ASCENT 1:
Future global alternative jet fuel production potential and associated GHG emissions benefits

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Summary

This project assesses the production potential of alternative jet fuel (AJF) in the near- and long-term, and quantifies the associated life cycle greenhouse gas (GHG) emissions benefits. Based on fuel production announcements and existing life cycle assessment (LCA) studies, we find that 0.0-2.0% of 2020 jet fuel demand could be satisfied by AJF, resulting in a reduction of 0.0-1.2% of life cycle GHG emissions from aviation. For 2050, we find that 0.0-100.0% of jet fuel demand could be satisfied by AJF, resulting in a reduction of 0.0-62.7% in life cycle GHG emissions from aviation. We also quantify the rate at which new AJF production facilities would need to be constructed, and the associated capital expenditures, in order to achieve different levels of aviation GHG emissions reductions by 2050.

Motivation and Objectives

Global air traffic is projected to grow at a rate of approximately 3-4% p.a. in future years [1], however the International Civil Aviation Organization (ICAO) has a goal of carbon neutral growth for international aviation beginning in 2020. This goal will be difficult to achieve with aircraft, infrastructure and operational efficiency improvements alone. Therefore, the ICAO Committee for Aviation Environmental Protection (CAEP) has convened the Alternative Fuels Task Force (AFTF) to address the question:

What is the potential for alternative jet fuel (AJF) to contribute to ICAO's goal of carbon neutral growth of global aviation in the near- and long-term?

We received funding under ASCENT Project 1 in order to participate in the US delegation to AFTF, and to provide technical expertise in answering this question.

Methods and Materials

The methodology developed for this analysis consists of three components, shown in **Figure 1**: assessment of AJF production potential; assessment of the life cycle GHG emissions of AJF relative to petroleum-derived jet fuel; and the combination and feasibility assessment of the results in order to estimate total potential reductions in aviation GHG emissions from the use of AJF.

For the purposes of this analysis, near-term is defined as 2020 and long-term is defined as 2050. AJF production potential in 2020 is estimated by a systematic review of production announcements for drop-in jet and diesel fuels, and scenarios are developed based on the credibility of the announcements and the potential to use small quantities of renewable diesel blended with jet fuel. Scenarios of AJF production potential in 2050 are developed by quantifying potential bioenergy availability, the proportion of available bioenergy actually produced as a result of price and policy emphasis on bioenergy, and the proportion of produced bioenergy used to produce AJF as opposed to other bioenergy end-uses. This scenario space is shown in **Figure 2**.

The life cycle GHG emissions of AJF and petroleum-derived jet fuels are gathered from existing studies on the fuel pathways of interest, and analysis assumptions (eg. energy allocation method, time period of interest) are harmonized where necessary in order to ensure consistency across data sources. The sensitivity of AJF life cycle GHG emissions to technology performance and process inputs is quantified using the GREET model, and high and low emissions cases are developed to capture the impact of expected changes in these parameters to 2050.

