Title: Drivers and Barriers to the Adoption and Diffusion of Sustainable Jet Fuel (SJF) in the U.S. Pacific Northwest

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Abstract

Sustainable Jet Fuel (SJF) represents an important component of the airline industry's strategy to simultaneously reduce GHG emissions while meeting a growing demand for international air travel. SJFs also have the potential to provide fuel supply diversification and security, enhance fuel price stability and provide regional/rural economic development benefits. This paper measures and ranks perceived drivers and barriers to an economically viable SJF industry in a unique U.S. region, the U.S. Pacific Northwest (PNW), through personal interviews with key aviation fuel supply chain stakeholders conducted from June to September 2015. In addition to providing a fertile arena for this first effort to systematically assess these drivers and barriers, the U.S. PNW is unique due to the region's long strategic focus on aviation innovation and its importance to the regional economy, the seminal efforts in the region to outline a path forward on SJF beginning in 2010, and the relatively small population spread over a large geographic area with a limited number of "hub" airport nodes which geographically concentrates aviation fuel demand and distribution. Nineteen stakeholder interviewees acknowledge that, in order for regional SJF adoption-diffusion to occur, airline jet fuel buyers must drive the process, particularly as they deal with greenhouse gas (GHG) emission issues and related policy considerations. Important perceived barriers to SJF industry scale-up in the U.S. PNW include the high production costs of SJF and related issues, such as fuel logistics and quality control in the transport, storage, and blending of SJFs. Perceptions around chain-of-custody issues, such as blending, tracking, and crediting of SJFs and future SJF market share projections for the year 2030 were also examined. Incorporating stakeholder input into discussions about adding blended SJF into the U.S. aviation fuel supply provides needed insight for the biofuels industry, policymakers, and researchers.

Keywords: Sustainable jet fuel (SJF); Drivers and barriers; Aviation fuel logistics; ASTM approved SJF production pathways; SJF blending, tracking and crediting; U.S. Pacific Northwest (PNW) region.

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1. Introduction

Volatile crude oil prices, political and public pressure on carbon emissions, more stringent environmental targets, a continued interest in fuel security, and a growing global demand for air travel have collectively driven research toward Sustainable Jet Fuels (SJFs) (Gegg et al. 2014). SJFs are hydrocarbon-based, “drop-in” fuels derived from non-petroleum sources (Ibarrola 2015). To be drop-in, SJF must be fully compatible with existing aircraft and fueling infrastructure, and meet the same safety and reliability standards as conventional petroleum-based jet fuel (Zuckerman et al. 2015).

SJFs can reduce aviation emissions, provide supply diversification and security, enhance price stability and provide regional/rural economic development benefits (Macfarlane et al. 2011; Wyman 2013; Miller et al. 2013; Maniatis et al. 2013). Hileman and Stratton (2014) add to these considerations the ameliorating effect of competition for energy sources due to unique aviation fuel requirements necessitating a safe, liquid, high energy density fuel to be carried aloft. To date, the aviation industry has progressed toward SJF goals in terms of research and development, certification of approved production pathways, flight demonstrations, off-take agreements, and global buy-in (CAAFI 2014). Remaining barriers include capital availability, supply chain development and cost competitiveness with petroleum-derived jet fuel (CAAFI 2014).

Several interdisciplinary research projects and public-private-partnerships are examining the viability of sustainable aviation biofuels with initial emphasis in the PNW states of Washington, Oregon, Idaho, and Montana. These groundbreaking efforts were initiated in 2010 through the Sustainable Aviation Fuels Northwest (SAFN) project, whose final report outlined specific actions that were needed to create a sustainable aviation biofuel industry in the region. This foundational effort has led to further activities in the region: two Coordinated Agriculture Projects funded by the U.S. Department of Agriculture (the Northwest Advanced Renewables Alliance [USDA-NARA] and the Advanced Hardwood Biofuels Northwest [USDA-AHB]); the establishment of the Federal Aviation Administration’s Aviation Sustainability Center (FAA-ASCENT), and the Washington Aviation Biofuels Working Group (Nararenewables.org; Macfarlane et al. 2011; Wyman 2013; FAA-ASCENT.aero). The geographic context, as well as the prominence of the aviation industry, and regional interest in SJFs as evidenced by numerous public-private partnerships to create a viable industry, makes the PNW region an interesting case to examine these important SJF issues.

This research effort represents USDA-NARA and FAA-ASCENT research collaborations undertaken to better understand regional stakeholder perceptions, utilizing semi-structured interviews with key aviation fuel supply chain stakeholders. This study provides a relative ranking of the drivers and barriers to a sustainable aviation biofuel industry in one geographic U.S. region, the Pacific Northwest, and examines key downstream SFJ fuel blending, tracking and crediting issues. This contextual analysis provides insights for the SJF enterprise to consider, as informing an action plan to ameliorate potential obstacles to scale up.

2. Background

Approximately 23 billion gallons of jet fuel were consumed by the combined jet-powered aviation enterprise of the U.S. (commercial, business, and military) in 2015 (CAAFI 2016). SJF is expected to be more easily diffused into the aviation sector, as opposed to the ground transportation sector, due to its drop-in nature and the concentrated and comparatively smaller scale of airport operations (ATAG 2012). In the U.S. alone, there are about 160,000 gas stations, whereas 381 U.S. airports handle approximately 99 percent of all commercial passengers (ATAG 2012; FAA 2015a). Worldwide, 190 airports handle over 80% of the world's aviation fuel (ATAG 2012).

Key players in this industry have adopted goals of moving to SJFs to assist the aviation enterprise in meeting its self-ascribed goals of achieving carbon neutral growth from 2020. For instance, the Federal Aviation Administration (FAA) has stated a near-term aspirational target of 1 billion gallons of SJF in use by 2018, based on an aggregate of renewable fuel targets for the US Air Force, the US Navy and US commercial aviation industry (GAO 2014; FAA 2015c). The Navy recently contracted with AltAir Fuels to supply 77 million gallons of cost-competitive, drop-in, non-food advanced biofuel blends from October 2015 to September 2016 (EESI 2016; Lane 2016). The target for the US Navy is for half of total energy consumption, currently about 3.5 million gallons per day, to be derived from alternative sources by 2020 (U.S. Navy 2016).

