incentives. Without these incentives, they may produce only renewable diesel.

Even if a producer elects to produce SAF, the fraction of SAF it produces will depend on incentives. Van Dyk and Saddler suggest that current and proposed projects are likely to produce 15% of their announced volumes as SAF.[95] However, *Clean Skies for Tomorrow* argues that higher SAF fractions could be optimal (see Figure 6). The feedstock projections in this roadmap use these conversion rates and optimal product slates to calculate SAF potential.

FIG 6 ENERGY CONVERSION RATES AND OPTIMAL SAF FRACTIONS FOR SAF PATHWAYS[96]

Values represent conversion factors used for analyses

APPROXIMATE OUTPUTS SHARES OF JET-OPTIMISED PRODUCTION PROCESSES

Product slate can be varied, for example, by changing H_2 use and operating conditions in the long term, technology improvements could raise jet optimal share of SAF output to 70% for HEFA and FT

- JET FUEL
- ROAD FUEL [iv]
- LIGHT ENDS [v]

Feedstock	Pathway	Conversion rate [ii]	Product slate optimized for jet fuel
Lipids	HEFA	**90%**	Jet fuel 46% / Road fuel 46% / Light ends 8%
Biomass (mainly lignocellulosic	Alcohol-to-jet [i]	**13%**	Jet fuel 77% / Road fuel 6% / Light ends 17%
Biomass	Gasification / FT	**20%**	Jet fuel 60% / Road fuel 22% / Light ends 18%
CO_2	Power-to-liquid	**17%** [iii]	

i. Ethanol route;
ii. Yield of total output (including aviation and road fuel) relative to feedstock;
iii. For electrolysis with RWFS; co-electrolysis with SOEC may have slightly higher conversion rate;
iv. Gasoline or diesel; road fuel resulting from HEFA process is called hydrotreated renewable diesel (HRD);
v. Light hydrocarbon gases and liquids eg. LPG or Naphtha

Source: McKinsey Global Energy Practice; ICCT; International Renewable Energy Agency (IRENA); expert interviews

The feedstock projections in this roadmap use these conversion rates and optimal product slates to calculate SAF potential. But it is important to note that achieving these high rates depend on new incentives that drive biofuel producers toward SAF. At present, the economically optimal slate favours renewable diesel production.

The policy community in the United States recognized this and pushed for the inclusion of production tax credits in the *Inflation Reduction Act* (IRA). In the end, the IRA includes two credits.[97] The Sustainable Aviation Fuel Tax Credit (40B), which applies in 2023 and 2024, is a tax credit of $US1.25/gallon for fuels that achieve a 50% carbon emissions reduction. Beyond 50%, the credit rises $0.01 for every percentage point of carbon reduction to $US1.75/gallon.

A second credit, the Clean Fuel Production Tax Credit, takes effect in 2025. It applies to SAF produced in the US and offers $0.35/USG for fuels achieving a 57% carbon reduction, rising to $1.75/USG for 100%. Furthermore, US producers can stack these credits with Renewable Identification Numbers (RINs) and credits from the California LCFS. These are major markets and revenues from these sources are well-known and bankable. As with the IRA generally, the production tax credits can be claimed on goods that are exported. This puts Canadian producers at a disadvantage.

To build processing value-added here in Canada, Canadian refiners need additional incentives and funding programs that take an active role in supporting the SAF supply chain.

These create a major competitiveness concern for Canadian SAF refining. Without similar incentives in Canada, Canada may be reduced to a feedstock provider, while all the processing moves to the United States. This is a pattern we could see across industries—Canada provides primary commodities but fails to capture the downstream value-added.[98] It also means that the core of the innovation ecosystem would be located elsewhere and Canada's expertise in hydrocarbons and green chemistry would be wasted.

Building an innovation ecosystem is key to climate politics. Driving down costs and creating indirect economic benefits for suppliers and technology providers makes decarbonization a win-win proposition. But we can only build these systems and create these opportunities if the midstream of fuel production is located in Canada.

To build an innovation ecosystem, we need to act fast to fund first-of-a-kind facilities for multiple SAF pathways. Existing federal and provincial funding programs do not make it easy to fund large ($200 million to $1 billion) first-of-a-kind (FOAK) and early-stage commercial facilities—many of these are needed in the SAF supply chain.

These projects need to be integrated into an overall plan. To create a sustainable ecosystem for SAF supply, building projects systematically and strategically will be more effective than one-off investments in a few facilities. This report elaborates on these considerations in the final section.

Permitting timelines also require attention. This has been a significant point of discussion in the critical minerals space, but the same considerations apply in refining.[99] If it takes 10 years to get permits to build a new refinery, then 2030 is not achievable. Governments at all levels need to figure out a way to prioritize clean energy initiatives.

In short, to build processing value-added here in Canada, Canadian refiners need additional incentives and funding programs that take an active role in supporting the SAF supply chain.

Governments at all levels need to figure out a way to prioritize clean energy initiatives.

Key actions needed to deliver on the near-term goal (target start date)

1. Advance a policy package that will incentivize the investment we need to close the gap (Q2 2023).

» C-SAF should create a Policy Task Force that will seek to advance

- Production incentives for SAF. This is critical to Canadian competitiveness, but there is also an opportunity because the *Inflation Reduction Act* credits only run for 5 years. A longer credit at a lower level could tip the scales in Canada's favour.
- Short-term incentives and programs that enable early adoption and use of SAF (i.e. imports) while scaling the Canadian SAF market. The IRA supports a short-term SAF blender's tax credit.

» See Policy & Program Action Area for more details on this.

2. Work to ensure that federal and provincial funding programs take an active role in supporting innovative SAF production here in Canada (Q3 2023).

» Explore whether existing industrial strategy funds can be utilized to support first-of-a-kind refining facilities and collection operations. The $1.5 billion Clean Fuels Fund and $15 billion Canada Growth fund have the potential to be better leveraged to support the SAF sector.

» Propose preferred lending rates for SAF facilities through the Canada Growth Fund or the Canada Infrastructure Bank.

3. Create an active project pipeline with pilots, demonstrations, and first commercial projects in critical SAF production pathways (Q3 2023).

- C-SAF should work with government and industry to create a pipeline of projects that balance the goals of decarbonization, feedstock activation, and innovation.
- Advance projects for sections 6 and 9

4. Explore opportunities to collaborate with other net-zero sectors (Q4 2023).

- Liaise with other prospective users of clean electricity and low carbon hydrogen to help build demand.[100]
- C-SAF should forge partnerships with other industries and work to advance the creation of decarbonization hubs. Decarbonization hubs bring together clean energy, low-carbon hydrogen, carbon management, green transportation corridors, and chemical expertise to realize co-benefits.

5. Ensure investment in new HEFA-based renewable diesel and SAF facilities (Q3 2023).

- Work with project proponents to ensure SAF policies and programs incentivize investment. See 1 in Feedstocks Action Area and 1 and 2 in Policy and Programs Action Area for more details on how this can be done.
- Support proposed projects in securing land, permits, feedstock, and offtakes.
- Work to ensure these projects can produce high SAF fractions in the product slate.

6. Co-processing: advance changes to jet specifications that would allow up to 15% (or higher) co-processing in refineries (Q3 2023).

- Canada should work with international colleagues through the relevant ASTM and CAAFI committees to ensure co-processing levels can increase.
  - This is another proven production method. However, given that co-processing is not a net-zero pathway in the long term, investments need to be balanced so as not to crowd out other net-zero economic opportunities. But it is a beneficial route for forestry residue, via hydrothermal liquefaction and pyrolysis, and should be explored.

SAF is a new product. That means that both new and existing producers must grapple with technological uncertainty and outlay significant capital.

7. Biomass-to-SAF: work with the industry partners and governments at federal and provincial levels to advance demonstration projects in this area (Q3 2023).

» Work with developers and technology providers to explore site selection for gasification and Fischer-Tropsch in Canada.

