INSTITUT C.D. HOWE INSTITUTE
*Trusted Policy Intelligence | Conseils de politiques dignes de confiance*

E-BRIEF

November 12, 2024

ENERGY AND NATURAL RESOURCES POLICY

# Scaling Up: The Promise and Perils of Canada's Biofuels Strategy

by Werner Antweiler

- Canada has great potential to produce biofuels to aid in the transition to a low-carbon economy, but developing the full potential requires using sustainable feedstocks and driving down production costs.
- Canada's biofuels industry is evolving from first-generation fuel, made from sugar crops, starch crops (e.g., corn), oilseed crops (e.g., soybean, canola), and animal fats, to second-generation, made from non-food crops (energy crops such as perennial grasses and fast-growing trees) and waste biomass.
- Next-wave products like sustainable aviation fuel, renewable diesel, and renewable natural gas all have unique challenges for scaling up production and reducing costs. Recognizing the limitations of industrial policy and letting the market drive innovation will avoid costly subsidies and mistakes.
- Biofuel mandates in British Columbia, and at the federal level, set targets for carbon intensity reductions and employ rigorous life-cycle models to assess the carbon intensities of different fuels. Applying these principles nationwide, harmonizing approaches, and reducing the potential for trade frictions, will create a level playing field while incentivizing the most sustainable biofuels.

## Introduction

Biofuels can play an important role in decarbonizing economies. Canada is well-positioned to take advantage of emerging economic opportunities in biofuels production because of its vast agricultural resources and extensive experience with conventional fuel production. But can this emerging sector overcome the profound challenges of scaling up sustainably – without causing harm to the environment or food production? And what role should the federal and provincial

---

The author thanks Charles DeLand, Mawakina Bafale, Tasnim Fariha, Serge Dupont, Carolina Gallo, Fred Ghatala, Doug Greening, Katie Kachur, Ian Thomson and anonymous reviewers for helpful comments on an earlier draft. The author retains responsibility for any erros and the views expressed.

governments play in supporting this nascent industry? Policies need to fully account for repercussions across the economy and avoid creating new distortions.

Why should Canadians care about biofuels production? On the upside, it creates a new market with new employment opportunities and potential for economic growth, and it can help reduce carbon dioxide emissions. It can also improve Canada's energy security and stabilize energy prices. Agricultural waste can be turned into a useful product, benefitting ancillary industries such as forestry.

Biofuels are already helping lower emission intensities today by being blended with conventional fuels. Wherever transitioning away from fossil fuels proves difficult, because of a paucity of suitable alternatives, biofuels can help. However, they are not a perfect solution. Production of biofuels creates emissions of its own, lowering the net environmental benefit. Growing feedstocks for biofuels can also induce land-use change that in turn offsets some of the environmental gains – or even negates them. The promise of biofuels is also tempered by the perils of creating adverse environmental effects "upstream," and adverse economic effects "downstream."

"Upstream" global biofuels production can either shift or increase the use of agricultural land. Where land use increases abroad, it is often through deforestation, which shrinks an important carbon sink, reduces biodiversity, and reduces habitat for other species. Expanding frontiers of agricultural production can also develop new land conflicts with local or Indigenous communities.

As for "downstream," there are concerns that rapid expansion of biofuels production could drive up food prices through diverting agricultural production away from food to biofuels (Chakravorty et al. 2017). As biofuels compete with conventional fuels, substitutability may also link prices across these markets. While today this link remains rather weak and confined to vegetable oils, it is not yet possible to rule out a growing link in the future. If biofuels production boosts biofuels exports at the cost of reducing food exports, vulnerable food markets in emerging economies would be impacted far more than relatively affluent domestic markets.

Biofuels production also needs energy as an input, and today this still means mostly fossil fuels. Their emissions reduce the environmental appeal of biofuels. Incentives for biofuels production are typically linked to the life-cycle carbon emissions, for example under *BC's Low Carbon Fuels Act.*[1] Carbon intensities of biofuels vary widely, and therefore it is critical to link incentives for biofuels to their environmental footprint. Biofuels also create a virtuous cycle: their increased use in producing biofuels lowers their life-cycle emissions.

This report examines 1) how Canada's biofuels industry is evolving from first-generation to second-generation biofuels; 2) where the industry is running into difficulties meeting innovation and cost-reduction challenges; and 3), how scaling up production can be done sustainably and responsibly. The near future of biofuels lies in developing renewable diesel, sustainable aviation fuel, and biomethane. Other innovations are possible. This paper also examines which public policies help steer biofuels production in the right direction, which remain problematic, and how domestic and international approaches differ.

---

[1] BC Ministry of Energy, Mines, and Low Carbon Innovation: Approved Carbon Intensities under the *Low Carbon Fuels Act*, as of July 4, 2024.

## What Are First-Generation and Second-Generation Biofuels?

The US Environmental Protection Agency offers concise definitions for first-generation and second-generation biofuels.[2]

- First-generation biofuels are made from sugar crops, starch crops (e.g., corn), oilseed crops (e.g., soybean, canola), and animal fats. Sugar and starch crops are converted through a fermentation process into bioalcohols, primarily ethanol. Oils and animal fats can be processed into biodiesel.
- Second-generation biofuels are cellulosic biofuels, which are available from non-food crops (energy crops such as perennial grasses and fast-growing trees) and waste biomass (e.g., corn stover, corncobs, wheat straw, wood and wood byproducts, municipal waste, and used cooking oil).

First-generation biofuels have reached technological and market maturity and are already widely available commercially. They include mostly ethanol and biodiesel, which are blended with regular gasoline and diesel. Canadian motorists are familiar with ethanol-blended gasoline; E10 – 10 percent ethanol blended with 90 percent gasoline – is the "regular" fuel available at pumps in Canada. E15 has been approved, is already rolled out in Ontario and Quebec, and is compatible with most of Canada's vehicle fleet. Higher ethanol blends (E85) are available but are only suitable for flex-fuel vehicles. Heavy-duty trucks can run on B20 biodiesel blends, and B100 can be used in some marine engines. In North America, the feedstock used for ethanol production is mostly corn (and some wheat), while sugarcane is widely used in Brazil. Biodiesel relies more on oil-bearing crops, vegetable oils, animal fats, but also waste cooking oil. First-generation biofuels have in common that they are mostly derived from food crops – and thus compete with food production.

Second-generation biofuels[3] differ from first-generation biofuels primarily in their biomass source: energy crops rather than food crops. They are also "drop-ins" for existing fuels rather than "blend-ins" because their chemical composition is almost identical to the fossil fuels that they replace.[4] Making second-generation biofuels tends to be more expensive than making the simpler first-generation biofuels, but this cost gap is shrinking. Second-generation biofuels include: sustainable aviation fuel (SAF); renewable diesel (RD) for heavy-duty trucks, trains, and maritime use; and renewable natural gas (RNG), also known as biomethane, for use by households and industry. Each of the three have unique challenges and market opportunities, examined below. Other second-generation biofuels will be explored briefly.

Second-generation biofuels are made from energy crops as well as from suitable agricultural, forestry, and industry waste. Importantly, energy crops can often be grown on marginal agricultural land not used for food production. Sustainable feedstocks use non-food sources (including wastes) and do not induce agricultural land conversion from food to non-food production. Biofuel in a gaseous form draws initially on landfill gas, wastewater treatment plants, livestock farms, food production facilities, and composting facilities.

---

[2] https://www.epa.gov/environmental-economics/economics-biofuels

[3] The terminology about second-generation and "advanced" biofuels can be slightly confusing and mean different things. "Second generation" refers to both feedstock and technology. Second-generation feedstocks are non-food crops and residues. Second-generation technologies enable processing of these feedstocks. Several second-generation technologies can also be used in conjunction with first-generation feedstocks such as canola, and thus the definition of first-generation and second-generation biofuels is somewhat fluid.

[4] Drop-in fuels may initially be offered as blend-ins, relying on an existing commercial entry point.

The third generation of biomass-derived fuels lies further out in the future because the related technologies remain mostly at the laboratory and demonstration stage. These are synthetic fuels, e-fuels, or renewable synfuels. They are not biofuels in the conventional sense. Third-generation fuels are synthesized from gasification of biomass, or are made as electro-fuels. The latter involve electrolyzers that convert renewable energy into hydrogen, which in turn is combined with carbon monoxide or carbon dioxide to synthesize the fuels. These third-generation technologies rely on complementary technologies, and thus their cost needs to fall dramatically before they can reach commercialization.

## The State of Biofuels Production in Canada

Production of conventional (first-generation) biofuels in Canada is relatively mature, as Figure 1 reveals. Over the last decade there has not been much growth either in ethanol production or in biodiesel production. Except for the pandemic bump, overall monthly production remains in the 150-200 million-litres range – except for a significant jump in the "biodiesel etc." category production in March 2024. The statistics do not distinguish between biodiesel and renewable diesel yet.

Figure 2 shows that biofuels production is almost exclusively based on food crops, primarily corn and to a lesser extent wheat. About 400,000 metric tonnes are converted into biofuels every month. The increase in the share of oils during 2024 is likely the result of the increase in biodiesel and renewable diesel production. It is fair to predict that this segment is about to grow significantly.

