Economic Evaluation of Drop-In Hydrotreated Renewable Jet (HRJ)* Fuel Production

From

Camelina sativa (Camelina) and *Brassica carinata* (Carinata)

~ Executive Summary ~

With increasing transportation costs and growing environmental concerns, demand for new and sustainable sources of energy is on the rise. Around the world, research and development initiatives are underway with a special focus on biofuels derived from non-food sources. In Saskatchewan, camelina and carinata have shown promise as dedicated industrial oilseed crops for the production of aviation bio-jet fuel.

The macro bio-jet fuel* value chain analysis of dedicated industrial oilseed crops *Camelina sativa* (camelina) and *Brassica carinata* (carinata) suggests a potential business opportunity to develop an aviation biofuel (or bio-jet fuel) sector in the Prairies.

The global airline industry (as represented by the International Air Transport Association) has set a goal of becoming carbon neutral by the year 2020. This target represents a 3-6% (9.6 to 19 billion litres) opportunity for sustainable second-generation bio-jet fuel as a share of a 319 billion litre per year global annual consumption of jet fuel. The jet fuel market in the Prairie Provinces (Alberta, Saskatchewan, Manitoba and Territories) is 1.40 billion litres per year and growing. The potential market opportunity for bio-jet fuel is at least 350 million litres annually based on historical import levels. Conventional jet fuel is priced at a premium relative to other North American jet fuel markets.

Camelina and carinata offer significant opportunities for cropping diversification in Saskatchewan. Using these crops for the production of bio-jet fuel also offers opportunities through the establishment of a value chain; from oilseed crushing, to fuel refining and distribution, to animal feed protein from the meal co-products. However, for Saskatchewan stakeholders to fully capture the benefits, it is critical that they understand the economic and technological realities surrounding the bio-jet fuel value-chain.

This report provides an overview of the dynamics affecting the potential development of camelina- and carinata-based bio-jet fuel production in the province and offers valuable insights into the opportunities and challenges for industry players, policy makers and other stakeholders. Specifically, it compiles extensive information and initial estimates in key areas of the bio-jet value chain, from the cultivation of camelina and carinata, to oilseed crushing, refining, and the sale of bio-jet fuel and co-products.

In terms of crop production, the potential for adoption of camelina and carinata by farmers presents a challenge in assessing the opportunity for bio-jet. Farmers will likely diversify their operations and include these dedicated industrial oilseeds if seed yield and financial returns are high enough and competitive with other cropping options. Strong demand and a well-established market for the oilseeds would also help develop sustainable production.

With inherent capacity for hardiness and drought tolerance (compared to other oilseed crops like canola) camelina and carinata are suitable for cultivation in Saskatchewan's drier regions. The ability to grow these crops in dry zones represents a new opportunity for Saskatchewan farmers. Researchers with Genome Prairie's Prairie Gold project are working to increase yield and oil content, and improve the oil profile of camelina and carinata.

The average seed yield for camelina is currently 0.82 metric tonnes per acre (MT/ac) and 0.92 MT/ac for carinata. Oil content is currently around 40% for both crops. Newer varieties are being developed with oil content above 45%, with yields consistently exceeding 1.0 MT/ac. With ongoing research and the development of new elite lines, seed yield and oil content is expected to increase, making oil feedstock from these crops a competitive choice.

The cost of industrial oil-based feedstock is tied to the percentage of oil yield from the seed. In turn, feedstock costs have a significant impact on the profitability of a crushing/refining facility. To illustrate this, the report provides price sensitivity analyses, which offers insight into the impact of a number of variables on profitability. The break-even cost for oil feedstock acquisition is calculated at approximately $475/MT for camelina and carinata, given current yields and oil contents.

The feasibility study considered 69 and 230 million litre per year (MLPY) facilities based on plant equipment and available markets. A 230 MLPY refining facility represents a viable business option for a Saskatchewan bio-jet producer (based on the conditions considered). A 69 MLPY facility was also analyzed; however the smaller plant size would not likely be viable because cost-efficiency would be reduced by the high capital-cost-per-liter of capacity.

The main economic drivers are the cost of feedstock, the value of the oilseed meal and the price of crude oil (which influences the prices of bio-jet fuel as well as renewable diesel, naphtha and propane co-products). This analysis was based on using UOP Honeywell technology and parameters; Honeywell has one of the only approved first-generation (1G) technologies available for producing bio-jet fuel from vegetable oils. Research companies such as Applied Research Associates (ARA) are working to develop a second generation (2G) process for lowering the cost of producing aviation biofuel through reduced hydrogen requirements. This technology could make bio-jet fuel more competitive with petroleum Jet A1* fuel. In October 2012 NRC Aerospace in Ottawa flew the world's first commercial flight powered by 100% bio-jet fuel, using ARA process technology with carinata oilseed sourced from Agrisoma.

