Electronic Supplementary Material (ESI) for Energy Advances.

Supporting information for

A framework to estimate national biofuel potential by siting production facilities: A case study for canola Sustainable Aviation Fuel in Canada

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Table of Contents

1. Existing biofuel plant locations and capacities

The data on existing biofuel plants in Canada was collected to estimate the average distance of existing plants from rail, road, and population centres and use them as a benchmark for potential locations for new biojet plants in Canada. Table *1* shows the canola crush plants located in Canada, along with their company names, geospatial coordinates, and name-plate capacity. Similarly, Table *2* and Table *3* show Canada's biodiesel and bioethanol plants, along with their geospatial coordinates, plant capacities, and feedstocks used for biofuel production. The data on bioethanol and biodiesel plants were obtained from biofuel magazines and industry reports (1,2). The geospatial location coordinates were manually obtained from Google Maps.

Table 1 Canola crush plants in Canada, industry name, geospatial coordinates, and plant capacity in tonnes per year (TPY)

Feedstock	**Company**	**Latitude**	**Longitude**	**Capacity TPY**
Canola	Cargill	52.937272	-112.713563	850000
Canola	Bunge	53.72841879	-113.2379854	280000
Canola	ADM	53.28263301	-110.0324591	875000
Canola	Richardson	49.70175925	-112.8018442	700000
Canola	Bunge/Viterra	53.32546706	-104.0190007	525000
Canola	Cargill	52.032456	-106.3854	1575000
Canola	Richardson	51.23828228	-102.5311288	1050000
Canola	LDC	51.22832581	-102.5036968	1050000
Canola	Bunge	50.75952133	-101.4584156	700000
Canola	Vietrra	49.56345898	-97.21512411	350000
Canola	Bunge	49.11162457	-97.56023329	875000
Canola, Soybeans	Vietrra	46.38854821	-72.37633614	1050000
Canola, Soybeans	Bunge	43.2688887	-79.84743644	240000
Canola, Soybeans	ADM	42.26642695	-83.09886368	1296000

Table 2 Biodiesel plants in Canada, with their locations, company name, geospatial coordinates, feedstock type, and capacity in million litres per year (MLPY)

Company	Location	Latitude	Longitude	Feedstock	Capacity (MLPY)
Archer Daniels Midland	Lloydminster, Alberta	53.28291	-110.0328	Canola	265
Atlantec Bioenergy Corporation	Cornwall, Prince Edward Island	46.24356	-63.199811	Energy Beets	0.1
Atlantic Biodiesel	Welland, Ontario	42.950994	-79.241331	Canola and soy	170
BIOX Corporation	Hamilton, Ontario	43.269731	-79.841672	Multi-feedstock	66
BIOX Corporation	Sombra, Ontario	42.775688	-82.36785	Multi-feedstock	50
Consolidated Biofuels Ltd.	Delta, British Columbia	49.140654	-123.010772	Yellow grease	11
Cowichan Biodiesel Coop	Duncan, British Columbia	48.777917	-123.707794	Recycled vegetable oil	0.2
Ensyn Corporation	Renfrew, Ontario	45.478781	-76.650061	Wood residues	11
Evoleum	Saint-Jean-sur-Richelieu, Quebec	45.30584	-73.215809	Multi-feedstock	19
Innoltek	Thetford Mines, Quebec	45.305947	-73.219172	Yellow grease	6
Milligan Bio-Tech Inc.	Foam Lake, Saskatchewan	51.64458	-103.5339	Canola	20
NorAmera BioEnergy Corporation	Weyburn, Saskatchewan	49.672836	-103.880786	Wheat and Corn	25
Methes Energies Canada Inc.	Sombra, Ontario	42.693222	-82.483439	Multi-feedstock	50
Methes Energies Canada Inc.	Mississauga, Ontario	43.530642	-79.719979	Yellow grease	5
Noroxel Energy Ltd.	Springfield, Ontario	42.83362	-80.916149	Yellow grease	5
Rothsay Biodiesel	Montreal, Quebec	45.405914	-73.586701	Animal fats, recycled cooking oil	55
Pound-Maker Agventures Ltd.	Lanigan, Saskatchewan	51.85085	-104.862237	Wheat	15
Total Biodiesel production					773.3

Table 3 Bioethanol plants in Canada with their location, geospatial coordinates, capacity, and feedstock

Location	**Latitude**	**Longitude**	**Capacity (MLPY)**	**Feedstock**	**Product**
Sherbrooke, Quebec	45.394184	-71.952543	0.475		Ethanol
Westbury, Quebec	45.489651	-71.633987	5	Cellulosic	Methanol/ Ethanol
Edmonton, Alberta	53.592682	-113.339341	38	Cellulosic	Methanol/ Ethanol
Tiverton, Ontario,	44.308007	-81.553622	27	Sugar/Starch	Ethanol
Varennes, Quebec	45.7069	-73.424119	175	Sugar/Starch	Ethanol
Chatham, Ontario	42.385111	-82.221201	195	Sugar/Starch	Ethanol
Johnstown, Ontario	44.735133	-75.484255	260	Sugar/Starch	Ethanol
Hairy Hill, Alberta	53.761731	-111.976709	40		Ethanol
Lloydminster, Saskatchewan	53.294108	-110.036519	130	Sugar/Starch	Ethanol
Minnedosa, Manitoba	50.255544	-99.861657	130	Sugar/Starch	Ethanol
Aylmer, Ontario	42.78336	-80.975309	172	Sugar/Starch	Ethanol
Ottawa, Ontario	45.336529	-75.68562	2	Cellulosic	Ethanol
Havelock, Ontario	44.442208	-77.825316	100	Sugar/Starch	Ethanol
Unity, Saskatchewan	52.436509	-109.124895	25	Sugar/Starch	Ethanol
Red Deer, Alberta	52.31112	-113.85738	42	Sugar/Starch	Ethanol
Belle Plaine, Saskatchewan	50.441526	-105.222026	150	Sugar/Starch	Ethanol
Sarnia, Ontario	42.930833	-82.444407	400	Sugar/Starch	Ethanol
Sarnia, Ontario	42.97252	-82.404693	2	Cellulosic	Ethanol
Varennes, Quebec	45.706795	-73.42414	38		Proposed plant
Lanigan, Saskatchewan	51.850774	-104.862216	15	Sugar/Starch	Ethanol