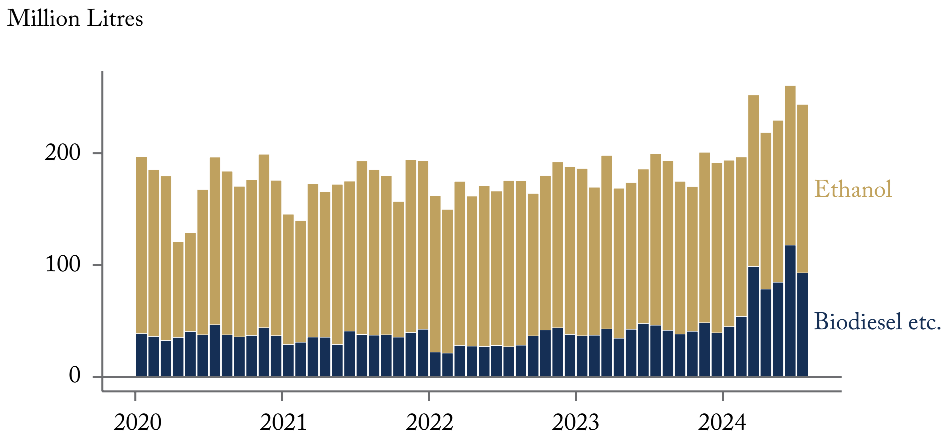
Hydrogenation-derived biofuels, in particular renewable diesel, have entered commercialization and, in many places, production is ramping up. Other second-generation pathways are emerging out of the demonstration stage and are approaching commercialization. Several projects have been announced and are under development in Alberta, British Columbia, Newfoundland and Labrador, Quebec, and Saskatchewan. These facilities could add up to 4 billion litres per year in production capacity (Canada Energy Regulator 2023a). Strathcona County in Alberta will see Imperial Oil expand its Strathcona refinery, with $720 million in construction costs and an expected capacity of one billion litres once operation starts in 2027.

The high investment cost will be offset in part through government incentives such as Alberta's agri-processing investment tax credit, which offers a 12 percent non-refundable tax credit. However, the single largest revenue component will come from the compliance value associated with the federal Clean Fuel Regulation and the BC Low Carbon Fuel Standard. The feedstock will be local canola.[5] Canola seeds contain roughly 43 percent oils. Canola is, of course, also a food crop; it is used for cooking and baking. If canola production expands to support biofuels, it will be interesting to see how much cropland will be diverted from food to biofuels production; how much land will be diverted from other uses into canola production; and how much marginal land is brought into dedicated new production.

---

[5] Jeff Melchior: "Renewable diesel facility to run on Alberta canola." *The Western Producer*, April 22, 2024.

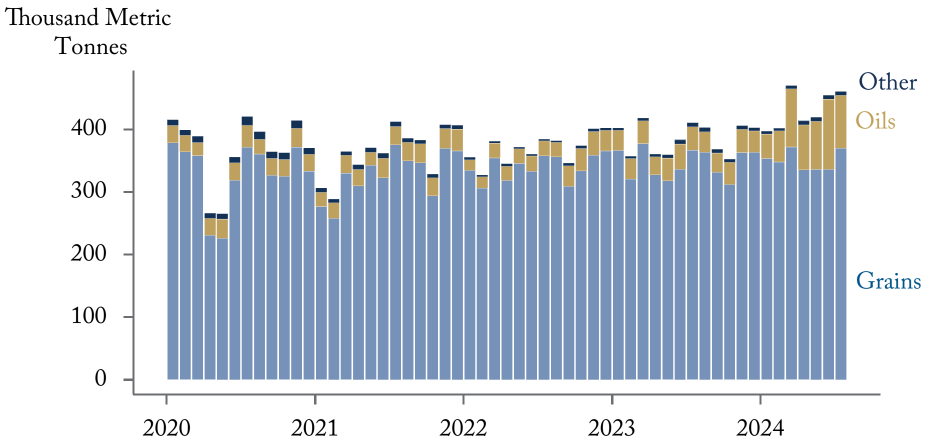
## Figure 1: Renewable Fuels Production, Canada, Monthly



Note: Biodiesel etc. includes other renewable fuels such as renewable diesel and sustainable jet fuel.

Source: CANSIM Table 25-10-0082-01.

## Figure 2: Renewable Fuel Feedstock Inputs, Canada, Monthly



Source: CANSIM Table 25-10-0082-01.

## Biofuels Policies and Initiatives

Canada's biofuels policies must be understood in the context of US policies, which dominate the North American market for biofuels. The 2022 *Inflation Reduction Act* of the Biden administration has introduced a set of policies that accelerate biofuels development. Canadian biofuels policies are still catching up to the lead taken by the US, even though many of Canada's biofuels policies have been in place for years.

Biofuels policies can be looked at through their implicit carbon price, which can in turn be compared to the social cost of carbon (SCC). Economic theory suggests that carbon policies with an implicit carbon price below the SCC are economically justifiable, and ideally should be at the level of the SCC, but not above. Estimates of the SCC vary, but the government of Canada uses a reference SCC of $266/tonne.[6]

In its simplest form, the implicit carbon price of a biofuel is the difference in production cost between biofuel and conventional fuel divided by the difference in emission intensities between the two types of fuel. If, hypothetically, the cost difference between sustainable aviation fuel and regular A1 jet fuel is $1.10/L, and the carbon intensity difference is 1.52kg$CO_2$/L, then the ratio of these two numbers is $723/tonne. In this case it would not be socially optimal to replace conventional jet fuel with SAF. However, early-stage support can still be justified economically as an innovation policy that brings about a lower production cost, also promoting economies of scale in production. Innovation can also widen the carbon intensity difference.

### Canadian Policies:

Blending mandates exist across Canada. The federal Clean Fuel Regulations require fuel suppliers to gradually reduce the carbon intensity of the gasoline and diesel that they sell in Canada by about 12 percent between 2023 and 2030.[7] British Columbia has its own Low Carbon Fuel Standard (LCFS) that is more demanding than the federal standard, requiring reductions of 30 percent for gasoline and diesel.[8] BC's LCFS also includes jet fuel and it is thus the first jurisdiction to mandate sustainable aviation fuel (SAF), commencing in 2026 with a 2 percent reduction in carbon intensity and increasing in 2 percent steps until 2030, when it reaches 10 percent. In volumetric terms, the mandate is for 1 percent in 2028, 2 percent in 2029, and 3 percent in 2030, when SAF use is projected to reach 100 million litres per year.

Blending mandates for conventional biofuels have technical limitations because of engine compatibility. BC's blending mandate for 2030 can be achieved with a 15 percent blending rate for gasoline, and in fact E15 is already being sold today as a premium version of gasoline. There are currently few locations with pumps that provide E85 for flex-fuel vehicles. Abel et al. (2021) found no engine compatibility problems at the E15 level, and E15 was approved by the US Environmental Protection Agency in 2019. In Canada, there appear to be no barriers even to higher E20-E25 blends.

---

[6] https://www.canada.ca/en/environment-climate-change/services/climate-change/science-research-data/social-cost-ghg.html

[7] Clean Fuel Regulations (SOR2022-140), Interpretation, section 5(1). See https://laws-lois.justice.gc.ca/eng/regulations/SOR-2022-140/page-2.html#h-1358853

[8] Government of British Columbia, LCFS Requirement as of May 2024; see https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/renewable-low-carbon-fuels/requirements. The LCFS was originally implemented in 2012 and overhauled in 2022 through the *Low Carbon Fuels Act*.

The stringency of biofuel mandates determines their "compliance value," which tends to be lower than implicit carbon prices. They also change over time, by location, and by biofuel type. Buyer power can even result in "carbon intensity giveaway." Low stringency of carbon intensity targets in some markets will result in low value for some biofuels with a low carbon intensity difference, because compliance can be met with higher-difference biofuels.

Both BC's Low Carbon Fuel Standard and Canada's Clean Fuel Regulations (CFR) introduce a carbon price indirectly through a credit market where compliance credits can be traded. Both mandates establish carbon intensities for each pathway – that is, each type of biofuel and feedstock – through life-cycle analyses. For example, there were over $500 million worth of compliance credits transferred in BC in 2023, with an average price of $474/tonne.[9]

## United States Policies:

The United States pursues a different approach to supporting biofuels that relies heavily on production tax credits. Until 2011, production of conventional biofuels was supported with a US$0.45/gallon tax credit (and matching import tariffs). Over the preceding decade, ethanol production had skyrocketed from 6.4 billion litres per year in 2000 to 48.8 billion litres in 2011. The subsidy had become fiscally unsustainable.[10] Congress also passed the Renewable Fuel Standard (through the *Energy Policy Act* of 2005 and the *Energy Independence and Security Act* of 2007) that ensured a minimum share of ethanol blending. After dropping subsidies in 2011, blending mandates were expanded from 7.5 billion gallons in 2012 to 36 billion gallons by 2022. Individual US states have additional support policies.

The 2022 *Inflation Reduction Act* (IRA) in the United States supports biofuels development in several directions. Most important is a provision that inserts section 45Z[11] into the Internal Revenue Code, which provides a tax credit for production of low-emission transportation fuels (known as the "Clean Fuels Production Tax Credit," or CFPC). The tax credits apply to fuels produced and sold during 2025–2027 and accrue to the fuel production plant owners. Meanwhile, production tax credits under section 40B (known as the "Blenders Tax Credit," or BTC) of US $1/gallon (35¢/L) are already in operation during 2023–2024, but are replaced by the CFPC at the end of 2024. The magnitude of the tax credit is measured by the carbon intensity of the fuel (assessed through the GREET model) against a baseline of 50 kg/mmBTU [47.4 g/MJ]. Under 45Z provisions the maximum credit is US$0.20/gallon (7.1¢/L) for non-aviation fuel and US$0.35/gallon (12.5¢/L) for sustainable aviation fuel, and can rise to US$1/gallon (35.4¢/L) and $1.75/gallon (62.4¢/L) if certain labour standards for wages and apprenticeships are met. The exact subsidy level depends on the emission factor, which is the emission reduction below the threshold divided by the threshold. Xu et al. (2022) put the carbon intensity of currently available feedstocks for RD in the 21-31 g/MJ. For example, a feedstock assessed at 30 kg/mmBTU would have an emission factor of (50-30)/50=0.4, making it eligible for a US$0.14/gallon tax credit for SAF, or US$0.54 if the labour standards are met.