- Wood and agricultural waste are essential to the production of SAF volumes in the long-run. However, only USA Bioenergy in Texas has a commercial facility in the pipeline.
- Recent developments hold a lot of promise, but we need to accelerate the timeline to final investment decisions and production volumes.[101]

8. Power-to-liquids (PtL): develop a plan to prove out and scale PtL in Canada (Q1 2024).

» Work with developers and technology providers to explore site selection for PtL in Canada.

- PtL will play an important role post-2030. It is viable in a number of jurisdictions low-cost, low-carbon hydrogen can be combined with CO_2.
- Canada has an existing demonstration project, by the SAF+ consortium, which utilizes CO_2 from industrial flue gas.[102]
- In addition to identifying CCUS opportunities,work should be complemented by demonstrations that capture and use atmospheric CO_2.

9. Alcohol-to-jet (AtJ): accelerate commercialization timelines (Q3 2024)

» Work with developers and technology providers to explore site selection for PtL in Canada.

- AtJ is now an emerging commercial technology which is poised to generate significant SAF volumes.
- As gasoline consumption declines with electrification, more and more biocrop ethanol would be available for conversion to biofuels including SAF. Future regulatory changes could accelerate or decelerate this. For example, the rollout of the clean fuel regulation may incentivize more ethanol to go into ground transportation, crowding out use for SAF. Ground transportation fuel blending is a greater existing market with policy certainty compared to SAF.
- A number of firms are looking at converting ethanol to jet in Canada. Carbon Engineering's demonstration with Lanzatech, although based in the UK, should be monitored closely.

Technology & Innovation

Success in 2030

Canada is a world leader in second and third generation SAF and is ready to deploy hydrogen combustion and electric propulsion technologies at scale.

Near-term goals

Establish the technological building blocks of an SAF innovation ecosystem and coordinate with Canada's aviation decarbonization strategy and action plan.

Strategic assessment

- In a net-zero competitiveness lens, there are two critical areas of technology:
  - advancing SAF pathways, and
  - developing new propulsion technologies.
- For SAF, Canada must advance emergent pathways, especially gasification and Fischer-Tropsch (for biomass waste), alcohol-to-jet pathways and PtL pathways (which also makes use of Fischer-Tropsch and ATJ). Canada's biomass residues and clean grid are resources we can leverage over the transition.
- Not only is hydrogen is a key input in producing more SAF, but in addition, hydrogen and electric propulsion will be important elements of a net-zero fleet, but they will only serve niche, local markets until 2035. Both hydrogen and electric propulsion are ill-suited to long-haul flights. Canada must position itself to benefit from these technologies, but near- and long-term decarbonization hinges on SAF.
- The industry continues to explore how to transition more rapidly to using 100% SAF.

There are two main strands of the technology action area. The first strand is advancing SAF pathways while building an innovation ecosystem. Table 4 outlines a rough timeline for when we should expect the various SAF pathways to start delivering volumes. A technology strategy needs to ensure that these processes are piloted early and works to catalyze collective learning. Each pathway needs its own strategy that seeks to identify Canada's opportunities in global value chains.

TABLE 4 SAF COMMERCIALIZATION TIMELINE[103]

2021–2025	2026–2030	2030–2040	2040–2050
HEFA	HEFA	HEFA	HEFA
Gasification–FT	Gasification–FT	Gasification–FT	Gasification–FT
ATJ	ATJ	ATJ	ATJ
Coprocessing lipids	CHJ	CHJ	CHJ
	Coprocessing lipids	Coprocessing lipids & biocrudes	Pyrolysis / HTL
		Pyrolysis / HTL	PtL
		PtL	

These plans should be focused on identifying areas for cost reductions. Each pathway should be broken down into its technological systems to identify areas where costs could be lowered significantly, either through deployment or incentives. For example, an analysis of PtL value chain suggests that hydrogen prices are a key target. Reducing hydrogen costs to below $1/kg would reduce the cost of PtL by a third.[104]

In addition, more research must be done on conversion rates and optimal SAF fractions in biofuels production. In Figure 6, estimated conversions and fractions are provided, but commercial operations differ, and various fractions can be achieved. At the moment, product slates are targeted to maximize netbacks from credit systems with are built to favour renewable diesel.

Within a broader national strategy, understanding and adjusting conversions and fractions is important because it has implications for the allocation of biomass across sectors. Consider a scenario in which SAF was prioritized: there would still be a portion of renewable diesel and other renewable fractions remaining, which may be appropriate to decarbonize certain marine, manufacturing or off-road markets.

Air Canada has announced a purchase agreement for 30 ES-30 electric-hybrid aircraft under development by Heart Aerospace of Sweden. Image: CNW Group/Air Canada

Each pathway should be broken down into its technological systems to identify areas where costs could be lowered significantly, either through deployment or incentives.

SAF can help aviation decarbonize now and in coordination with a long-tern aerospace decarbonization strategy allow developing technology to switch to net-zero propulsion systems. Canada must also develop a technology development strategy for new propulsion technologies: battery-electric, hydrogen electric and hydrogen combustion. These are important pieces of net-zero aviation, but they are not a focus of this work. Air Canada's recent purchase of 30 electric regional aircraft, to be delivered in 2028, demonstrates that the electric future is coming soon.[105] On the hydrogen front, Airbus has announced that it will conduct hydrogen demonstration flights on an A380 by 2026.[106] Now is the time to start building the ecosystem for these technologies[107] in coordination with this SAF roadmap.

Key actions needed to deliver on the near-term goal (target start date)

1. Secure funds for technology demonstrations (Q3 2023).

» A key task for budget 2024 engagement should be to ensure that there is a dedicated investment fund for net-zero aviation that can be used to support an industrial strategy for SAF and aerospace development.

» Incorporate digital process improvement strategies to monitor and optimize production processes. Demonstrations must be conducted with high quality digital infrastructure to maximize shared learning and optimization.[108]

2. Create clear technology development plans for SAF that correspond to the technological readiness level (TRL) status and feedstock availability of each pathway in Canada (Q1 2024).

- The government and industry should collaborate to set cost reduction targets for 2030 that are integrated with policy considerations such as tax credit levels and fuel regulations' stringency. These targets can be used to backcast needed experiments, demonstrations, and infrastructure investments.
- New projects should continue the practice of coordination with the national laboratories to maximize learning and capacity building from demonstration projects.
- As Fischer-Tropsch and alcohol-to-jet are keys to both biomass and PtL pathways, a clear strategy to build Canadian expertise and drive cost reductions is needed.
- Power-to-liquids is essential for long-term goals also needs a strategy.

3. Canada to create clear technology development plans for new propulsion technologies in coordination with the SAF Roadmap (Q1 2024)[109]

- Support industry partners in conducting rigorous evidence-building activities to ensure engines are compatible with 100% SAF, hydrogen combustion, battery electric, and hydrogen electric technologies should be a key component of the ecosystem. Such evidence-building activities should include feasibility studies, technology testing, demonstration, and safety certification.
- To determine what Canada can contribute to hydrogen-powered engines and airport infrastructure, C-SAF, AIAC and other partners should organize the aerospace sector to collaborate with the emerging hydrogen economy on a scoping study.
- To determine what Canada can contribute to electric propulsion, AIAC, and other partners should collaborate with the emerging battery metals and electric vehicle supply chain on a scoping study.

SAF can help aviation decarbonize now and in coordination with a long-term aerospace decarbonization strategy allow developing technology to switch to net-zero propulsion systems.

4. Work with partners to establish a national centre of excellence for the future of aviation in a net-zero world that brings together C-SAF, the Aerospace Industries Association of Canada, and others (Q3 2024).

