THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Alternative jet fuels: Case study of commercial-scale deployment

Authors: Anastasia Kharina, Nikita Pavlenko
Date: October 24, 2017
Keywords: Alternative Jet Fuels, AJF, United Airlines, AltAir Fuels

Executive summary

Alternative jet fuel (AJF) is expected to play an important role in reducing CO_2 emissions from aviation and meeting the carbon reduction goals of the International Civil Aviation Organization (ICAO). The organization's goal of carbon neutral growth from a 2020 baseline could require AJF to replace a substantial amount of conventional jet fuel. Although the substantially lower carbon intensity of some AJF makes it environmentally attractive, this is a difficult challenge because the industry is still under development. Some governments, including those of the United States and California, have either put policies in place to promote AJF production and use or are planning to implement them in the future. Lessons from existing policies and practices may be helpful in developing and refining policies to spur AJF uptake.

Several airlines around the globe have conducted or participated in pilot projects to demonstrate the feasibility of using AJF on regular flights. However, most of these projects did not develop further into long-term uptake agreements, generally because of the lack of financial or legal incentives to deploy greater volumes of AJF. At the moment, there is only one commercial-scale AJF producer in operation in the United States, with a few others in development. Few airlines have agreed to buy AJF from producers, meaning that AJF volumes remain a minute fraction of airlines' fuel consumption.

An AJF uptake agreement between United Airlines and AltAir Fuels, now in its second year, is unique in many ways. The AJF is produced in AltAir's facility, the first commercial-scale AJF refinery in the United States. AJF is blended with conventional fuel in United Airlines' day-to-day operations at Los Angeles International Airport.

Canada is one of the other governments putting policies in place to support AJF use, or planning to do so. Research, development, and demonstration of AJF is part of Canada's action plan to reduce greenhouse gas emissions from aviation. In addition, the government of Canada is working on a Clean Fuel Standard that may include AJF. An understanding of how United Airlines and AltAir overcame the substantial challenges facing AJF users may help inform this effort.

This report aims to contribute to the discussion of the potential and challenges of commercial-scale AJF production and use based on United Airlines and AltAir's experience. It looks into United Airlines and AltAir's fuel agreement, including its challenges, successes, and lessons learned. United Airlines and AltAir's endeavor was facilitated by several factors that may or may not available to others. However small, the cost disparity between AJF and conventional fuel is still a hurdle that market forces alone are unlikely to overcome. Without strong government incentive policies, AJF uptake will not happen as a matter of course.

1. Introduction

As an effort to mitigate increasing greenhouse gas emissions from international aviation in coming decades, the International Civil Aviation Organization (ICAO) agreed to the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) at its 39th Assembly in 2016. CORSIA aims to achieve carbon-neutral growth after 2020. Under CORSIA, airlines will be required to purchase offsets for increases in CO_2 emissions covered by the scheme. Airlines can partially reduce this offsetting burden by directly reducing emissions.

The growth in airline carbon emissions can be partially reduced through the use of more fuel-efficient aircraft as well as through increased operational efficiency, as demonstrated by Kwan and Rutherford (2015). In addition, the use of alternative jet fuel (AJF) is regarded by many as an important way to reduce CO_2 emissions from aviation. In its triennial report, ICAO (2016) predicts that the use of AJF could completely close the CO_2 emissions gap between a 2050 business-as-usual scenario and a carbon-neutral growth target for international aviation. That would amount to a total reduction of 1,039 million tonnes of CO_2, assuming nearly complete replacement of petroleum-based fuels with AJF. As a reference, the whole international aviation sector emitted approximately 504 million tonnes of CO_2 in 2014 (International Energy Agency, 2016).

Several countries and U.S. states have taken steps to encourage AJF use in their jurisdictions through research initiatives, policy incentives, and biofuel mandates. Canada, for example, is developing a Clean Fuel Standard policy that may include the aviation sector (Environment and Climate Change Canada, 2017). However, Canada does not have commercial-scale AJF production in use in day-to-day operations.

Several of the world's airlines, including Air Canada and Porter Airlines, have conducted or participated in pilot projects incorporating AJF into operations, demonstrating the feasibility of using AJF on regular flights (International Air Transport Association [IATA], 2015). Only a few airlines have used AJF in daily operations or set firm plans to do so in the near future. In the United States, a handful of airlines have signed longer-term agreements with AJF producers, as shown in Table 1. Only United Airlines, through its agreement with AltAir, is currently purchasing AJF for regular operations. Most other AJF deliveries are scheduled to start in the next few years.

The United-AltAir contract at present is the largest-volume AJF agreement in the United States and represents the first AJF use in normal business operations. United's experience could therefore be used as an example and benchmark for future ventures in continuous biofuels procurement for other airlines or airports.

This study reviews the United Airlines experience with the introduction of biofuels at Los Angeles International Airport (LAX), featuring lessons learned and possible policy options to support potential application in Canada and elsewhere.