2. Canola production prediction for 2030

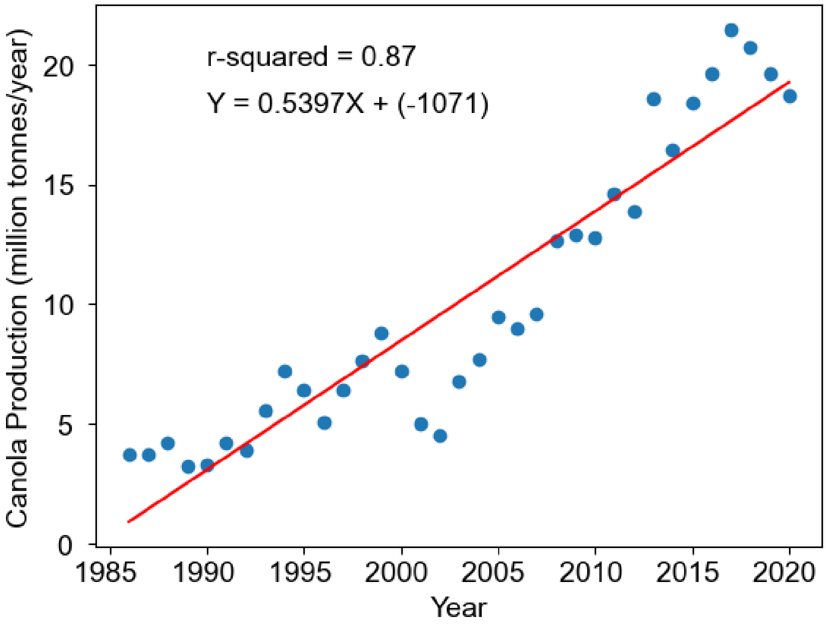

Figure 1 Historical canola production in Canada (million tonnes) between 1986-2020 fitted to simple linear regression for projecting up to 2030

The canola production in 2030 was projected based on the historical canola production data in Canada sourced from the Canola Council of Canada (3). Figure *1* shows the canola production in millions of tonnes per year between 1986 and 2020. The data points suggest that the canola production was constantly increasing from 1985 to 2000, slumped for about two years and increased constantly between 2003 to 2020. The data points were fitted with a simple linear regression model, and the model suggests that Canada can produce 24.7 MT of canola by 2030, which is 31% more than 2020 production. On the other hand, the Canola Council of Canada (4) expects a much higher output of 26 MT by 2025. However, we stuck to our model projection of 24.7 MT to stay conservative in our biojet projections.

The historical data on yield and harvest area between 1986-2020 is shown in Figure *2* and Figure *3*. The potential increase in production could be explained by the anticipated increase in yield and harvested area in 2030, both of which have been growing over time. The historical data on yield and harvest area between 1986-2020 is shown in Figure 2 and Figure 3. Fitting simple linear models to each of these parameters would project a 15.4% increase in canola yield and a 31% increase in canola harvested area in 2030 compared to the 2020 benchmark. Note that a linear growth rate in both harvested area and yield would lead to a greater than linear growth rate in total production increase. As a result, constructing future production from these disaggregated projections would lead to an even greater future projection of 27.2 MT canola by 2030. As a simpler and more conservative approach, this paper relies on the aggregate projection based on total production (i.e., 24.7 MT in 2030)