» A centre is needed to develop a coherent industrial strategy that integrates SAF development and new propulsion technologies into a clear plan. It would be formed as an independent organization co-funded by government and industry. The Centre should work closely with government and industry on actions 1-4 above, plus:

- Leverage Aéro Montréal and the whole aerospace cluster in Canada.
- Activate the SIF-funded Aerospace Innovation and Research Network (AIR) to contribute to net-zero goals.[110]
- Reach out to National Research Council (NRC) and NRCAN CanMET Energy to draw on their expertise.
- Liaise other research centres: Waterloo Institute for Sustainable Aviation, University of Toronto Institute for Aerospace Studies, BCSmart, etc.
- Leverage airports working to build regional supply chains to serve their clients.
- Acquire world-leading testing and demonstration equipment to facilitate shared learning.
- The centre of excellence would be technology focused. In Policy and Programs, this roadmap proposes creating a broader public-private platform that would focus on SAF, but liaise with this centre of excellence and other national net-zero technology initiatives.

Representative value chains

Building regional supply lines is critical to supporting the production and consumption of sustainable aviation fuel (SAF) industry in Canada. To help specify the roadmap, this document outlines representative value chains (RVCs)—regional clusters of feedstock, pre-processing, refining, and use.

Thinking at the level of regional supply chains helps bring together the overarching themes of this work:

- seizing economic opportunities in Canada;
- building an integrated, innovative supply chain that will deliver economic value-added through the energy transition;
- generating deep emissions reductions and other environmental co-benefits for land and forests;
- realizing co-benefits with other pieces of decarbonization infrastructure.

Regional supply lines have emerged as a key focus area for SAF roadmapping exercises in the US and Europe. In the US, the Federal Aviation Administration roadmap highlights the need to "support SAF production expansion through regional supply chains ensuring R&D transitions, field validation, demonstration projects, supply chain logistics, public-private partnerships, bankable business model development, and collaboration with regional, state and local stakeholders."[111]

Every region of the country can build efficient, homegrown feedstocks-to-fuels value chains that could support the production of SAF and the creation of low-carbon aviation hubs at the airports.

In Europe, SkyNRG has piloted the creation of regional supply chains they call "direct supply lines."[112] Direct supply lines source feedstock for new refining capacity locally to build efficiency and resilience into the SAF ecosystem.

The goal of our representative value chains is to provide a concrete visualization of what SAF in Canada might look like. They allow CSAF to specify concrete tasks for building SAF in Canada and to improve costing estimates. They are representative—they are not the product of an assessment of the best or most likely value chains.

The ten value chains presented here are:

1. **HEFA or coprocessing in the Prairies**
2. **HEFA or coprocessing in Eastern Canada**
3. **Wood pyrolysis/HTL in BC**
4. **Wood HTL in Ontario**
5. **Wood gasification in Quebec**
6. **MSW to jet in Edmonton**
7. **Power-to-Liquids (PtL) with green hydrogen in Quebec**
8. **Power-to-Liquids (PtL)with blue hydrogen in Alberta**
9. **Ethanol AtJ in Ontario or Quebec**
10. **CO_2 AtJ in BC**

These 10 RVCs combine almost all the possibilities hidden within the commonly cited 7 ASTM pathways. Those pathways can be realized in different forms in different locations. Taken together, the pathways incorporate:

- Commercial and near-commercial (HEFA, co-processing, Gasification-FT, and ATJ) as well as medium-term commercial (Pyrolysis/HTL and PtL) pathways.
- All feedstocks: HEFA, wood, agricultural residue, CO_2, blue and green hydrogen, ethanol, and MSW.
- A variety of regions: from BC to Atlantic Canada.

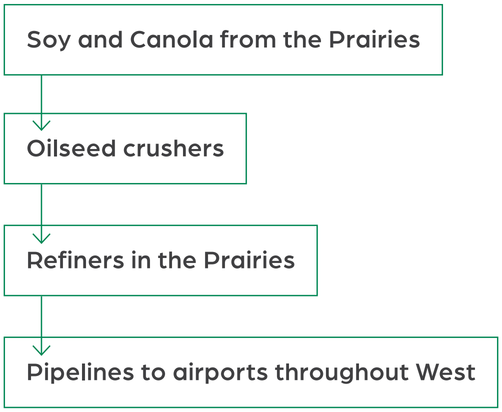
While all of the 10 pathways are actionable pathways in the Canadian context, a number of them could be realized in a variety of locations.

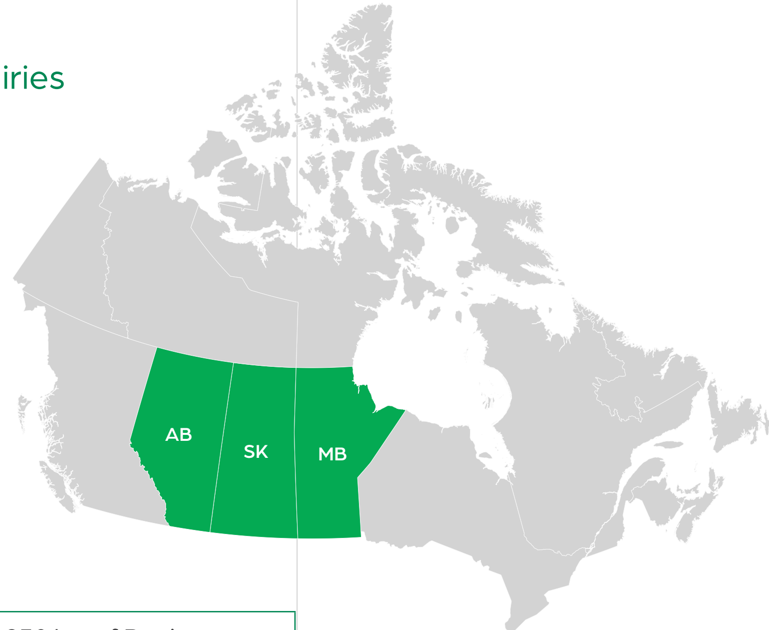
Each RVC puts together these 3 elements into a place-based combination with an estimate of available feedstock.[113]

The point is to be illustrative rather than exhaustive. While all of the 10 pathways are actionable pathways in the Canadian context, a number of them could be realized in a variety of locations. For example, woody biomass to SAF via HTL or PtL with green hydrogen would be possible in a number of locations. Or different combinations of technologies could be deployed to lower CI scores and combine feedstocks.

RVC 1

HEFA or coprocessing with oilseed in the Prairies





Feedstock availability	~1,920,000 t of canola within 250 km of Regina
SAF Production Potential	124 ML of SAF
Hydrogen Requirements	104 t/ML of SAF

