Project 001(F) Alternative Jet Fuel Supply Chain Analysis

Massachusetts Institute of Technology

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- P.I.: Professor Steven Barrett; Co-PI: Dr. Robert Malina
- FAA Award Number: 13-C-AJFE-MIT, Amendment No. 003, 012, 016, and 028
- Period of Performance: August 1, 2014 to August 31, 2017 (reporting here with the exception of FAA funding and cost share for October 1, 2015 to September 30, 2016)
- Task(s):
    1. Economic and environmental feasibility of alternative jet fuels derived from municipal solid waste (MSW)
    2. Future lifecycle GHG emissions from alternative jet fuel
    3. 2050 alternative jet fuel production potential and associated GHG emissions reductions
    4. LCA methodology development and default value calculation for ICAO global market-based measure
    5. Support of the US FAA at ICAO AFTF on development of sustainability criteria for alternative jet fuels and policy and feasibility assessment of ICAO climate change goals, including in person support at meetings of ICAO CAEP AFTF
    6. Long-term production and GHG emissions' reduction potential of alternative jet fuel in the US
    7. Economic and environmental assessment of alternative jet fuels accounting for the potential for technology maturation

Project Funding Level

$1,185,000 FAA funding and $1,185,000 matching funds. Sources of match are approximately $226,000 from MIT, plus 3rd party in-kind contributions of $326,000 from Byogy Renewables, Inc. and $633,000 from Oliver Wyman Group.

Investigation Team

Principal Investigator: Prof. Steven Barrett (MIT)
Co-Principal Investigator: Dr. Robert Malina (formerly MIT, now Hasselt University)
Co-Investigator: Dr. Raymond Speth (MIT)
Graduate Students: Mark Staples, Pooja Suresh, Cassandra Rosen, Timothy Galligan

Project Overview

The overall objectives for ASCENT Project 1 funding provided to MIT for the reporting period 10/1/2015 to 9/30/2016 are to derive information on regional supply chains to create scenarios for future alternative jet fuel production, identify the key supply chain-related obstacles that must be overcome to produce 1 billion gallons of alternative jet fuel by 2018, and to achieve an order of magnitude larger production in the longer term.
Following these overall objectives, the MIT's work on ASCENT Project 1 during AY 2015/2016, as defined in the ASCENT 2015-1 Grant Proposal Narrative, is focused on: developing long-run scenarios for future alternative jet fuel production and the associated savings in greenhouse gas (GHG) emissions attributable to global aviation for use at the International Civil Aviation Organization (ICAO); supporting the FAA in the development of a methodology for lifecycle CO_2 emissions of alternative jet fuels for use in the market based measures scheme currently under discussion at ICAO, and estimating the costs of producing alternative jet fuel using municipal solid waste (MSW) as a feedstock.

For AY 2016/2017, MIT's work under ASCENT Project 1 is defined in the ASCENT 2016-1 Grant Proposal Narrative as focusing on: supporting US participation in ICAO-CAEP AFTF to develop a methodology for the appropriate accounting of alternative fuels life cycle greenhouse gas (GHG) emissions in a global market-based measure; support FAA assessment of policy options for alternative jet fuels in the context of AFTF; build upon and extend previous work to estimate the economic production costs and lifecycle GHG benefits of alternative jet fuel production from MSW; assess the long-term potential for alternative jet fuel production in the US; and explore the time- and path-dependent characteristics of alternative jet fuel technologies, including the effects of learning-by-doing on production costs and environmental performance.

In order to capture work that occurred during the reporting period of this report (10/1/2015 to 9/30/2016) and overlaps with both funding periods, MIT's work under ASCENT 1 is described here under 7 categories:

1. AY 2015/2016 Task 1 & AY 2016/2017 Task 3 – Economic and environmental feasibility of alternative jet fuels derived from municipal solid waste (MSW);

2. AY 2015/2016 Task 2 – Future lifecycle GHG emissions from alternative jet fuel;

3. AY 2015/2016 Task 3 – 2050 alternative jet fuel production potential and associated GHG emissions reductions;

4. AY 2015/2016 Task 4 & AY 2016/2017 Task 1 - LCA methodology development and default value calculation for ICAO global market-based measure;

5. AY 2015/2016 Task 5 & AY 2016/2017 Tasks 2 and 6 – Support of the US FAA at ICAO AFTF on development of sustainability criteria for alternative jet fuels and policy and feasibility assessment of ICAO climate change goals, including in person support at meetings of ICAO CAEP AFTF;

6. AY 2016/2017 Task 4 - Long-term production and GHG emissions' reduction potential of alternative jet fuel in the US;

7. AY 2016/2017 Task 5 - Economic and environmental assessment of alternative jet fuels accounting for the potential for technology maturation

Because 11 of the 12 months of the reporting period correspond to AY 2015/2016, the bulk of this annual report focuses on work accomplished during that time. The plan to accomplish the tasks under ASCENT 1 for AY 2016/2017 is also summarized.

1. AY 2015/2016 Task 1 & AY 2016/2017 Task 3 – Economic and environmental feasibility of alternative jet fuels derived from municipal solid waste (MSW)

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Objective(s)

For AY 2015/2016 Task 1, the objective of the funded work is to use material and energy balances for MSW-to-jet fuel production technologies in order to build a techno-economic model based on discounted cash flow rate of return (DCFROR) analysis. The model will be used to estimate the production costs and calculate minimum selling price (MSP) of MSW-derived jet fuels, as described more fully in Suresh (2016). Work during AY 2016/2017 for Task 3 builds on this and other work in order to assess the economic and environmental feasibility of MSW-to-jet production for additional conversion technologies and locations of fuel production.

Research Approach

Note that the economic assessment of MSW-to-jet fuel production technologies described here is a summary of the work contained in Suresh (2016).

Introduction

The economics of using MSW as an alternative jet fuel feedstock are potentially favorable as municipalities currently pay to dispose of MSW in landfills. This translates to a negative feedstock cost or source of revenue for MSW-derived jet fuels and may (partially) offset higher fuel production costs. Additionally, waste management infrastructure for collection and sorting of MSW already exists and can be utilized, reducing the net production costs.

At present, MSW-derived jet fuels have not been produced at an industrial scale because significant challenges remain to be resolved, primarily the heterogeneity of the feedstock (requiring expensive pretreatment) and the lack of maturity of the conversion technologies (low efficiency and yields). As a result of these remaining challenges, it is not yet known empirically how these technologies will develop and perform commercially. Therefore, this work considers three MSW-to-fuel conversion pathways that are better suited to the heterogeneity of MSW and currently show the most commercial promise: 1) conventional/plasma gasification followed by Fischer-Tropsch, 2) conventional/plasma gasification followed by catalytic synthesis and alcohol-to-jet, and 3) conventional/plasma gasification followed by gas fermentation and alcohol-to-jet. A sensitivity analysis is carried out using Monte Carlo simulations on the MSP results in order to quantify the effect of various economic assumptions and critical input parameters, such as feedstock composition, feedstock cost and feedstock-to-fuel conversion efficiency.

In AY 2016/2017, the resulting stochastic techno-economic model, as well as modeling tools developed in year 1 of ASCENT funding, are being used to assess the economic and environmental feasibility of additional MSW-to-jet conversion technologies and locations.

Methods

In order to calculate MSW-to-jet MSP, facility capital cost estimates are obtained from the literature for each pathway (Niziolek et al. 2015, Jones et al. 2009, Motycka 2013) and, in some cases, estimates are supplemented with additional capital costs of the processes that are not modeled in the particular studies. The additional capital costs for upgrading naphtha to gasoline are estimated from Niziolek et al (2015). The capital costs of the dehydration, oligomerization and hydroprocessing equipment necessary to convert ethanol to MD fuel are estimated from Staples et al (2014). Variable operating costs and sales revenues are calculated from the prices of gasoline, jet fuel, diesel, electric power and natural gas, and are based on historical and projected data. Fixed operating costs are estimated as a function of capital expenses. Insurance, local taxes, maintenance and contingency costs are estimated using heuristics from the petroleum refining industry from Gary et al (2007).