More than 20 airlines have flown over 1,700 SJF-blend commercial passenger demonstration flights between June 2011 and October 2014 using fuel derived from a variety of feedstocks in different aircraft and engine types (IATA 2015). Several airlines have also sought SJF supply chain agreements with fuel producers. For example, in 2013, United Airlines announced a purchase agreement with AltAir for HEFA fuel from the Paramount, California refinery. Also, FedEx Express and Southwest Airlines agreed to purchase the entire SJF output (6 million gallons) of Red Rock biorefinery from 2017 through 2024 (Lane 2015). Other airline efforts include developing direct cooperation either for technology breakthroughs or to set-up production supply chains (ICAO 2014).

In addition, a variety of multi-stakeholder joint initiatives have formed to promote the coordinated development and commercialization of SJF worldwide. In North America, the industry formed the Commercial Aviation Alternative Fuels Initiative (CAAFI) to pursue SJF. More regionally-focused efforts have also been executed in the U.S., including the Sustainable Aviation Fuels Northwest (SAFN) and Midwest Aviation Sustainable Biofuels Initiative (MASBI). The U.S. Department of Agriculture (USDA) has also initiated several regionally focused efforts through the National Institute of Food and Agriculture (NIFA) Agriculture and Food Research Initiative Coordinated Agricultural Projects (AFRI CAP) program.

2.1. Airline emissions

Aviation currently produces about 2 percent of the world's GHG emissions and is responsible for 12 percent of CO₂ emissions from all transport sources¹ (Zuckerman et

¹ For comparison, 74 percent of emissions emanate from road transport (ATAG 2015; IATA 2015).

al. 2015; ATAG 2015; IATA 2015; FAA 2015b; Nair and Paulose 2014). Due to a growing middle class in the world's developing economies, aviation is growing faster than other transportation modes with the number of passengers expected to grow from 3.1 billion in 2013 to approximately 7.3 billion a year by 2035 (ATAG 2015; Fahey and Mayerowitz 2015; Zuckerman et al. 2015). As a result, the aviation industry established aggressive carbon reduction targets in 2009 to reduce GHG emissions by 50 percent by 2050² (ATAG 2015; IATA 2015). Emission reduction targets may be achieved via operations, infrastructure and technology (including the use of SJF) (Zuckerman et al. 2015; ATAG 2015; Miller et al. 2013).

2.2. ASTM-Approved SJF pathways

Conventional jet fuel for commercial airlines, primarily Jet A in the U.S., is a blend of hydrocarbons produced from petroleum distillation and refinement (CAAFI 2016). In 2009, the American Society for Testing and Materials (ASTM) International approved the world's first semi-synthetic aviation fuel specification: the "Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons" [D7566]. "Drop-in" fuel specification D7566 was a significant milestone toward promoting the development of SJFs as it allows the use of these certified fuels in all existing engines and aircraft (Altman 2012). D7566 also allows oil companies, refiners and producers of aviation turbine fuel and new SJF producers to use the D7566 specification in their operations. Currently, four ASTM-approved production pathways for SJFs include (Table 1): Fischer-Tropsch (FT) (certified in 2009); Hydroprocessed Esters and Fatty Acids (HEFA) (2011); Synthetic Iso-paraffin from Fermented Hydroprocessed Sugar (SIP) (2014); and FT-SPK/A Fischer-Tropsch plus Aromatics (Fall 2015). In addition, Alcohol to Jet Synthetic Paraffinic Kerosene (ATJ-SPK) passed two levels of ASTM technical balloting and is currently in the final stages of review, with final publication expected by April 2016 (Lane 2016). Several additional SJF pathways are currently under ASTM review, including: Alcohol to Jet Synthetic Kerosene with Aromatics (ATJ-SKA); CH (lipids); Hydroprocessed Depolymerized Cellulosic Jet (HDCJ); and HEFA+ (wider-cut HEFA with RD) (CAAFI 2014; ICAO 2014; Miller et al. 2013; IATA 2015; Toop et al. 2015).

Table 1. Sustainable Jet Fuel (SJF) Production Pathways and ASTM Approval Details (Source: Toop et al. 2015; CAAFI 2016; Lane 2016).

SJF Production Pathway	ASTM Approved Blend
Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK)	Maximum blend of 50% with conventional jet fuel as of 2009
Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK)	Maximum blend of 50% with conventional jet fuel as of 2011
Hydroprocessed Fermented Sugar-Synthetic Isoparaffins (HFS-SIP)	Maximum blend of 10% with conventional jet fuel as of June 2014

² Reduction targets used a 2005 level baseline with zero net carbon emissions growth beyond 2020 (ATAG 2015; IATA 2015).

Fischer-Tropsch Synthetic Paraffinic Kerosene plus Aromatics (FT-SPK/A)	Maximum blend of 50% with conventional jet fuel as of Fall 2015
Alcohol to Jet Synthetic Paraffinic Kerosene (ATJ-SPK)	Maximum blend of 30% with conventional jet fuel. Final balloting expected to be completed by April 2016.

2.3. Issues impacting SJF adoption and diffusion

2.3.1. Drivers and barriers

Clearly, SJFs are gaining momentum in the United States and internationally, and much research has addressed key drivers and barriers to the increased production and use of biofuels (Adams et al. 2011; Cherubini 2010; Golden & Handfield 2014; Su et al. 2015). However, only two studies were found (Adams et al. 2011; Gegg et al. 2014) which quantified a relative ranking of these factors. And little research has examined SJF production from a regional perspective, particularly in terms of stakeholder perceptions and concerns.

Adams et al. (2011) examined developers/owners of bioenergy projects in the United Kingdom and Gegg et al. (2014) interviewed leading global aviation stakeholders from airframe manufacturers, airlines, environmental consultants and (bio)fuel companies. In the latter study, carbon reduction was found to be the single most mentioned driver of SJFs with energy security, volatile oil prices, legislation, lack of alternative technology and new business opportunities also driving SJFs (Gegg et al. 2014). Gegg et al. (2014) also identified high production costs as the most mentioned constraint to SJFs, with lack of investment, sustainable feedstock supply, inadequate legislation, strict environmental controls for SJFs and lack of supply chain certification as additional barriers.

In contrast, this regional study provides an *airport-focused ranking* of the drivers, barriers and key factors impacting the adoption and diffusion of SJF by airport management and fuel purchasing/handling³ stakeholders located at or in near proximity to large, small and non-hub airports in the U.S. Pacific Northwest. One rationale for this approach is to better identify potential insertion points and key logistical issues related to initial use of blended SFJ in regional aviation.