---

[9] See https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/renewable-low-carbon-fuels/information-bulletins.

[10] US Energy Information Administration; see https://www.eia.gov/energyexplained/biofuels/ethanol-use.php

[11] See 26 U.S. Code § 45Z – Clean fuel production credit. See also Congressional Research Service "The Section 45Z Clean Fuel Production Credit", September 27, 2023.

Existing 40B rules give SAF a more valuable credit than other types of biofuels, in particular renewable diesel. Eligibility for the SAF tax credit requires life-cycle greenhouse gas emission reductions of at least 50 percent compared to regular jet fuel, while ethanol does not automatically qualify unless certain environmentally friendly agricultural practices are used (no-till techniques to reduce soil disturbance, cover crop, and enhanced efficiency fertilizers that reduce harmful runoff). The SAF credit varies between US$1.25 and US$1.75 per gallon (45¢/L–63¢/L in Canadian terms) depending on how much SAF exceeds the 50 percent emission reduction target. The ethanol exemption, even though attempting to limit environmental harm, has been roundly criticized (Temple 2024). If it took 45¢/L–63¢/L of subsidies to achieve price parity of SAF, it would calculate as a $300-$400/mt carbon price: high but not indefensible. However, subsidies alone will not achieve price parity at the current level of production costs (see section 5.1). With 40B rules soon becoming obsolete, all eyes are on the new 45Z rules.

The current 45Z rules make Canadian biofuels producers ineligible for the US tax credit. However, US agriculture secretary Tom Vilsack stated in September 2024 that section 45Z should "not be off limits to foreign feedstocks," potentially opening the door to Canadian canola producers.

Several US states also have biofuel mandates of their own, in particular California, Oregon, Washington, and New Mexico. The US Department of Energy's Alternative Fuels Data Centre maintains a database with a list of all of the specific programs and incentives.[12] The California LCFS shares many traits with the BC and Canada LCFS.

### The Policy Frontier:

Canada's federal budget 2024 came with an announcement of $776 million towards a retooled Clean Fuels Fund to support biofuels between 2024/25 and 2029/30, and the government is also intending to disburse up to $500 million per year from Clean Fuel Regulations (CFR) compliance payments in support of biofuels production in Canada. Ethanol was left out purposefully – to the chagrin of an industry that was expecting to receive benefits similar to those in the United States.[13] How the Clean Fuels Fund program will support biofuels production depends on forthcoming regulations that are still being worked out, while $500 million in CFR funding and another $500 million support from the Canada Infrastructure Bank were already committed to in the 2024 budget.

There are also international efforts to promote biofuels. The most important such scheme concerns the aviation industry and is known as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), spearheaded by the International Commercial Aviation Organization (ICAO). ICAO member states, including Canada, have joined this voluntary effort that only in 2027 will turn into a mandatory system. CORSIA will cover all international flights. Originally built as a carbon offsetting system, it also welcomes emission reductions through the use of SAF. Canada has established regulations for monitoring, reporting, and verification

---

[12] https://afdc.energy.gov/fuels/laws/BIOD

[13] Ethanol production in Canada is mature and does not require further subsidies; see Wolinetz and Harrison (2023). Criticism about the ethanol exclusion was not the only point of contention. Industry associations such as RICanada, which represents a business coalition of biofuels producers, would have preferred a much closer alignment with US measures.

under the CORSIA system.[14] CORSIA lists eligible fuels and their carbon intensity by pathway, including production location. When compliance becomes mandatory in 2027, prices for these carbon credits are expected to approach the price of regular allowances in Europe's emission trading system (currently near $96/tonne). Because of its broad international reach, CORSIA is likely going to be a key policy driving the adoption of SAF.

## Challenges for Second-Generation Biofuels

The challenges to advanced biofuels production can be summarized in three words: cost, scale, and spillovers. First, production costs for second-generation biofuels come with a significant price premium over conventional fuels. Innovation can reduce this cost over time, but it is likely that some second-generation biofuels will remain more expensive to produce than conventional fuels for some time. Already, subsidies are making some second-generation biofuels competitive in fuel markets. Second, the volume of fuels used today will make it difficult to scale up production of biofuels if there are feedstock limitations. At present, the cheaper feedstocks tend to be those in more limited supply, or those that involve food crops. And third, feedstock production may induce negative spillovers. The sustainability challenge is to prevent land-use change that impedes food production or induces new environmental problems, such as deforestation or water scarcity.

### Sustainable Aviation Fuel:

Sustainable aviation fuel has received much attention because commercial aviation has been harder to reach with climate policies than other sectors. This is in part because much of aviation is international and thus harder to regulate. Aviation is also technologically difficult to decarbonize because planes require fuel with high-energy density, and thus a substitute for regular jet fuel is needed. SAF as a "drop-in" fuel is more suitable and cost-effective than other solutions that have been proposed (e.g., hydrogen or hybrid-electric planes).

Sustainable aviation fuel has significant potential to reduce $CO_2$ emissions by up to 80 percent, according to an IATA fact sheet (IATA 2024). However, a recent survey of life-cycle analyses of current HEFA-type SAF finds $CO_2$ emissions that are only about 58 percent lower than for conventional jet fuel: 3.14kg/L down to 1.32kg/L (Kurzawska-Pietrowicz 2023). To reduce emissions further, innovation is needed for alternative SAF production technologies. North American life-cycle greenhouse gas models produce more favourable results. Results obtained with the GHGenius[15] model suggest that producing SAF based on canola oil in Canada may well be in reach economically, based on current support levels for biofuels.[16]

How much SAF will be needed? Figure 3 shows how much jet fuel is consumed in Canada every year. In the last pre-pandemic year, over 8 billion litres were consumed, and demand is starting to catch up to pre-pandemic levels. A blending mandate of 10-15 percent would translate into about 0.8-1.2 billion litres of SAF per year.

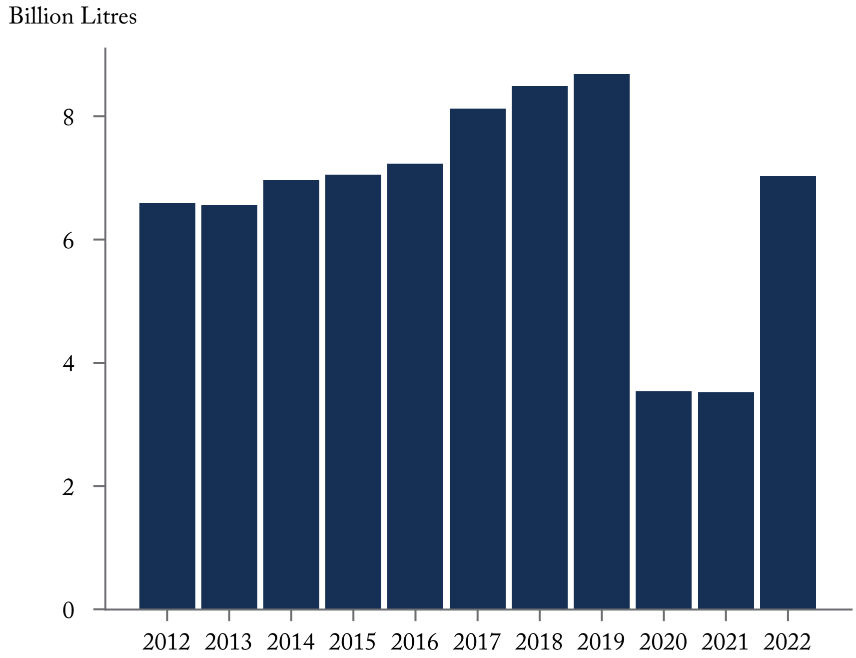
---

[14] Transport Canada: https://tc.canada.ca/en/aviation/carbon-offsetting-reduction-scheme-international-aviation-corsia

[15] https://www.ghgenius.ca

[16] A potential pathway for Canadian production of SAF is discussed in the BioPortYVR "Toward a Made-in-BC Clean Fuel Supply Chain", September 2020.

Figure 3: Jet Fuel Consumption, Canada, Annual



Source: CANSIM Table 23-10-0267-01.

The Canadian Council for Sustainable Aviation Fuel (C-SAF) released a roadmap with an ambitious plan: delivering 10 percent of jet fuel as SAF, or roughly 1 billion litres, by 2030 (Bentley et al. 2023). No significant amount of SAF is produced in Canada today, although some projects (Azure SF[17]) have been announced and have received government support. Indeed, a small volume of SAF is co-processed at a refinery in Burnaby, BC. Questions about scaling-up remain; a 2023 report by Deloitte estimates that at most 0.5 billion litres are feasible by 2030.[18] Other studies (Antony 2024) see 1-1.8 billion litres as feasible.

Emission reductions from the use of SAF are now tracked and regulated through the ICAO (ICAO 2024). Importantly, it assesses emission reductions for each feedstock separately, as well as for different regions. It shows great variation. Energy crops such as miscanthus have very low (even negative) life-cycle emissions but involve high-cost production methods. SAF from corn grain has the highest life-cycle emissions.