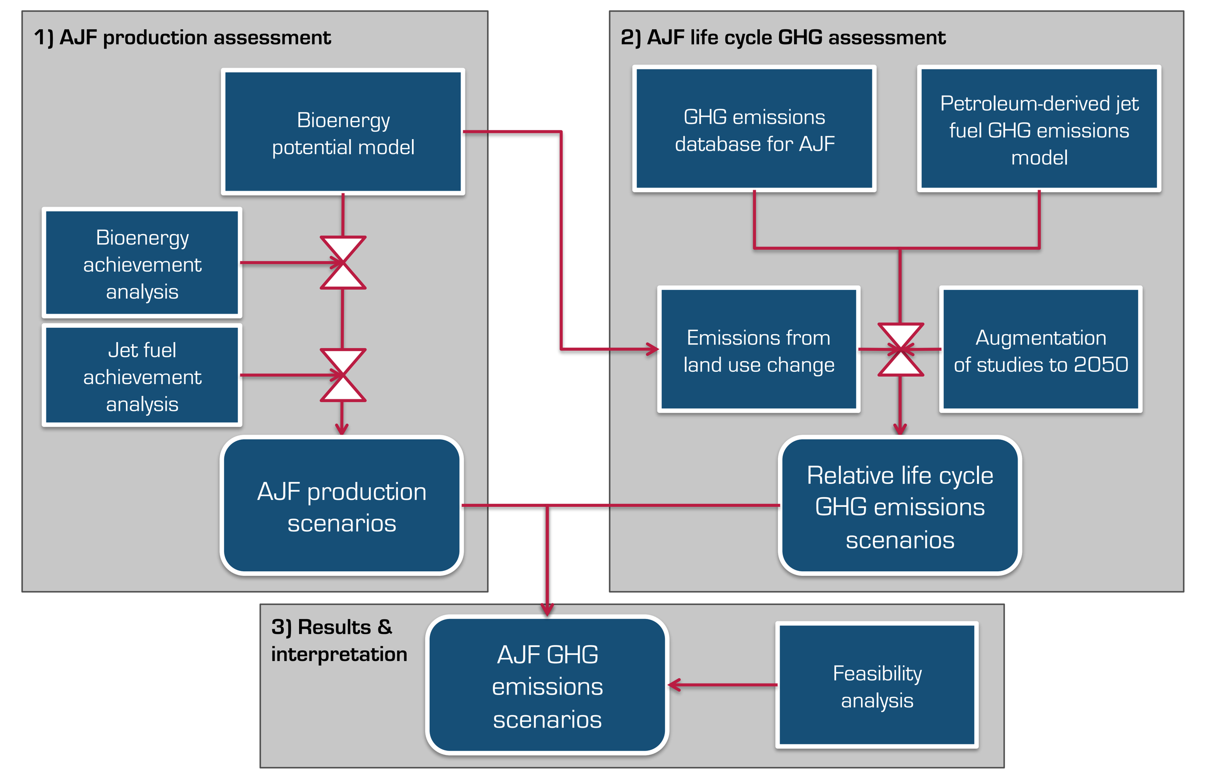

Figure 1: Schematic of the steps involved with estimating 1) AJF production potential, 2) life cycle GHG emissions of AJF relative to petroleum derived jet fuel, and 3) potential reductions in aviation CO_2 emissions from the use of AJF.