A stochastic assessment of MSP is carried out using Monte Carlo simulations, wherein parameters are randomly sampled from their probability distributions for 10,000 iterations of the model calculations. This translates the uncertainty in the input parameters to uncertainty in the results. Parameter uncertainty in this study stems primarily from data limitations. Uniform distributions are assigned when available data are considered equally likely. When data is available to estimate minimum and maximum bounds, as well as a most likely value, triangular or pert distributions are assigned. A second type of parameter uncertainty in this analysis is statistical uncertainty associated with availability of a large number of data samples, for example, availability of historical data for commodity prices. In this case, the uncertainty distributions are dictated by the samples, based on best fit using the Anderson-Darling test (Stephens 1974).

The uncertainty associated with the conversion efficiency of the pathway is captured by assigning probability distributions to the overall fuel yield (including MD fuels, gasoline and higher alcohols). The capital cost estimates from literature used for this analysis are based on empirical data or chemical engineering models that apply equipment factor estimates and cost all major equipment individually. The error associated with these estimates is typically assumed to be ±20% (Gary et al. 2007).

This work also applies Geometric Brownian motion (GBM) to capture uncertainty in fuel and energy prices. A normal distribution is fitted to the year-to-year price variations of the past 20 years from 1996 to 2015. This distribution is randomly sampled from in order to predict price deviations in future years.

Results

The median MSP results are 0.99, 1.78 and 1.20 $ per liter for FT, Plasma FT and ATJ MD fuels, respectively. Parameter uncertainty results in ranges of values that 95% of the Monte Carlo simulation results lie within: 0.72 – 1.28, 1.24 – 2.39 and 0.68 – 1.75 $ per liter for FT, Plasma FT, and ATJ MD fuels, respectively. These results, even at the lower bound, are above the approximate current US price of conventional middle distillate fuel of 0.50 $ per liter. The probability of achieving positive NPV for the project is calculated from the NPV results to be 14%, 0.1% and 7% for FT, Plasma FT, and ATJ MD fuels, respectively.

Capital costs and fixed operating expenses, which are a function of the capital costs, are the major cost contributors for all three pathways, making up 70-75% of total expenses. The net capital costs are highest for the Plasma FT MD pathway and the lowest for the ATJ MD pathway but when normalized to the MD fuel yield, the FT MD pathway has the lowest median capital cost per liter of $0.89/L.

The variable operating expenses attributable to water, catalysts, cleaning chemicals and disposal of wastes are only 2-3% of MSP for all three pathways. Comparison of the results indicates that revenues from the sale of gasoline, and of scrap metals and glass, vary among the three pathways due to technology-specific differences in conversion process product slates and plant feed capacities. The Plasma FT and ATJ MD pathways have higher co-product revenues from higher export of excess electricity and sale of higher alcohols. Non-energy co-products such as slag and construction aggregates contribute less than 3% to reducing the overall cost.

The majority of variance in the NPV results arises from uncertainty associated with fuel prices. Since the fuel yields are higher for the FT MD pathway, the total variance and standard deviation are also greater than that of the other two pathways. On the other hand, the MSP of the FT MD pathway has the lowest standard deviation (0.14 $/L) of the three pathways because calculation of the MSP divides the net costs over the fuel yield, thereby resulting in an inverse relationship.

The ATJ MD pathway has the least negative median NPV because the relative reduction of net capital costs outweighs other costs compared to the other two pathways. However, to achieve a positive NPV, the ATJ MD pathway requires a higher selling price for the fuel than the FT MD pathway, because the lower fuel yield implies that each unit of fuel needs to be sold at a higher price.

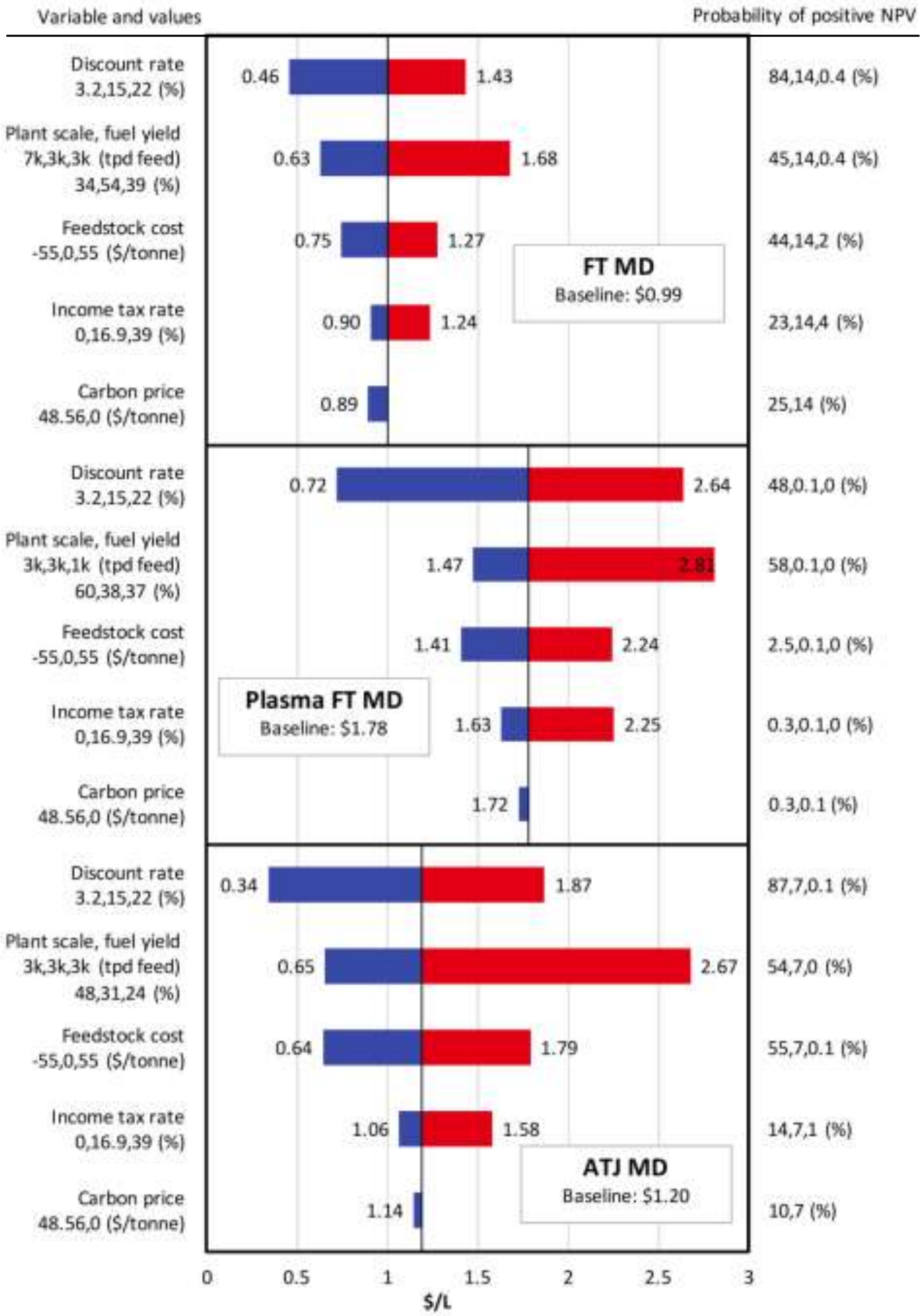

Figure 1: MSP sensitivity analysis showing the resultant median values. The variables and assumptions are listed on the left axis (low, baseline, high). On the right axis, the probability of positive NPV associated with each case (low, baseline, high) is listed.