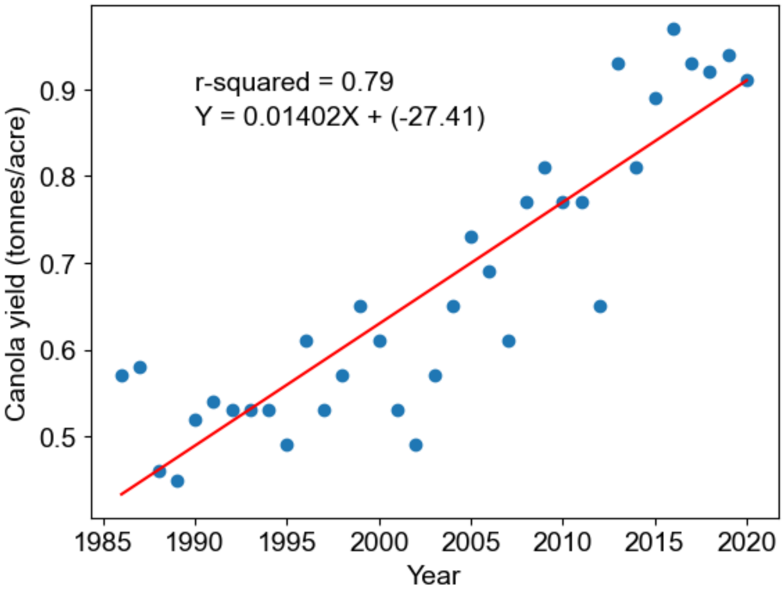

Figure 2 Historical canola yield in Canada (million tonnes) between 1986-2020

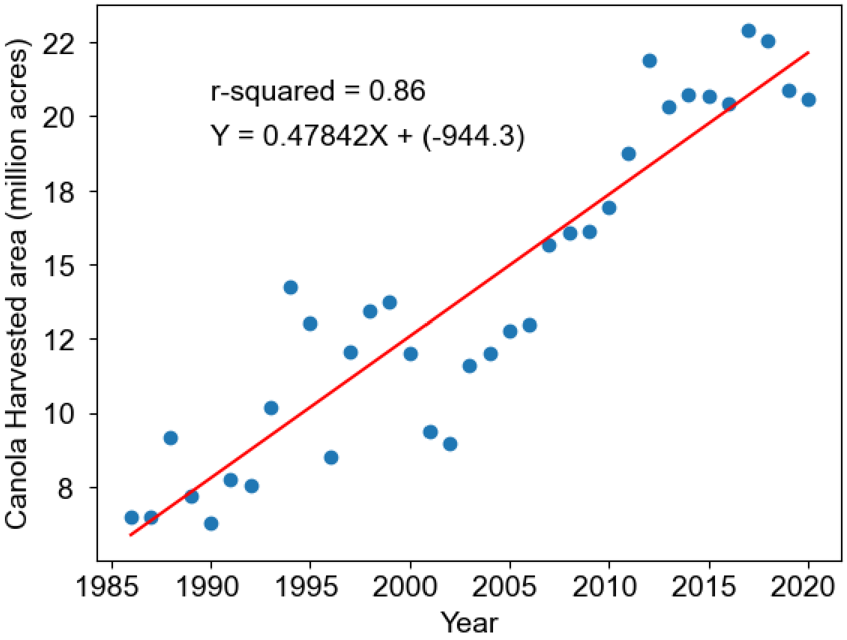

Figure 3 Historical canola harvested area in Canada between 1986-2020

3. Canola Material Flow Analysis

A simplified material flow analysis (MFA) of canola was developed to understand the canola availability at a national systems level and to verify the bottom-up canola availability estimations. It was also developed to identify and confirm the sources of canola that can be potentially captured for local SAF production (5). Figure *3* shows a simplified canola MFA diagram with the key inputs, outputs, and stocks. Multiple sources of literature were consulted to obtain data for the MFA diagram. The data on domestic canola production, seed export, and canola oil export was obtained from the Canola Council database (6) . Canola imports, meal exports, domestic oil production and domestic meal consumption were obtained from Canadian Oilseed Processors Association (COPA) (7). The canola consumed for biodiesel production within Canada was obtained from the canola council (8) and the change in stocks of canola was estimated based on the balance of inputs and outputs.

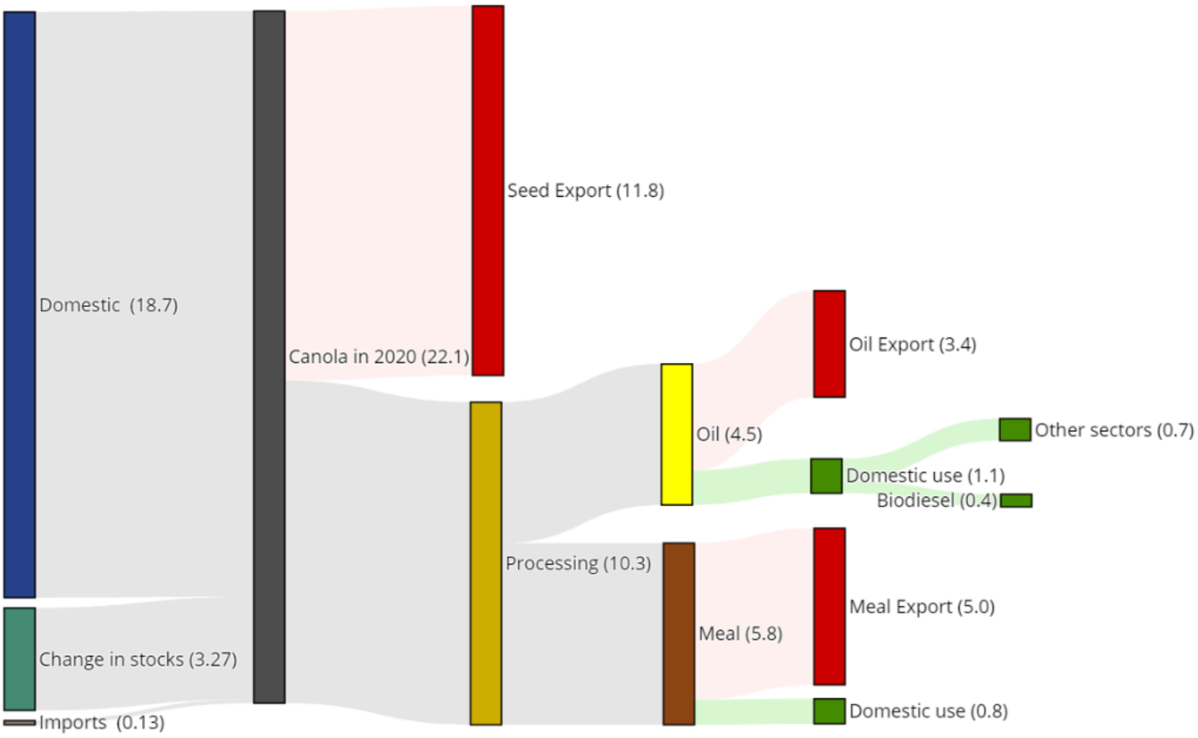

Figure 4 A simple material flow diagram of canola (in million tonnes) in Canada for the year 2020

About 92% of canola produced in Canada is exported to other countries as raw seed or processed products, i.e., canola oil and canola meal. Out of 92% exported in 2020, 53% is exported as seeds, and the rest, 47%, is crushed locally to export as canola oil and meal. After processing 10.3 MT of canola locally, 75% of the canola oil and 86% of the meal are exported to US and Asian markets. Due to the current domestic consumption and established food markets, we assumed that the canola oil produced from crush plants may not be readily available or cannot be easily diverted because of existing food markets. The canola that is likely to be available for domestic SAF production is the anticipated increase in production by 2030 and the exported canola. This is consistent with IEA Bioenergy Task 39 (5) reports that these exported seeds can provide an opportunity for local SAF production. Given that the canola is likely to be available as feedstock, we considered only integrated facilities (crushing + oil processing) for the supply chain model in this study. Integrated plants also have better IRR than stand-alone SAF plants with canola oil as feedstock (9).

4. Distance between sites in the map data

The actual distance between two points on the ground is different from the plain straight-line distance estimated in a GIS map. The following steps were used to account for the differences.

i. Firstly, the Python GeoPandas package estimates distance between two BIMAT sites using a straight-line distance. However, in reality, the roads are not simple straight lines. Hence, to account for the road winding, a tortuosity factor of 1.27 was multiplied after the map distance was calculated from Python. The tortuosity factor was adapted from Miller et al. (10), which was used for Western Canada.
ii. Secondly, when GeoPandas estimates the distance between two BIMAT sites, the distance is calculated from the edge of one BIMAT polygon to the edge of another BIMAT polygon. A single BIMAT polygon is a square with a 10×10 km area. For instance, the distance formula in Python would give a zero value if two BIMAT sites are located adjacent to each other. Since we assume that a site's biomass collection point is in the centre of the 10×10 km site, to account for the extra distance, an additional 10 km was included if they are located adjacent and an approximate 15 km $(2 \times 5 \times \sqrt{2} = 14.14)$ was included if they are located diagonally. We acknowledge that the distance will vary between when the sites are located and how far they are located. However, for simplicity, we have considered 10 km if they are adjacent and 15 km if they are diagonally located. Since the distances are small, they do not significantly affect the final results.