2.3.2. Accounting, tracking and blending

To be certified, SJF must be equivalent to petro-jet in terms of freeze point, flash point, heating value, density, wear on fuel systems and electrical conductivity (Miller et al. 2013; Miller et al. 2011). Aviation fuel distribution, blending and logistics costs, although secondary elements to the cost of production, will be factors influencing the economic feasibility of SJF uptake (Macfarlane et al. 2011). Due to a lack of commercial production, current SJF is typically produced and delivered in specified batches. Future scale-up of commercial volumes of “drop-in” SJFs, however, will be fully integrated into conventional jet fuel storage and distribution systems.

³ Fuel Purchasing/Handling participants included airlines, fixed-based operators (FBOs), pipeline and terminal operators, and aviation fuel resellers. This grouping is designed to maintain participant anonymity.

One of the principle challenges for airlines, verifiers and regulators is the uncertainty surrounding SJF fuel purchases and the integration of SJFs into the aviation fuel supply chain. An agreed-upon system to track fuel for technical, regulatory, and commercial reasons may be warranted, beginning with a logical point of origin or control point, where ASTM D7566 (SJF) is blended with ASTM D1655 (petro-Jet A) and reclassified as a renewable D1655 blend (IATA 2015; Miller et al. 2011; Toop et al. 2015). Beyond this point, it is assumed that blended SJF will be used in the commercial aviation sector. An international Market Based Mechanism (MBM) for aviation GHG emissions is currently under discussion by the Global Market-based Measure Task Force (GMTF) of the International Civil Aviation Organization (ICAO) to investigate approaches for offsetting emissions of international aviation, with a goal of implementation by 2020 (IATA 2015).

The aforementioned concepts, while adequately addressing the technical needs of the aviation community, may cause confusion to those who are not immersed in the process. Jet A fuel supply chain stakeholders may not necessarily be cognizant of the various approaches being pursued to diffuse SJF blends into the aviation fuel system, and many questions will no doubt remain. As a result, this study was conceived to address this potential uncertainty and to better understand the perceived barriers to the addition of SJF blends into the jet fuel supply chain at commercial airports in the U.S. PNW region.

2.3.3. Rationale for a regional perspective

The issues surrounding SJF development, adoption, and diffusion are well-documented and, while several studies have examined these issues, very few provide a regional perspective to better address logical biorefinery siting and potential insertion points for blended SJF. With growing regional partnerships between industry, government, and academia attempting to “stand up” sustainable SJF supply chains and regional analysis of these factors allows for more nuanced understanding of key issues, both across regions and those that are region-specific.

The U.S. Pacific Northwest (PNW) region provides an interesting and useful geographic perspective within which to initially examine these transformative SJF issues facing U.S. aviation due to three main factors. First, primarily through the Boeing Company, the PNW is a global center of aviation innovation; a key economic engine for the region. Boeing’s strong support of biofuels and, in particular, the SJF approval process, is helping align supply with existing demand (Morgan 2016). Second, the sparsely-populated 4-state PNW region contains 10.5 percent of the U.S. area, but only 4.3 percent of the U.S. population (Anon. 2012; Anon. 2010). Within this region, SEA (Seattle-Tacoma International Airport) represents approximately half and PDX (Portland International Airport) consumes about 16 percent of the entire region’s aviation fuel demand, thus reflecting the population dispersion of the PNW region (Figure 1) (Mcfarlane et al. 2011). Accordingly, the limited number of FAA designated “hub”

airports⁴ in the region focuses aviation fuel distribution on fixed airport nodes rather than on airlines, fuel suppliers, and other storage and distribution network locations, thus presenting what may be a unique set of logistics issues, and also easing the challenge of stakeholder selection and interview administration.

2.4. Aviation fuel demand in the U.S. Pacific Northwest (PNW) region

Jet fuel represented approximately 8 percent (23 billion gallons) of all U.S. petroleum consumption in 2014 (EIA 2015) (Fig. 1). That year, the 4-state U.S. Pacific Northwest Region consumed about 1 billion gallons or about 4% of the nation's jet fuel (EIA 2014; EIA 2015). In this respect, the Pacific Northwest region provides perhaps the clearest example of market concentration.

Figure 1. U.S. Petroleum and Jet Fuel Consumption and U.S. Pacific Northwest Share of U.S. Jet Fuel (source: EIA 2014; EIA 2015).

In terms of commercial aviation demand, the two largest airports, Seattle-Tacoma International Airport (SEA) and Portland International Airport (PDX), represent the majority of commercial fuel usage, consuming 50 and 16 percent, respectively, of the PNW region's 970 million gallons of jet fuel in 2014 with the state of Washington accounting for nearly 73 percent of the region's jet fuel, followed by Oregon (20%), Montana (4%) and Idaho (3%) (EIA 2014). Approximately 14 percent of the region's aviation fuel is consumed by the military with the balance (86%) consumed by commercial aviation (Macfarlane et al. 2011).

⁴ Two large hub, zero medium hub and six small hub airports are located in the states of WA, OR, ID and MT. These "hub" airports represented approximately 97 percent of all U.S. enplanements in 2012 (FAA 2014).

3. Research Objectives

This study examines the perceived drivers, barriers and key issues impacting the adoption and diffusion of blended SJF into the aviation fuel supply chain in the U.S. Pacific Northwest (PNW) region through personal interviews with key stakeholders.

4. Research Design

4.1. Study population development

A 2015 FAA database includes 506 U.S. airports certified under Part 139 (FAA “Commercial Service by Aircraft with 9 or More Seats”). According to FAA (2015), U.S. primary⁵ airports are categorized in terms of their annual passenger boardings, with Large-Hubs having >1%, Medium-Hubs have 0.25-1.0%, Small-Hubs have 0.05%~0.25%, and Non-Hub are <0.05% of U.S. annual passenger boardings. In 2014, 395 primary airports enplaned 99.9 percent of all U.S. passengers, of which 30 were categorized as Large-Hub, 33 Medium-Hub, 71 Small-Hub, and 261 Primary Non-Hub airports (FAA 2015) (Table 2). That year, the 4-state U.S. PNW region contained 30 primary airports, of which 2 were Large-Hub, 6 Small-Hub, and 22 Primary Non-Hub airports (FAA 2015) (Table 2). This study’s participants included six from the two Large-Hubs, 3 from the 6 Small-Hubs and 3 from the 22 Non-Hub airports in the U.S. PNW Region – plus three fuel purchasing/handling participants who operate at multiple airport sites (Table 2). Overall, the 8 airports included in this study represented approximately 93 percent of the 4-state PNW regional enplanements in 2014 (FAA 2015).