2. United-AltAir collaboration overview

In 2013, United Airlines and AltAir Fuels signed an AJF offtake agreement with a duration of three years. United agreed to purchase as many as 5 million gallons of AJF a year from AltAir with deliveries starting in March 2016 under a variable pricing structure. Where the purchase price varies based on market conditions, United bears more risk than it would under a normal agreement with a set price. If biofuel feedstock prices go up, United may have to bear extra cost. However, if the feedstock is less expensive in procurement, United pays less. The same goes with the conventional jet fuel mixed with AJF because AltAir is also responsible for blending the fuels before delivery. United Airlines and AltAir Fuels say that this structure has worked successfully in practice (A. Foster-Rice, personal communication, April 14, 2017; B. Sherbacow, personal communication, May 12, 2017).

AltAir's fuel is blended into LAX's common fuel distribution system, meaning that all airlines buying from the "fuel farm" use small volumes of AJF in their operations, although United pays the incremental cost. To agree to this approach, other LAX fuel farm users requested that United demonstrate the safety of the AltAir fuel via dedicated flights. United treated this as a promotional period of higher visibility use. During the first two weeks of the AJF delivery, AltAir delivered blended AJF directly to aircraft via dedicated, marked trucks for use on a route between LAX and San Francisco International Airport. The deliveries were clearly visible to passengers in the gate area, raising awareness for the AJF use. The blend ratio during the promotional period and subsequent deliveries to the fuel farm was 30/70, or 30% AJF and 70% conventional fuel.

Table 1. U.S.-based airline AJF uptake agreement volume compared with 2016 total fuel consumption

Airline	Volume (million gallons/yr)	AJF producer	Target for first delivery	Fuel consumption in 2016 (million gallons/yr)	% AJF uptake
United	5	AltAir Fuels	2016	3,166	0.16%
	90	Fulcrum	2019		1.6%
FedEx	3	Red Rock	2017	1,115	0.27%
Southwest	3	Red Rock	2017	1,999	0.15%
Jet Blue	9.9	SG Preston	2019	760	1.30%
TOTAL	**110.9**			**7,040**	**1.58%**

Sources: IATA (2016) and U.S. Department of Transportation (2017).

3. Review of manufacturing process

3.1. FEEDSTOCK

AltAir's primary source of feedstock consists of inedible waste oils and fats, mostly animal fats such as tallow and lard. These waste materials are cheaper than virgin vegetable oils yet have similar physical properties for conversion into jet fuel (U.S. Department of Agriculture, Economic Research Service, 2017). However, the production of used cooking oil (UCO) and waste fats is, by definition, fixed—realistically, no matter the amount of additional demand, additional production is unlikely to occur. These materials are merely relatively low-value components of an outside product system; additional demand for tallow is unlikely to spur the production of additional cattle because tallow is merely a byproduct of beef production (Searle, Pavlenko, El Takriti, & Bitnere, 2017). Only a finite amount of this resource is available, limiting its potential for use in high-volume AJF production. For AltAir's operations, these feedstocks are nationally sourced and shipped from California, the upper and lower Midwest, and elsewhere, though transport emissions are relatively small compared with the baseline jet fuel carbon intensity (B. Sherbacow, personal communication, May 12, 2017).

The use of these feedstocks for AJF production faces competition from the road sector and other uses in livestock feed and the oleo chemicals industry. Given these competing demands, it is likely that supplies of this feedstock will go to the sector that can pay the highest price.

3.2. PATHWAY/MANUFACTURING PROCESS

At AltAir's facility in Paramount, California, the company uses Honeywell UOP's proprietary technology to convert vegetable oils or waste oils and fats into hydro processed esters and fatty acids as described by El Takriti, Pavlenko, and Searle (2017). This feedstock-to-fuel pathway is at a relatively high level of technological readiness for the production of renewable diesel and has already reached commercial volumes in the road sector. The AltAir Paramount plant produces renewable diesel in addition to AJF.

The Paramount plant formerly produced asphalt. Because of low demand, the asphalt operation was suspended in 2012. The primary issue AltAir faced in preparing the idle refinery for AJF production in 2016 was that the renewable feedstocks require different, upgraded metallurgy to minimize corrosion related to higher water content compared with fossil-based materials (B. Sherbacow, personal communication, May 12, 2017).

The AJF produced in AltAir's plant is designed to meet ASTM D7566, *Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons*. The standard specifies that no more than 50% of a fuel can be synthetic; at least 50% must be conventional commercial jet fuel, or Jet A and Jet A-1. According to ASTM (2016), "aviation turbine fuel manufactured, certified, and released to all the requirements of D7566 meets the requirements of Specification D1655 and shall be regarded as Specification D1655 turbine fuel." ASTM D1655 is the standard used to certify conventional jet fuel. This means that the blended fuel delivered by AltAir can be treated as standard, conventional jet fuel.

3.3. ENVIRONMENTAL PERFORMANCE

Greenhouse gas impacts

According to Honeywell (2016), fuel such as AltAir's that is produced using the UOP Renewable Jet Fuel Process™ has a carbon intensity 65% to 85% lower than petroleum jet fuel, depending on the source of the feedstock. This estimate is generally consistent with certified renewable diesel pathways for UCO and tallow-derived fuels within the California Low Carbon Fuel Standard (LCFS), which range from 15 to 35 gCO_2e/MJ for fuels used in the road sector (California Air Resources Board [CARB], 2016a), compared with 87.5 gCO_2e/MJ for conventional jet fuel (Stratton, Wong, & Hileman, 2010).