5. Remoteness index of existing biofuel industries in Canada

The remoteness index was included in the site selection criteria to eliminate sites that do not have access to industrial infrastructure. Industry infrastructures such as rail/road access, electricity, natural gas, waste treatment, labour, maintenance, and community services are essential for smooth operations, and a remote region may not supply some of these services. We have identified these extremely remote sites using the Canadian remoteness index (RI) from Statistics Canada (11) . Figure *5* shows the remoteness index of regions in Alberta, Saskatchewan, and Manitoba provinces in Canada ranked in a range of 0-1, where '0' means non-remote (light yellow on the map) and '1' being highly remote (dark red on the map). In order to identify the remote regions, we used the existing canola crush plants and biodiesel plants to find the RI that are favourable for industries. The biofuel industries layered over the RI map (Figure *5* shows) indicate that most industries prefer the least remote locations (0.025 < RI < 0.4), meaning that they have high access to industrial and civil infrastructure.

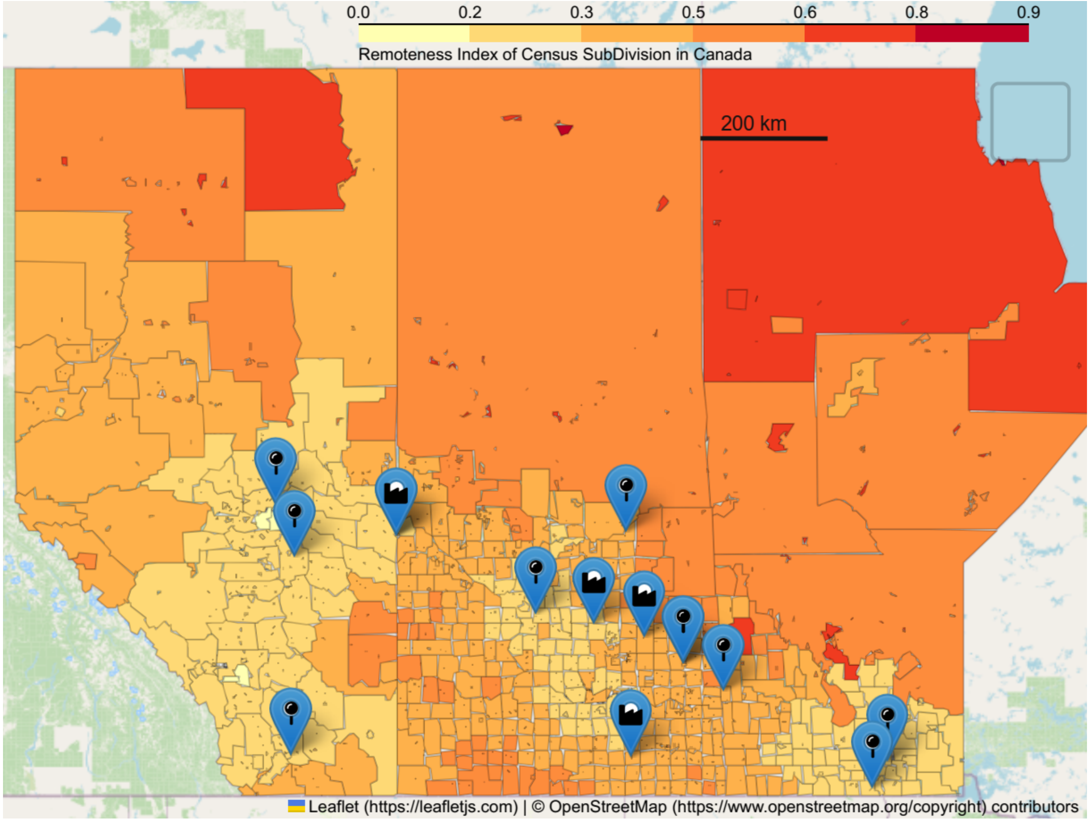

Figure 5 Remoteness Index (RI) of canola-producing regions in Alberta, Saskatchewan, and Manitoba in Canada. The location tags point to the existing canola crush plants and biodiesel plants.

6. Distance to rail, road, and cities from existing canola biofuel plants

We estimated distances to existing rail lines, major roads, and cities from existing canola biofuel plants to select potential sites for SAF plants. Table *4* shows the distance between rail, road, and cities from oilseed crush plants and biodiesel plants in Canada, along with their geospatial coordinates. The road distance denotes the distance from the industry location to the nearest trans-Canada Highway, the National Highway System, and the Provincial Major Highway (12) . The distance to rail denotes the distance from the industry to the nearby railway line, where we have considered the existing inter-provincial rail lines. The distance to cities denotes the distance from the industry to nearby population centres, whose population is a minimum of 1000.

Table 4 Distance to rail, road, and cities from the existing canola crush plants, and biodiesel plants, plants in Canada

Seed	**Latitude**	**Longitude**	**Capacity TPY**	**Rail (km)**	**Road (km)**	**Cities (km)**
Crush plant	52.937272	-112.713563	850000	0.236	0.019	11.789
Crush plant	53.72841879	-113.2379854	280000	1.272	3.856	3.719
Crush plant	53.28263301	-110.0324591	875000	0.277	0.492	0.270
Crush plant	49.70175925	-112.8018442	700000	0.103	0.395	2.024
Crush plant	53.32546706	-104.0190007	525000	0.378	0.304	3.480
Crush plant	52.032456	-106.3854	1575000	0.257	3.088	11.587
Crush plant	51.23828228	-102.5311288	1050000	0.462	0.823	5.219
Crush plant	51.22832581	-102.5036968	1050000	0.424	0.350	3.391
Crush plant	50.75952133	-101.4584156	700000	0.225	0.837	7.250
Crush plant	49.56345898	-97.21512411	350000	1.204	0.189	10.743
Crush plant	49.11162457	-97.56023329	875000	0.060	0.767	0.877
Biodiesel	53.28291	-110.03282	265 MLPY	0.238	0.522	0.281
Biodiesel	51.64256	-103.53393	20 MLPY	0.229	0.555	0.821

7. The site selection criteria from the industry report

We included various site selection criteria in our study to narrow down to a few sites that are potential for SAF plants in the western region of Canada. Table *5* shows site selection factors used by biofuel industries for selecting potential plant locations (13) . The site selection criteria contain key factors such as proximity to feedstock, access to transportation infrastructure, access to energy, water infrastructure, proximity to coproduct markets, and community services. The table suggests that multi-criteria decision-making is used when selecting one among the multiple sites. We have used many of the important site selection factors that are discussed in the manuscript.

Table 5 Site selection factors used in biofuel industries.