Figure 1 presents the results of the sensitivity analysis for the MSP and NPV in terms of discount rate, income tax rate, feedstock cost, plant scale and associated technology parameters, and carbon pricing as an example of a policy driver. The discount rate, which is dictated by the rate of required return for equity and loan interest rate for debt, has the greatest impact on the results. At larger feed input capacities, economies of scale are achieved for the conversion technologies. At the same feed capacity and level of capital investment, improvements in fuel yield increase the probability of positive NPV to greater than 50%. In the case of the FT MD pathway, at the same feed capacity, lower fuel yield (39%) and 8% higher capital costs than the baseline results in a decrease of the probability of positive NPV to 0.4%.

In order to quantify the impact of feedstock cost, 2013 US average landfill tipping fees are used [6]. In the discount rate and feedstock cost cases, the ATJ MD pathway demonstrates the lowest median MSPs ($0.34/L, $0.64/L) and highest probability of positive NPV (87%, 55%) compared to the other two pathways. Figure 1 also presents the results of implementing a carbon price of $48.56 (2014 dollars) based on the revised social cost of carbon guidance provided by the US Interagency Working Group on Social Cost of Carbon (2013).

Milestone(s)

This work was completed in May 2016, and is contained in Pooja Suresh's 2016 Master's thesis submitted to MIT. The thesis is also available as a lab report on the website of the Laboratory for Aviation and the Environment at MIT.

Major Accomplishments

During this period, the MSP of MSW-to-jet fuel production technologies, and the NPV of projects using these technologies, were estimated. A summary of the work is contained in Suresh (2016), and the models used to perform this analysis were documented such that they can be used in subsequent projects under ASCENT 1.

Publications

Peer-reviewed journal publications

P. Suresh, R. Malina, M. D. Staples, D. Blazy, M. N. Pearlson, S. R. H. Barrett "Lifecycle greenhouse gas emissions and costs of production of diesel and jet fuel from municipal solid waste," (*in preparation)*

Written reports

P. Suresh, "Environmental and economic assessment of transportation fuels from municipal solid waste," Master of Science thesis, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, 2016. Available online: http://lae.mit.edu/uploads/LAE_report_series/2016/LAE-2016-002-T.pdf

Outreach Efforts

None.

Awards

None.

Student Involvement

Pooja Suresh, Masters student at MIT's Department of Aeronautics and Astronautics, carried out the majority of this analysis, as it constituted her masters thesis. She graduated in June 2016, and now works at Boston Consulting Group in Toronto, Canada.

Mark Staples, PhD student at MIT's Institute for Data, Systems and Society, also assisted with this work. Mark finished his PhD at MIT in December, 2016.

Plans for Next Period

During AY 2016/2017, the economic and environmental feasibility of alternative jet fuels derived from MSW will be assessed for additional conversion technologies, as well as additional locations. This work will be carried out at Hasselt University under the leadership of Professor Robert Malina.

Work in year 1 and year 2 (as described here) of this project has led to the development of models to quantify the US-average costs of production and lifecycle GHG emissions of several thermochemical pathways for MSW conversion into liquid transportation fuels, accounting for parameter uncertainty through a Monte-Carlo Framework. In the current year, the existing model is being extended to account for biochemical pathways that are currently in the process of being commercialized. Candidate pathways include:

- Hydrolysis and fermentation to alcohols, followed by alcohol to jet fuel conversion
- Gasification and gas fermentation to alcohols, followed by alcohol to jet fuel conversion
- Anaerobic digestion to biogas, followed by steam reforming and Fischer Tropsch or catalytic synthesis to jet fuel

This ongoing work uses the existing modeling capabilities for the gasification, alcohol-to-jet conversion, Fischer-Tropsch and catalytic synthesis steps, and will incorporate additional modules for hydrolysis, fermentation, anaerobic digestion and steam reforming. Since these pathways use only the biogenic proportion of MSW, they could be environmentally advantageous as they convert only the carbon proportion, which would have been released as methane in landfills, to biogenic carbon dioxide at the end of the life cycle. Biochemical processes also tend to be less capital-intensive but they require more feedstock pretreatment and have lower conversion yields. Though there is some existing literature on MSW-to-ethanol and MSW-to-energy biochemical pathways, a large research gap remains to be bridged in the area of evaluating the environmental and economic performance of MSW-to-jet biochemical pathways.

The model is currently tailored to calculate costs of production and GHG emissions as a US-average. However, the model is now being augmented to account for spatial variation, both within the United States, and for non-US locations. In terms of non-US analyses, a case-study on the economic and environmental viability of MSW to jet fuel production in Indonesia will be conducted. This work would also entail training Indonesian researchers in the use of life cycle emissions and economic modeling to help build modeling capacities in Indonesia, if requested by FAA. By doing so we will support FAA in its agreement with the Indonesian Directorate General of Civil Aviation (DGCA) to promote developing and using sustainable alternative aviation fuels.

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S. A. Motycka, "Techno Economic Analysis Of A Plasma Gasification Biomass To Liquids Plant " Doctor of Philosophy thesis, School of Engineering and Applied Sciences, George Washington University, 2013.

A. M. Niziolek, O. Onel, M. M. F. Hasan, and C. A. Floudas, "Municipal solid waste to liquid transportation fuels – Part II: Process synthesis and global optimization strategies," Computers & Chemical Engineering, vol. 74, pp. 184-203, 2015.

M. D. Staples, R. Malina, H. Olcay, M. N. Pearlson, J. I. Hileman, A. Boies, et al., "Lifecycle greenhouse gas footprint and minimum selling price of renewable diesel and jet fuel from fermentation and advanced fermentation production technologies," Energy & Environmental Science, vol. 7, p. 1545, 2014.

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AY 2015/2016 Task 2 – Future lifecycle GHG emissions from alternative jet fuel

Massachusetts Institute of Technology

Objective(s)

In this task, lifecycle emissions studies for different alternative jet fuel production technologies were adjusted to year 2050 by, *inter alia*, using assumptions about efficiency improvements for different conversion pathways and by forecasting the GHG footprints of input requirements to 2050. The purpose of this analysis is to inform the ICAO CAEP AFTF decision-making process, by quantifying the potential for GHG emissions savings per unit of alternative jet fuel used in future years.

Research Approach

Introduction

In order to assess the range of potential GHG emissions from reductions from the use of alternative fuels in aviation to 2050, the ICAO CAEP AFTF agreed to 1) develop and use ranges for lifecycle GHG emissions for different types of alternative jet fuels, and 2) assess the potential availability of those fuels in the short- and long-run, where long-run is defined at 2050.

In order to carry out this work MIT developed a methodology to augment existing LCA studies to 2050, and to quantify the effects on the GHG emission intensity of these technology options for producing alternative jet fuels. The studies covered include a variety of feedstock (oily, starchy, sugary and lignocellulosic crops, crop and forestry residues, waste oils, microalgae and municipal solid waste) and three different feedstock-to-fuel conversion technologies: Hydroprocessed Esters and Fatty Acids (HEFA), Fischer-Tropsch (FT) and Advanced Fermentation (AF).

Methods

In order to capture the potential range of LCA values in 2050, low, baseline and high scenarios are defined for the major parameters considered. The parameters values that are identified that could change in future years and have an appreciable impact on lifecycle GHG emission, include:

- Agricultural productivity in terms of yield improvements, associated nutrient application rates and farming energy estimates
- Process efficiencies for both the pre-processing step (if any) and the fuel production process
- Emission factors of electricity and hydrogen energy inputs

Other lifecycle inputs and parameters such as transportation emission factors, herbicide/pesticide and other chemical inputs were found to have negligible impact on pathway GHG intensities overtime. Therefore, these parameters are not adjusted to 2050. The methodology uses energy allocation for allocating emissions among all co-products, including energy products, animal meals, chemicals, liquid fuel products and electricity at the process level and along the conversion process. This is consistent with AFTF's agreed upon LCA methodology. The LCA results include only the core lifecycle greenhouse gas emissions (CO_2, N_2O and CH_4 emissions in terms of gCO_2e/MJ_{fuel}). The results do not include land-use change.