---

[17] https://www.azuresf.com

[18] "Reaching cruising altitude: A plan for scaling up sustainable aviation fuel." Deloitte, 2023. https://www2.deloitte.com/content/dam/Deloitte/ca/Documents/strategy/ca-en-strategy-sustainable-aviation-pov-aoda.pdf

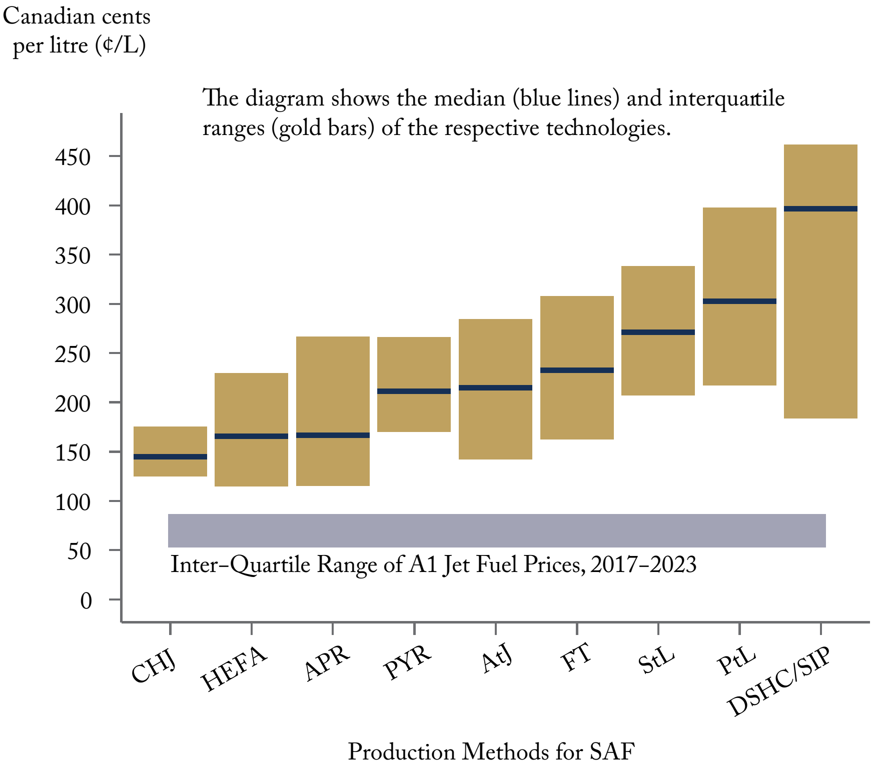
Figure 4: A1 Jet Fuel Prices, Monthly

Sources: US Energy Information Administration, Bank of Canada.

To understand the magnitude of the cost challenge, it is necessary to compare different production methods along with their associated feedstocks. A recent paper by Braun et al. (2024) compares these methods, and the results of their paper are summarized in Figure 5. The most mature production methods include the Fischer-Tropsch synthesis (FT), Hydroprocessed Esters and Fatty Acids (HEFA), and alcohol-to-jet (AtJ) pathways. Other pathways that are being developed include Catalytic Hydrothermolysis Jet fuel (CHJ), Aqueous Phase Reforming (APR), and Pyrolysis (PYR). Synthetic fuel pathways include power-to-liquid (PtL) and solar-to-liquid (StL), and involve hydrogen. The authors estimate production costs that are at least about twice as high as ordinary jet fuel, and for some of the third-generation fuels about five times as high. The diagram shows the median (blue lines) and interquartile ranges (bars) of the authors' estimates.

Jet fuel prices have been volatile as Figure 4 shows. Prices mostly follow the international price of crude oil. The price for SAF is more predictable, but remains significantly higher than for regular jet fuel without the benefit of subsidies or compliance credits. According to market reports for fuel prices at US airports, commercially available

## Figure 5: Sustainable Aviation Fuel Production Costs



Note: For abbreviations see text.

Source: Braun, Grimme, and Oesingmann (2024).

SAF is sold at an 80¢/L price premium over regular Jet A1 fuel.[19] The current price differences are of course mitigated by the significant production incentives. The actual production cost of SAF remains significantly higher than for conventional jet fuel.

To make SAF truly sustainable requires a feedstock that offers high life-cycle emission reductions and is also scalable. On a global scale, forestry and agricultural residues are the prime candidates, along with so-called energy crops. Miscanthus (also known as silver grass) offers the highest emission reductions. On the other hand, palm oil and corn grains can even have a negative impact due to induced land-use changes.

---

[19] Global Air reports full-service retail prices: https://www.globalair.com/airport/region.aspx. Argus Media and S&P Global Insights/Platts provide time series to subscribers. Signature Aviation also provides SAF retail prices: https://www.signatureaviation.com/fbo-pages/1323-L29. Different sources report different numbers. Global Air shows average SAF prices of US$8.29/gallon versus US$6.20/gallon as national averages; Signature Aviation shows US$10.71 per gallon for SAF at LAX airport, versus US$9.13/gallon for regular jet fuel. The implied differences in Canadian terms are 97¢/L and 56¢/L.

**Table 1: Existing and Planned Renewable Diesel Plants**

| RD Plant | Location | Capacity ($10^6$L/a) |
|---|---|---|
| Imperial Oil | Edmonton, AB | 1,145 |
| Braya RF (operational) | Come-By-Chance, NL | 1,030 |
| Co-Op Refinery | Regina, SK | 860 |
| Parkland (cancelled) | Burnaby, BC | 360 |
| Covenant Energy | Estevan, SK | 315 |
| Tidewater | Prince George, BC | 170 |
| Varennes Carbon Rec. | Vareness, QC | 120 |

Source: Canada Energy Regulator.

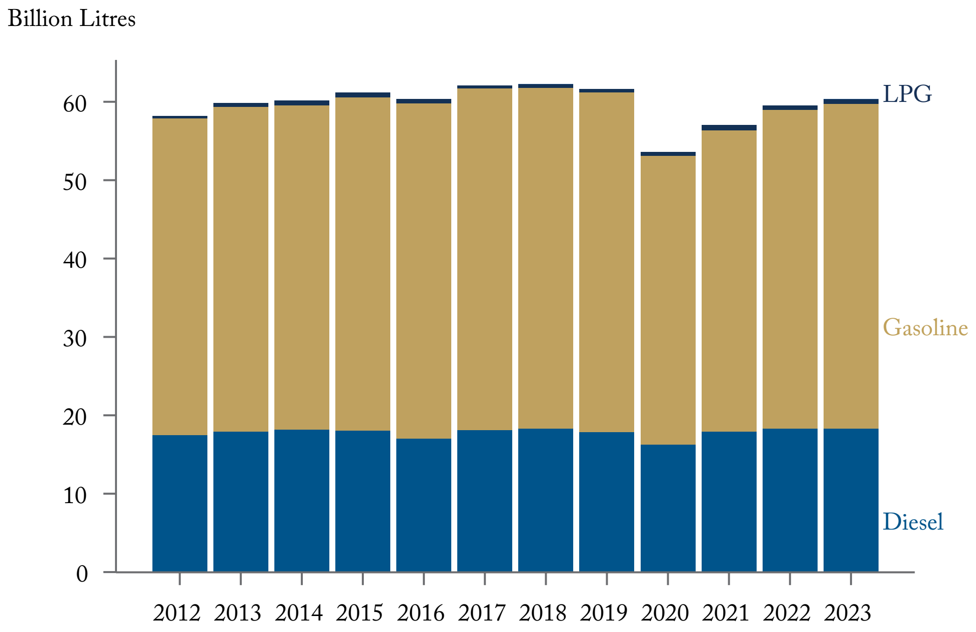
## Renewable Diesel:

Renewable Diesel (RD) has a high technological readiness level. The main technological process is known as Hydrotreated Esters and Fatty Acids (HEFA). The same process can also be used for producing SAF, while other SAF pathways still have a lower technological readiness level. Some RD is produced through co-processing (for example at the Parkland refinery in BC), where suitable feedstocks are co-processed in hydrocracking units, Fluid Catalytic Cracking units, or hydrotreating units. Co-processing can be a cost-effective option for utilizing existing refinery infrastructure, essentially utilizing unused capacity.

Plants for renewable diesel are already in use or on the drawing board in Canada, and they connect well with existing refinery systems at existing locations. By 2021, production had exceeded 500 million litres per year. Table 1 shows the existing and planned renewable diesel facilities in Canada and their targeted production capacity in million litres per year, as reported by the Canada Energy Regulator. At the beginning of 2024, only the Parkland Refinery and the Tidewater facility were producing renewable diesel, and the Braya facility opened during 2024. The status of Covenant remains unclear, while the expansion of production at the Parkland refinery was cancelled in March 2023. Parkland cited "rising project costs, a lack of market certainty around emerging renewable fuels and the *US Inflation Reduction Act* of 2022, which advantages US producers" as the reasons for the cancellation. In August 2024, Imperial Oil maintained its commitment to finish construction of its RD plant at its Strathcona refinery near Edmonton.

Renewable diesel is chemically different from biodiesel. The latter is produced through transesterification (and is thus often referred to as FAME – fatty acid methyl ester). Feedstock such as vegetable oil and fats undergo a separation process with methanol and a catalyst to generate FAME biodiesel and glycerin. By comparison, renewable diesel is produced through hydrotreating, which works very similar to the process of "cracking" crude oil into gasoline in a refinery. Because of this process, RD is also referred to as Hydrotreated Vegetable Oil (HVO) and Hydrogenation-Derived Renewable Diesel (HDRD). Chemically, renewable diesel is a "drop-in" fuel as it can

Figure 6: Conventional Fuels Demand, Canada, Annual



Note: LPG is liquefied petroleum gas.