Plant Criteria	**Available**	**Distance (miles)**					**Site score**
		20	**40**	**60**	**80**	**100**	
Feedstock Proximity		10	8	5	3	2	
Proximity of Communities	6						
Transport							
Rail	10						
Barge	8						
Roads/Highways	8						
Energy							
Electricity	8						
Natural Gas	9						
Water							
Water	7						
Wastewater discharge	5						
Product proximity							
Ethanol market		10	8	6	4	2	
Coproduct market		10	8	6	4	2	
Labour availability		7	5	3	2	0	
Community services	Within 20 miles						
Electrical Maintenance	5						
Machine Shop/Welding	5						
Pipe Fitting/Plumbing	5						
Hospital	6						
Airport	4						
Schools	4						
Fire Protection	6						
						Total	

8. Data sources for the financial model

The SAF plant financial model required to estimate the profitability of the biojet sites was adapted from our previous work (14,15). It was a mass-energy balance model developed in ASPEN, and the economic model was developed in spreadsheet. Therefore, we needed specific data on prices of feedstock, fuel, energy, and incentives to run the financial model to estimate the profitability. A variety of sources were consulted to get the data required for TEA.

On the feedstock side, the prices for canola seed, canola oil, and canola meal were obtained from Canola Council of Canada (3). On the energy front, bulk natural Gas and electricity prices were weighted averaged from Alberta, Saskatchewan, and Manitoba provinces since almost 99% of canola is produced in this region (16) . The electricity prices were obtained from Alberta Electric System Operator (AESO) (17), Swift Current (18), and Manitoba Hydro (19). The natural gas prices were obtained from EPCOR (20), SaskEnergy (21) , and the public utilities board (22). Although there are some minor spatial variations in the electricity and natural gas prices between the provinces, we used averages because of lack of significant variations and their low contributions to the total costs.

On the product side, the jet fuel price was obtained from the US jet fuel market (23,24), whereas the diesel and gasoline prices were sourced from Natural Resources Canada (25,26). Table *6* shows the price of jet fuel, canola, canola oil, gasoline, diesel, electricity, and natural gas that were used in the financial model. The prices were a five-year average between 2016-2021. The electricity and natural gas prices were averages of three canola producing provinces (Alberta, Saskatchewan, and Manitoba). Since the canola prices have significantly increased since 2020, we have also conducted a sensitivity analysis, with results shown in SI section 15.

The HEFA based SAF pathway is not economically viable independently, and therefore, we assumed a total incentive of 0.6 $/L as discussed in the main text.

Table 6 Parameters and their values used in the financial model for SAF production. All currencies are in Canadian dollars.

TEA	Model parameter	Values	Unit
Prices	Canola	542	$/tonne
	Canola meal	354	$/tonne
	Canola oil	961	$/tonne
	Average electricity	9.1	Cents/kWh

	Average natural gas	4.8	$/GJ
	Jet fuel	0.57	$/L
	Diesel	0.74	$/L
	Gasoline	0.66	$/L
	Total incentive	0.6	$/L
Expenditure: Scale:104 MMLPY at canola price of 542$/tonne	CAPEX	0.19	$/L
	OPEX	0.31	$/L
	Feedstock	2.09	$/L
Product yield	Oil content in canola (moisture free)	48.1	kg/kg-seed
	Canola oil yield	99%	kg-oil/kg-canola
	Total products	0.467	L/kg-feed
	SAF	0.268	L/kg-feed
TEA assumptions	Debt	50%	
	Amortization period	20	Years
	Interest rate for loan	8%	
	Working capital	10%	of total capital investment
	Corporate tax rate	25%	
	Inflation	2%	Per year

9. Canola availability and Life cycle GHG emissions of RU

The life cycle GHG emissions of the canola biojet at the optimal locations were estimated based on our previous study (27), which quantified the LC-GHG emissions from canola produced from each reconciliation units (RU). RU is a local geographic region divided based on ecological framework and administrative boundaries. Table *7* shows the amount of canola available in each reconciliation unit in Canada and the LC-GHG of canola-derived biojet in each reconciliation unit grouped with and without land management changes. The LC-GHG emissions of canola are different between RU regions due to differences in soil conditions, farming practices, and fertilizer consumption.

The LC-GHG emissions of biojet between RU, without accounting for LU and LMC, were fairly constant and ranged between 44-48 g CO$_2$e/MJ. However, LC-GHG emissions significantly varied between 16-58 g CO2e/MJ when accounting for LU and LMC. The variations in the emissions between RUs suggest that industries should consider not only the amount of feedstock available but also the local LC-GHG emissions of the locations from which the feedstock is obtained. The influence of local LC-GHG emissions could alter the LC-GHG emission of the biojet, which in turn can influence the incentives available for the fuel.

Table 7 Life cycle greenhouse gas emissions (LC-GHG) excluding and including land-use (LUC) and land management changes (LMC) for every reconciliation unit in Canada, along with canola availability estimated in the maximum profitability scenario for a 25% feedstock availability rule-of-thumb

RU	Canola availability		LC-GHG	LC-GHG with LU and LMC
	tonnes	%	SAF: g CO_2e/MJ	
34	609,000	19.6	47	58
24	548,000	17.6	46	34
30	474,000	15.2	46	16
35	465,000	14.9	44	32
29	461,000	14.8	46	25
28	335,000	10.8	45	52
37	190,000	6.1	44	26
23	32,000	1.0	48	54