The parameters listed above are varied for the existing LCA study scope described in Table 1, and 2050 results are generated by updating the models used for those studies.

Table 1: Feedstock, technology and geographical scope

Feedstock group	Feedstock	Technology	Geographical Scope	Analysis Year	MIT References
Vegetable oily crops	Soybean	HEFA	US	2015	Stratton et al. (2010)
	Rapeseed		UK, France/US		
	Oil palm fruit		Malaysia/US		
	Jatropha		India/US		
Starchy crops	Maize	AF	US	2014	Staples et al. (2014)
Sugary crops	Sugarcane		Brazil	2014	
Lignocellulosic energy crops	Switchgrass		US	2014	
		FT		2015	Stratton et al. (2010)
Energy, food crop and forestry residues	Corn stover		US	2015	
	Forest residue		US	2015	
Other	Tallow	HEFA	US	2012	Seber et al. (2014)
	Yellow grease			2012	
	Microalgae			2010	Carter (2012)
	MSW	FT		2016	Suresh (2016)

The GHG emissions attributable to the cultivation step in the lifecycle depend on nutrient use and cultivation energy, which are both a function of agricultural yields in future years. Therefore, projections of future agricultural yields are combined with projections of nutrient application rates and cultivation energy to 2050. An example of agricultural yield projections for soybean oil, from the Global Agro-ecological Zones model and United Nations FAOSTAT data, is given in Figure 2.

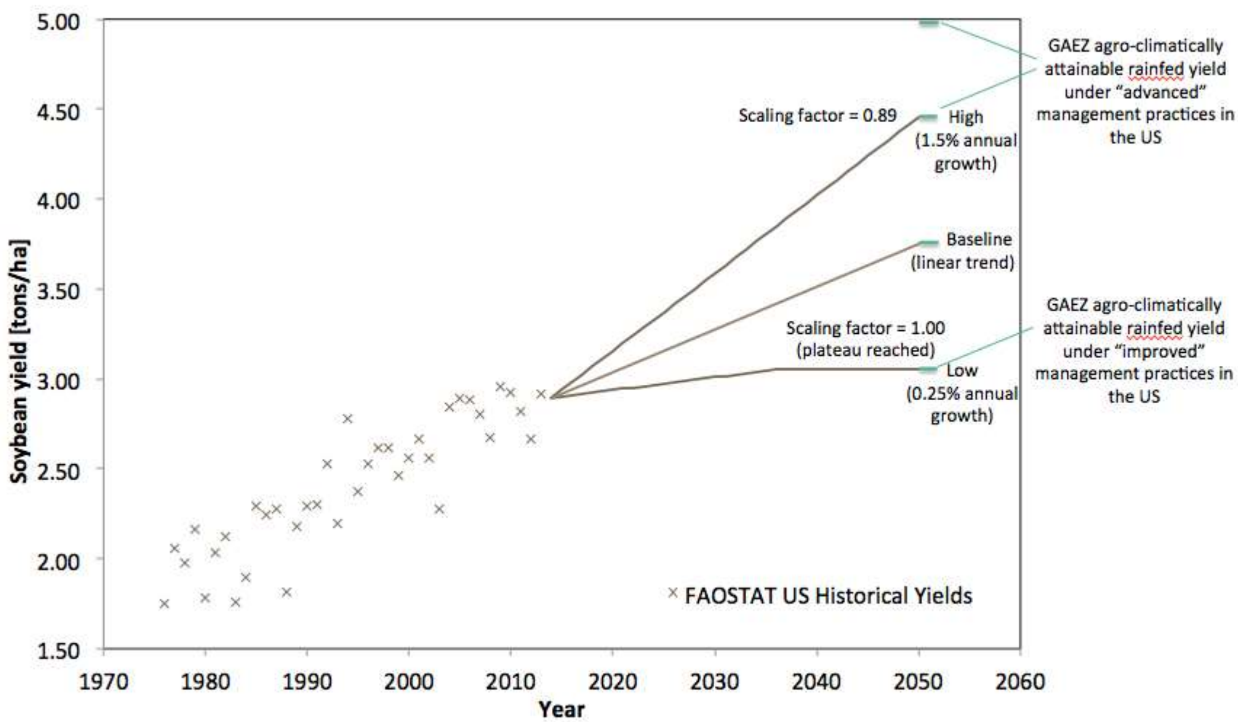

Figure 2: Historical and projected soybean yield in the US

Improvements in the lifecycle GHG emissions of alternative jet fuels could also potentially come from improvements in feedstock-to-fuel conversion efficiency. Therefore, this potential contribution to reductions in lifecycle GHG emissions is estimated by modeling the most efficient fuel production process described in the engineering literature. The references used to generate these results are given in Table 2.

Table 2: Feedstock-to-fuel conversion efficiency projections for 2050

Pathway	2050 feed to jet conversion efficiency	Improvement from existing baseline	Units	Key references
Soybean HEFA	21.79	0%	MJ jet/kg oil	Pearlson et al. (2013)
Rapeseed HEFA	21.79	0%	MJ jet/kg oil	
Jatropha HEFA	21.79	0%	MJ jet/kg oil	
Oil palm HEFA	21.79	0%	MJ jet/kg oil	
Tallow HEFA	21.79	0%	MJ jet/kg oil	
Yellow grease HEFA	21.79	0%	MJ jet/kg oil	
Microalgae HEFA	21.79	0%	MJ jet/kg oil	
Switchgrass FT	13.00	4%	% MJ jet/MJ biomass	Stratton et al. (2010)
Corn stover FT	13.00	4%	% MJ jet/MJ biomass	
Forest residue FT	13.00	4%	% MJ jet/MJ biomass	
MSW FT	14.80	NA	% MJ jet/MJ MSW	Niziolek et al. (2015)
Switchgrass AF	8.21	40%	MJ jet/kg dry biomass	Staples et al. (2014)
Maize AF	9.96	25%	MJ jet/kg grain (15.5% mst)	
Sugarcane AF	2.88	34%	MJ jet/kg sugarcane (50% mst)	

Finally, the results for 2050 also account for potential reductions in the emissions factors of electricity and hydrogen required for fuel production. The key references and resulting emissions factors are given in Table 3.

Table 3: 2050 projections for the emission factors of electricity and hydrogen

Energy inputs	Emission factors (gCO_2e/MJ)				Key references
	Current	2050 Low	2050 Baseline	2050 High	
US grid electricity mix	174.36	25.86	112.03	159.41	ETP (2014)
Brazil grid electricity mix	20.84	10.66	26.93	50.83	ETP (2014)
North American hydrogen mix	94.53	26.69	35.90	94.53	WETO – H_2 (2006) and ANL (2005)

Results

The methodology described above was implemented to calculated three 2050 lifecycle GHG values for the alternative jet fuel pathways of interest, and these results are shown in tabular format in Table 4, and graphical format in Figure 3.