Source: CANSIM Table 23-10-0066-01.

replace ordinary diesel, and in fact has some benefits.[20] The similarity in production technology makes it more scalable, as production can be linked up with existing refineries and infrastructure.

The US Alternative Fuels Data Centre (AFDC) tracks the retail price of renewable diesel, primarily from California.[21] Because renewable diesel is a drop-in fuel, its price tracks that of regular diesel closely. Of course, the price of regular diesel is influenced by California's clean fuel standard and carbon credits. Combined with other drivers of fuel prices, California's diesel is about 30-40 percent more expensive than the national average. Market conditions in Canada are different, and currently there are no solid numbers available to assess the price of RD.

---

[20] RD improves engine performance slightly because it has a higher cetane number (75-90) than ordinary diesel (40-45). The cetane number is a measure of fuel quality and indicates how well the fuel burns in the engine's cylinders. A higher cetane number reduces ignition time and improves combustion. RD also has higher lubricity and performs better under colder temperatures than ordinary diesel. RD also has a longer shelf life and lower content of aromatics, which are responsible for much of the soot from combustion.

[21] See US Department of Energy. "Clean Cities Alternative Fuel Price Report." January 2024. https://afdc.energy.gov/files/u/publication/alternative_fuel_price_report_january_2024.pdf

According to Xu et al. (2022), renewable diesel can achieve higher $CO_2$ emission reductions compared to biodiesel, but only when the most low-carbon-intensive feedstock is used. Compared to petroleum diesel, biodiesel and renewable diesel from soybean, canola, and carinata oils can achieve 40-69 percent reductions once land-use changes are taken into account, while renewable diesel pathways that involve tallow, used cooking oil, and distillers corn oil could achieve 79-86 percent reductions.

The BC Ministry of Energy, Mines and Low Carbon Innovation assesses carbon intensities based on the GHGenius life-cycle analysis model for purposes of determining compliance credits. Information Bulletin RLCF-012, current as of September 2024, shows approved carbon intensities for Hydrogenation-Derived RD in the 6–46 g/MJ range, with a mean of about 20 g/MJ. These approved carbon intensities imply significantly larger reductions than are reported in the literature, suggesting that conditions for producing biofuels in Canada are particularly favourable.

But how scalable is renewable diesel production? New plants are coming into operation rapidly and renewable diesel has the potential to displace biodiesel. As Table 1 shows, up to 4 billion litres per year of production capacity are under development, with at least one billion litres of capacity having come online in 2024. As Figure 6 shows, over 18 billion litres of diesel fuel are consumed in Canada every year. Canada could be on its way of replacing up to a quarter of this volume with renewable diesel.

But will there be a feedstock crunch because waste and residues remain limited in supply? Renewable diesel will likely contribute most of the expected growth in biofuels production, with ethanol and biodiesel production stagnant (Cybulsky et al. 2023).

The International Energy Agency forecasts that most of the global growth in renewable diesel and SAF will be driven by policies in the United States (*Inflation Reduction Act*, state-level low-carbon fuel standards and the RFS blending mandate) and Europe's Renewable Energy Directive (RED III) (IEA 2023). A key question for Canadian renewable diesel producers will be whether Canadian exports to American and European markets qualify for receiving benefits offered in these markets.

## Renewable Natural Gas (Biomethane):

Renewable Natural Gas (RNG) is fully interchangeable with conventional natural gas. Thus, it can utilize existing infrastructure and distribution systems for heating homes or generating power, for example. RNG comes from the decomposition of organic matter and is processed and purified for commercial sales. The main sources are landfills (then called landfill gas, LFG), wastewater treatment plants, and livestock operations equipped with biogas recovery systems. Production in Canada started in 2003 when RNG was captured from a landfill near Sainte-Geneviève-de-Berthier, Quebec (Canada Energy Regulator 2023b). Emission reductions can vary widely by source (Brons et al. 2023) and, just like ordinary natural gas, some methane may leak during transportation and storage. Emission savings essentially come from methane capture and burning methane into carbon dioxide, which has lesser greenhouse warming potential than methane. Methane capture has been recognized as an important pathway for rapid emission abatement. At best, RNG emission savings can be higher than for other biofuels, according to an analysis by the California Air Resources Board.[22]

---

[22] California Air Resources Board "LCFS Pathway Certified Carbon Intensities." https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities

RNG can also be manufactured through thermal gasification, a process that remains in early stages of commercialization and relies on different feedstocks – crop and logging residues, and energy crops. A December 2019 report[23] from the American Gas Foundation points to limited supply from all these sources and suggests that growing RNG supply beyond landfill gas and animal manure will be challenging. Production cost increases as feedstock sources become more difficult to access. The study's combined supply curve shows that production costs would increase from about US$8/Gigajoule to about US$18/Gigajoule when production volume reaches 1,000 Petajoules; expressed in Canadian terms, this is equivalent to 3.9¢/kWh and 8.7¢/kWh. A 2017 consulting report prepared for the provincial government of BC[24] found a short-term potential of about 12 Petajoules/year, and a long-term potential more than seven times larger – but all at a high production cost of $28/Gigajoule (≈10¢/kWh). Unlocking the full potential of RNG remains a relatively expensive proposition, considering that natural gas prices have been moving between just 1-2¢/kWh (US$2-4/Gigajoule), except in 2022.

RNG is available commercially. In BC, all gas customers will have a portion of their gas designated as RNG as of July 1, 2024.[25] RNG will be blended with regular gas. Fortis BC provides a price comparison: RNG is priced at 6.99¢/kWh compared to 4.74¢/kWh for conventional gas, a 48 percent mark-up. RNG can also be purchased voluntarily by customers. Assuming a typical reduction of 50 $gCO_2$/MJ for RNG, Fortis BC's 2.25¢/kWh price difference would be equivalent to a $125/tonne carbon price – well below the federal target of $170/tonne by 2030. The benefit of RNG crucially depends on the feedstock: processing agricultural manure has significant potential but is currently also the costliest to process.

RNG production is not without controversy.[26] A planned RNG plant by a joint venture between Taurus RNG and the Semiahmoo First Nation in British Columbia lost the backing of the federal government, which included funding from the federal Clean Fuels Fund. The proposed plant would have processed 70,000 tonnes of organic waste per year to convert it into RNG. Concerns were raised that the plant would contribute significantly to local air pollution. This is a type of "green-on-green conflict" where reducing one environmental problem creates a new environmental problem.

### Renewable Propane, Biocrude, and other Biofuels:

There are other biofuels that are commercially available. Renewable propane is produced in a similar fashion to RD and SAF, and is at the same level of commercialization. Just like RD and SAF, it is a "drop-in fuel" that is chemically identical to propane from fossil fuel.

---

[23] American Gas Foundation: "Renewable Source of Natural Gas: Supply and Emissions Reduction Assessment." December 2019. https://gasfoundation.org/wp-content/uploads/2019/12/AGF-2019-RNG-Study-Full-Report-FINAL-12-18-19.pdf

[24] Hållbar Consulting: "Resource Supply Potential for Renewable Natural Gas in B.C." March 2017. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/transportation/renewable-low-carbon-fuels/resource_supply_potential_for_renewable_natural_gas_in_bc_public_version.pdf

[25] British Columbia Utility Commission, Order G-77-24. https://www.ordersdecisions.bcuc.com/bcuc/orders/en/522191/1/document.do

[26] "First Nation taken aback as biofuel plant loses federal backing." *CBC News*, 11 March, 2024. https://www.cbc.ca/news/canada/british-columbia/resources-canada-bc-biofuel-indigenous-1.7132337

Biocrude, a viscous liquid biofuel that is suitable as refinery input, has limited technological readiness. One company, Vyterra, (a subsidiary of US-based Ensyn) uses a proprietary rapid thermal processing technology to make a version of biocrude known as Renewable Fuel Oil. Biocrude can also be produced through hydrothermal liquefaction (HTL). HTL uses water as a reactant as well as a catalyst to transform biomass with high moisture content and low heating value into biocrude with low moisture content and high heating value (Chaudhary et al. 2024). This process shows promise and could open up new feedstocks, in particular forestry residue. The National Research Council of Canada (NRC) operates a hydrothermal conversion facility that is developing related technologies, including HTL and catalytic hydrothermal gasification (HTG).

Renewable gasoline is not yet on the menu of biofuels. Gasoline-like biofuels are being developed but can currently not be used in existing gasoline engines as a "drop-in" fuel.

## Canada's Potential for Biofuel Feedstocks

Canada's vast resources should make it an ideal location for growing biofuel feedstocks. However, there are also large regional differences. The maximum energy potential from biofuels for each province was estimated by the Canada Energy Regulator, relying on a biomass inventory from Agriculture and Agri-Food Canada (Canada Energy Regulator 2023c). In British Columbia, Quebec, and Ontario, most of the biomass for feedstocks is available from forestry residue and forestry products. In the prairie provinces, there is significant potential for using biomass from crop residue as well as purpose-grown energy crops. Taken together and assuming a conversion efficiency of 35 percent, Canada could produce 630 Petajoules of bioenergy per year – equivalent to about 16.3 billion litres of renewable diesel per year.[27] Improvements in conversion efficiency can raise this number significantly.