10. BIMAT sites located close to rail lines

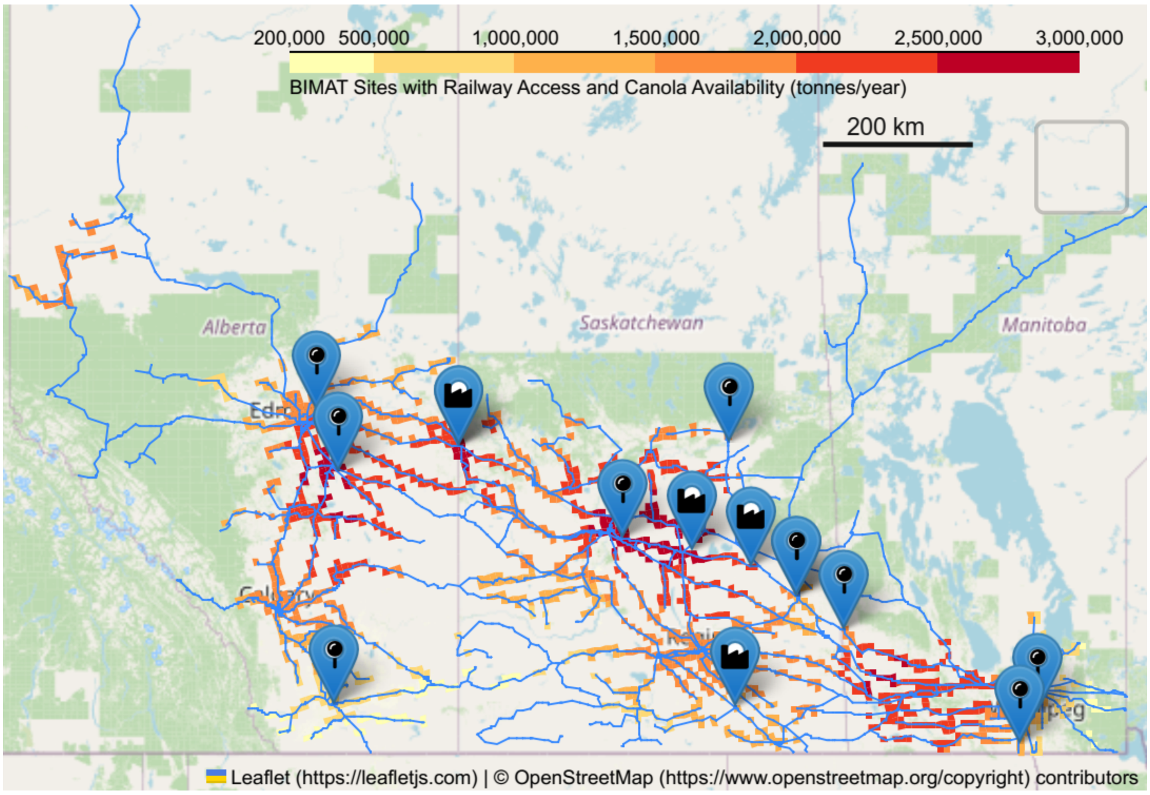

Figure 6 BIMAT sites for biojet that have access to rail infrastructure. The yellow and red square boxes (10-by-10 km) indicate a canola production site, the blue lines indicate intra-provincial and inter-provincial rail lines, and the location tags indicate biofuel plants.

Access of rail infrastructure is paramount to transport the canola from the farm gate or grain elevator to the SAF plant site and also to transport products (e.g., SAF, renewable diesel) to the market (e.g., distribution centres). The steps followed to estimate BIMAT sites that have access to rail infrastructure are given in the methods section of the main article. Note that the sites are selected based on access to rail infrastructure, in addition to access to roads, and population centres, suggesting that rail is only one of the site selection criteria.

Figure 6 shows the BIMAT sites, existing canola crush plants and biodiesel plants that are closest to the rail lines in western Canada. The maps clearly show that all existing canola industries are located next to existing rail infrastructure for the ease of feedstock/product transportation. The locations of existing biofuel plants in Alberta almost follow a line pattern because they are located next to Canada's existing inter-state rail network, suggesting that the rail infrastructure has been considered as one of the key criteria for site selection.

11. Transport models

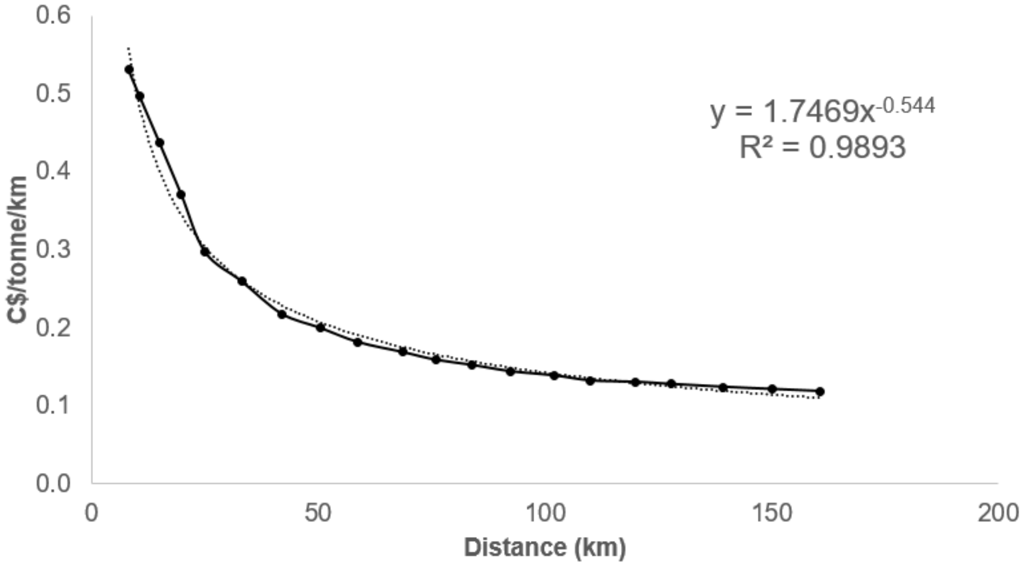

Figure 7 Canola seed trucking cost in Canada for 2018-2019. This cost model was used to estimate the cost of transporting canola from the farm to the integrated crushing and processing facility producing biojet fuel.

The canola transportation model was used in the financial model to account for the cost of transporting canola from the farm gate to the SAF plant site. The feedstock transportation model for Canola oil seeds has been adapted from the Canola Council of Canada (8). In western Canada, typically, canola seeds are transported via truck, if they are delivered directly to processing facilities and via rail if they are transported across provinces. Since canola is never trucked more than 205 miles, in our study, we assumed that truck transport from farm to facility or elevator to facility.

The transport cost is a function of distance and tonnage. The cost data from the literature was fitted to a simple exponential regression model, as shown in Figure *7* and subsequently used to estimate the cost of transporting canola from canola-producing sites to potential biojet locations in the supply chain model. The cost of transporting canola per unit distance decreased with an increase in the distance because the overhead and fixed costs (eg., loading/unloading) appear lower when normalized over longer distances.

12. Regional CI differences in SAF on costs

The differences in carbon intensities (CI) of regionally produced SAF will influence the siting decisions for a plant. The carbon intensities of canola-derived biojet can vary depending on the regional variations in agricultural practices, and legacy emissions from land use and land management changes (27). In the best profitability scenario, we found that seven optimal locations (P1 to P7) are feasible in the canola-producing regions and the average carbon footprint of the optimal location P4 is 20.1 g CO_2e/MJ and the P6 is 58 g CO_2e/MJ (Table 8, section 3.4, main text).