Within life-cycle assessments, byproducts and waste materials generally have lower carbon intensities because they are low-value materials that do not drive the value chain for a product system.[1] In other words, the primary market driver for an industrial process is demand for a separate good. The wastes and byproducts are generated regardless of consumer demand for them. Therefore, the emissions from the upstream processes used to manufacture those primary materials, such as cattle production and oilseed agriculture, generally are not attributed to byproducts and wastes from those product systems. Instead, only the emissions occurring from the point of material extraction, such as UCO collection, through to consumption—the bulk of which are associated with the jet fuel conversion itself—are attributed to the product.

Though byproducts, residues, and wastes are not the primary drivers for a product system, they may still have existing uses and markets. Diverting these materials may generate indirect

1 Waste materials such as tires and the fossil-based components of municipal solid waste are a notable exception because both of these feedstocks contain high non-biogenic carbon content, in some cases generating higher emissions than petroleum when diverted to energy uses.

emissions, as another product may need to be substituted (Searle et al., 2017). An indirect emissions analysis by Searle et al. (2017) suggests that the impact of diverting inedible animal fats from heat and power and the oleo chemical sector can generate indirect emissions of 16 to 30 gCO_2e/MJ. This figure is on the order of the direct emissions associated with waste oils and fat conversion to renewable diesel.

Non-greenhouse gas impacts

The lack of sulfur content in AJF compared with conventional jet fuel leads to lower sulfur oxide (SO_x) emissions from engine combustion. SO_x can react with other compounds in the atmosphere and form small particles that lead to severe health problems. Several studies in the United States and Europe have explored avenues to mitigate health effects of the aviation sector by desulfurizing jet fuel (Gilmore et al., 2011; Barrett et al., 2012; QinetiQ, 2010).

The emissions profile for aircraft engines burning alternative fuels and their impact on local air quality is still somewhat uncertain and needs further testing. However, past studies have indicated that the use of AJF in gas turbine engines may reduce air pollution from aircraft engines. In a study comparing nonvolatile particulate matter (nvPM, equivalent to black carbon) emissions of an engine with different AJF fuel blend ratios, Lobo, Christie, Khandewal, Blakey, and Raper (2015) concluded that a higher ratio of AJF in the fuel blend results in a reduction of nvPM emissions, both in number and mass. This conclusion is corroborated with a multiorganizational experiment study by Kinsey et al. (2012), which also shows reduction in total hydrocarbon and carbon monoxide emissions compared with conventional jet fuel, albeit using a different type of AJF.

4. Review of the distribution process

All AJF produced for United's consumption is mixed with conventional fuel at AltAir's facility in Paramount, where it is tested for quality to ensure that the blend meets ASTM D7566 before being brought to the airport. The blended fuel is then transported biweekly via truck to LAX. This method was chosen over pipeline because of the short, 15-mile distance.

Instead of delivery directly to United, the destination for AltAir's blended jet fuel is LAX's fuel farm, a storage facility near the airport where all airlines operating out of LAX store and comingle fuel. The use of fuel farms instead of separate fuel storage for each airline is common at many of the world's major airports. There is no segregation between airlines under this system, meaning that AltAir's fuel is not used exclusively on United's flights but is shared among all flights from LAX.

From the storage at the fuel farm, jet fuel is delivered to each terminal via an underground hydraulic system and discharged into aircraft fuel tanks using a fuel hydrant system.

5. Cost

5.1. PRODUCER COSTS

Producing alternative fuels, especially during initial deployment, can be quite expensive because of upfront capital investments in manufacturing capacity on top of production costs such as feedstock acquisition, chemical inputs, and staff time. AltAir found ways to minimize both capital and operating costs.

Rather than taking on the prohibitive capital expense of building a new refinery, AltAir repurposed an existing but idle asphalt plant. As of June 2017, 25% of the original facility had been converted. The project still faces retrofit costs in the range of several hundred million dollars. Altair received a few government grants to help defray some of the cost, including $5 million from the California Energy Commission (2014).

To reduce production costs, AltAir took advantage of policies offering financial support for alternative fuel production, such as the California LCFS and the U.S. Environmental Protection Agency's (EPA's) Renewable Fuel Standard (RFS).

California's LCFS allows AltAir's renewable diesel fuel to receive credits on the basis of its greenhouse gas (GHG) reductions. Credit values fluctuate based on the underlying carbon price in California's LCFS credit market. However, AltAir's jet fuel is ineligible for LCFS credits because aviation fuel doesn't yet qualify under the program. This may change soon. AJFs are likely to be added as an "opt-in" source of credits. AJF production could generate LCFS credits without a binding carbon intensity target (CARB, 2017). According to AltAir president Bryan Sherbacow (personal communication, May 12, 2017), although the raw materials cost of AltAir's AJF is relatively close to that of conventional jet fuel, the additional processing and transportation/logistics make production more expensive.