Table 2. National Plan of Integrated Airport Systems (NPIAS) Certified Primary Airports in the U.S. and PNW Region (source: FAA 2015).

Airport Category	Total # of U.S. Certified Airports	Certified Airports in the PNW Region	Enplanement (2014) and % of PNW total	PNW Airports (& Participants)
Primary Large-Hub	30	2	25,766,840 (89%)	2 (n=6)
Primary Medium-Hub	33	0	---	0
Primary Small-Hub	71	6	2,368,453 (8%)	3 (n=5)
Primary Non-Hub	261	22	665,334 (2%)	3 (n=5)
All FAA Certified Primary Airports	395	30		8 (n=16*)

*In addition, three “Fuel Purchasing/Handling” participants conducted business at a variety of hub and non-hub airports, resulting in 19 total participants.

⁵ The Primary airport discussed in this paper is classified as an airport with commercial service that has more than 10,000 passenger boardings each year (FAA 2015).

4.2. Research design – in-person interviews

A criterion-based stratified purposeful sampling scheme was developed to ensure representation using airport size and geography in the PNW region as the salient criteria for selection (Creswell 2007). From this design, 19 semi-structured interviews with key regional aviation fuel supply chain stakeholders in the U.S. PNW region were conducted between June and September 2015 (Table 3). Participants included airport management, airlines, Fixed-Based Operators (FBOs), pipeline and terminal operators, and aviation fuel resellers. To maintain participant anonymity, participants are categorized as either “Group A - Airport Management” (n=8); or “Group B - Fuel Purchasing/Handling” (n=11) (Table 3). Initial contact was made via email with an attached request letter and interview script outline, followed by phone calls to schedule the interviews. Figure 2 illustrates the distribution of airports in the U.S. PNW region by airport size category.

Table 3. Interview Participants by type of airport and their group affiliation (n=19).

Respondent Type	Group
1. Large Hub	A - Airport Mgmt.
2. Large Hub	A - Airport Mgmt.
3. Large Hub	A - Airport Mgmt.
4. Small Hub	A - Airport Mgmt.
5. Small Hub	A - Airport Mgmt.
6. Small Hub	A - Airport Mgmt.
7. Non Hub	A - Airport Mgmt.
8. Non Hub	A - Airport Mgmt.
9. Small Hub	B – Fuel Purchasing/Handling
10. Small Hub	B – Fuel Purchasing/Handling
11. Non Hub	B – Fuel Purchasing/Handling
12. Non Hub	B – Fuel Purchasing/Handling
13. Non Hub	B – Fuel Purchasing/Handling
14. Large Hub	B – Fuel Purchasing/Handling
15. Hub & Non Hub	B – Fuel Purchasing/Handling
16. Large Hub	B – Fuel Purchasing/Handling
17. Large Hub	B – Fuel Purchasing/Handling
18. Hub & Non Hub	B – Fuel Purchasing/Handling
19. Hub & Non Hub	B – Fuel Purchasing/Handling

Interviews consisted of open-ended questions addressing the following topics: aviation fuel distribution, barriers and drivers to an economically viable Sustainable Jet Fuel (SJF) production industry in the U.S. PNW region, views on SJF molecule blending/tracking/crediting and projections for SJF adoption-diffusion by 2030. The interviews were transcribed and participants were provided draft copies of the interview transcriptions for their review and edit.

* Plus 3 fuel purchasing/handling participants operated at multiple airport sites.

Figure 2. Distribution of airports by size category in the PNW region (n=30) and by size category of participating airports (n=16*).

4.3. Population and respondent detail

Airports in the U.S. PNW region receive their jet fuel by pipeline, barge and/or truck. The following analysis considers airport categories according to the volume of aviation fuel consumed for those who participated in the interviews.

4.3.1. Large-Hub participants

The two Large Hub airports in the PNW region consumed approximately two-thirds of all aviation fuel in the 4-state PNW region in 2014 (EIA 2014). Both Large Hub airports use aviation fuel purchasing consortiums to acquire aviation fuel. Fuel costs constitute up to 30 percent of airline operating expenses, thus making efficient fuel logistics an aviation priority (Sturtz and Smith 2010). Consortia provide synergistic opportunities for airlines and airport management to coordinate fuel management activities. Therefore, these aviation fuel purchasing consortiums offer the most likely pathway for SJF insertion into the existing delivery framework, given the consolidated purchasing, handling and distribution logistics represented. This concentration may set the Pacific Northwest apart from the rest of the country, and also provides a very fertile arena in which to conduct a preliminary assessment of drivers and barriers for adoption.

Due to the importance of the Large-Hub airports to the U.S. PNW region, 6 of our 19 study participants were based in Large-Hub airports in this region. One of these large hubs receives its aviation fuel via a pipeline from 3 nearby refineries. From the airports' fuel storage site, aviation fuel is then transported to the wing via an underground hydrant system or by truck. The other large hub obtains approximately half of its

aviation fuel via pipeline and the other half by barge; both methods deliver fuel to a terminal, where all fuel is then transported to on-site airport storage tanks via a dedicated pipeline and then moved to wing via a hydrant system and truck.

4.3.2. Small-Hub participants

The state of Washington has two Small-Hubs, Oregon and Idaho have one Small-Hub each and Montana has two Small-Hub airports. Our interviews included 5 airport managers and fuel purchasers/handlers from 3 of these 6 Small-Hub airports.

4.3.3. Non-Hubs and multiple hub participants

Our interviews also included 5 airport management and fuel purchasing/handling participants from 3 of the 22 Non-Hub airports in the PNW Region. In addition, three Group B (fuel purchasing/handling) participants, who operate at both Hub and Non-Hub airports in the PNW region, were interviewed.