Table 4: Final 2050 LCA projections for low, baseline and high scenarios

Feedstock group	Pathway	Current lifecycle GHG emissions (gCO_2e/MJ_{fuel})	2050 lifecycle GHG emissions projections (gCO_2e/MJ_{fuel})			Difference between the current and 2050 baseline values
			Low	Baseline	High	
Oily crops	Soybean HEFA	42.15	24.53	29.56	39.61	-29.9%
	Rapeseed HEFA	58.34	34.87	39.38	53.29	-32.5%
	Oil palm HEFA	39.09	21.92	26.08	35.93	-33.3%
	Jatropha HEFA	58.27	40.24	47.18	58.61	-19.0%
Starchy crops	Maize AF	52.20	21.30	27.80	31.30	-46.7%
Sugary crops	Sugarcane AF	10.70	3.50	3.80	4.20	-64.5%
Lignocellulosic energy crops	Switchgrass AF	37.40	12.80	18.40	25.90	-50.8%
	Switchgrass FT	19.38	9.81	16.34	24.95	-15.7%
Energy, food crop and forestry residues	Corn stover FT	13.82	10.89	12.00	17.49	-13.2%
	Forest residue FT	7.71	6.92	7.16	7.40	-7.1%
Other	Tallow HEFA	29.80	11.19	16.54	25.84	-44.5%
	Yellow grease HEFA	19.40	6.69	8.47	16.48	-56.3%
	Microalgae HEFA	68.08	11.07	27.00	39.78	-60.3%
	MSW FT	27.63	32.89	38.16	43.42	38.1%

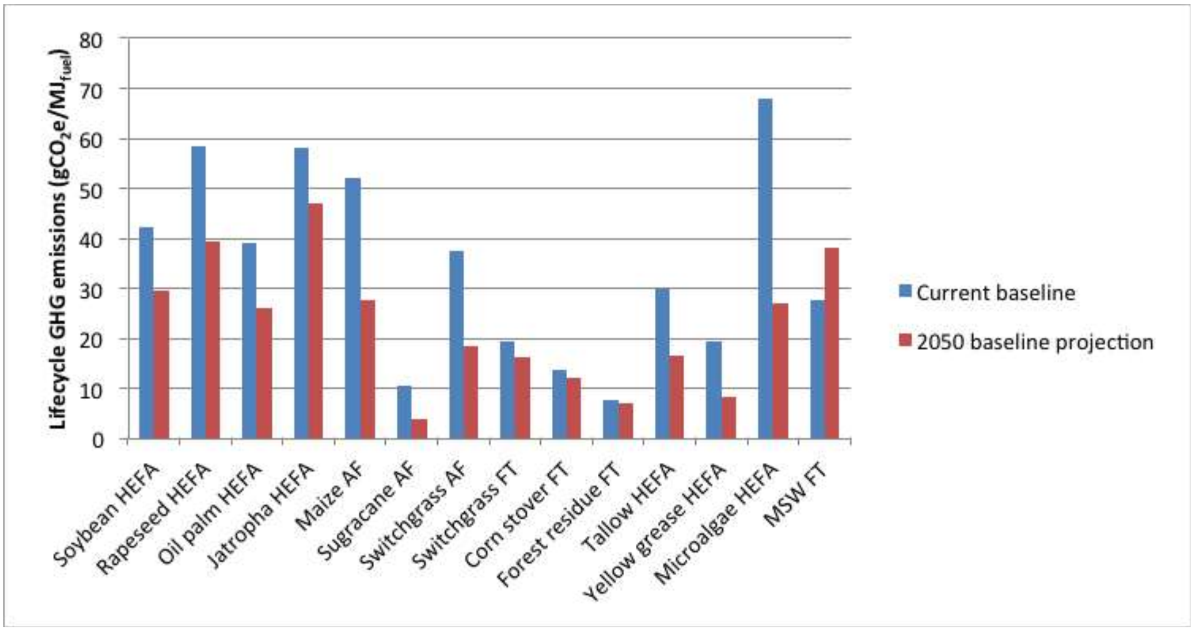

Figure 3: Final 2050 baseline LCA projections compared to the current baseline LCA values

The primary conclusions from this analysis are summarized by the following points:

- Adjustment of agricultural yields, nutrient application rates, and cultivation energy inputs to 2050 produces variations or approximately 2% for most of the crops studied. Maize, rapeseed and oil palm are the exceptions to this finding, with variations of 4 to 6 gCO_2e/MJ_{fuel} (~10%)
- In most of the cases investigated, adjusting the farming energy inputs only changed the LCA results by less than 4%.
- The greatest difference in LCA results is observed for the AF pathways, leading to reductions in LCA emissions of 6 to 20 gCO_2e/MJ_{fuel}
- Adjusting electricity emissions factors results in variations of 2-4% for all of the pathways except for those with high electricity requirements, such as maize AF, and tallow and microalgae HEFA.
- The impact of adjusting the hydrogen emission factor is significant, leading to reductions of 7-8 gCO_2e/MJ_{fuel} for the HEFA pathways.

Milestone(s)

This work began in the summer of 2015, and was completed in early October 2015. This compressed timeline was required in order to present the findings of this analysis to AFTF in the face-to-face meeting in Montreal.

Major Accomplishments

The major accomplishment of this work was to complete the analysis, have it reviewed and accepted by AFTF in October 2015, and then to use the resulting data in order to calculate the potential contribution of alternative jet fuels to GHG emissions reductions.

Publications

This work is carried out in support of an international negotiation. As such, the methodology and results have not be published in scientific journals or presented at conferences, in order to respect the sensitive nature of the negotiation. The major publication associated with MIT's work on this project is the information paper (IP) presented to AFTF, and ultimately to CAEP in CAEP/10-IP/13 and CAEP/10-IP/14.

Outreach Efforts

This work was presented to other members of AFTF in teleconferences leading up to the October 2015 meeting of the group in Montreal, as well as in person to the member of AFTF at that meeting.

Awards

None.

Student Involvement

Pooja Suresh, Masters student at MIT's Department of Aeronautics and Astronautics, carried out the majority of this analysis, as it constituted her masters thesis. She graduated in June 2016, and now works at Boston Consulting Group in Toronto, Canada.

Mark Staples, PhD student at MIT's Institute for Data, Systems and Society, also assisted with this work. Mark finished his PhD at MIT in December 2016.

Plans for Next Period

There is no plan for this specific task in the next period. The data that was generated has been used for its purpose. If an updated assessment of how alternative jet fuel LCA values might change in future years is required in the context of AFTF or ICAO CAEP, this analysis could be used as a starting point.

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AY 2015/2016 Task 3 – 2050 alternative jet fuel production potential and associated GHG emissions reductions

Massachusetts Institute of Technology

Objective(s)

The objective of this task is to finalize estimates for bioenergy potential and jet fuel achievement in 2050, for the purposes of informing the ICAO CAEP AFTF process. This work was initiated in year 1. The scenario results for potentially available jet fuel volumes are combined with the 2050 lifecycle GHG emissions estimates for different feedstock to fuel pathways as described above. Overall, this yields a range of GHG emissions reductions from alternative jet fuel usage in 2050. Results were presented to CAEP in early 2016, and were used in the update to the ICAO-CAEP trends assessment.

Research Approach

Introduction

This task was to carry out analysis that supports AFTF's task to evaluate the range of potential GHG emissions reductions from the use of alternative jet fuels to 2050. The results were used as an input in CAEPs environmental trends assessment to 2050.

Methods

For this analysis, short-term is defined as 2020, and alternative jet availability is established for this from fuel producers' announcements and targets set by States. Six scenarios were developed for the short-term assessment, varying by the credibility requirements for inclusion of companies' production plans, and the consideration of green diesel as a potential future low-percentage blending opportunity with conventional jet fuel.

For the long-term, defined as 2050, alternative jet fuel availability is estimated by first calculating the primary bioenergy potential constrained by environmental and socio-economic factors; then estimating the proportion of bioenergy potential that could actually be achieved or produced; and finally by calculating the quantity of alternative jet that could be produced from the available bioenergy. 9 different feedstock types are considered (starchy crops; sugary crops; lignocellulosic crops; oily crops; agricultural residues; forestry residues; waste fats, oils and greases; microalgae; municipal solid waste (MSW)). Five different sets of assumptions for primary bioenergy potential, three sets for bioenergy achievement, and four sets of alternative jet achievement assumptions were developed, yielding a total of 60 different production scenarios. The quantity of potentially available alternative jet fuel also involves the calculation of emissions from direct land-use change (LUC) due to biomass feedstock cultivation.