Considering the average volumetric density of jet fuel is 35 MJ/L (28), the LC-GHG emissions of jet fuel produced from P6 translates to 2050 g CO_2e/L, and P4 translates to 700 g CO_2e/L. The difference in carbon emissions between the high and low carbon-intensive locations is 1.35 kg CO_2e/L of SAF. If we consider a carbon price of 170 C$/tonne in 2030 (29), the difference in cost due to the life cycle carbon emissions is 23 cents/L. Note that in this study, we used an average jet fuel price of 56 cents/L and an incentive of 60 cents/L, which means the added cost from the LC-GHG emissions of the SAF could be as high as 40% of the jet fuel price and 38% of incentives.

13. Proposed renewable diesel/SAF plants in Canada using canola

Although our analysis only considered anounced facilities, we reviewed other proposed facilities to illustrate the shifting landscape and compare them to our proposed viable locations. We obtained the proposed renewable/SAF plants in Canada from the ICAO tracker of SAF facilities to provide an idea about the potential canola consumption anticipated in the coming years (30). Table *8* lists the potential renewable diesel and SAF plants that are proposed to be constructed in Canada. In total, seven facilities are planned, out of which six were expected to use canola as one of their feedstocks. Out of the seven, the Enerkem facility in Edmonton is closed, and the Parkland project in Burnaby is cancelled.

Table 8 Proposed and status of renewable diesel/SAF facilities in Canada that are using canola as one of their feedstocks.

Announced date	Entry in Service	Company and city	Total fuels (MLPY), feedstock	Comments and references
24-Mar-21	2023	Covenant Energy, Estevan,	325, Canola, Soy	(31,32)

		Saskatchewan		
17-Jan-22	2027	Federated Co-operatives Limited (FCL), Regina, Saskatchewan	1000, Canola	(33)
15-Nov-22	No data	Green Energy Transformation Inc, Calgary, Alberta	377.2, Canola	(34)
26-Jan-23	2025	Imperial Oil, Edmonton, Alberta	1000, Multi-feedstock	(32)
18-Jan-24	2027	Azure, Manitoba	1160.7, Canola and Soy	(35)
02-Feb-18	2016	Enerkem, Edmonton, Alberta	31.6, MSW/Residues	(36) Closed
10-May-22	2026	Parkland, Burnaby, British Columbia	377, Canola, Animal fat	(37) Standalone plan cancelled but co-processing is still in place

Figure *8* illustrates the proposed Sustainable Aviation Fuel (SAF) plant locations in Canada, mapped alongside potential sites identified in the study, featuring access to canola, rail, road, and other infrastructure. All proposed SAF plant locations, except Burnaby and Vancouver, align with the identified potential sites. Publicly available information on the proposed plants indicates that most, including Estevan, Regina, Calgary, Edmonton, and Burnaby, are strategically located adjacent to existing industrial/refinery infrastructure. For instance, FCL in Regina, Green Energy Transformation in Calgary, and Imperial Oil in Edmonton benefit from proximity to established industrial hubs and access to (potentially low-carbon) hydrogen. Similarly, Covenant Energy in Estevan, known as the 'energy city,' is strategically positioned due to its infrastructure and access to rail lines. Although the Parkland SAF facility in Burnaby was cancelled, it planned to use canola oil sourced from the prairies, with the potential to intercept exports that would otherwise be shipped via the Vancouver ports.

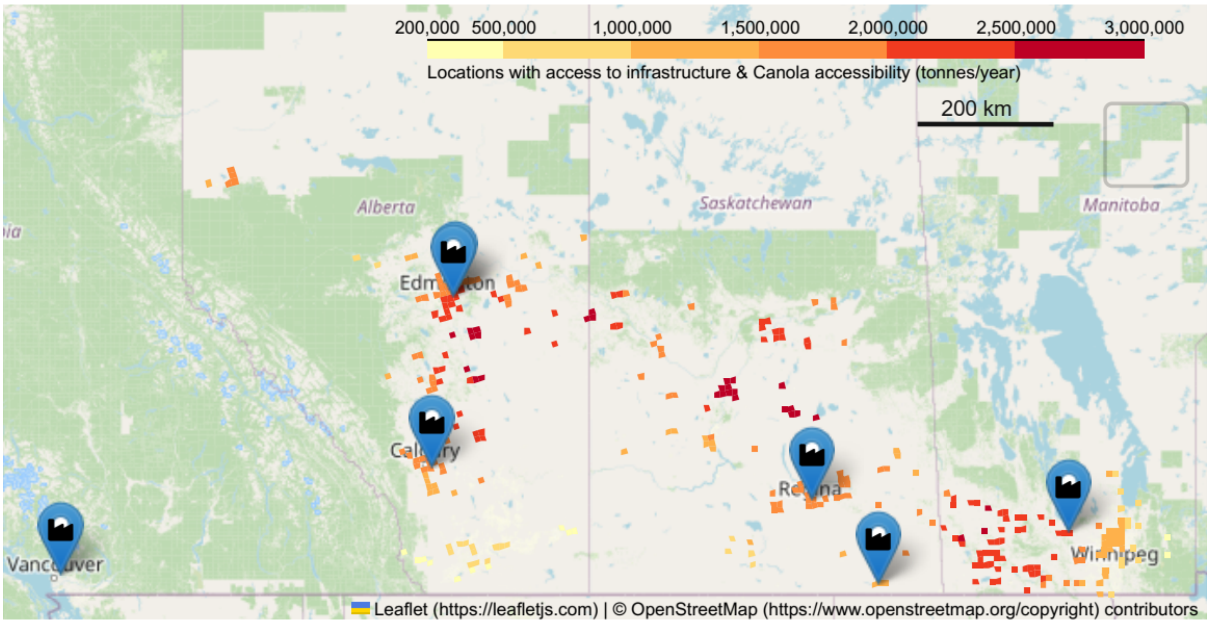

Figure 8 Proposed SAF plants in Canada mapped alongside with the potential sites for SAF plants identified. The location tags indicate the proposed SAF plants in Canada and the yellow-red marks indicate the potential sites that has access to abundant canola, rail, road, and infrastructure.

14. Passenger air traffic on major Canadian airports

In section 3.3.1 of the manuscript, we report the jet fuel consumption of major international airports in Canada, but some of the jet fuel consumption numbers are outdated. Since we could not get the recent data points for jet fuel consumption, in this section, we report the change in passenger traffic from these airports as a proxy to estimate the change in jet fuel consumption expected compared to the baseline reported data.