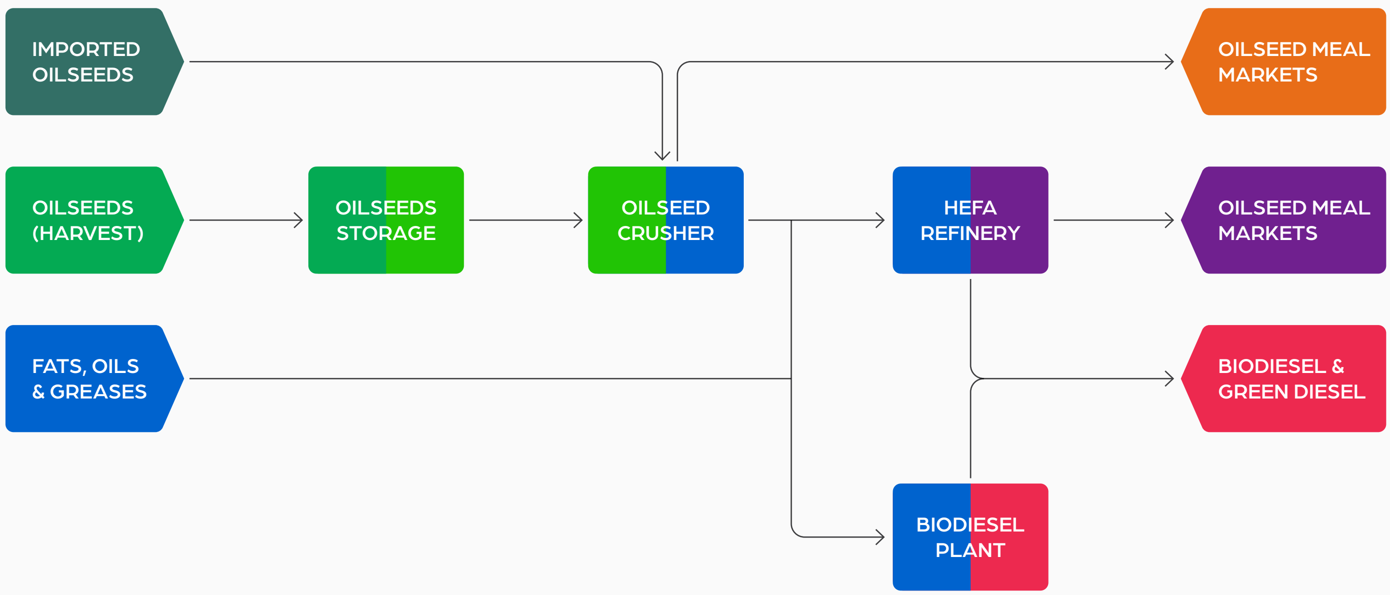
HEFA processes are already producing commercial volumes of renewable diesel in Canada. Canola and tallow are already co-processed at Parkland in BC. Covenant, Tidewater, Braya, Imperial, FCL, and others have also put forward proposed renewable diesel facilities that could produce SAF volumes.

Production and processing of oilseed is concentrated in the prairies (see Figure 9). The cluster stretches from southern Manitoba through Saskatchewan to central Alberta. There is no shortage of feedstock or refining capacity in this area.

The regional supply chain for the production of canola and soy oil is mature, and so the development of an oilseed RVC in Canada would only require the modification of existing refineries for co-processing or the deployment of existing HEFA technologies.

Transport networks are also mature. Existing rail links that already transport oilseed crops for export can direct feedstock to BC refineries. Alternatively constructing HEFA refineries located within Saskatchewan would reduce the total mass to be transported, with the refined fuel product exported by railcar.

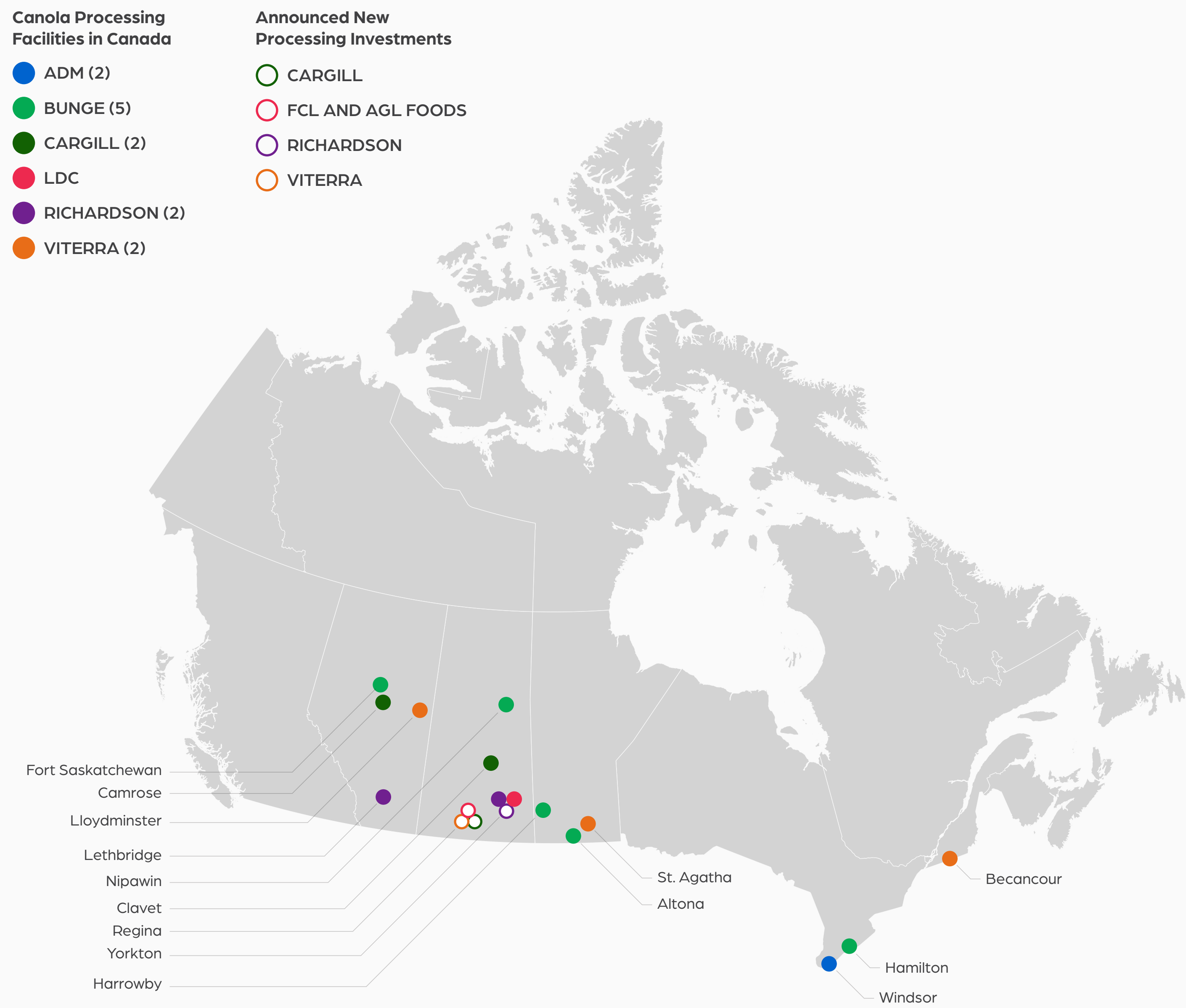
FIG 8 HEFA SUPPLY CHAINS[114]



The key question for this value chain is how much feedstock will be available for renewable diesel and SAF. Canola oil and similar feedstock often costs more than jet fuel so significant incentives would be needed to bring canola into the SAF supply chain.

Canola agriculture.

FIG 9 CANOLA PROCESSING[115]



RVC 2

HEFA or coprocessing with oilseed, tallow, and UCO for Quebec–Atlantic Canada loop

Soy and Canola from Ontario/Quebec
↓
Becancour crusher
↓
Refineries in Quebec and Atlantic Canada
↓
Montreal and Quebec city airports

Feedstock availability	~600,000 t of soybeans within 250 km of Montreal
SAF Production Potential	16.4 ML
Hydrogen Requirements	104 t/ML SAF

Becancour is home to a large and growing industrial park. There is an oilseed processing facility there already and it is centrally located for feedstock from Quebec and Ontario. Processed oil from Becancour could feed the Montreal refinery, or the Braya refinery in Newfoundland, via marine transport. Braya is otherwise cut off from good HEFA feedstock. If Braya is committed to offtakes from foreign feed, then Quebec refineries could be adapted to produce RD and SAF.

Tractor spraying soybean field.