In order to quantify the lifecycle GHG emissions associated with the production volumes, a database of existing LCA results for different feedstock-to-fuel technology combinations was developed. For the 2020 GHG intensities, existing study results were adapted to reflect allocation of emissions to co-products based on their energy-content, and the average emissions value of each bioenergy feedstock was calculated for all studies. The results described in the previous task were used to quantify lifecycle GHG emissions from alternative jet fuels in 2050.

Results

For 2020, the range of results for AJF production are between 56 kt/y to 6.5 Mt/y, corresponding to 0-2% of global aviation fuel demand in 2020. This corresponds to a reduction of lifecycle GHG emissions by 0-1.3% compared to only using petroleum-derived jet fuel, as shown in Figure 4. Among the different scenarios considered for 2020, emission reduction values increase assuming that green diesel could be used jet engines (in low blends up to 5%).

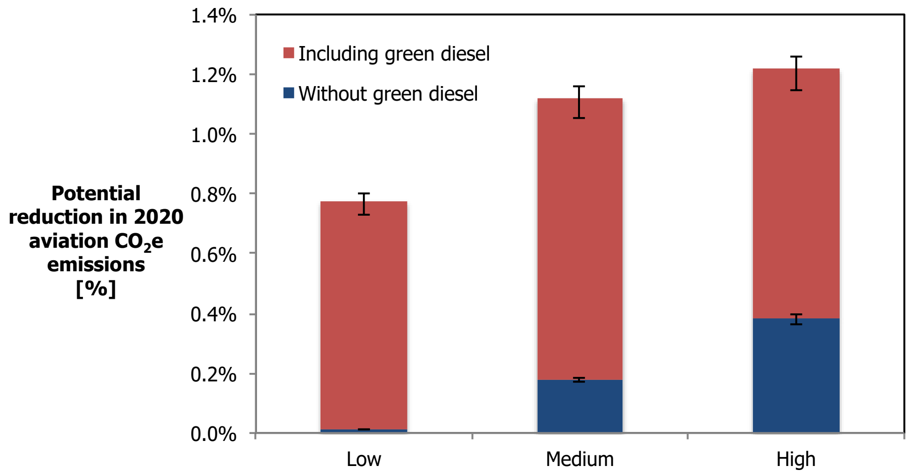


Figure 4: Potential reducton in 2020 aviation lifecycle GHG emissions, compared to the 100% petroleum-derived jet baseline. The variability bars reflect different fuel burn projections for 2020.

Emissions from LUC were calculated for each scenario in 2050, and were found to vary among scenarios from 1g to 20gCO_2e/MJ on average, depending on the mix of alternative jet fuel pathways produced. The average emissions from LUC associated with a certain mix of alternative jet fuels decreases, inter alia, as the share of feedstocks not requiring dedicated land conversion, such as wastes, residues, and MSW, increases. Overall, scenarios with higher alternative fuel production volumes tend to show higher emissions from LUC per unit of fuel produced, as AJF production becomes increasingly dependent on the conversion of additional land area for feedstock cultivation. This is shown in Figure 5.

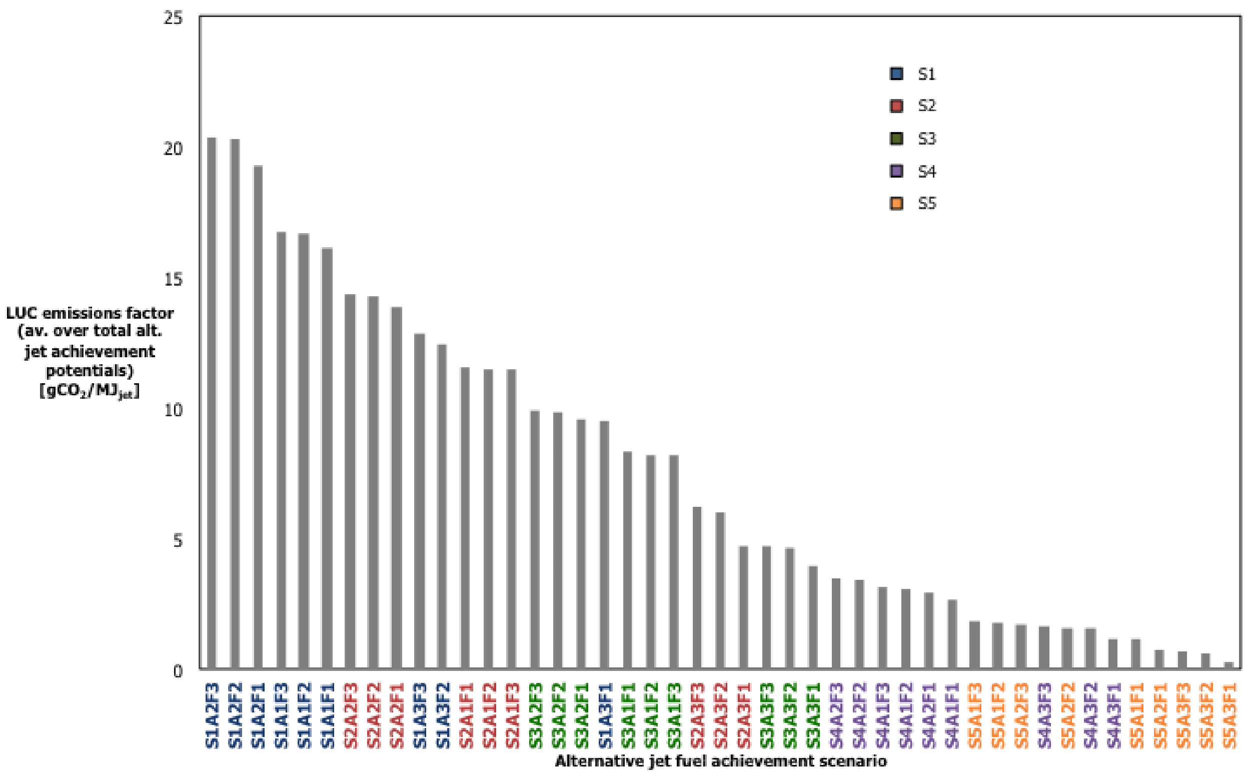


Figure 5: Allocated LUC emissions, averaged over total alternative jet fuel volumes, for each scenario and amortized over 25 years. Each label on the x-axis corresponds to a different alternative jet fuel achievement scenario.

Depending on the assumptions associated with different scenarios, alternative jet fuel production in 2050 could range from zero to 4.600 Mt per year, offsetting between 0-100% of the projected petroleum-derived jet fuel demand in 2050. This is shown in Figure 6. This translates into a reduction of total lifecycle GHG emissions reduction of between 0-63%. The range of potential GHG reductions is smaller than the fuel replacement range, as the alternative jet fuel mix in the different scenarios is associated with lifecycle GHG emissions of 31-64% of those of petroleum-derived jet fuel, on average.