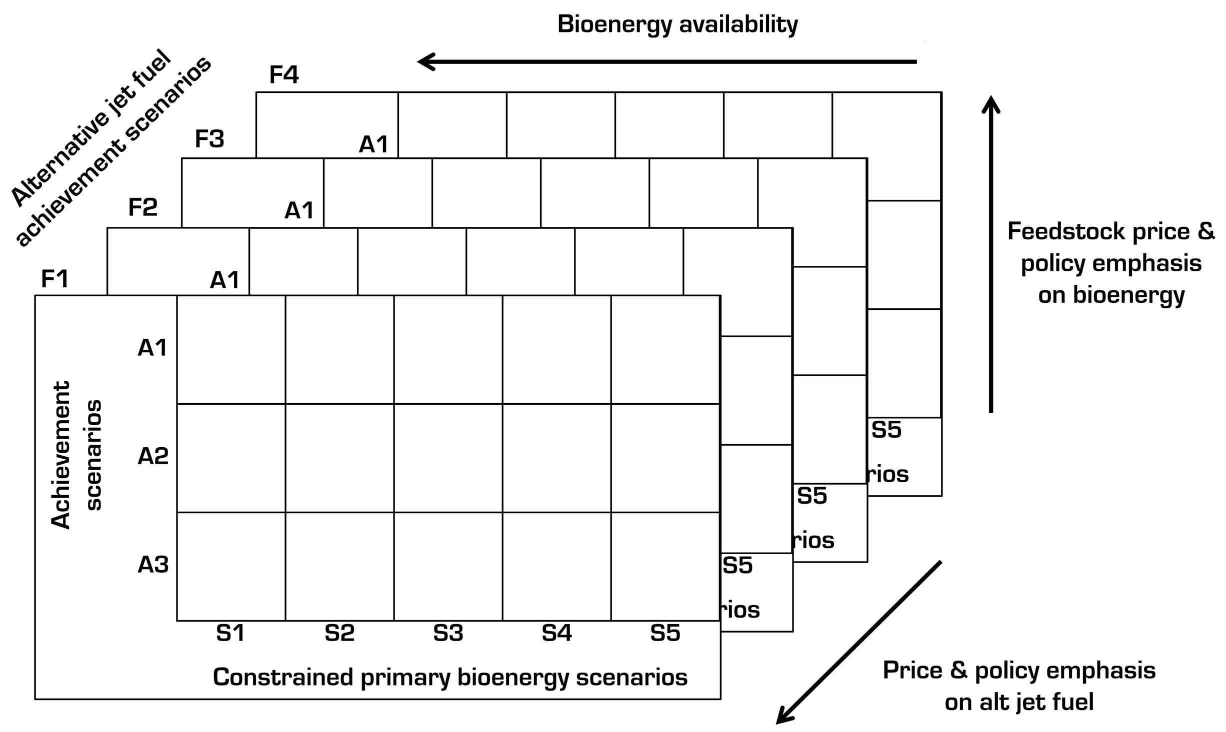

Figure 2: Scenario development for assessment of potential AJF production in 2050. The scenarios are designed to vary along three dimensions: the potential availability of bioenergy ("S" scenarios); the proportion of potentially available bioenergy actually produced ("A" scenarios); and the proportion of produced bioenergy used to produce AJF ("F" scenarios).

References: [1] International Civil Aviation Organization CAEP/10 Trends Assessment, A38-WP36 (2013)

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Results and Discussion

The fuel production assessment results indicate that 1-19 million barrels per year of AJF (0.0-0.7% of CAEP/10 projected 2020 fuel burn [1]) could be produced by 2020. If renewable diesel is considered to be available for aviation, this grows to 30-51 million barrels per year (1.1-2.0%). The scenario results also indicate that 111-38 253 million barrels per year of AJF could be produced by 2050, sufficient to satisfy 1.5-528.3% of CAEP/10 projected fuel burn for 2050 [1]. The 2050 results are shown in **Figure 3**.

The life cycle GHG emissions results are shown in **Table 1**. The 2050 results are broken out by high and low emissions cases, and the additional contribution of LUC to life cycle GHG emissions of the fuel pathways considered.