Operating costs at the AltAir plant are eligible for Renewable Identification Number (RIN) credits for renewably derived fuel, applying to both the road and the aviation fuels made there. While road fuels are an obligated sector within the U.S. RFS—meaning that refiners or importers must generate a set number of RIN credits—aviation fuel is an opt-in sector that is not obligated but can still generate RIN credits for sale to obligated parties.

According to AltAir, the costs of producing AJF and renewable diesel at the plant are essentially at parity. The facility has the capacity to increase AJF production relative to renewable diesel in the future, although that also would generate more of the coproduct naphtha, which also doesn't qualify for LCFS credits in California. Naphtha is a hydrocarbon with a variety of uses, including as a solvent, diluent, or octane booster.

Even with some production credits in place, the project is still exposed to cost-related risks stemming from variability in the feedstock cost as well as fluctuations in the value of credits. However, under AltAir's agreement with United, the airline bears the risk regarding price fluctuations for both AJF feedstock and conventional fuel.

5.2. AIRLINE COSTS

The United-AltAir agreement allows United to obtain blended AJF with "competitive pricing." Without divulging pricing details, United and AltAir said that under this provision United is not paying five to six times the conventional fuel cost as was the case with several trials in the past as reported by Gates (2011) and Alexander (2012), among others. Several studies have estimated that the price of AJF similar to AltAir's may be two to three times the cost of conventional jet fuel (Klauber et al., 2017; El-Takriti, Pavlenko, & Searle, 2017) and may decline to two times the cost by 2020 (Winchester, McConnachie, Wollersheim, & Waitz, 2013). United says that entering agreements entailing increased cost risk is the only way to get good pricing for jet biofuel and that price-competitive AJF is impossible to obtain with on-the-spot prices.

Under this agreement, there is no additional cost for LAX as the blended AJF delivered to the fuel farm is treated the same as conventional Jet-A (see Section 3.2).

6. Existing policy incentives

Several policy incentives for the use of AJF are in place, implemented by regional and national governments around the world. Not all of these policy incentives include aviation. In one case biofuel blending is mandatory.

1. The U.S. RFS includes AJFs and other biofuels, although aviation is not an obligated sector under the regulation (U.S. Environmental Protection Agency [EPA], 2010). Any eligible fuels used within the sector can generate a RIN that can then be sold to obligated parties, generating a profit. A RIN is a tradeable credit linked to a specific biofuel category and attached to an individual unit of biofuel until it is blended. The obligated parties, fuel blenders and refiners who mix the biofuel into finished fuel use those RINs to demonstrate compliance with the volume mandates of the U.S. RFS (International Council on Clean Transportation [ICCT], 2014). Any obligated parties whose blending falls short of the U.S. RFS statutory requirements can purchase RINs from suppliers with an excess, thus creating a RIN marketplace.
2. California and the United Kingdom are considering the same level of obligation for jet fuels as the U.S. RFS, under California's LCFS program and the U.K. Renewable Transport Fuel Obligation program (CARB, 2017; Department for Transport, 2016). If the LCFS is expanded to include aviation fuels as an opt-in category, fuel blenders and suppliers would be entitled to receive an LCFS credit, a tradeable credit generated by the production or import of an alternative fuel. The credit value is based on the carbon intensity of the fuel in question and the trading price of LCFS credits, in U.S. dollars per tonne of CO_2. The lower the carbon intensity of the fuel relative to the fossil fuel baseline—approximately 99 gCO_2/MJ for the road sector—the higher the value of the credit. The price of LCFS credits has fluctuated significantly in recent years, from a low approaching \$20/tonne of CO_2e in 2015 to more than \$120/tonne in early 2016 (CARB, 2016b).
3. The European Commission's October 2016 proposal for the 2020–2030 Renewable Energy Directive (ICCT, 2017) would have the same treatment as the opt-in clause in the U.S. RFS. In addition, alternative aviation fuels are assigned a factor of 1.2x in the accounting within the current proposal at time of publication, providing a moderate increase in the incentive value relative to fuels produced for the road sector.
4. The Canadian government is developing a Clean Fuel Standard under the federal renewable fuels regulation. At the time of writing, the inclusion of AJF within the standard along with rail and marine sectors was still under discussion.
5. Other federal tax credits that can be used to finance production in the United States are sometimes available. In this case, the biodiesel tax credit of \$1/gallon could be collected by domestic producers. This tax credit expired December 31, 2016, but could be reinstated in a tax overhaul by the U.S. Congress (Clean Energy for America Act, 2017).

6. A few countries have adopted mandates to spur the uptake of biofuels in the aviation sector. Indonesia has implemented a biofuels mandate under the jurisdiction of the Indonesian Ministry of Energy and Mineral Resources (2015). Under the mandate, the government of Indonesia requires the use of biofuels in all air transport with a blending target of 2% in 2016 and as much as 5% by 2025. At the time of writing, however, there was no publicly available information on compliance with this mandate.

7. Scale-up potential

7.1. UNITED'S PLAN FOR INCREASING AJF UPTAKE

United and AltAir say they consider their first contract a success. Plans to extend and increase the volumes of the cost-plus contract are being discussed, although the specifics are still to be determined.