5. Research Findings

Qualitative interviews provided in-depth information regarding key issues regarding the adoption and diffusion of SJF in the U.S. Pacific Northwest region. To address each of these important issues more in depth, the findings are organized as follows: SJF drivers and barriers, chain of custody issues, and future market share projections. The interviews illustrate that many of these issues are inherently complex and interdependent; however, they also highlight key factors propelling and constraining SJF adoption in the region. The following analysis combines small and large hub responses to maintain participant confidentiality.

5.1. Drivers

The three most important drivers for the adoption and diffusion of SJF's identified by participants included airlines, emissions, and government policy (Figure 3). Other drivers identified included public relations, energy security and economic development. While many of these drivers are supported by other research, such as government policy, emissions, and economic development (Gegg et al. 2011), the role of airlines in this process has received less focus.

5.1.1. Airline-driven

Over half of the 19 participants (53%) stated that the development of a regional SJF industry will be driven by the major airlines (Figure 3). Many simply stated that airline buyers are the dominant SJF driver. Illustrating the interdependence of individual factors, this perspective was often related to GHG emissions and government policy with airlines as the arbiter of these larger issues. Interestingly, Gegg et al. (2014) found carbon reduction to be the most mentioned driver by his global-picture stakeholders as contrasted by the regional view taken by our study's stakeholders. In addition, airlines have – through the potential use of long-term contracts – the most immediate ability to contribute to long-term market stability and predictability.

“We’re just the middleman; It’s really up to the buyers (airlines)” (Group B – Small/Large-Hub)

“Biojet fuel [SJF] development will be airline driven as they drive the investment decisions” (Group A – Small/Large-Hub)

“In terms of biofuel into the aircraft, we really look at it as an airline prerogative. If the airlines are interested in it [SJF], of course we will be interested in it, as we work with them on a regular basis” (Group A - Non-Hub)

“This [interest in SJF] is all coming from big commercial airlines – as a marketing tool to promote their environmental record.” (Group B – Small/Large-Hub)

Clearly, most stakeholders envision the airlines to be the critical demand driver for SJF. Most stakeholders participating in the interviews believe that the SJF industry in the PNW region will only succeed if the airline buyers are an active participant. Indeed, many respondents stated that airlines are leading this process. It is easy for researchers and policymakers to focus on technical and logistical impediments to biofuel commercialization; however, this key finding underscores the fundamental challenge of airline buyer commitment to the ultimate success of an economically viable SJF industry. It also makes more visible the strong role which airlines may have in the adoption of SJF, not only in the PNW, but in other U.S. regions.

5.1.2. Emissions

Environmental benefits related to emissions were identified as a key driver of SJF industry development by seven of the nineteen (37%) participants whereas Gegg et al. (2014) found all twenty-five of their study’s participants mentioning this driver. One participant indicated that public and political pressure on environmental issues in the PNW region is a generational phenomenon. Most participants agree that the PNW region is more environmentally aware and sensitive than other U.S. regions.

“Sustainability/green issues are a key driver [of SJF]. [And] air quality is an important health issue.” (Group A – Small/Large-Hub)

“The #1 driver (SJF industry) is climate change as it relates to emission reductions.” (Group B – Small/Large-Hub)

Emissions were acknowledged as a major driver in the PNW region; however, not all respondents felt that SJFs were the best way to address these concerns. One FBO participant suggested that manufacturing more fuel efficient aircraft is a better solution than adding aviation biofuel blends. This finding, interestingly, supports the important role of airlines as SJF drivers in this region.

“[Airlines] can deal with emissions issues by updating their old fleet; by getting fuel efficient airplanes into the market.” (Group B – Small/Large-Hub)

Despite some suggestions more efficient methods for reducing carbon emissions exist, emissions are clearly a prominent driver of SJFs in the PNW as evidenced by the various stakeholders in multiple sectors of the aviation industry that identified it as such. Additionally, many stakeholders stated that the PNW is more concerned with these issues in comparison to other U.S. regions, which further enhances the importance of this regional perspective.

Figure 3. Participants' (n=19) views regarding the drivers to SJF development in the U.S. PNW region [NOTE: Overall, this study's 19 interviewees provided 31 responses to this "drivers" question].

5.1.3. Government policy

In terms of policy, participants suggested that policy stability was critical to attract long-term investment. Also, the importance of a clear regulatory path for SJF was mentioned.

"A regulatory path for SJF exists through FAA and the processing technology is available, but the focus must include capital for scale-up. Basically, we support a stable business and policy environment." (Group A – Small/Large-Hub)

"Government leadership is needed to encourage and incubate a public-private partnership toward this goal [SJF industry development]." (Group A – Small/Large-Hub)

Government policy was mentioned by 5 participants as a key driver in the PNW. Specific legislation supporting this process was not discussed, rather participants focused on the role of a stable policy environment, particularly in terms of supporting public-private collaborations, and creating an investment-friendly environment. Some participants linked the role of government policy directly to economic concerns and

costs, suggesting that government policy is necessary to ensure capital to support industry scale-up.

5.1.4. Additional drivers

While airlines, emissions, and government policy were the primary drivers identified, respondents mentioned several other drivers impacting development in the region. These drivers include energy security, public perception, and economic development. Three participants mentioned or suggested that energy security is an important concern.

“... peak fuel prices were a (SJF industry) driver to expand a secure supply of fuel, particularly when oil supplies are volatile.” (Group B - Hub & Non-Hub)

“Down the road, when there is an oil shortage, we don’t want to be left without alternatives. We need to plan ahead, but at what scale; at what level? We should have these programs for planning and development to stay ahead of the power curve, but we don’t have to do it all now.” (Group B - Non-Hub)

Concerns over energy security were often linked to supply and cost of oil, and SJFs were viewed as one method for decreasing dependence. Additionally, 4 respondents mentioned that public perception is also a driver of these activities, and that public demand is really driving this process. Lastly, 2 respondents stated that economic development was a driver of SJFs in the region, but that economic development was a much less prominent driver.

“Societal perspectives and customer demand [are key SJF industry drivers].” (Group B - Hub & N-Hub)

“Job creators, brand managers, and economic development folks would support a regional SJF industry.” (Group A – Small/Large Hub)

Clearly there are many drivers of SJF in the PNW and nationally, including emissions, policy, public perceptions, and economic issues. However, the principle driver in the U.S. PNW region is the long-term commitment of the commercial airline industry.

5.2. Barriers

Participants identified several barriers to the adoption and diffusion of SJF in the PNW. The most prominent barriers included: cost of biofuels, logistics/quality control, safety, and policy stability (Figure 4).