Using current production and processing technologies and at current yield and oil content averages for camelina and carinata, 900,000 to 1 million acres of arable land would be required to produce enough oilseed for a 230 MLPY plant. With improvements in seed and oil yields, this acreage could be reduced to 780,000+/- 15,000 acres. Since the aviation industry is considering a 50% or lower blend of bio-jet fuel with regular Jet A1 fuel, a 230 MLPY facility could potentially supply bio-jet fuel to regions beyond the Prairies.

The capital cost to construct a 230 MLPY greenfield bio-jet refinery ranges from $165-245 million with an average annual net income estimated at $50 million, based upon an oilseed feedstock acquisition cost of $350/MT. Capital costs are wide ranging and depend on whether a plant can access existing infrastructure, (hydrogen, water, electricity etc.) or is built as a "greenfield facility." Note that the feedstock acquisition cost ($350/MT) used in the refining cost-analysis differs from the "breakeven feedstock acquisition cost" ($475/MT) cited earlier. The difference is the annual net income ($50M) of the profitable bio-jet refinery. For this study, the end-user acquisition cost of bio-jet fuel was set at $0.80/L (FOB Destination) to be competitive with the current estimated cost of petroleum Jet A1 at $0.87/L delivered to the end user (the difference being transportation cost).

Cost competitive bio-jet fuel produced in Saskatchewan could potentially serve several customers in Western Canada and outside the region, including commercial and military users. The distribution area of bio-jet fuel would depend on the cost of transportation. For the short term, trucking was identified as the most cost-efficient and feasible mode of transportation within an 800km distance. If less expensive delivery methods (rail or pipeline) can be introduced to reduce costs, bio-jet fuel could be delivered to a wider range of commercial customers.

The table below summarizes the projected annual operating profitability of a 230 million litre per year refinery producing bio-jet fuel at $0.80 /L, (FOB destination) which would be considered cost-competitive with an average petroleum Jet A1 price of $0.87/L delivered to the end user.

Operating profitability (millions of dollars) of a 230 MLPY (million litres per year) refinery based on feedstock cost (2012 yield and oil content - carinata)

OILSEED FEEDSTOCK COSTS $/MT ($/Bu)	**$331 ($7.50)**	**$375 ($8.50)**	**$419 ($9.50)**	**$463 (10.50)**	**$507 (11.50)**	**$551 (12.50)**	**$591 (13.50)**
Annual Operating Profit (Millions) # of 230 MLPY Refinery	$123	$85	$47	$9	-$29*	-$67*	-$105*

*Notes: *-($) is not profitable at 2012 processing, seed oil content and feedstock costs.*
 # Does not include capital Costs

Belle Plaine, SK, was chosen as a hypothetical location for a bio-jet fuel refinery to facilitate a more detailed cost analysis within the report. Belle Plaine is located within a geographic and transportation hub well-suited to serve the Western Canadian jet fuel market. It is also close to potential producers in the southern, drier region of Saskatchewan. In addition, Belle Plaine is home to several large industrial operators which may allow for co-access to hydrogen, water, electricity and other infrastructure requirements important for a bio-jet refinery.

The cost of vegetable oil feedstock is the single most important contributing factor to the final price of bio-jet fuel. The cost depends on variable on-farm expenses, seed cleaning, transportation and highly volatile crude oil prices (which affects the cost of agricultural production).

Fluctuations in the cost of feedstock significantly affect profitability for bio-jet fuel refineries. A 230 MLPY plant requires about 850,000 MT of camelina or carinata oilseeds, based on current technology. An increase in the price of feedstock reduces annual operating revenue. However, fluctuations can be mitigated with a predetermined feedstock price between the bio-jet fuel producer and farmers. For this reason, contracting most of the seed production would be preferable. Contract feedstock production, along with a fixed price would also encourage farmers to include dedicated industrial oilseeds in crop rotations. Risk for the bio-jet fuel producer would also be reduced by long-term off-take agreements with end users.

Improving seed yield and oil content through R&D and development of a 2G refining process will ensure adequate returns to growers and to the bio-jet fuel producer as the fuel becomes cost-competitive with petroleum Jet A1. If the anticipated production volume of 230 MLPY is met, Saskatchewan-produced bio-jet fuel would help diversify Western Canada's jet fuel supply. This would benefit commercial airlines, military users and Saskatchewan businesses and residents, as jet fuel users and consumers would be less affected by crude oil price volatility. Reducing the use of petroleum-based jet fuel would also lower net carbon emissions related to the burning of fossil fuels.

Camelina and/or carinata will also offer more options for farmers to diversify crop production, especially in regions where other oilseed crops are not always viable. As is the case with canola, it is critical that a market for meal and other co-products be developed. Camelina and carinata meal are not yet registered for use as feed meal in Canada. In order for the industrial oilseeds value-chain to be economically feasible, value in the meal must be fully realized. Feed meal trials are currently underway at the University of Saskatchewan's Feeds Innovation Institute and commercial proponents are researching other high-value uses for meal co-products. For this study, oilseed meal was valued at $265/MT, based on equivalent long-term average canola meal prices. As novel co-products are developed, the meal may ultimately find markets higher in value than current animal protein meal markets.