United has made an equity investment of $30 million in Fulcrum BioEnergy, another AJF developer based in California. The long-term plan under this investment is to codevelop as many as five bio refineries near United's hub locations that would provide United 90 million gallons a year of AJF for 10 years. Fulcrum BioEnergy has signed agreements with other companies as well and is building its first facility in Reno, Nevada, with plans to start production by 2019.

7.2. AIRPORTS' PLANS FOR EXPANDING USE OF BIOFUELS

Los Angeles World Airports, which operates two airports in Los Angeles County, has not announced its own plans to integrate the use of biofuels across LAX beyond United's agreement with AltAir. The Port of Seattle (2015), which operates Seattle-Tacoma airport in Washington, was the first airport to announce a plan to provide AJF for all flights operating from the airport. WSP, 3 Square Blocks, Argus, and PT&C (2016) conducted a feasibility study for the Port of Seattle to identify the best approach for delivering as many as 50 million gallons of AJF a year to the airport. Klauber et al. (2017) recommended a few funding mechanisms to enable 1% percent AJF use in the airport.

7.3. ALTAIR'S PLAN ON REACTING TO INCREASED DEMAND IN THE FUTURE

AltAir reported significantly greater demand for AJF than supply and says it plans to expand its facilities and production. With just 25% of the Paramount plant converted, AltAir has the capacity to scale up production four-fold.

Although the feedstock used in AltAir's AJF production has limited expansion potential, the company's hydro processing technology is suitable for different kinds of oils. The company is also interested in exploring using UCO and inedible vegetable oils, such as corn oil from ethanol production. The company is working to obtain certification from the Roundtable for Sustainable Biomaterials for these other feedstocks.

8. Lessons learned and implications for Canada

8.1. STATE OF THE INDUSTRY

The AJF industry is very much in its infancy. While progress has been made in the certification of AJF, a mix of technological and commercial barriers to widespread deployment remains. Thus far, AJF use has been generally discontinuous and small in scale, usually aiming at a proof of concept rather than a tangible plan for continuous use. Additionally, a wide variety of potential fuels from different feedstocks and pathways is being tested, often with very different carbon intensities.

On the technical side, many potential AJF pathways suffer from the same barriers as second-generation fuels in the road sector. These barriers include issues of feedstock quality and consistency and the difficulty of feedstock pretreatment, compounded by the time and expense of testing and certification to meet aviation specifications (Hamelinck, Cuijpers, Spoettle, and Bos, 2013; Radich, 2015). Only certain fuel pathways such as hydro processing of fats and oils have reached technological maturity. For commercialization, barriers include policy uncertainty and high initial capital expenses, which together make investment in a commercial facility risky without supply agreements (Pavlenko, Searle, Malins, & El Takriti, 2016).

Several production facilities are either planned or under construction in the United States, with none in Canada (see Table 1). United is the only airline in North America purchasing AJF for day-to-day operations, and AltAir is the first and only AJF producer in operation on a commercial scale. Despite having the largest AJF purchase agreement, United is covering only 0.16% of its total fuel use with AJF from AltAir. For the industry to scale up, there would need to be a clearer vision of what the actual goals are for AJF, which fuels will help meet those goals, and a plan for bridging the cost gap between conventional and alternative fuels.

8.2. COST ISSUES

High capital and operating expenses are key issues for any next-generation fuel industry. Although Canada is a smaller market than the United States or Europe, AJF producers are likely to face the same cost constraints and barriers as in other jurisdictions. The fungibility of petroleum jet fuel and the international scope of ICAO's forthcoming CORSIA agreement will aid in the development of a common market for AJFs across national boundaries. While the upfront capital cost of building a new refinery is an obvious challenge, AltAir showed that this can be reduced significantly as the company repurposed and retrofitted an existing asphalt refinery.

Although the production cost of AJF is highly dependent on the type of feedstock and pathway used, in general AJF is more expensive to produce than conventional jet fuel. In United and AltAir's case, the risk of high production costs is mostly carried by United. However, the agreement still enables United to purchase AJF at a price more competitive with petroleum-based jet fuel. This suggests that a purchase agreement in which the buyer assumes at least some production-cost risk is a good way to reduce prices relative to the spot market.

Biofuel incentive policies are also important. On one hand, AltAir receives credits for every gallon of AJF it produces via U.S. RFS and LCFS, helping to offset production costs. In the long term, such credits may lower AJF production costs and help develop the industry, which in the end will reduce costs for airlines. On the other hand, incentive structures for road fuels are much better than for AJF at the moment. According to Angela Foster-Rice (personal communication, April 14, 2017), it would be more economical for United to buy AltAir's road fuel and resell it than to buy AJF from AltAir.

United's investment in Fulcrum BioEnergy is a somewhat unusual financing model for procuring AJF given the large upfront investment and additional complications involved. However, ownership gives an airline more ability to influence decisions and product pricing. Foster-Rice says that if an airline wants the ability to procure well-priced AJF very far in the future, the ownership model is probably the only option (personal communication, April 14, 2017).