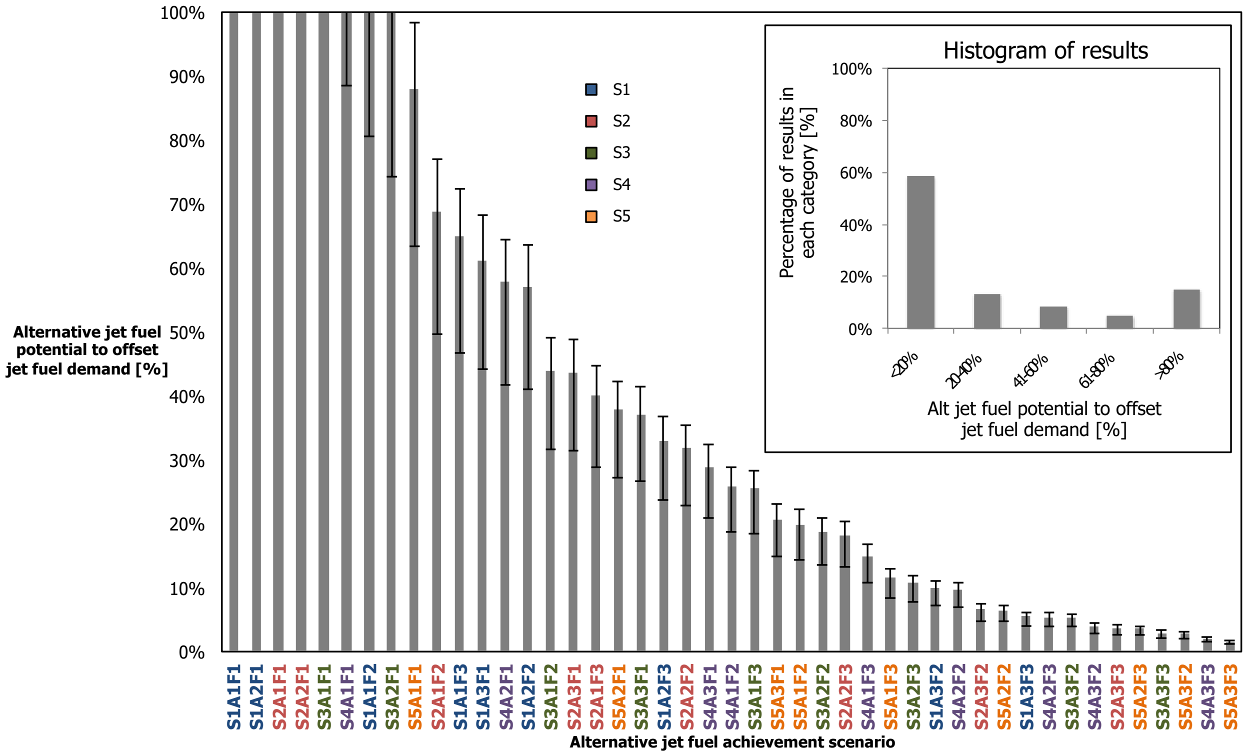


Figure 6: Percentage of 2050 jet fuel demand potentially satisfied by alternative jet, in decreasing size of offset potential. The whiskers indicate the change in percentage of potential offset due to the range of fuel burn projections.

The results indicate that the potential to reduce GHG emissions from aviation via the use of alternative jet fuel increases with assumptions that imply greater availability of alternative jet fuel. These assumptions include factors such as: larger agricultural yield increases; greater land availability; higher accepted rates of residue removal; increases in feedstock and fuel production efficiencies; reductions in GHG emissions from utilities; increased policy emphasis on bioenergy production relative to other land usages in general, and on alternative jet fuel production in particular; and other factors.

An “illustrative example” based on one specific scenario of 17% GHG emissions reduction with 220 Mt/yr of alternative fuel production in 2050 was further explored to assess the feasibility. The selected scenario assumes a mid-level of overall bioenergy potential, high actual achievement rates for this potential, equal policy-emphasis on all potential end-usages of bioenergy, and relatively low GHG intensity of alternative jet fuel produced in 2050. In addition, the conditions that would need to be in place in order for alternative jet fuel to potentially to yield particular levels of GHG reductions were also explored.

For example, a 2% reduction of lifecycle aviation GHG emissions would require a global production volume of alternative jet of about 30 Mt/yr in 2050. A 17% reduction in GHG emissions would entail alternative jet fuel production of approximately 220 Mt/yr in 2050. Under a linear growth assumption between 2020 and 2050, this would require approximately 70 biorefineries to be constructed every year (required capital investment of approximately $6B-$25B/yr) and exponential growth implies that 200-300 facilities will have to be built per year closer to 2050 (required jet-fuel specific capital investment of approximately less than $1B/yr to $2B/yr in 2025 and $30B-$110B/yr in 2050). These investments would cover the capital expenditure for the refineries and not the operational expenditures of the entire alternative fuel supply chain. (e.g. feedstock and utility costs).

For the highest modelled GHG emissions reduction under all scenarios assessed of 63%, approximately 870 Mt/yr of alternative jet fuel would need to be produced in 2050. In addition to the significant capital investment in biorefineries required, this emissions reduction would require the realization of the highest assumed increases in agricultural productivity, the highest considered availability of land for feedstock cultivation, residue removal rates, conversion efficiency improvements, and significant reductions in the GHG emissions of utilities, as well as a strong market or policy emphasis on bioenergy in general, and alternative jet fuel in particular. The latter would entail large shares of the available bioenergy pool be devoted to producing alternative jet as opposed to other end uses such as transportation fuels or electricity and heat. These scenarios are shown in Table 5.

Table 5: Required fuel production volume in 2050, number of new 500 bpd facilities required annually, and range of annual capital investment required for different GHG emission reduction percentages.

Aviation GHG emissions reduction	Required AJF production volume in 2050 (Mt/yr)	Requirements under linear growth		Requirements under exponential growth	
		Number of new biorefineries/yr	Capital investment/yr	Number of new biorefineries/yr	Capital investment/yr
2%	30	10	\$1B - \$3B	<5 (2025) to 30 (2050)	<\$1B - \$2B (2025) to \$3B - \$10B (2050)
10%	130	40	\$3B - \$14B	<5 (2025) to 200 (2050)	<\$1B - \$2B (2025) to \$15B - \$60B (2050)
17%	220	70	\$6B - \$25B	<5 (2025) to 300 (2050)	<\$1B - \$2B (2025) to \$30B - \$110B (2050)
40%	570	170	\$15B - \$60B	<10 (2025) to 1000 (2050)	\$1B - \$3B (2025) to \$80B - \$330B (2050)
63%	870	260	\$20B - \$90B	<10 (2025) to 1600 (2050)	\$1B - \$3B (2025) to \$130B - \$550B (2050)
Average historical global ethanol and biodiesel production		**Total annual volumes (Mt/yr)**		10 (years 1975 - 2000) to 45 (2001 - 2011)	
		Number of new biorefineries/yr		5 (years 1975 - 2000) to 60 (2001 - 2011)	
Projection for average annual investment in petroleum refining in 2035				\$55B	

This results of this analysis indicate that in order to achieve significant reduction in aviation GHG emissions by 2050, high capital investments are required and these might be feasible only if the investments begin in time and consistently grow over time, or if existing infrastructure can be leveraged to reduce the initially required capital investments. Comparison to the development in global ethanol and biodiesel production shows that the growth in alternative aviation fuel production would need to be on the order of recently observed growth of 5-15 Mt/yr in global biofuel production capacity to achieve a 10% and 17% emissions reduction by 2050, and would have to significantly exceed historical global biofuel production growth rates for total GHG emission reductions above 20%.

Milestone(s)

The major milestone of this work was presentation of final results to CAEP in February 2016.

Major Accomplishments

Completion of the task, such that AFTF could provide an estimate of the potential contribution of alternative jet fuels to reduction in CO_2 emissions from aviation. This result was included in the CAEP environmental trends assessment.

Publications

This work is carried out in support of an international negotiation. As such, the methodology and results have not be published in scientific journals or presented at conferences, in order to respect the sensitive nature of the negotiation. The analysis is summarized in information papers (IP) CAEP/10-IP/13 and CAEP/10-IP/14 presented to CAEP, and working paper (WP) CAEP/10-WP/44 presented to CAEP.

This element of the work of AFTF concluded with the CAEP 10 cycle in February 2016. However, MIT is currently drafting a journal article to publish these results. The journal to which it will be submitted has not yet been decided.

Outreach Efforts

The work described here was discussed at length during face-to-face meetings of AFTF in Montreal in October 2015 and June 2016. Between the meetings, a number of teleconferences were held to discuss methodological decisions and initial results with the other members of AFTF.