RVC 3

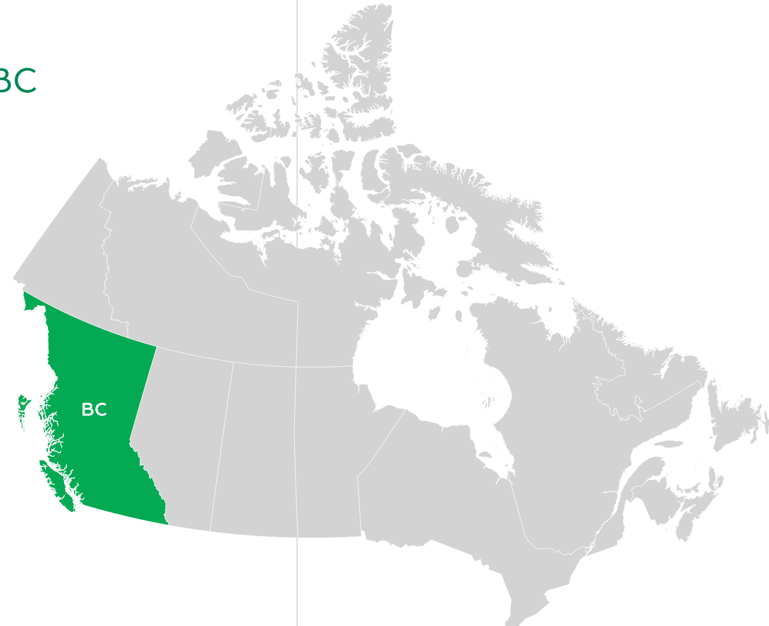
Pyrolysis or HTL from woody biomass in BC

Prince George Area

BC forestry operations → Drying and processing → Pyrolysis → Biocrude → Co-processing at renewable diesel facilities in BC

Vancouver Area

BC forestry operations → HTL → Biocrude → Co-processing at renewable diesel facilities in BC



	Prince George Area	Vancouver Area
Feedstock availability	High End: ~10.5M ODT of forest and mill residues within 250 km of Tidewater Low End: ~600,000 ODT of forest and mill residues from logging operations within 50km of Chetwynd (its logging operations proximate to Tidewater)	High: ~6,000,000 ODT of forest and mill residues within 250 km of Parkland Low: ~1,300,000 ODT of forest within 50 km of Parkland
SAF Production Potential	619 ML HTL within 250km of Tidewater 248 ML pyrolysis 35 ML HTL within 50km of Chetwynd 14 ML pyrolysis	354 ML HTL within 250km of Parkland 142 ML pyrolysis 77 ML HTL within 50km of Parkland 31 ML pyrolysis
Hydrogen Requirements	40.32 t/ML SAF	40.32 t/ML SAF (upgrading the H_2 intensive step in both pyrolysis and HTL)

In this RVC, biocrude is produced via hydrothermal liquefaction (HTL) or pyrolysis from wood residues. Biocrude is then upgraded or co-processed in the hydrotreater.[116] While pyrolysis requires drying, HTL can exploit wetter biomass (including algae), so the supply lines for these two methods are slightly different.[117] However, pyrolysis is at a higher technology readiness level than HTL and it will be some years before HTL is ready to produce SAF at volumes in Canada.[118] Nonetheless, Arbios, which has backing from Canfor, plans to create an HTL facility near Prince George.

Either pathway could end at Tidewater.

RVC 4

HTL from woody biomass in Northern Ontario

Northern Ontario forestry operations
↓
HTL
↓
Biocrude
↓
Co-processing in Sarnia or the Prairies
↓
Airports in the Prairies or YYZ

Feedstock availability	Within 250 km of Dryden, ON: ~1,500,000 ODT of forest and mill residues
SAF Production Potential	Woody Residues 93 ML HTL
Hydrogen Requirements	40.32 t/ML of SAF produced

Northern Ontario forestry operations produce considerable residues. In addition, there are significant opportunities for indigenous co-development. Without drying infrastructure, HTL to biocrude might be a better option here.

The key question is where to co-process the fuel and which airports would be available. Refineries in Saskatchewan or Sarnia are accessible via rail. However, extensive land based journeys of green biomass added must be assessed for feasibility based on their added transport costs, carrying an additional 40-45% in water weight.

RVC 5

Gasification with woody biomass in Quebec

Quebec forestry operations
↓
Gasification
↓
FT
↓
Quebec airports

Feedstock availability	~5,000,000 ODT of forestry and mill residue within 250km of Trois Rivieres. ~650,000 ODT of forestry and mill residues within 50km of St. Georges
SAF Production Potential	Within 250km of Trois Rivers: 333 ML Within 50km of St. Georges: 53 ML
Hydrogen Requirements	FT synthesis is self-sufficient in H_2 production

Quebec has ample forestry operations with waste that could be used to make SAF. Enerkem has pioneered gasification in Quebec, which is being successfully commercialized by USA Bioenergy in Texas. The Bioénergie La Tuque project with Neste has not announced which pathway it is pursuing, but gasification is the most likely.

Timber harvest and processing has developed in clusters on both sides of the St Lawrence along and just north and south of the Quebec Montreal corridor. Among the largest of these clusters is the community of St.Georges. Combination roadside slash and mill residues leave ~650,000 ODT's of woody biomass that could be utilized in gasification projects. FT-Gasification facilities could be established onsite to procure industrial quantities of SAF.

Alternatively, woody residues could be shipped the 82 km's north to Quebec City, where gasification infrastructure could be co-located with Valero's refinery in Levis. Benefits of co-locating gasification infrastructure with existing refinery capacity is the improved economies for CCUS which could serve the entire industrial park. Future PTL facilities that choose to site operations at the Jean Gaulin refinery would also have greater potential CO_2 feedstock to utilize.

Gasification with agricultural waste in the Prairies is also an interesting possibility. ~5,750,000 million tonnes per year of straw and stover are available within 250km of Winnipeg. Manitoba is also among the hydro dominant provinces with the 2nd cheapest provincial power rates nationally (better than BC).

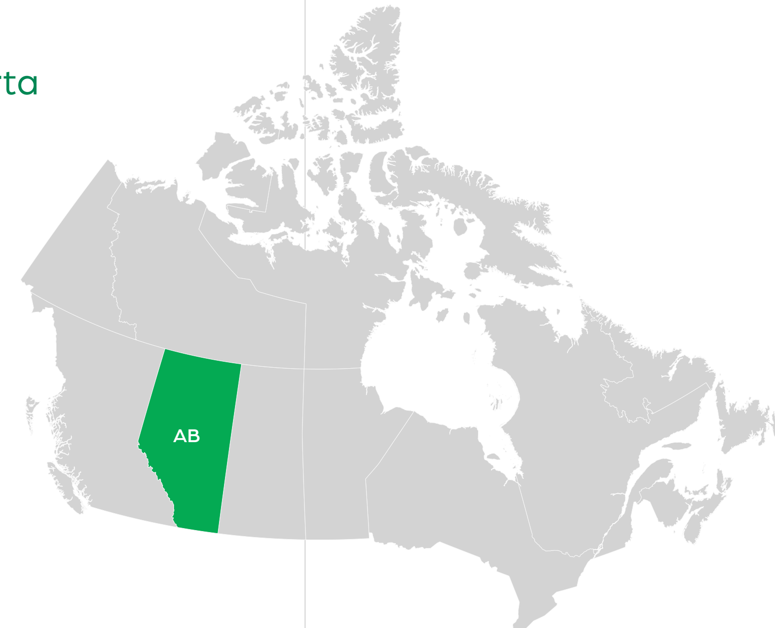
Manitoba's potential to provide industrial quantities of low-cost clean power for SAF refining makes it a promising potential production hub. While Manitoba is rail connected, its lack of sea connected water routes for shipping hurt its export capabilities in comparison to the other hydro provinces QC, BC. Manitoba SAF refining capacity would, however, be well placed to serve by rail export the consumer aviation market of the US Midwest.

Jacques Cartier river park, Quebec, Canada.