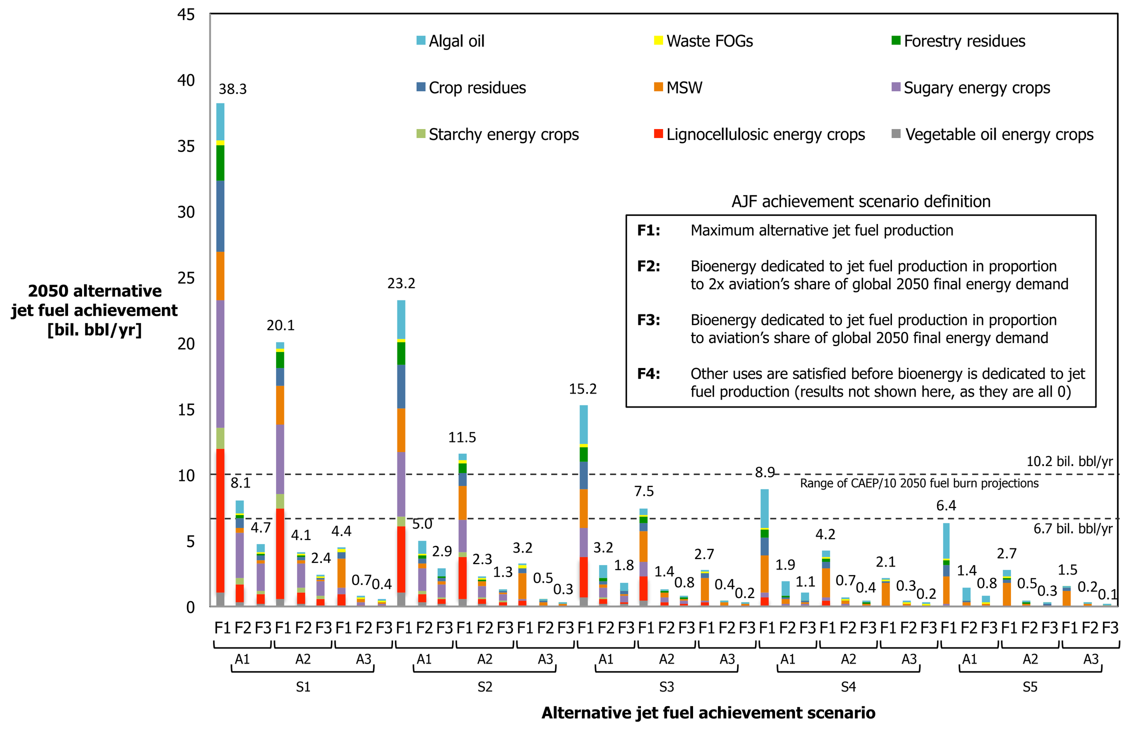

Figure 3: Scenario results of the 2050 AJF production assessment, broken out by feedstock type. Results are shown for all combinations of S, A and F scenarios (with the exception of F4), and are compared against CAEP/10 fuel burn projections.

	2020 life cycle GHG emissions	2050 Attributional life cycle GHG emissions		LUC emissions*
		High case	Low case	
Petroleum-derived jet fuel	89	89	89	-
Alternative jet fuel derived from:				
Vegetable oil crops	46	46	33	16 (2-28)
Strachy crops	63	64	34	15 (0-27)
Sugary crops	26	26	9	11 (4-29)
Lignocellulosic energy crops	16	14	10	26 (0-32)
Municipal solid waste	58	63	63	-
Forestry residues	7	8	7	-
Agricultural residues	17	17	15	-
Waste fats, oils and greases	29	29	15	-
Microalgae	53	53	21	5 (2-8)

*Median (Min-Max) for all alternative jet fuel achievement scenarios

Table 1: Results of the AJF life cycle GHG assessment for 2020 and 2050 in units of gCO_2e/MJ_{jet}. 2050 results are broken out by high and low attributional emissions cases, and the contribution of LUC emissions. Note that estimates are specific to the CAEP assessment and that they should not be used for other purposes.

Figure 4 shows the scenario results for life cycle aviation GHG emissions reductions from the use of AJF. For 2020, we find that the use of AJF could reduce aviation GHG emissions by 0.0-0.4%, or 0.8-1.2% if renewable diesel is considered available for aviation.

For 2050, we find that the use of AJF could result in life cycle aviation GHG emissions reductions of 0.0-62.7%. The results in **Figure 4** are shown for the scenario definitions given in **Figure 2**, and assuming the 'low' attributional life cycle GHG emissions case from **Table 1**. For the scenarios with the highest calculated emissions reductions (S1A1F1, S1A2F1, S2A1F1, S2A2F1, S3A1F1) we find that there is sufficient AJF to satisfy 100% of CAEP/10 fuel projections for 2050 [1]. This means that reductions in life cycle aviation GHG emissions are limited by the life cycle GHG emissions of AJF. For all other scenarios, the limiting factor is the availability of AJF in 2050.