Financing sources and mechanisms for developing the AJF industry are still to be explored. One possible alternative, as suggested by the Office of the New York City Comptroller (2016), is to apply a local sales tax on jet fuel to fund the necessary infrastructure for biofuels. Another alternative, requiring more government investment, would be a contract for difference scheme wherein producers enter a long-term contract with the government that pays out the difference between the market value of their finished fuel and an agreed-upon "strike price" (Pavlenko et al., 2016).

8.3. GOVERNMENT POLICIES

The high cost of AJF production means market forces alone are probably insufficient to drive fuel-switching, and stronger deployment of AJF may not be realized in the current policy environment.

One policy approach for promoting AJF in Canada would be inclusion in its Clean Fuel Standard of an opt-in clause for jet fuels. As the program is still in its development phase, a few lessons learned in terms of policy as described below could be considered.

Policy certainty with sufficient time horizon

Policy uncertainty is a key barrier to commercialization for biofuel producers because incentive programs are subject to change at all times. Although the policy environment may be fickle in the short term, new biofuel production facilities often have a long operational lifetime that requires a stable and predictable rate of return to attract investment. A supporting policy should be in effect for long enough to give investors time to recover their upfront investment, especially for something like building a new refinery.

Inconsistency in program terms and duration can discourage investment and support for new biofuel technologies. For example, the U.S. RFS has been in place for 10 years but is subject to change in the future, as the value of RINs within the program fluctuates reflecting activity in the secondary RIN market. Similarly, California's LCFS program has dealt with legal challenges and policy uncertainty since its implementation, resulting in periodic volatility in credit prices. Volatility causes investors to discount the present value of credits for a proposed project, and near-term policy uncertainty may scare away potential investors for facilities with a long operational lifetime and high initial capital requirements (Miller et al. 2013).

Flexibility

The potential mismatch between available incentives and commercial opportunities also should be considered. Before an AJF pathway is certified for policy support, it needs to be certified for commercial airplane use. The AJF certification process is more difficult than for road fuels because additional testing for commercial aviation use may take longer than commercial opportunities are available (Hamelinck et al. 2013; Radich, 2015).

Even after certification for a certain pathway, challenges still exist for integration of different feedstocks. The lead time to integrate a new feedstock under the U.S. RFS may also take too long for a producer to take advantage of a commercial opportunity (McCubbins & Endres, 2013).

Program integrity and durability

As Canada develops its Clean Fuel Standard (CFS), care should be taken to ensure that the carbon intensities of alternative fuels consumed under the program are consistent with their regulated values, and that carbon reductions occurring as a result of fuel-switching within the program are not double-counted within the context of other fuel policies. These steps would help to protect the integrity of the program and ensure that stated carbon reductions actually occur in implementation, thus fostering greater confidence within the CFS credit market. The issue of double-counting is particularly significant because Canada currently has a variety of provincial-level alternative fuels policies either implemented or in the design process, such as British Columbia's Renewable and Low-Carbon Fuel Requirements and Ontario's proposed LCFS. Canada also has a federal RFS standard as well as several provincial-level RFS mandates for biofuel blending rates that also promote the deployment of alternative fuels.

To ensure that the Clean Fuel Standard achieves its intended greenhouse gas reduction goals, the program could require all alternative fuel producers to submit documents verifying feedstock and key attributes of the production facilities before allowing those facilities to produce CFS-compliant fuel, as is done in both California's LCFS and the U.S. RFS. Periodic audits could help prevent fraud. The California Air Resources Board currently plans to implement a monitoring, reporting, and verification scheme within the LCFS to improve data quality, support CARB auditing, and improve the transparency of the program (CARB, 2016c). To avoid double-counting, a robust tracking system, similar to CARB's planned verification system or the EPA's RIN system, would help to ensure that only one party receives credit for a finished fuel, regardless of its origin, whether it is imported or produced within Canada.

Acknowledgement

We would like to acknowledge the help of Angela Foster-Rice, managing director of environmental affairs and sustainability at United Airlines, and Bryan Sherbacow, the founder, president, and COO of AltAir, who graciously provided their time to discuss the AltAir Fuels-United Airlines collaboration with us.

This study was funded through the generous support of the Environment and Climate Change Canada.

9. References

Alexander, D. (2012). U.S. Air Force tests biofuel at $59 per gallon. *Reuters*. Retrieved from https://www.reuters.com/article/us-usa-military-biofuels-idUSBRE86E01N20120715

ASTM International. (2016). ASTM D7566-16b, *Standard specification for aviation turbine fuel containing synthesized hydrocarbons.* Retrieved from https://www.astm.org/Standards/D7566.htm

Barrett, S. R. H., Yim, S. H. L., Gilmore, C. K., Murray, L. T., Kuhn, S. R., Tai, A. P. K., … Waitz, I. A. (2012). Public health, climate, and economic impacts of desulfurizing jet fuel. *Environmental Science & Technology*, 2012, 46 (8), 4275–4282. doi: 10.1021/es203325a

California Air Resources Board. (2016a). *LCFS pathway certified carbon intensities.* Retrieved from https://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm

California Air Resources Board. (2016b). *Low carbon fuel standard reporting tool quarterly summaries*. Retrieved from http://www.arb.ca.gov/fuels/lcfs/lrtqsummaries.htm