RVC 6

Municipal Solid Waste with CCUS in Alberta

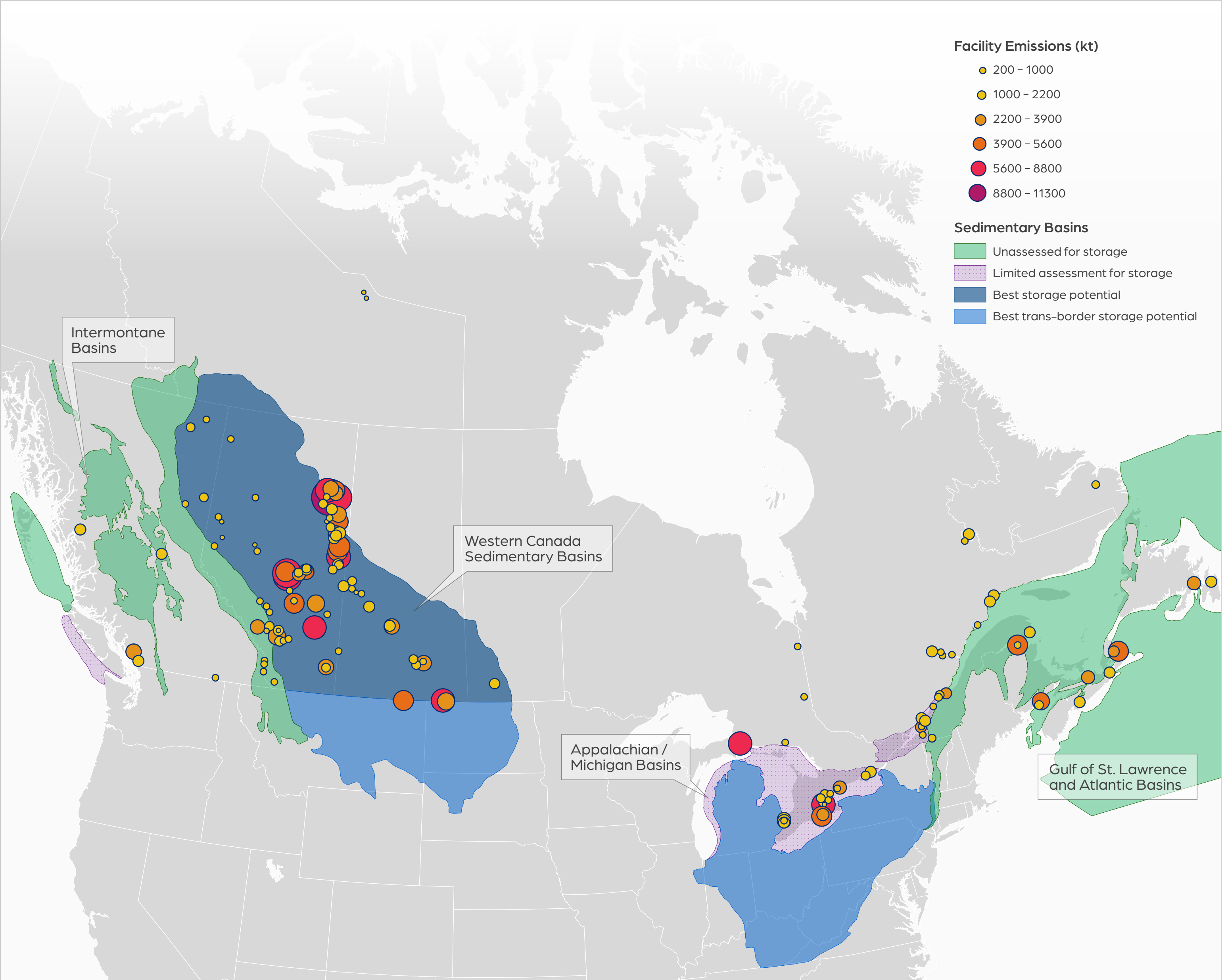
Municipal solid waste in Edmonton–Calgary Corridor
↓
Gasification
↓
CCUS
↓
FT
↓
Pipelines to airports throughout West



Feedstock availability	1,000,000 t within 250 km of Red Deer along the Edmonton–Calgary corridor
SAF Production Potential	~25–40 ML
Hydrogen Requirements	FT synthesis is self-sufficient in H_2 production
CCUS potential	Existing injection through the Alberta Trunkline

Municipal solid waste is available in all major city centers, but Edmonton and Red Deer have a special advantage: the Alberta Trunkline. Carbon capture and geologic storage can be used to lower the CI score by cleaning up the syngas before the Fischer-Tropsch (FT) process. Enerkem's demonstration project currently uses gasification to produce biomethanol, not FT fuels, so it would have to be adapted for this flowsheet to work.

FIG 10 CARBON STORAGE POTENTIAL[119]



Recreated from International CCS Knowledge Centre. 2021. Canada's CO2 Landscape: A Guided Map for Sources & Sinks. https://ccsknowledge.com/pub/Publications/CO2-Sources_&_Sinks_Map_Canada%20(2021-05-12).pdf

RVC 7

Power-to-liquids in Quebec

Industrial CO_2 + green low CI hydrogen

↓

Fischer-Tropsch

↓

Blending

↓

Montreal airports

Feedstock availability	Clean power: 1.5 grams of CO_2e per kilowatt-hour; 99% of electricity comes from renewable sources.[120] CO_2: ~20 Mt emitted from QC industry. H_2: ~730,000 t of H_2 to produce 10% of 2030 domestic Canadian aviation demand via PTL
SAF Production Potential	Grid capacity required to produce H_2 sufficient to meet 10% of domestic aviation demand via PTL: 4,200 MW*Electrolyzer Efficiency 50kwh/kg
Hydrogen Requirements	730 t/ML of SAF produced

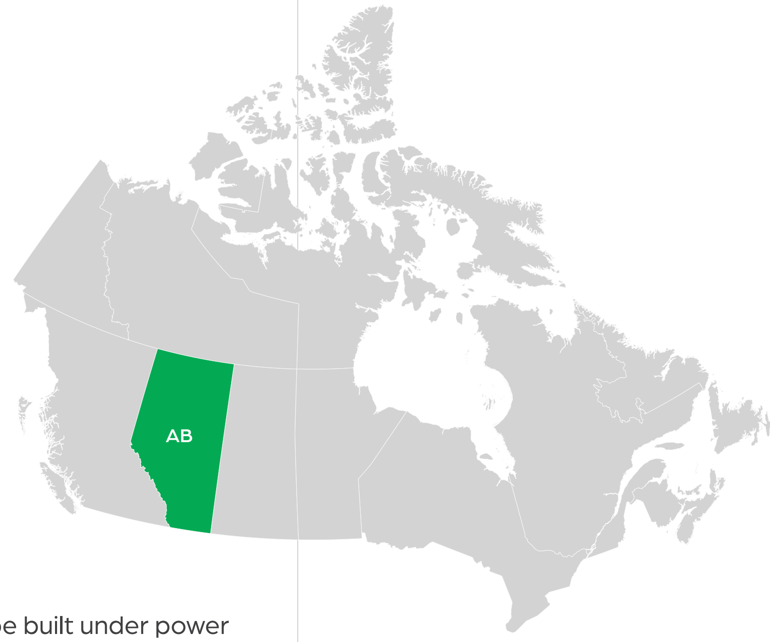
In the PtL pathway, CO_2 and low CI hydrogen are combined via Fischer-Tropsch process to produce SAF. Assuming a readily available local CO_2 source, the vast majority of PTL's energy requirements stem from electrolysis. Eighty percent of electrolysis costs are tied to operating costs, the majority of which is power costs.

The key input in PTL is therefore lots of clean power. Van Dyk and Saddler recommend that "PtL technology should be based in provinces with **abundant-and-additional** renewable electricity." Baseload power sources (hydro, long duration storage) are preferable as current Alkaline & PEM electrolyzers as more efficient electrolysis occurs if the process is operated continuously.

CO_2 from QC's manufacturing base (18Mt) and refining capacity (2Mt) are in excess of the 15.2 Mt of CO_2 input required to produce 20% of domestic aviation demand via PTL processes. Much of Quebec industrial capacity lies along the Montreal-Quebec corridor creating good economics for the construction of CO_2 transport infrastructure. Construction of CO_2 transport infrastructure for CCUS would also enable future DAC deployment.