5.2.1. High cost of biofuels

Consistent with other research, cost was the most frequently mentioned barrier to the commercialization of a regional SJF production industry and these costs were closely linked to the subsequent issue of logistics and quality control. Nearly half of the participants stated that the price of SJF, given the current SJF production pathways and low petroleum oil prices, is not competitive and that the cost of SJF production and

logistics is limiting market entry and scale up (Figure 4). This finding appears to be universal as the global perspective by Gegg et al. (2014) found that high costs of SJF was mentioned as a constraint by all twenty five of his study's participants.

“The biggest impediment [to SJF production] would be price ‘parity’ with petro-jet fuel in terms of production, supply chain, storage, compatibility to the engines, plus any potential credits.” (Group B – Small/Large-Hub)

The quote above is an example of the concern regarding costs associated with industry scale-up which is a considerable barrier to SJF. Just over forty-seven percent of respondents mentioned the high cost of fuels, specifically referencing parity with petro-jet, costs associated with shipping, and other production issues. It also supports the role of airlines as a driver, particularly in terms of engine compatibility and the price of fuel.

5.2.2. Logistic and quality control (Not proven) technical and infrastructure issues

Logistic and quality control issues related to infrastructure interface were an important perceived barrier to the regional scale up of the SJF industry according to over 40 percent of participants (Figure 4). However, the cost associated with these technical issues was implied in the previous “high cost of biofuels” category. Logistical issues related to infrastructure interface were shared across fuel purchasing/handling participants who suggest that new rules are required to address transporting SJF.

“Rules must address pipeline interface issues to transport SJF in pipelines. For example, the interface may include up to 500 barrels which must be cleaned (filtered). And, at the terminal or fuel farm, plumbing, filtering, and blending will require capital for dedicated (neat or blended) SJF storage.” (Group B – Small/Large-Hub)

“With a few exceptions, fuel handlers do not have an aviation fuel mindset and proper SJF logistics from refinery-to-wing, including blending with conventional Jet A, requires expertise & experience.” (Group B - Hub & N-Hub)

“The most important barriers include certification, testing, and validation (quality assurance) of SJF. It must be 100% effective 100% of the time. The existing petro-focused safety, quality assurance, and distribution issues must be met by SJF.” (Group B - Hub & N-Hub)

“A [SJF] study should be conducted to examine pipeline flow, residues and stickiness left in the pipelines, filtration requirements (from SJF in the pipelines) and other potential SJF contaminants.” (Group B – Small/Large-Hub)

Participants are clearly concerned with SJF quality control issues, particularly in terms of infrastructure. And, the interdependence of cost and logistics was also an important concern voiced primarily by our fuel purchasing/handling stakeholders. Participant concerns over SJF certification, integration and infrastructure represented factors that

received must less focus in Gegg et al. (2011) whose study only found one stakeholder expressing this concern.

5.2.3. Safety (Not proven)

Safety is a primary issue in aviation, and nearly one-third of participants expressed concerns regarding SJF safety (Figure 4). One airport operator stated that:

“SJF has some reliability issues, particularly under extreme conditions, that I don’t think have been worked out. Safety is paramount and you cannot tolerate an “engine putter”, risking a stall at 45,000 feet and 10 degrees below zero.” (Group B – Small/Large-Hub)

Aviation fuel supply chain stakeholders in the PNW are clearly concerned about SJF safety, with many participants expressing that the safety of these fuels has not been proven. This finding suggests that perceptions regarding safety warrants further attention, and continues to serve as a potential barrier to SJF market development.

5.2.4. Lack of stable policy

Supporting the importance of government policy as a driver of SJF, lack of stable policy was also identified as a barrier in the PNW. Five respondents also mentioned this issue as a regional SJF production industry barrier (Figure 4). One respondent stated:

“There is not policy stability or harmony for SJF. In contrast, on-road fuels have better incentives for renewable fuel than jet fuel.” (Group A – Small/Large-Hub)

Figure 4. Participants’ (n=19) views regarding the barriers to SJF development in the U.S. PNW region [NOTE: Overall, this study’s 19 interviewees provided 41 responses to this “barriers” question].

5.2.5. Biorefinery siting (environmental) issues

Environmental issues related to siting a regional SJF production industry were seen as an important barrier according to five participants (Figure 4). Environmental Non-Governmental Organizations (ENGOS) and/or local community opposition or support may also impact biorefinery siting decisions.

“Siting refineries is a contentious issue with environmentalists, particularly for new greenfield sites. Brownfield siting or co-siting with existing manufacturing may be the answer.” (Group B - Hub & Non-Hub)

“Not-In-My-Back-Yard (NIMBY-ism) is a key factor. Most like the idea of SJF, but are not interested in a refinery in their back yard due to transportation impacts and feedstock “attractiveness” (food vs fuel). Some ENGOS may oppose or support SJFs, depending on the conversion process and other externalities.” (Group A – Small/Large-Hub)

5.2.6. Additional Barriers

Participants identified a number of barriers to SJF adoption and diffusion in the region. While costs, logistics and safety received the most attention, additional barriers mentioned included capital availability, biofuel availability and forest regulation. Three respondents indicated that capital availability is needed for scale-up of production, and to attract investment. One participant identified “no available supply” as the number one barrier (Group B – Hub & Non-H). Lastly, a concern perhaps more specific to the U.S. PNW region is forest regulation. Two respondents mentioned forest regulation, one focused on unused biomass and concerns regarding forest fires, stating:

“SJF is a great use of [forest] biomass. We have so much biomass out there, but we’re not managing our own forests. And we are going to continually have [forest] fires unless something happens to that biomass.” (Group A - Non-Hub)

Another stakeholder pointed to political issues regarding feed stock from U.S. Forest Service land, stating:

“In terms of forest residues as a feedstock, using U.S. Forest Service [Federal] land will make it [SJF production] politically difficult. Mixed land ownership feedstock is probably a better option.” (Group B - Hub & Non-Hub)

In essence, the factors representing SJF barriers can be summed up as economic, social, and safety issues. The dominant concern expressed by stakeholder participants was the relatively high costs of SJF vis-à-vis petro-jet fuel associated with logistics, policy, capital availability, and SJF availability. These economic factors inter-relate to, and may be either positively or negatively influenced by, social concerns. Social

concerns relate to policy, biorefinery siting, and feedstock availability (forest regulation). Safety is also a paramount concern for any innovation in this industry context.