A US Department of Energy (2024) study explored both availability and costs. Today's solid and wet wastes can be found at a cost as low as $18 per dry metric tonne (dmt). However, agricultural residues and purpose-grown energy crops are generally expected to have a cost of about $75/dmt. While there is significant variation across feedstocks, a rule of thumb is that about 1 kilogram of feedstock is needed to produce 1 litre of renewable diesel (Xu et al. 2022).[28] The cost of feedstock is therefore not the major component of the overall production cost of RD or SAF. The major cost components are technology and other inputs.

If feedstock cost is not a major challenge, what about land availability? This is a question of crop yields. Energy crops such as switchgrass are found to have yields between 8–13 dry metric tonnes per hectare. Canola has a yield of roughly 3 tonnes per hectare. If we apply our rule of thumb for biomass-to-RD conversion, how much land would be needed to produce 20 billion litres of RD, which is roughly the amount of diesel used in Canada (see Figure 6)? The answer is: as little as 1.5 million hectares in the best case, and about 7 million hectares if canola is used. Canada reported about 35 million hectares of harvested cropland in use. Alberta alone has 21 million hectares of farmland in use – not all of it cropland, and only a fraction of that would be suitable for farming energy crops.

---

[27] Using an energy density of 38.65 MegaJoule/Liter. 1 PetaJoule=$10^{15}$ Joule.

[28] This ratio is higher for other feedstocks. For HTL and HTG processes, one needs roughly 2.2kg of dry forestry residue to make one litre of biocrude.

Liu et al. (2017) find that Canada has approximately 9.5 million hectares of marginal land, composed of two-thirds grassland and one-third shrublands, located mostly in Alberta and Saskatchewan. They estimate that about 24 million tonnes of switchgrass or 51 million tonnes of hybrid poplar could be grown on this land. However, putting marginal land into use may have limited value in the short term. The Canada Energy Regulator (CER) has developed a Bioenergy Supply Model that tries to identify the availability of feedstocks, with the largest potential in forest residue, livestock residue, urban wastes, and crop residues. Energy crops have significant potential under the net-zero-by-2050 scenario, but not under existing current measures.

If neither cost nor land availability are major impediments to biofuel growth, then what is? Will feedstock sustainability imperil progress? Some biofuels could induce land-use change that raises emissions rather than lowers emissions, and some feedstocks could be more profitable than others but don't reduce emissions sufficiently when improperly incentivized. It is therefore of paramount importance to identify the life-cycle carbon intensity of each feedstock, and provide carbon credits in proportion to the implied emission reductions. This is precisely what the federal Clean Fuel Regulations and BC's Low Carbon Fuel Standard accomplish, as life-cycle carbon intensity determines eligibility for compliance credits. By incentivizing low-carbon-intensive feedstocks, both systems promote sustainable biofuels growth. As long as incentives are clearly aligned with metrics for sustainability, and these rules are applied equally for domestic and imported biofuels, negative environmental consequences can be reduced and avoided.

Carbon intensity is of course not the only relevant sustainability metric, as water use and water contamination through fertilizer run-off are other potential issues. Developing sustainable biofuels will require taking all relevant environmental consequences into account – essentially putting a price on them equivalent to marginal damage where necessary.

In Canada, canola (rapeseed) remains the most promising feedstock for developing second-generation biofuels, at least in the short term. Canola is the second-largest crop produced in Canada (after wheat), with a total production volume of about 19 million tonnes in 2023 and 2024, as shown in Figure 7. Canola production has been rising steadily over the last two decades. According to one study (Antony, 2024), there is potential for increasing production to 24 million tonnes and diverting 15.2 million tonnes to produce 1-1.8 billion litres of SAF by 2030. Of course, the same output could also be used for producing renewable diesel.

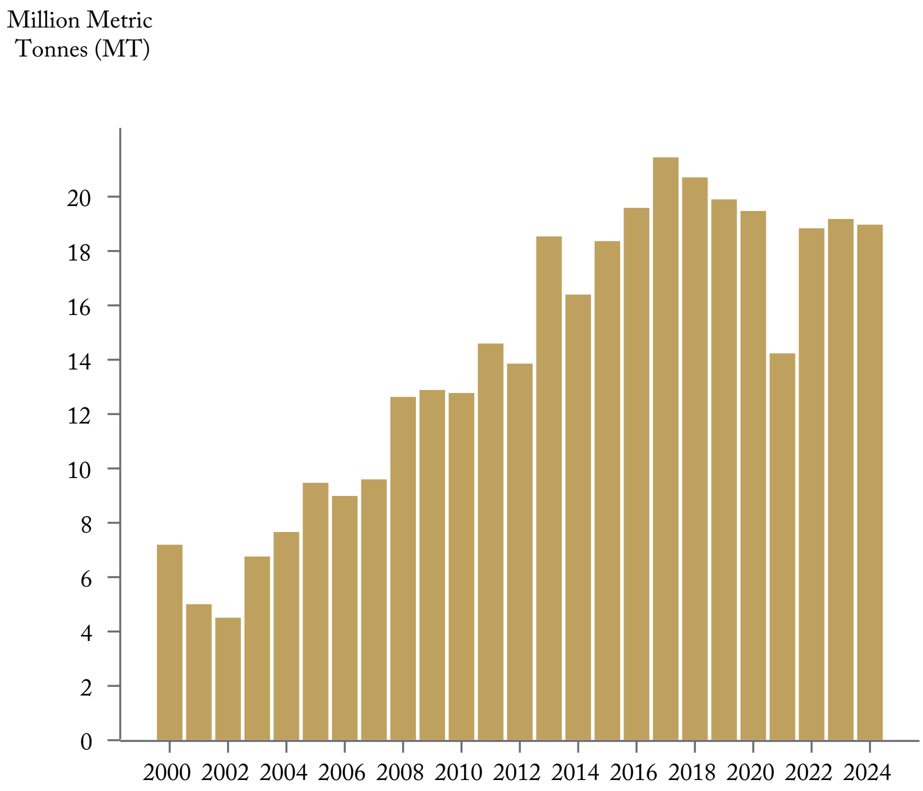
In recent years a significant share of canola production has been exported, primarily to China. Diverting a larger share of Canadian canola output to biofuels production could make economic sense if biofuels production is more profitable than exporting canola seeds. Additionally, this would reduce Canada's exposure to trade risks. Canadian canola exports to China have made Canadian farmers vulnerable to retaliatory actions from the Chinese government in response to new tariffs imposed on Chinese-made electric vehicles. Today's canola prices hover around $600-700/tonne and they peaked in early 2022 at over $1,000/tonne. Faced with significant price volatility, biofuels producers may find it beneficial to secure supplies through long-term contracts with feedstock producers.

## Looking Ahead: Policies for Sustainable Biofuels

There is a myriad of policies in place that all support biofuels: blending mandates, production subsidies, investment subsidies and tax credits, and carbon prices. Not all of these policies are equally efficient economically.

Biofuel policies aim to reduce carbon emissions. The most efficient, economical approach puts a price on carbon emissions through a market mechanism: either by setting an emissions cap and letting the market discover the carbon price, or by setting a carbon price and letting the market figure out the most efficient response. Biofuel

## Figure 7: Canola Production in Canada



Source: Statistics Canada Table 32–10–0359.

mandates work like a cap-and-trade system; they stipulate a target for emission reductions in terms of the carbon intensity of fuels, and provide a market for trading compliance credits.

In Canada, biofuel policies work in parallel to carbon pricing, and can be justified as "policy stacking" because the current carbon price at $80/tonne is well below estimates of the social cost of carbon, which reflects the marginal damage from carbon emissions. Regulations and mandates are often preferred by policymakers because they are less visible and thus less controversial. However, when mandates come with a market mechanism such as BC's Low Carbon Fuel Standard, they can be economically efficient within their scope (motor fuels). For the transportation sector, the economic efficiency of carbon pricing is met with a lack of environmental efficacy because demand for fuels is highly price-inelastic, and technological alternatives through electrification are not economical for long-haul heavy-duty trucks, ships, and trains. Biofuel mandates can accomplish what carbon pricing alone cannot and, politically, biofuel mandates fall into the low-visibility category, potentially rendering them less vulnerable to political pushback. Furthermore, if consumer-side carbon pricing was discontinued, biofuel mandates may well become one of the most important remaining carbon reduction policies.

Canada's reliance on biofuel mandates is preferrable to production subsidies that would inevitably strain scarce fiscal resources. While the United States' approach relies heavily on subsidies, past evidence with first-generation biofuels shows that support can drop suddenly when the scale of subsidies becomes fiscally unsustainable. Biofuel mandates are safe from falling into this fiscal trap.

Of course, mandating carbon intensity targets may raise fuel prices if the cost of biofuels exceeds that of fossil fuels. First-generation biofuels such as ethanol are in fact somewhat cheaper than regular gasoline at wholesale prices, and thus the expanded use of biofuels does not come at an economic cost.[29] Developing second-generation biofuels will initially be costlier than conventional fuels, but there is ample indication that innovation can rapidly bring down the cost of new technologies. Biofuel mandates can bring about a "virtuous cycle" of innovation that ultimately makes biofuels an economic-environmental "win-win."

Defining the optimal policy level is somewhat trickier. The BC-LCFS requires a 30 percent reduction of carbon intensity by 2030. The implicit assumption is that this policy meets the test of an implied carbon price below the social cost of carbon. The upper limit of the policy is defined by the penalty for non-compliance, currently $600/tonne. The market for assignment of compliance credits in British Columbia has seen prices increase from about $170 per credit in 2015 to $475 per credit in 2023, significantly higher than predicted by Cybulsky et al. (2023). The upside is that this price level is a strong incentive for biofuels innovation. If carbon pricing for motor fuels were to be abolished at the federal level, more ambitious federal biofuel targets (matching BC's) could help close the resulting climate action gap.