RVC 8

Power-to-liquids in Alberta Heartland



DAC CO_2 + low-CI blue hydrogen

Fischer-Tropsch

Blending

SAF

Clean power: excellent solar and wind resources that can be built under power purchase agreements.

Feedstock availability	Full Operating Capacity of Alberta Trunkline: 14.6 Mt CO_2 Current Utilization of Alberta Trunkline: 1.9 Mt
SAF Production Potential	2,636 ML *all CO_2 from the trunkline at full operation is utilized 348 ML *only the current annual CO_2 load of the trunkline is utilized
Hydrogen Requirements	730 t/ML SAF ~1.9 Mt of H_2 ~250,000 t of H_2

The sustainability of PtL is thought to be dependent on green hydrogen. However, hydrogen "colours" will soon be replaced by hydrogen with various carbon intensities. Depending on methane leakage, blue hydrogen has the potential to be very low-carbon, and thus could be the basis of a PtL industry in Alberta.[121]

Waste CO_2 will be widely available in the Alberta Heartland, however, for SAF it is likely that atmospheric CO_2 will be a better play. Atmospheric CO_2 is energy intensive, and so to produce low-CI feedstock, it needs to be captured with clean power. Alberta has exceptional wind and solar resources as well as regulations that permit behind the fence power. In recent months, Alberta has added more renewables capacity than any other jurisdiction in Canada.[122] This presents opportunities for collocating clean energy and SAF production.

RVC 9

Ethanol alcohol-to-jet in Ontario and Quebec

Corn from Ontario and Quebec

↓

Ethanol

↓

Alcohol-to-jet (AtJ)

↓

Toronto or Montreal airports

Feedstock availability	~4,300,000t per year of corn within 250 km of Toronto, ON ~2,800,000t per year of corn within 250 km of Becancour, QC
SAF Production Potential	Within 250 km of Toronto: 190 ML Within 250 km of Becancour: 133 ML
Hydrogen Requirements	10.6 t/ML of SAF

In the long-run, ethanol that currently goes into gasoline will be available to be diverted into jet. If vehicle electrification continues to grow at an exponential, and mandated, pace, as much as 50% of ethanol production might be available by 2035.

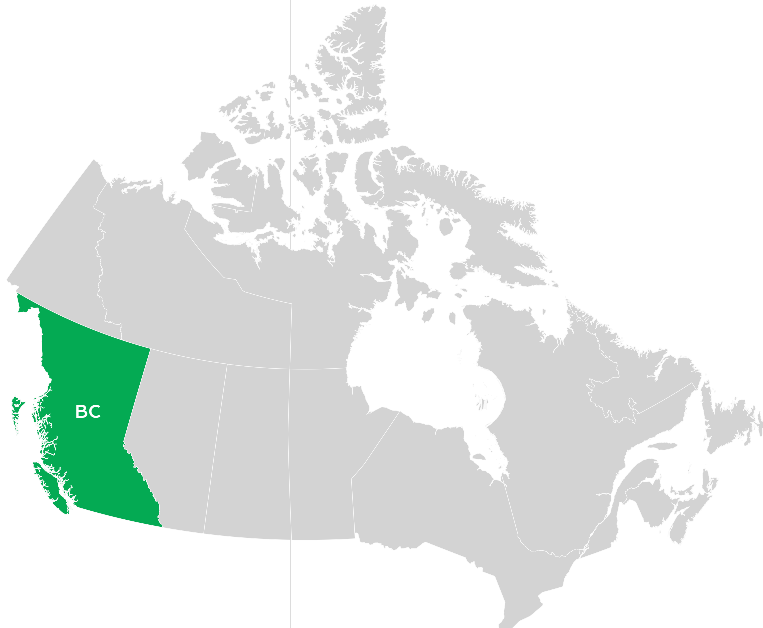
Corn from Ontario and Quebec provides the majority of the feedstock for ethanol. An AtJ facility in the Horseshoe could feed Pearson and other Toronto area airports. An AtJ facility in Quebec could provide SAF for Montreal airports.

This may involve converting ethanol facilities to isobutanol facilities, as Gevo's partnership with ADM likely does.[123]

RVC 10

CO_2 alcohol-to-jet in BC

DAC CO_2
↓
Gas fermentation
↓
Ethanol
↓
Alcohol-to-jet (AtJ)
↓
Vancouver airport



Feedstock availability	CO_2 from industrial Facilities Along Hypothetical Parkland-Tidewater Trunkline Route: ~4.9 MT[124] Clean power: 7.6 grams of CO_2e per kilowatt-hour in BC; 97% of electricity comes from renewable sources.[125]
SAF Production Potential	Dependent on which combination of biochemical/ physicochemical processes are utilized
Hydrogen Requirements	10.6 t/ML of SAF

Unlike PtL (also a suitable industrial process for regional development), gas fermentation uses biochemistry as opposed to a chemical catalyst to convert CO_2 and H_2 into SAF. Acetogenic bacteria fed carbon rich gases in an anaerobic environment convert it into ethanol or butanol. Clean power is a critical input for both the direct-air-capture process and hydrogen production.

Carbon Engineering conducted a pilot of its Air to Fuels technology in 2017.[126] Carbon Engineering and Lanzajet have a project to further develop the DAC-AtJ pathway in the UK. If the demonstration is successful, BC has the clean power necessary to replicate the project.

A Flight Plan for SAF:
Projects and timelines

In alignment with Canada's Aviation Climate Action Plan, this Roadmap has laid out an ambitious production and use target of 1 billion L of SAF by 2030.[127]

There are many ways to achieve that goal. Canada has available biomass feedstocks for 7–10 billion litres per year– well beyond the 1 billion litres needed in 2030 to reach that 10% goal and, when the potential for power-to-liquids is considered, enough to achieve 100% of 2050 demand. This means that there are a variety of combinations of feedstock and technologies that could deliver on the 2030 goal. But that 10% target is just a waypoint on the way to net-zero. By 2035, Canada must be prepared to supply 25% of total jet fuel demand with SAF. Canada must build for scale now.[128]

To make achieving the target more concrete, this section of the roadmap outlines portfolios of projects that would produce the volumes needed to meet these targets. No roadmap can specify what will or should happen at the project level. But we can think clearly about the broader national objectives that could be realized through a dynamic production project pipeline.

The 10% target is just a waypoint on the way to net-zero. By 2035, Canada must be prepared to supply 25% of total jet fuel demand with SAF. Canada must build for scale now.

The goal of industrial strategy ultimately is a vibrant project pipeline adequately supported by policies, incentives, collaborative forums, and implementation mechanisms. The strategy must be dynamically produced and deployed, acting and reacting in response to real-world developments.

But we can still chart a clear series of waypoints, knowing that we may need to change tack in order to seize opportunities or correct errors.

The first place to start is to specify the broader national objectives that we are trying to achieve. There are three main pieces necessary to produce a vibrant, competitive SAF ecosystem in Canada:

» Decarbonize now: reduce emissions in the aviation sector.

» Feedstock activation: build economic benefits for all Canadians by adding value to our natural resources.

» Innovation drive: support the homegrown capacity and knowledge necessary to compete over the energy transition.

Through strategic collaboration, industry and government can work together to create a portfolio of projects that will achieve all three of these objectives.

To **decarbonize now,** Canada must maximize SAF from commercial ready pathways. That means HEFA and coprocessing with oilseeds, tallow, and used cooking oil feedstocks.[129] Canada already has a strong group of feedstock providers and refiners that are proposing renewable diesel and SAF facilities from coast-to-coast. Under conservative assumptions, these facilities will be ready to produce 500 million litres of SAF by 2025.[130] They could produce much more. But to get these facilities to final investment decision, we need a clear policy signal now.

Starting now, the government needs to clarify that SAF is an essential component of the clean fuels market. It needs to begin to deploy the policy and program package as presented in this Roadmap. That will stimulate the project pipeline and get SAF production moving.