California Air Resources Board. (2016c). *Framework for development of a low carbon fuel standard verification program.* Retrieved from https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/verification_whitepaper_102116.pdf

California Air Resources Board (CARB). (2017). *Low carbon fuel standard: Evaluation of alternative jet fuel inclusion* Presented at the Public Working Meeting for Stakeholder Groups, March 17, 2017. Retrieved from https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/031717presentation.pdf

California Energy Commission. (2014). California Energy Commission approves $13 million in grants for natural gas technologies and advances in biofuels. Retrieved from http://www.energy.ca.gov/releases/2014_releases/2014-09-10_naturalgas_biofuels_grants.html

Clean Energy for America Act, S.1068, 115th Congress, 1st Session. (2017). Retrieved from https://www.congress.gov/bill/115th-congress/senate-bill/1068

Department for Transport. (2016). *The renewable transport fuel obligations order proposed amendments*. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/572971/rtfo-consultation-document-2016.pdf

El Takriti, S., Pavlenko, N., & Searle, S. (2017). *Mitigating international aviation emissions: Risks and opportunities for alternative jet fuels.* Retrieved from the International Council on Clean Transportation, http://www.theicct.org/publications/mitigating-international-aviation-emissions-risks-and-opportunities-alternative-jet

Environment and Climate Change Canada (ECCC). (2017). *Clean fuel standard: Discussion paper*. Retrieved from http://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=D7C913BB-1

Gates, D. (2011). Alaska Air starts test of biofuel-powered flights. *The Seattle Times*. Retrieved from http://www.seattletimes.com/business/alaska-air-starts-test-of-biofuel-powered-flights/

Gilmore, C. K., Barrett, S. R. H., Yim, S. H. L., Murray, L. T., Kuhn, S. R., Tai, A. P. K., … Waitz, I. A. (2011). *Environmental cost-benefit analysis of ultra low sulfur jet fuel* (Partnership for AiR Transportation Noise and Emissions Reduction Project 27 Final Report). Retrieved from http://web.mit.edu/aeroastro/partner/reports/proj27/proj27finalrept.pdf

Hamelinck, C., Cuijpers, M., Spoettle, M., & Bos, A. (2013). *Biofuels for aviation*. Utrecht: Ecofys. Retrieved from http://www.ecofys.com/files/files/ecofys-2013-biofuels-for-aviation.pdf

Honeywell. (2016). Honeywell UOP technology powering commercial-scale biorefinery in California, making renewable fuel a commercial reality. Retrieved from https://www.honeywell.com/newsroom/pressreleases/2016/03/honeywell-uop-technology-powering-commercial-scale-biorefinery-in-california-making-renewable-fuel

Indonesian Ministry of Energy and Mineral Resources. (2015). *Peraturan Menteri Energi dan Sumber Daya Mineral No. 12/2015 Tentang Perubahan Ketiga Atas Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 32 Tahun 2008 Tentang Penyediaan, Pemanfaatan, dan Tata Niaga Bahan Bakar Nabati (Biofuel) Sebagai Bahan Bakar Lain* (Minister of energy and mineral resources regulation no. 12/2015 concerning the third amendment to minister of energy and mineral resources regulation no. 32/2008 regarding the supply, utilization and procedure of biofuels as other fuels). Retrieved from http://jdih.esdm.go.id/peraturan/Permen%20ESDM%2012%20Thn%202015.pdf

International Air Transport Association (IATA). (2015). *IATA sustainable aviation fuel roadmap.* Retrieved from https://www.iata.org/whatwedo/environment/Documents/safr-1-2015.pdf

International Air Transport Association (IATA). (2016). *Fact sheet alternative fuels* . Retrieved from https://www.iata.org/pressroom/facts_figures/fact_sheets/Documents/fact-sheet-alternative-fuels.pdf

International Civil Aviation Organization. (2016). *ICAO environmental report 2016*. Retrieved from https://www.icao.int/environmental-protection/Pages/ENV2016.aspx

International Council on Clean Transportation (ICCT). (2014). *How the renewable fuel standard works.* Retrieved from http://www.theicct.org/sites/default/files/publications/ICCTBriefing_RFS2_20140211.pdf

International Council on Clean Transportation. (2017). *The European Commission's renewable energy proposal for 2030*. Retrieved from http://www.theicct.org/sites/default/files/publications/RED%20II_ICCT_Policy-Update_vF_jan2017.pdf

International Energy Agency. (2016). *CO_2 Emissions from fuel combustion highlights 2016*. Retrieved from https://www.iea.org/publications/freepublications/publication/CO2EmissionsfromFuelCombustion_Highlights_2016.pdf

Kinsey, J. S., Timko, M. T., Herndon, S. C., Wood, E. C., Yu, Z., Miake-Lye, R. C., ... Knighton, W. B. (2012). Determination of the emissions from an aircraft auxiliary power unit (APU) during the aternative aviation fuel experiment (AAFEX). *Journal of the Air & Waste Management Association.* 62, 420-430, 2012. Retrieved from http://www.tandfonline.com/doi/full/10.1080/10473289.2012.655884