International policies, such as CORSIA for SAF, create an explicit link to a carbon price (set by the European Union's Emission Trading System) rather than stipulating carbon intensity targets.[30] Such a link can help level the playing field among competing carbon mitigation measures, but relies on having a sufficiently strong price signal. Canada's approach is more ambitious and BC's approach evidently has higher policy stringency. With goals of reaching net-zero emissions in 2050, a clearer focus on necessary reductions appears paramount, as carbon pricing has generally been well below the estimated social cost of carbon.

In its 2024 budget, the federal government also announced a $776 million boost to the Clean Fuels Fund. Previously, much of the Clean Fuels Fund has been devoted to FEED (Feasibility and Front-End Engineering Design) studies. The announced objective of the new funding is "to de-risk the capital investment required to build new or expand existing clean fuel production facilities."[31] Federal and provincial governments have put billions of dollars into industrial policy related to the energy transition, especially EV battery plants. A press release by Canada's Parliamentary Budget Officer put the total cost of government subsidies for EV battery plants at $43.6 billion over a 10-year period.[32] By comparison, the contributions to the biofuels industry look miniscule.

---

[29] The Navius Research Inc. (2024) report actually shows that ethanol blending does not increase costs to motorists – and indeed has a negative(!) carbon price. Because ethanol blending increases the fuel's octane rating, lower-cost gasoline blend-stock can be used. This reduces the effective cost for motorists.

[30] As of January 2024, passenger ships and cargo ships above 5,000 gross tonnes are required to participate in the EU Emission Trading System, and this has created demand for biofuels for marine vessels as well. In addition, the International Maritime Organization (IMO) aims at reducing the carbon intensity of international shipping by an average of at least 40 percent by 2030, and an uptake of at least 20 percent of near-zero GHG fuels.

[31] Natural Resources Canada: "Clean Fuels Fund." https://natural-resources.canada.ca/our-natural-resources/energy-sources-distribution/clean-fuels/clean-fuels-fund/23734.

[32] See "Costing Support of EV Battery Manufacturing." https://distribution-a617274656661637473.pbo-dpb.ca/eaafeb418199ab141962f0b62dae824e9ab2efa95e5baddd1fb5ad774a3fe984, November 17, 2023.

Political motives for industrial policy do not always coincide with economic justifications. Industrial policy may be justified economically when there are market failures to correct such as coordination failures or principal-agent problems (where an agent would act contrary to the best interest of the principal). Such issues can arise in the construction of shared infrastructure. Another market failure is insufficient innovation when firms are not able to fully internalize the benefits from their innovation due to technological leakage and imperfect protection of intellectual property rights. A third problem arises in the presence of dynamic economies of scale, when new technologies need to scale up sufficiently to bring down production costs (and compete with foreign producers who are already down the "learning curve"). Much of the recent government support is directed at playing catch-up to more rapid innovation and scaling-up among trade partners. Governments struggle with turning off the tap when support is no longer needed. Canada's fossil fuel industry has received some indirect support, though there remains debate over whether these constitute subsidies – from taking ownership in the $35 billion Trans Mountain expansion, to various favourable tax deductions, R&D support programs, flow-through shares, and crown royalty reductions. It is therefore difficult to argue that the support for the growing biofuels industry is misplaced.

In addition to conquering the innovation frontier, there are two market challenges for Canada's biofuels industry: uncertainty about the future of biofuel mandates, and the divergence of biofuel support policies across the North American market. Political uncertainty about the continuation of policies creates a barrier to investment on both sides of the border. Differences in policy approaches across the border can lead to distortions as biofuels production chases the most profitable opportunities, which can lead to glut conditions in one place and scarcity in another when policies change abruptly. The international trade dimension of biofuels remains a source of promise (market opportunities) and peril (protectionism and policy shifts).

Biofuels and their feedstocks are already, and will become increasingly, globally traded commodities. Use of subsidies helps and hinders at the same time. Subsidies can become the source of trade frictions; the EU, which imports significant volumes of biodiesel and feedstock, implemented anti-dumping and countervailing duties against US biodiesel, which also extend to some producers in Canada. This is another argument in favour of biofuel mandates: because they are not subsidies, they are not vulnerable to trade actions.

What is still missing in Canada is a rigorous system of *nation-wide* certification (or determination of carbon intensities) for imported biofuels, based on their particular feedstock. It would be beneficial to develop Canada-wide standards for life-cycle analysis that harmonize federal and provincial approaches, and that help make it easier for foreign producers to participate in Canada's biofuels system. This needs to be combined with rigorous methods of verification for imported biofuels to prevent undermining the Canadian system.

A key role for governments in designing biofuels policies is to avoid new "green-on-green" conflicts. Solving one environmental problem should not come at the cost of creating significant new environmental problems. Scaling up agricultural production of biofuels can have adverse effects on water use, fertilizer run-offs, in addition to food prices and food security. These effects need to be monitored more closely, and ultimately the government needs to devise policies that internalize negative externalities. Greater transparency through rigorous monitoring will ultimately benefit the green image of the biofuels industry. The federal Clean Fuel Regulations establish a set of land-use and biodiversity criteria as a compliance requirement. Evolving this catalog of criteria to embrace "best practice" for agricultural production practices and protecting wildlife habitat may be a prudent step.

Possible adverse effects on food prices remain another focal point. Biofuels that rely on food crops have been said to pose a significant risk to increasing food prices (Chakravorty et al. 2017). However, the available empirical evidence does not support the notion of a broad effect on food prices (Shrestha et al. 2019). Abolishing biofuels policy would not automatically improve food security (Araujo-Enciso et al. 2016).

**Figure 8: International Food Commodity Prices**

Source: Food and Agriculture Organization (FAO).

Figure 8 shows the evolution of global food prices for an index of agricultural commodities, and separately for vegetable oils. The latter shows more volatility, and the link to energy markets may indeed be visible during the 2022 spike. Decoupling food crops and energy crops will limit the potential for adverse repercussions. In Canada, food prices for edible fats and oils have risen faster than other food categories. While other global factors have likely played a larger role, a small contribution of price pressure from biofuels production cannot be ruled out. Stillwater Associates (2024) reported that the impact of biofuels was stronger in agricultural commodity markets than in markets for final consumer products. Their meta-analysis found that biofuels increased corn prices by an average of 14 percent, while the impact on final consumer prices in the United States averaged about 1 percent.

In theory, biofuel mandates could exaggerate supply shortages because demand for biofuels would react less to price changes than demand for food. In that instance, rising food prices cannot be countered by shifting supply from biofuel to food production. This is essentially a short-term distortion, but not a long-term problem.

Countries may also be tempted to restrain feedstock exports, which would drive up global prices further (as witnessed by Indonesia's 2022 short-lived ban on palm oil exports). Biofuel mandates will need flexibility mechanisms to adjust and ease pressure off food prices when biofuel feedstocks rely on food crops. Nevertheless, if the supply of biofuels grows and draws on marginal land and energy crops, rather than food crops, the potential for adverse consequences on food prices appears rather small.

The bottom line is this: there remains a significant innovation and cost gap for several of the second-generation biofuel pathways, but innovation is well under way and several pathways are already at a high level of technological readiness, and are entering commercialization. While scalability challenges remain for sustainable, non-food feedstocks globally, there exists within Canada significant potential for scaling up production. While canola is currently favoured as feedstock for second-generation biofuels in Canada, new types of energy crops appear promising. Farmers will need to experiment to maximize yields and match the most suitable energy crop to available croplands. Forest residue provides another large source of biomass if cost-effective processing technologies can be developed. Life-cycle analysis (LCA) is already rigorously used within the federal and provincial fuel mandates. To reduce frictions in international trade, harmonization of LCA models may ultimately benefit all trading partners, especially within an integrated North American market.

## Conclusions and Takeaways

- Second-generation biofuels, including renewable diesel, sustainable aviation fuel, and renewable natural gas, have significant potential for helping decarbonize transportation – especially for heavy-duty trucks, ships, and planes. Several technological pathways are at high levels of technological readiness and are entering commercialization. Some pathways require more innovation to reduce costs, and government help focused on innovation and infrastructure for biofuels can be very helpful at this critical stage.
- The federal Clean Fuel Regulations and British Columbia's Low-Carbon Fuels Standard establish mandates for the reduction of carbon intensities for all types of fuels that are based on rigorous life-cycle analysis of the carbon intensity of each low-carbon fuel product, by manufacturer and method. These principles should be used widely across Canada, and should ultimately be harmonized nation-wide, and with key trade partners.
- To ensure a safe environment for investments into biofuels production, cross-partisan consensus is needed that guarantees the long-term viability of the biofuels mandate. Uncertainty about policy direction would be detrimental to the growth of the industry. Perhaps the alignment of agricultural and environmental interests may provide fertile ground for cross-party consensus building.
- Policy harmonization across the North American market will be a larger challenge. Biofuels policies vary, and different levels and methods of support will likely persist. Canadian biofuels producers seek access to the US market, and in particular hope to become eligible for the production tax credit under provisions of the *Inflation Reduction Act* (45Z). Full reciprocity of access may help grow the biofuels industry on both sides of the border.
- Whereas carbon intensities of biofuels are addressed through life-cycle analysis and certification, ancillary environmental consequences (induced land-use change, water supply, water contamination, wildlife habitat and biodiversity effects) may need to be taken into account through related safeguards in the biofuel certification process. Important steps have already been taken on both sides of the border to promote "best practices" in feedstock production, and these protective measures may need to evolve further. Problematic foreign biofuels or feedstocks are already excluded from the federal fuel mandate (e.g., palm oil), and provincial mandates should follow.