HEFA will play a key role in the early stages of the SAF market in Canada. But there are medium and long-run constraints on HEFA feedstocks. Since canola and soy are used for both fuel and food, there will always be market competition for the inputs. Moreover, the number of sustainable calories available from HEFA has an upper limit of about 3,500–4,000 million litres of SAF. So, even if we diverted all oilseeds into SAF, it would still only account for 35–40% of 2050 demand. Other feedstocks will be needed in the long run.

Starting now, the government needs to clarify that SAF is an essential component of the clean fuels market. It needs to begin to deploy the policy and program package as presented in this Roadmap. That will stimulate the project pipeline and get SAF production moving.

Feedstock activation means getting ready to scale those other feedstocks after 2030. But if we start after 2030, it will be too late. This roadmap must chart a path to 2030 volumes that contain the conditions for lift-off after 2030. This is what building for scale now looks like: making sure that the logistics and supply chains for multiple feedstocks are online now.

In practical terms, we need to stimulate the development of so-called advanced feedstocks now. Forestry and agricultural residues will be needed so we need projects that draw on these and work to ensure that the technologies are ready to scale. Municipal solid waste and sewage sludge could also be important sources of SAF. While lower priority than natural biomass, a project in this area would be beneficial. Finally, Canada and the world will need power-to-liquids in the long-run, so it is best to ensure that there is demand-pull now.

To compete in the long run, we need an **innovation drive**. This means building ecosystems that conduct research, development, and deployment iteratively in a thoughtful, evidence-based process. This will improve efficiency, potentially improving yields, and generate cost reductions.

Roadmaps often present abstract principles such as these. But to make them concrete they must be operationalized in a project pipeline. How can Canada meet SAF production targets while balancing the three goals? The Roadmap proposes a SAF take-off strategy that includes a project portfolio consisting of:

SAF TAKE-OFF PORTFOLIO:	
Advance decarbonization, feedstock, and innovation goals	
HEFA	600 ML
Forestry (FT)	200 ML
Ag residue (FT)	100 ML
PtL	100 ML
Next Gen Demonstrations	50 ML
2030 SAF Production	**1,050 ML**

If we just wanted to maximize decarbonization, bringing more HEFA online would be the priority. HEFA could potentially provide the whole 1,000 million litres by diverting canola into the SAF supply chain. However, that would underdevelop other pathways that are needed after 2030. If we just wanted innovation, we would seed as many demonstrations as possible to build homegrown capacity. But that might not produce the volumes we need to decarbonize now. The key is to build a project pipeline that contains a balanced portfolio of projects advancing all three goals.

The SAF take-off portfolio balances these considerations to advance a range of projects. The goal of the portfolio is not to be prescriptive in a deterministic or rigid way. Rather, it is to lay out a pathway specific enough to enable strategic action. But any strategy and its associated priorities must be adjusted in light of new information. Some promising avenues will end up being closed and new opportunities will arise. But to begin, we need a flight path that can motivate and focus action. That is the impetus for this roadmap and for the collaborative work we can do together.

Action Plan and Next Steps

This roadmap has laid out key actions in 37 areas. In order to determine next steps, C-SAF and its members have distilled the critical near-term priorities into a two-year action plan. C-SAF will work with its members, governments, Indigenous Peoples, civil society organizations, and financial institutions to advance these items. To drive implementation, C-SAF will form task forces in five areas: Policy and programs, Sustainability, Feedstocks, SAF production capacity, and Technology and innovation.

This roadmap is a flight plan—a starting point for action and is meant to flex as new information is produced and science evolves.

The first job of the task forces will be to create a workplan based on the priorities identified here as well as the full list of key actions laid out in each Action Area above. To guide this planning, the figures below identify the quarters in which each action item should begin. Further refinement will be needed to specify deliverables and timelines for the work.

These timelines give the ecosystem focus and direction, but implementation should not be rigid. Rather, each task force should respond to new events and changing opportunities. The vision for success in 2030, the near-term goals, and the strategic assessment for each action area should be treated dynamically, as aids to active, collective problem-solving.

Canada has a once in a generation opportunity to get in on the ground floor of a feedstock to fuels supply chain. This supply chain can drive decarbonization while creating economic opportunities for Canadians from coast to coast to coast.

The following C-SAF 2 year Action Plan sets out the priorities that each Task Force will focus on to progress the five SAF Action Areas.

C-SAF 2 year Action Plan (from June 2023 to May 2025)	
POLICY AND PROGRAMS	» Advance a policy package that will incentivize the investment needed to meet 2030 and longer-term SAF targets. » Ensure that federal and provincial funding programs take an active role in supporting innovative SAF production here in Canada, including final investment decisions and maximum SAF fractions for proposed facilities. » Build the strategic collaborations necessary to advance a successful long-term industrial policy for SAF and aerospace development in Canada. » Develop a Canadian SAF registry (book and claim SAF accounting system).
SUSTAINABILITY	» Map the GHG emissions footprint from all steps of cultivation, collection and production of biomass and CO_2 derived SAF. » Conduct rigorous analysis of the sustainability of Canadian feedstocks for ecosystem productivity, biodiversity, and other environmental benefits. » Ensure clarity on the differences between Canadian and international sustainability requirements (i.e. CORSIA), lifecycle analysis methodologies, and consumer preferences and work to facilitate and standardize SAF accounting and certification methodologies. » Articulate sustainability case for Canadian feedstocks, including oilseeds.
FEEDSTOCKS	» Build the infrastructure and policy frameworks needed to bring all feedstocks into SAF regional supply chains. » Build upstream collection and delivery logistics for forestry and agriculture residues.
SAF PRODUCTION CAPACITY	» Create an active project pipeline with first commercial, demonstrations, and pilots in critical SAF production pathways. » Ensure proposed HEFA projects reach final investment decision. » Seed projects in emerging commercial pathways such as gasification with Fisher-Tropsch and alcohol-to-jet.
TECHNOLOGY AND INNOVATION	» Canada to establish a national centre of excellence for the future of aviation in a net-zero world to ensure that SAF and aerospace decarbonization priorities are aligned and complimentary. » Canada to create a national industrial and innovation strategy with two clear streams: » Create clear technology development plans for SAF pathways that activate Canadian feedstocks. – Create clear technology development plans for new propulsion technologies. – Secure demonstration funds for SAF. » Coordinate R&D with leading universities and international partners.

Technical Appendix: Fuel potential estimates methodology

For the roadmap, we pulled together existing data and feedstock availability studies to create an estimate of fuel potential from six main feedstocks (see Figure 5). Our approach had four pieces.

Data

Our study relied on leading scientific studies and government sources. Our starting point for government data was the Biomass inventory and mapping tool.[131] For each feedstock, we sourced at least two estimates of Canadian biomass and used the midpoint between them as our estimate.

Raw energy available

We used the feedstock data to calculate raw energy available using the existing literature on these feedstocks. For agricultural and forest residues, we ensured either that the underlying study or our calculations left at least 30% (agricultural residues) or 50% (forest residues) to maintain soil health and carbon stocks.

SAF yields

We moved from raw energy available to SAF via McKinsey's energy conversion and optimal SAF fraction numbers.[132] This yielded the 2022 numbers in Figure 5 which tally to ~6.8 billion litres.

Future projections

For 2030, we estimate the six feedstocks could provide 9.5 billion litres. If we allow for modest improvements in energy conversion and increases in optimal SAF fractions, the same volume of feedstocks could produce 8.5 billion litres.[133] If we then assume a modest 2% growth rate in all feedstocks except for forestry (because forested acres is flat to declining), these six sources could produce about 9.5 billion litres. Add to this the likelihood of plentiful CO_2 and hydrogen feedstocks for power-to-liquids fuels, and Canada has the potential to produce 100% of jet fuel demand in 2030 and beyond (10.6 billion litres).[134]

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