It should be noted that this analysis did not include the very real economic benefits of reduced carbon emissions and increased fuel efficiency from burning a fuel that is cleaner than petroleum kerosene. Initial inflight tests using bio-jet fuel, conducted by Agrisoma Biosciences in collaboration with the National Research Council in 2012, confirmed particulate emissions, including aerosols of black carbon, sulphates and by-products of the combustion of aromatic compounds, are significantly lower. Ultimately, when a price is put on carbon emissions from air travel and incentives put in place to reduce those emissions, the economic feasibility of bio-jet fuel will be further improved. The European Union has taken a lead position in this area, incorporating air travel into its emissions trading scheme beginning in 2012, effectively taking the first step in setting a global price on carbon emissions from air travel.

The development of ethanol and biodiesel industries for ground transportation was enhanced by government mandates and tax incentives. While this report makes no recommendations for bio-jet fuel in this regard, to develop a viable aviation biofuel industry, governments must develop a supportive and innovative policy framework in this emerging sector.

For reference, the Saskatchewan Renewable Diesel Producer Incentive program, (currently in year two of a 5-year program), is a 13 cent/L incentive program that applies to the first 20 million litres of production per company, which equates to a $2.6 million incentive and would apply to the production of bio-jet fuel. Marketed volumes of bio-jet fuel would also be eligible for meeting the Saskatchewan's renewable diesel mandate.

Other federal policies that would help advance the development of a bio-jet fuel industry could include tax credit consideration, production subsidies and mandates similar to those used in the development of the biodiesel and ethanol industries.

Summary:

A 230 MLPY bio-jet refinery can be a viable economic proposition, (based on the conditions considered in the report) for the province of Saskatchewan and would require 800,000 to 1,000,000 acres of sustainable, consistent annual production in Western Canada of camelina and/or carinata at current yields and oil content.

The cost to construct a 230 MLPY plant would range from $165 to 245 million based on current estimates. When compared to an equivalent $100 per barrel cost of petroleum, this plant could:

1) Earn an annual net income of approximately $50 million based on 1G process, a feedstock acquisition cost of $350/MT and an $0.80/L bio-jet selling price;
2) Have a break-even operating profit based on a 1G process, a feedstock acquisition cost (price paid to growers) of $475/MT and an $0.80/L bio-jet selling price; or
3) Earn an annual net income of approximately $50 million based on a 1G process, feedstock acquisition cost of $475/MT and a $1.22/L bio-jet selling price.

Contract-based production that delivers price certainty for growers and aviation biofuel manufacturers along with long term off-take agreements with end users is critical to the development of an aviation biofuel value chain.

Efforts to improve yield and oil content currently underway by Linnaeus, Agrisoma, M21, NRC and AAFC through the Prairie Gold project led by Genome Prairie will continue to enhance the economic feasibility surrounding the development of an aviation biofuel value chain in Saskatchewan.

Maximizing the value of co-products, such as meal and industrial co-products is critical for making bio-jet fuel competitive, and is essential for launching a viable aviation biofuel value chain.

Government has a role to play in encouraging the development of an emerging aviation biofuel value chain by establishing sound public policies. The analysis undertaken in this report does not include incentives for bio-jet fuels.

Airlines are highly motivated to develop sustainable options to current Jet A1 petroleum to lower their carbon footprint, improve efficiencies and diversify their fuel sources.

Saskatchewan has an enviable position in this emerging industry, with a large land mass capable of producing sustainable volumes of feedstock at competitive prices.

Primary producers have a proven track record of recognizing and capturing new cropping opportunities using highly advanced agronomic production methods. Saskatchewan has sophisticated research and development capacity, renowned for success in the improvement of oilseed crops.

Finally, as a land-locked region, Western Canada is one of the highest priced jet fuel markets in North America. This is a competitive advantage for developing a bio-jet fuel industry here.

Overall, there is little doubt that growing camelina and/or carinata as industrial oilseed feedstock will promote the development, diversity and sustainability of the agricultural economy in Saskatchewan.

Saskatchewan, and Canada as a whole, is blessed with the resources and expertise to develop a world class bio-jet fuel value chain. When combined with a clear vision and the will to make that vision a reality, the sky is truly the limit.

Glossary

* Aviation biofuel or bio-jet fuel - Biofuel used for jet engine aircraft.

*HRJ - The HRJ or hydrotreated renewable jet fuel process is a biofuel based synthetic process used to produce aviation bio-jet fuel. In the HRJ process, vegetable oils go through a deoxygenation process, followed by hydrocracking and isomerization, to produce a renewable Synthetic Paraffinic Kerosene jet fuel.

*Jet A1 - Jet A1 is the current global industry standard for petroleum-derived jet fuel with a freezing point of -47 Celsius. ASTM Specification 1655.

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