These findings suggest the multifaceted nature of these potential barriers and provide insights into areas for further study. For example, research into the technical infrastructure issues related to the transporting and storage of SJF in traditional petro-jet supply chains may be warranted. Further, the inclusion of social assets in greenfield versus brownfield biorefinery siting appears to be relevant and needed. Finally, this research underscores a need for favorable and stable policy incentives to support a long-term SJF industry in the PNW region.

5.3. SJF Chain-of-custody issues: blending, tracking and crediting

In addition to drivers and barriers for SJF adoption and diffusion, participants were asked their opinions regarding blending, tracking and crediting of SJF. As mentioned, full-scale SJF production presents numerous logistical issues that impact aviation stakeholders. Therefore, stakeholder perceptions of these logistical issues are important to understanding SJF adoption and diffusion.

5.3.1. Blending

Participants' opinions regarding the most logical location to blend SJF with conventional jet fuel for their respective locations varied (Figure 5). Terminals and the petro-refinery were the two most-mentioned SJF blending locations by participants (Figure 5). Three participants mentioned "upstream from the airport", which would include terminals and petro-refineries, two participants mentioned the airport fuel farm, and two participants indicated no opinion.

Figure 5. Participants' (n=19) views regarding the best SJF blending location.

“It would be very difficult to blend at the airport due to liability and storage economics.” (Group B - Non-Hub)

“My guess is the regional fuel terminal. At the airport, all blending issues are opaque.” (Group A – Small/Large-Hub)

“The best solution is to bring SJF into the terminal at 100% neat SJF.” (Group B – Small/Large-Hub)

Blending considerations varied by size of airport which relates directly to the relative location of fuel terminal/fuel farm infrastructure and access to pipeline/barge transportation.

5.3.2. Tracking

Nearly two-thirds (63%) of the participants acknowledged that it is important to track the SJF molecules (Figure 6). Reasons for tracking varied, including that tracking is important for efficiency, credits, and public perception and recognition.

“I think whomever buys the molecule will drive the tracking mechanism to derive value, both the monetary credits and the public perception.” (Group A – Small/Large-Hub)

“Tracking is valuable just from the efficiency stand point to understand what you make actually works.” (Group A - N-Hub)

However, not all respondents agreed that tracking is necessary or important. This is illustrated by quotes from two respondents below.

“It’s probably not important to track biojet since we deliver the product separately, but the customers are distinct; we deliver one product per customer type.” (Group B – Small/Large-Hub)

“I don’t think there should be any different tracking for biojet vs. our current handling of petro-jet. I don’t see a need to track it.” (Group A - N-Hub)

These findings provide useful insights into this important issue and show the division between participants. Generally, interviewees who supported SJF agreed that tracking was relevant and necessary. Less supportive participants thought that tracking SJF was unnecessary. Clearly, SJF molecule tracking is an important issue worth pursuing at an educational level whereby many aviation fuel stakeholders appear uncertain regarding the ramifications of adding blended biofuel into their aviation fuel operations.

Figure 6. Participants' (n=19) views regarding the tracking of SJF molecules.

5.3.3. Crediting

Sixty-three percent of participants indicated that SJF purchases should have a mechanism for crediting (Figure 7). Some participants stated that this will be particularly important for airlines, another finding that supports airlines as a major driver of SJF in the region.

“For airlines, it (crediting) is especially important. Saving money on fuel is one of the top initiatives for any airlines because that’s their major cost.” (Group A - N-Hub)

“It is important to credit SJF purchases; however, this gives a lot of power to some group – with the potential for abuse.” (Group B – Small/Large-Hub)

Figure 7. Participants' (n=19) views regarding the crediting of SJF purchases.

Similar to SJF molecule tracking, the SJF crediting issue was divided between those participants who generally favored and opposed the concept of SJFs. Those opposed

to SJF crediting worried about the potential for abuse. Researchers and policymakers may consider these findings if and when a SJF crediting system is considered.

5.4. SJF projections

Lastly, participants were asked to estimate what the U.S. market share for SJF would be by 2030. SJF market share guesses ranged from less than 0.5% to 20-30% of the total U.S. aviation fuel supply. In general, participants were reluctant to share their projections, with only 8 of the 19 stakeholders providing predictions with 4 stating 2% or less; 2 said 5-10%; and 2 stating 20-30%. One fuel purchaser/handler stated that the share would be higher for the large international airports vs. small regional airports.

Specific comments on this topic included:

“[US SJF market share in 2030 would be] less than 1%. I am skeptical that it would be over 5% due to cost of production and logistics which are still limiting market entry and production scale-up.” (Group B - Hub & Non-Hub)

“The trend toward more stringent environmental regulation will support development of this industry.” (Group A – Small/Large-Hub)

“5-10% would be a reasonable goal; might be positively influenced by cap-and-trade.” (Group A – Small/Large-Hub)

Additionally, participants were asked how the Pacific Northwest SJF market share would compare to the U.S. Nearly half (n=9) of participants stated that the 2030 SJF market share in the PNW region would be higher vs. the national average in 2030 with 2 participants saying it would be the same 8 having no opinion and, most importantly, zero stating that the PNW region would be lower vs. the national average in 2030 (Figure 8).

“The SJF market share would be higher in the PNW region as SJF has a good foundation here with fewer folks in the network, good stakeholder alignment, better relationships and the strong SAFN effort.” (Group A – Small/Large-Hub)

“Because of the progressive nature of the PNW, I would think the percentage would be a little higher here vs. other [U.S.] regions.” (Group B – Small/Large-Hub)

“It will probably be the same. Although the PNW region is more environmentally sensitive than other regions, it does not mean that there will be more companies in the region to produce biojet fuel at the level that could really meet the commercial aviation needs.” (Group A - Non-Hub)

These findings illustrate that the PNW is an interesting region to examine in terms of SJF market development given that half the aviation stakeholders estimated that PNW SJF market share would be higher than the U.S. Respondents specifically referenced

the good foundations in the PNW for such an industry, and the progressive nature of the region. While not all respondents agreed that it would be higher, no respondent stated that the PNW SJF market share would be lower than the national U.S. average in 2030.

Figure 8. The estimated SJF market share in 2030 by participants (n=19).