Klauber, A., Benn, A., Hardenbol, C., Schiller, C., Toussie, I., Valk, M., & Waller, J. (2017). *Innovative funding for sustainable aviation fuel at U.S. airports: Explored at Seattle-Tacoma International.* Rocky Mountain Institute, SkyNRG. Retrieved from https://www.rmi.org/insights/reports/innovative-funding-sea-tac-2017/

Kwan, I., & Rutherford, D. (2015). *Transatlantic airline fuel efficiency ranking, 2014.* International Council on Clean Transportation. Retrieved from http://www.theicct.org/transatlantic-airline-efficiency-2014

Lobo, P., Christie, S., Khandelwal, B., Blakey, S. G., & Raper, D. W. (2015). Evaluation of non-volatile particulate matter emission characteristics of an aircraft auxiliary power unit with varying alternative jet fuel blend ratios. *Energy & Fuels*, 29 (11). 7705 - 7711. ISSN 0887-0624.

McCubbins, J., & Endres, A. B. (2013). EPA biofuel pathways and petitions: Failure to launch? *FarmdocDAILY*. Retrieved from http://farmdocdaily.illinois.edu/2013/05/epa-biofuel-pathways-petitions.html

Miller, N., Christensen, A., Park, J. E., Baral, A., Malins, C., & Searle, S. (2013). *Measuring and addressing investment risk in the second-generation biofuels industry*. Retrieved from the International Council on Clean Transportation, http://www.theicct.org/sites/default/files/publications/ICCT_AdvancedBiofuelsInvestmentRisk_Dec2013.pdf

Office of the New York City Comptroller, Bureau of Policy and Research. (2016). *Green skies ahead: A plan to modernize and green New York City's airports.* Retrieved from http://comptroller.nyc.gov/wp-content/uploads/documents/Green_Skies.pdf

Pavlenko, N., Searle, S., Malins, C., & El Takriti, S. (2016). *Development and analysis of a durable low-carbon fuel investment policy for California*. Retrieved from the International Council on Clean Transportation, http://www.theicct.org/durable-low-carbon-fuel-investment-policy-CA

Port of Seattle. (2015). Port of Seattle Partners with Alaska Airlines and Boeing on plan to supply sustainable aviation biofuel at Sea-Tac Airport. Retrieved from http://www.portseattle.org/Newsroom/News-Releases/Pages/default.aspx?year=2015#555

QinetiQ. (2010). *Reduction of sulphur limits in aviation fuel standards (SULPHUR)* (Report QinetiQ/09/01835 Issue 1.1). Retrieved from: https://www.easa.europa.eu/system/files/dfu/2009-SULPHUR-Reduction%20of%20sulphur%20limits%20in%20aviation%20fuel%20standards-Final%20Report.pdf

Radich, T. (2015). *The flight paths for biojet fuel.* Energy Information Administration. Retrieved from https://www.eia.gov/workingpapers/pdf/flightpaths_ biojetffuel.pdf

Searle, S., Pavlenko, N., El Takriti, S., & Bitnere, K. (2017). *Potential greenhouse gas savings from a 2030 greenhouse gas reduction target with indirect emissions accounting for the European Union*. Retrieved from the International Council on Clean Transportation, http://www.theicct.org/sites/default/files/publications/RED-II-Analysis_ICCT_Working-Paper_05052017_vF.pdf

Stratton, R. W., Wong, H. M., & Hileman, J. L. (2010). *Life cycle greenhouse gas emissions from alternative jet fuels.* (Partnership for AiR Transportation Noise and Emissions Reduction Project 28 Report Version 1.2). Retrieved from: http://web.mit.edu/aeroastro/partner/reports/proj28/partner-proj28-2010-001.pdf U.S. Department of Agriculture, Economic Research Service. (2017). *Oil crops yearbook* [Database]. Retrieved from https://www.ers.usda.gov/data-products/oil-crops-yearbook/

U.S. Department of Transportation, Bureau of Transportation Statistics. (2017). *Air carrier financial reports (Form 41 financial data)* [Database]. Retrieved from https://www.transtats.bts.gov/Tables.asp?DB_ID=135&DB_Name=Air%20Carrier%20Financial%20Reports%20%28Form%2041%20Financial%20Data%29&DB_Short_Name=Air%20Carrier%20Financial

U.S. Environmental Protection Agency. (2010). *Regulation of fuels and fuel additives: Changes to renewable fuel standard program (p 14670-14904)*. Federal Register: EPA-HQ-OAR-2005-0161; FRL-9112-3. Retrieved from https://www.gpo.gov/fdsys/pkg/FR-2010-03-26/pdf/2010-3851.pdf

Winchester, N., McConnachie, D., Wollersheim, C., & Waitz, I. (2013). *Market cost of renewable jet fuel adoption in the United States* (Partnership for AiR Transportation Noise and Emissions Reduction Project 31 Report). Retrieved from http://web.mit.edu/aeroastro/partner/reports/proj31/proj31-jetfuel-market-costs.pdf

WSP, 3 Square Blocks, Argus, & PT&C. (2016). *Aviation biofuels infrastructure feasibility study.* Retrieved from https://www.portseattle.org/Environmental/Documents/Aviation_Biofuel_Infrastructure_Report_Condensed.pdf