- Concerns about adverse effects of biofuels production on food prices persist, but at least at this stage appear to be rather limited. Biofuel mandates can be equipped with flexibility instruments ("safeguards") to deal with acute shortages, but ultimately the development of energy crops on marginal land will help disentangle food supply and energy supply.
- Increased federal support for the Clean Fuels Fund raises questions about how funds are allocated across eligible projects (as details are still forthcoming), but the size of the fund pales in comparison to recent announcements of support for EV battery plants. Developing Canada's biofuels industry aligns with the country's vast agricultural resources and energy industry.
- If consumer-side carbon pricing was to be abandoned by a future federal government, the biofuels mandate will grow in importance along with the zero-emission vehicle mandate. Together, these two policies may be highly effective in reducing Canada's greenhouse-gas emissions from the transportation sector.

## References

Abel, Riley C., Kmyria Coney, Caley Johnson, Matthew J. Thornton, Bradley T. Zigler, and Robert L. McCormick. 2021. "Global Ethanol-Blended-Fuel Vehicle Compatibility Study." National Renewable Energy Laboratory Technical Report NREL/TP-5400-81242. https://www.nrel.gov/docs/fy22osti/81252.pdf

Allan, Bentley, Jonas Goldman, and Geoff Tauvette. 2023. "The C-SAF Roadmap: Building a feedstocks-to-fuels SAF supply chain in Canada." Canadian Council for Sustainable Aviation Fuel. https://c-saf.ca/download/2203/

Antony, Praveen Siluvai, Caroline Vanderghem, Heather L. MacLean, Bradley A. Saville and I. Daniel Posen, 2024. "A framework to estimate national biofuel potential by siting production facilities: a case study for canola sustainable aviation fuel." *Energy Advances* 3: 1612-1631. https://doi.org/10.1039/D3YA00579H

Braun, Matthias, Wolfgang Grimme, and Katrin Oesingmann. 2024. "Pathway to net zero: Reviewing sustainable aviation fuels, environmental impacts and pricing." *Journal of Air Transport Management* 117(102580). https://doi.org/10.1016/j.jairtraman.2024.102580

Brons, Kester, et al. 2023. "Renewable natural gas: A Swiss army knife for US decarbonization?" McKinsey & Co. November. https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/renewable-natural-gas-a-swiss-army-knife-for-us-decarbonization

Brown, Craig, and Ling Tao. 2023: "Biofuel Production and Greenhouse Gas Reduction Potential." Golden, CO: National Renewable Energy Laboratory (NREL) Technical Report NREL/TP-6A20-85351. https://doi.org/10.2172/2202642

Canada Energy Regulator. 2023a. "Market Snapshot: New Renewable Diesel Facilities will Help Reduce Carbon Intensity of Fuels in Canada." May 3.

____________________. 2023b. "Market Snapshot: Two Decades of Growth in Renewable Natural Gas in Canada." https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2023/market-snapshot-two-decades-growth-renewable-natural-gas-canada.html

____________________. 2023c. "Market Snapshot: Canada's Bioenergy Diversity and Potential." May 17. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2023/market-snapshot-canada-bioenergy-diversity-potential.html.

Chakravorty, Ujjayant, Marie-Hélène Hubert, Michel Moreaux, and Linda Nøstbakken. 2017. "Long-Run Impact of Biofuels on Food Prices." *The Scandinavian Journal of Economics* 119(3): 733-767. http://www.jstor.org/stable/45097683

Chaudhary, Vasu, Sreenavya Awadakkam, John Garret Bews Churchill, Venu Babu Borugadda, and Ajay K. Dalai. 2024. "Production of sustainable biocrude from Canadian agricultural biomass: Process optimization and product characterization." *Fuel Processing Technology* 261 : 108108. https://doi.org/10.1016/j.fuproc.2024.108108.

Cybulsky, Anna, Elizaveta Kuznetsova, Romain Chaffnon, and Alison Bailie. 2023. "Compliance Costs under the Clean Fuel Regulations: Estimating near-term credit prices, compliance costs and impacts on fuel prices." Final Report, Energy Super Modelers and International Analysists. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://esmia.ca/wp-content/uploads/2024/01/2023-12-29_ESMIA_CFR_ComplianceCosts_FinalReport.pdf

Araujo Encis, Sergio René, Thomas Fellmann, Ignacio Pérez Dominguez, and Fabien Santini. 2016. "Abolishing biofuel policies: Possible impacts on agricultural price levels, price variability and global food security." *Food Policy* 61: 9-26. https://doi.org/10.1016/j.foodpol.2016.01.007.

Environmental Protection Agency. 2022. "Draft Regulatory Impact Analysis: RFS Standards for 2023-2025 and Other Changes." November 2022. https://www.epa.gov/system/files/documents/2022-12/420d22003.pdf

Grim, R. Gary, Ling Tao, Zia Abdullah, Randy Cortright, and Brett Oakleaf. 2024. "The Challenge Ahead: A Critical Perspective on Meeting U.S. Growth Targets for Sustainable Aviation Fuel." Golden, Co: National Renewable Energy Laboratory (NREL) Technical Report NREL/TP-5100-89327. https://www.nrel.gov/docs/fy24osti/89327.pdf

International Aviation Transportation Association (IATA). 2024. "Net Zero 2050: sustainable aviation fuels." https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet---alternative-fuels/s

International Civil Aviation Organization. 2024."CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels." March. https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions%20-%20March%202024.pdf

International Energy Agency. 2023. "Renewables 2023. Analysis and Forecast to 2028." https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf and OECD/FAO (2023), *OECD-FAO Agricultural Outlook 2023-2032*, OECD Publishing, Paris, https://doi.org/10.1787/08801ab7-en.

Kurzawska-Pietrowicz, Paula. 2024. "Life Cycle emission of selected Sustainable Aviation Fuels – A review." *Transportation Research Procedia* 75: 77-85. https://doi.org/10.1016/j.trpro.2023.12.010

Lee, Uisung, Hoyoung Kwon, May Wu, and Michael Wang. 2021. "Retrospective analysis of the U.S. corn ethanol industry for 2005-2019: implications for greenhouse gas emission reductions." *Biofpr* 15(5): 1318-1331. https://doi.org/10.1002/bbb.22250

Liu, Tingting, Ted Huffman, Suren Kulshreshtha, Brian McConkey, Yuneng Du, Melodie Green, Jiangui Liu, Jiali Shang, and Xiaoyuan Geng. 2017. "Bioenergy production on marginal land in Canada: Potential, economic feasibility, and greenhouse gas emissions impacts." *Applied Energy* 205: 477-485. https://doi.org/10.1016/j.apenergy.2017.07.126

Morris, B., A. Dickie, and F. Seymour. 2018. "The Global Debate About Biofuels and Land-Use Change." Working Paper. Washington, DC: World Resources Institute. https://www.wri.org/research/ending-tropical-deforestation-global-debate-about-biofuels-and-land-use-change

Navius Research Inc. 2023. "Biofuels in Canada: Tracking biofuel consumption, feedstocks and avoided greenhouse gas emissions." Vancouver. https://www.naviusresearch.com/wp-content/uploads/2023/10/Biofuels-in-Canada-2023-2023-10-31.pdf

Shrestha, D.S., B.D. Staab, and J.A. Duffield. 2019. "Biofuel impact on food prices index and land use change." *Biomass and Bioenergy* 124: 43-53. https://doi.org/10.1016/j.biombioe.2019.03.003

Stillwater Associates. 2024. "Balancing the Benefits of Biofuels. The Economics of U.S. Crop-Based Fuel Production." Report for the Transportation Energy Institute, Alexandria, VA. https://www.transportationenergy.org/research/reports/balancing-the-benefits-of-biofuels/

Temple, James. 2024. "Why new ethanol aviation fuel tax subsidies aren't a clear climate win." *MIT Technology Review*. May 1. https://www.technologyreview.com/2024/05/01/1091988/a-us-push-to-use-ethanol-as-aviation-fuel-raises-major-climate-concerns/

U.S. Department of Energy. 2024. "2023 Billion-Ton Report: An Assessment of U.S. Renewable Carbon Resources." M. H. Langholtz (Lead). Oak Ridge, TN: Oak Ridge National Laboratory. ORNL/SPR-2024/3103. https://doi.org/10.23720/BT2023/2316165.

Wolinetz, Michael, and Sam Harrison. 2023. "Biofuels in Canada 2023. Tracking biofuel consumption, feedstocks, and avoided greenhouse gas emissions." Navius Research. October. https://www.naviusresearch.com/wp-content/uploads/2023/12/Biofuels-in-Canada-2023-2023-12-14.pdf

Xu, Hui, Longwen Oum Yuan Ti, Troy R. Hawkins, and Michael Wong. 2022. "Life Cycle Greenhouse Gas Emissions of Biodiesel and Renewable Diesel Production in the United States. *Environmental Science & Technolnology* 56(12): 7512–7521. https://doi.org/10.1021/acs.est.2c00289

This E-Brief is a publication of the C.D. Howe Institute.

Werner Antweiler is Associate Professor and Chair, Strategy and Business Economics Division, and Chair in International Trade Policy at the Sauder School of Business, University of British Columbia.

This E-Brief is available at www.cdhowe.org.