6. Discussion

Most biofuel research focuses on feedstock supply chain and production-technology biorefining issues. One particularly relevant study of twenty five leading global aviation stakeholders based in Europe and North America examined SJF drivers and constraints by airframe manufacturers, airlines, environmental consultants and biofuel companies (Gegg et al. 2014). This paper provides a regional *airport hub focused* examination of downstream stakeholders for one potential biorefinery value chain output – Sustainable Jet Fuel (SJF). Airport managers and aviation fuel purchasing/handling stakeholders in the U.S. Pacific Northwest region were interviewed in the summer and fall of 2015 to better understand perceived drivers, barriers and key issues impacting the adoption and diffusion of blended SJF into the regional aviation fuel supply chain. The U.S. PNW region provides a useful first look into these issues due to the economic importance of aviation the innovative work to articulate a vision for SJF in the region, and is focused by the limited number of hub airports that concentrates aviation fuel distribution.

Overall, participants generally agreed that the airline fuel buyer is the key driver for regional SJF demand. Secondary drivers include GHG emissions, policy, public perceptions, and economic considerations; however, airline buyer commitment will drive the adoption and diffusion of blended SJF into the aviation fuel supply. Additional identified drivers include the benefits associated with public relations, economic development, and energy security. While many of these drivers are supported by the literature, particularly GHG emissions and policy (Gegg et al. 2014), this U.S. PNW research illustrates that airlines are the predominant driver of SJF in this region, a factor

that has received less focus, and suggests a need for examination in other U.S. regions and beyond.

Similar to other research examining SJF adoption and diffusion, the most mentioned barrier to SJF production and use in the PNW was the high cost (price) of SJF vs. petro-jet, especially in terms of aviation fuel logistics and quality control issues in the transport, storage, and blending of SJF. Relevant logistical concerns include pipeline interface issues when considering pipeline transport of SJFs and plumbing, filtering and blending considerations at the fuel farm or terminal.

Policy, capital availability, and SJF availability are additional barriers related to the high cost of SJF, which may be re-cast as drivers or at least offsets to cost, if developed appropriately. Secondary barriers include biofuel safety (SJF is not yet proven) and social issues related to policy, biorefinery siting, and feedstock availability (forest regulation). Interestingly, many stakeholders expressed concerns over safety, a barrier that is not emphasized in the literature suggesting a need for further examination, particularly in other regions.

Chain-of-custody issues were also examined in terms of the blending, tracking and crediting of SJF's as they are inserted into the existing Jet A fuel supply chain. Approximately two-thirds of interview participants thought that SJF molecules may require tracking and SJF purchases should be credited (to the buyer). These same participants had a generally positive disposition toward SJF. This work may provide an impetus for further introspection by the aviation industry regarding these and other related issues and illustrates an education opportunity to better clarify how blended SJF may be seamlessly inserted into the aviation fuel supply chain.

In general, the region's Large Hub airports appear to be more attuned to all aspects of SJF production, policy, and logistics. We expect this is due to their size and/or their proximity to a more progressive west-coast population. Large Hub airports typically have more management resources allocated to special topic issues and the volume of fuel use allows for more options in fuel logistics. Finally, the region's large hub airports utilize aviation fuel purchasing consortiums which may offer the most seamless pathway for SJF insertion into the existing delivery framework through consolidated purchasing, handling and distribution logistics.

Regarding the viability of an SJF production industry in the U.S. PNW region, participants' market share projections ranged from less than 0.5% to 20-30% of the total aviation fuel supply by the year 2030 with half indicating that the 2030 SJF market share in the PNW would be higher than the national average. Compared to the overall U.S., participants indicated that PNW regional advantages for early SJF adoption include a strong foundation, simple networks, and good stakeholder alignment due to the earlier efforts of Sustainable Aviation Fuels Northwest (SAFN) and the current efforts of the USDA Northwest Advanced Renewables Alliance (NARA) and Advanced Hardwood Biofuels Northwest (AHB) projects. Feedstock availability and the generally more progressive nature of the PNW vs. other U.S. regions were also mentioned as factors leading to SJF regional potential.

Findings underscore the complexity of these issues, the diversity of stakeholder opinions, and potential misperceptions about SJF that may be prevalent in the aviation fuel community. For example, not all participants appeared to be aware of the stringent ASTM approval process for drop-in SJF, suggesting that reliability (quality assurance) issues remain and that these SJFs may not be approved for every engine.

It is also worth noting that fuel purchasers/handlers have generally stronger SJF opinions, both in support of and in opposition to SJFs, perhaps due to their perception that they will be required to comply with decisions made by others (primarily airlines and policymakers), and these decisions will have direct impacts to their operations.

7. Conclusions

Including consideration of key stakeholder perspectives in the regional development, scale-up, and insertion of blended drop-in Sustainable Jet Fuels (SJF's) into existing petro-based aviation fuel supply chains provides many practical benefits related to investment, policy, and SJF logistics. In particular, these insights allow more informed investor and policy decisions to facilitate SJF facility site selection and scale-up and insertion of blended SJF into the commercial airport fuel system. Academic, governmental, and industrial scientists may consider these regional findings as potential issues for consideration at a national scale to guide efforts to build and support economically viable regional biomass-to-wing supply chains.

The U.S. PNW region is unique due to the strong influence of aviation on the economy, the seminal work of Sustainable Aviation Fuels Northwest (SAFN), and the relatively limited number of major fuel demand hubs, thus simplifying stakeholder participant selection and interview administration.

Findings suggest the multifaceted nature of potential barriers to the adoption and diffusion of SJF and may provide useful avenues for future research. First, additional interviews in other U.S. regions will provide needed insights into differences and similarities concerning the drivers and barriers to SJF adoption and diffusion into the aviation fuel supply chain. Second, further research regarding the logistical issues of inserting blended SJF into the aviation fuel transportation and storage infrastructure is needed. Third, biorefinery siting decisions can benefit from the inclusion of social asset factors combined with biogeophysical assets. And, finally, findings support the need for practical, stable, and favorable SJF policy for the PNW region.

As policymakers strive to address overall carbon emissions and aviation fuel users seek mechanisms to demonstrate these reductions, it is important to incorporate SJF supply chain stakeholder input to consider an action plan to mitigate potential supply chain consequences and to tailor communications strategies to address potential SJF misperceptions.

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