Figure 9 shows the annual passenger traffic in major international airports in the prairies region (38). The change in passenger traffic in Saskatoon, Regina, and Winnipeg was nearly constant within a range of +/- 6%, suggesting that the jet fuel consumption may be reasonably assumed to be the same. On the other hand, passenger traffic in Calgary increased 24.8% between 2013 and 2019, and in Edmonton, it increased 28.2% between 2011 and 2019. Among airports reported in our study, the Vancouver airport has the largest increase, with about 55.6% between 2011 and 2019, suggesting that jet fuel consumption needs to be updated with latest data, if feasible. The sudden drop in passenger traffic for all airports from 2020 to 2021 is due to the COVID-19 pandemic and, therefore, is ignored in our calculations.

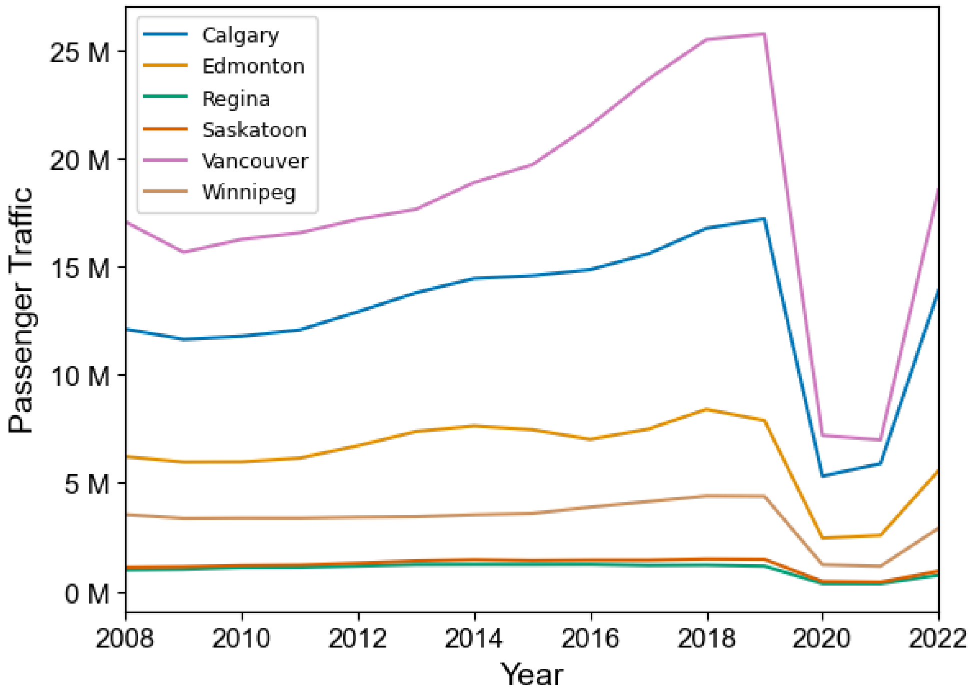

Figure 9 Change in passenger traffic between 2008 and 2022 in Canadian international airports such as Calgary, Edmonton, Regina, Saskatoon, Vancouver, and Winnipeg. The passenger traffic data is reported in million passengers.

15. Influence of increase in canola price on the profitability of optimal locations identified the maximum profitability scenario.

The canola prices have significantly increased since the conceptualization of the study. The average price of canola was $ 774 in 2021, rising to $1010 in 2022 and settling to $ 850 in 2023. Similarly, the average yearly price of canola meal was $ 425 in 2021, increasing to $518 in 2022 and settling to $ 542 in 2023. Therefore, we did a sensitivity analysis on the supply chain model to understand the influence of price of canola and meal on the profitability of optimal locations identified in the maximum profitability scenario. Since SAF is unviable without any incentives and the IRR is negative for higher prices of canola, to perform sensivitiy analysis, we did not directly estimate the change in IRR (profitability metric) with the increase in price of canola. Rather we used incentive required as a proxy variable and estimated the increase in incentives required to retain the same IRR (within +/- 2 IRR) for all profitable locations between 2016-2021. Although it is not a ideal approach, it served our goal of understanding how the increase in canola price will affect the overall viability of the SAF plant and provide us with a quantiative number that is digestible. With the increase in price of canola between 2021-2023, we adjusted the incentives in the TEA model to closely match the IRR observed in the 2016-2021 avg scenario. *Table 9* shows the incentives required to maintain the similar IRR for various canola seed and canola meal prices between 2016-2023.

Table 9 IRR (%) and minimum flat incentives ($/L) for various canola seed and canola meal prices (1 tonne basis) in a 25% feedstock accessibility criteria in the best profitability scenario.

Optimal Location	Capacity (tonnes)	IRR for canola seed meal price in 2021-2023			
		2016-21 scenario Canola: $ 542 Meal: $ 354	2021 scenario Canola: $ 774 Meal: $ 425	2022 scenario Canola: $ 1010 Meal: $ 518	2023 scenario Canola: $ 850 Meal: $ 542
P1	706,000	23.2	23.9	23.6	23.9
P2	643,000	22.6	23.2	22.8	23.2
P3	610,000	22	22.6	22.1	22.6
P4	315,000	17.7	17.7	16.5	17.7
P5	402,000	17.6	17.5	16.1	17.5
P6	215,000	16.2	16	14.5	16
P7	254,000	16.2	15.9	14.3	15.9
	Minimum incentive ($/L)	0.6 (base scenario)	1.08	1.53	1.12

The increase in the price of canola increased the incentives required to achieve the same profitability among the seven optimal locations (P1-P7) identified in the maximum profitability scenario. However, the optimal locations and canola capacity remained unchanged because there was no spatial variation in the incentives within Canada. With an increase in canola price from $542 (base scenario) to $774 (2021) and $1010, the incentive needs to be increased from 0.6 to 1.08 and 1.53 $/L. The almost doubling of canola price in 2022, demanded an increase of 1.5 times of the incentives to maintain the same profitability scenario. Although the price of canola seed and meal are correlated, at times, the prices may not vary proportionally, as in the case of 2021 and 2023. In such cases, when the meal price increases more than the price of canola, it can potentially compensate for the high cost of canola. Overall, we conclude that the cost of feedstock significantly influences the plant's profitability; therefore, it would be preferable to tie the incentives to feedstock price, at least during times of price shock, to manage risk.

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