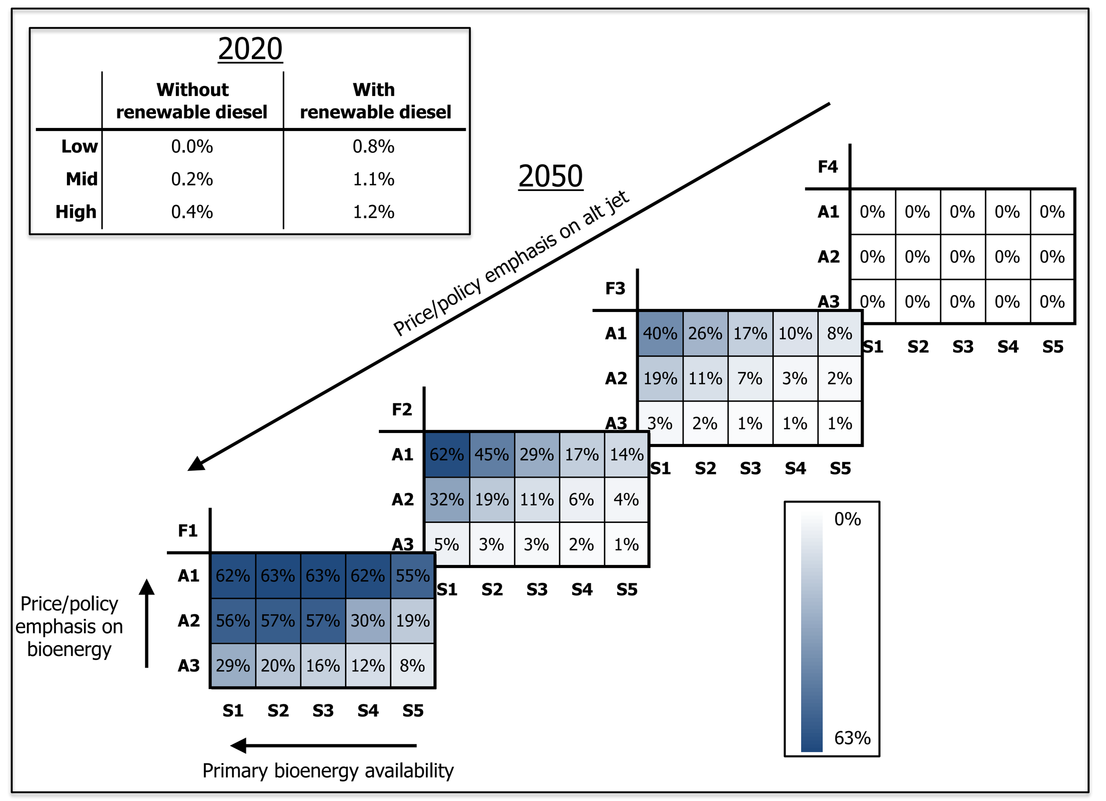

Figure 4: Scenario results for potential reductions in aviation GHG emissions. 2020 results (top left) are broken out by AJF availability scenario and the inclusion of renewable diesel. 2050 results are broken out by the scenarios defined in Figure 2.

Conclusions and Next Steps

To assess the feasibility of results, we quantified the production-ramp up required to yield the calculated reductions in life cycle aviation GHG emissions, shown in **Table 5**. For example, for a 17% reduction in aviation GHG emissions in 2050 with linear growth in AJF production, approximately 70 new biorefineries and $6-$25 bil. of capital investment would be required every year between 2020 and 2050. This implies growth in AJF production capacity greater than historically observed growth in global ethanol and biodiesel production capacity, and capital investment rates that are approximately 25% of those expected for the petroleum refining industry.

Aviation GHG emissions reduction	Alternative jet fuel production volume in 2050 (mil. bbl/yr)	Linear growth requirements		Exponential growth requirements	
		Number of new biorefineries/yr	Capital investment/yr	Number of new biorefineries/yr	Capital investment/yr
2%	235	10	$1B - $3B	<5 (2025) to 30 (2050)	<$1B - $2B (2025) to $3B - $10B (2050)
10%	1025	40	$3B - $14B	<5 (2025) to 200 (2050)	<$1B - $2B (2025) to $15B - $60B (2050)
17%	1725	70	$6B - $25B	<5 (2025) to 300 (2050)	<$1B - $2B (2025) to $30B - $110B (2050)
40%	4470	170	$15B - $60B	<10 (2025) to 1000 (2050)	$1B - $3B (2025) to $80B - $330B (2050)
63%	6825	260	$20B - $90B	<10 (2025) to 600 (2050)	$1B - $3B (2025) to $130B - $550B (2050)
Average historical ethanol and biodiesel production		Total annual volumes (mil. bbl/yr)		80 (1975 - 2000) to 360 (2001 - 2011)	
		Number of new biorefineries/yr		5 (1975 - 2000) to 60 (2001 - 2011)	
Projection for average annual investment in petroleum refining in 2035				$55B	

Table 5: Required fuel production volume in 2050, and capital investment and additional 5000 bpd fuel production facilities required annually, for different life cycle aviation GHG emissions reductions from Figure 4. We assume a 50% jet cut of the fuel product slate and no retrofitting of existing biofuel facilities, and assumptions of linear and exponential growth rates in AJF production are compared. Historical data on growth in ethanol and biodiesel production and capital investment rates in petroleum refining are also shown for comparison.

During CAEP/11, we will continue our work as part of the US delegation to AFTF, focusing on the development of a method to appropriately credit AJF under a proposed market-based measure for international aviation CO_2 emissions.

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