This work was also presented at the March 15, 2015 FAA AEE external tools call, and on the June 10, 2016 SOAP-Jet webinar.

Awards

None.

Student Involvement

Mark Staples was the primary developer of the 2050 fuel production assessment methodology. He drafted the iterations of the IP, prepared briefings for AFTF, and incorporated the requested and required changes. He also carried out the integration of the LCA and fuel production assessment analyses to generate final results, and drafted the IP that presents and explains the results. Mark completed his PhD at MIT in December 2016.

Pooja Suresh carried out the analysis of LCA values for alternative fuels in 2050. Her analysis involved calculating alternative jet fuel LCA results, taking into account changes in the technologies and process inputs to 2050. Pooja prepared briefings for the LCA analysis group during teleconferences, and face-to-face meetings. She graduated in June 2016, and now works at Boston Consulting Group in Toronto, Canada.

Plans for Next Period

The results of this analysis will continue to be used to inform the AFTF process in the coming period. For instance, these results will be used to quantify the effect of different policy decisions on the potential availability of alternative jet fuel.

In addition, MIT will draft and submit a journal paper documenting this work and its findings in the coming period.

AY 2015/2016 Task 4 & AY 2016/2017 Task 1 - LCA methodology development and default value calculation for ICAO global market-based measure

Massachusetts Institute of Technology

Objective(s)

The objectives of these tasks are two-fold. First, MIT is to help develop the core lifecycle assessment (LCA) methodology for the inclusion of alternative fuels in ICAO's global market-based measure. This entails developing recommendations for the choice of allocation rules, system boundary limits, the treatment of emissions from land-use change and sustainability requirements, as well as recommendations on the entity that shall conduct the actual calculations and the frequency of re-assessment of the calculations. The development of the proposal will be informed by calculations on the impact of methodological choices on CO_2 emissions attributed to alternative jet fuel.

Once the methodology has been agreed upon, it is to be used for the calculation of default LCA values to be applied to different feedstock-to-fuel technologies under GMBM.

Research Approach

Introduction

Over this reporting period, AFTF used the core LCA methodology developed previously for the fuel production assessment as a starting point. MIT summarized this methodology in a "Guidance Document" to be circulated amongst interested parties outside of AFTF, in order to solicit LCA data for the calculation of default values.

In addition, MIT carried out analyses to assess the appropriate level of aggregation for the calculation of default values. This involved examining the impact of feedstock, technology and regional aggregation on the accuracy of the calculated default values.

Summary of the LCA methodology as defined in the Guidance Document

The purpose of the guidance document is to describe the agreed upon LCA methodology for the calculation to default core values under GMBM, such that interested parties can submit data to aid in the calculation of these values. The requirements for data submitted to AFTF are also described.

Alternative jet fuel is defined as any fuel that generates lower carbon emissions than conventional kerosene on a lifecycle basis, and the LCA methodology only applied to the attributional emissions from alternative jet fuel. The system boundary of interest includes the full supply chain of AJF production and use, and shown in Figure 7.

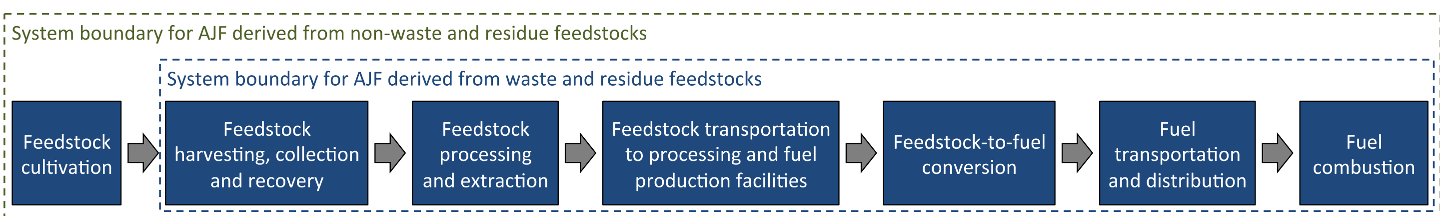


Figure 7: Alternative jet fuel lifecycle steps

The calculated LCA results include well-to-pump emissions of CH_4, N_2O and CO_2, and combustion CO_2 emissions. Emissions from on-going operational activities, as well as emissions from utility inputs are included, however emissions generated from one-time construction or manufacturing activities are not. Waste and residue feedstocks are assumed to generate zero GHG emissions during feedstock production. All results are expressed in 100-year global warming potential CO_2 equivalents. Energy allocation is used at all stages of the LCA, and the results are compared to a conventional jet fuel baseline of 89.0 gCO_2e/MJ_{jet}.

Criteria of submission of LCA data for consideration under GMBM
AFTF has limited capacity to assess submitted data and calculated LCA results. Therefore, the Guidance Document prepared by MIT contains a number of criteria in order to target the work of AFTF where it would be most fruitful.

Firstly, AFTF the pathways evaluated by AFTF should be likely to achieve commercial-scale production in the near-term. Therefore, a working list of feedstock-to-fuel pathways that are certified by ASTM and for which there are commercial entities planning to produce fuel is given in Table 6.

Table 6: Working list of the feedstock-to-fuel alternative jet fuel pathways for which default core LCA values will be established by AFTF by GMBM

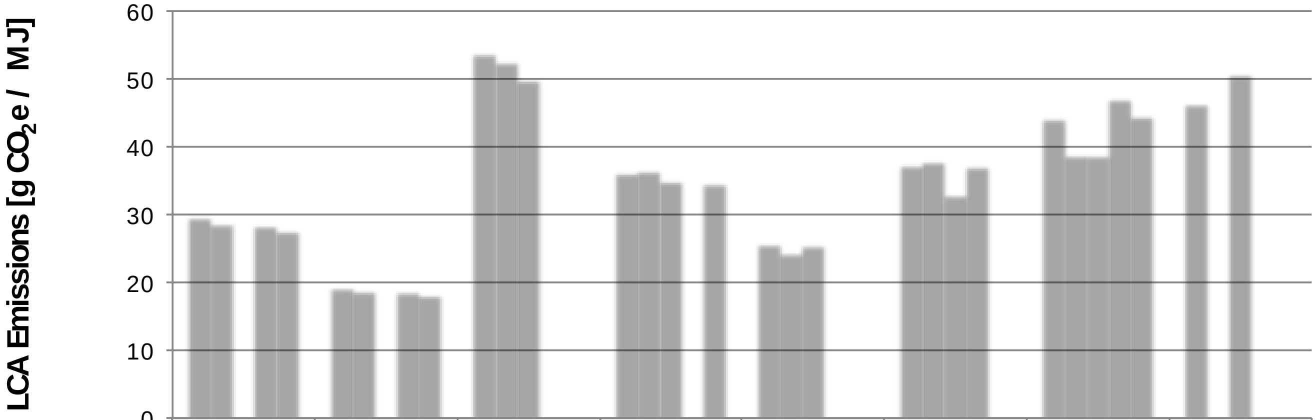
Technology	Feedstock
Fischer-Tropsch (FT)	Agricultural residues
	Forestry residues
	Short rotation woody crops
	Herbaceous lignocellulosic energy crops
	Municipal solid waste
Hydroprocessed esters and fatty acids (HEFA)	Waste tallow
	Used cooking oil
	Corn oil
	Canola/rapeseed
	Soybean
	Palm oil
	Camelina
	Palm fatty acid distillate (pending data avail.)
	Jatropha
	Tall oil
Synthesized Iso-Paraffins (SIP) aka. direct sugar-to-hydrocarbon (DSHC)	Sugarbeet (pending data avail.)
	Sugarcane
Alcohol (iBuOH)-to-jet (ATJ)	Sugarcane
	Corn grain
	Herbaceous lignocellulosic energy crops
	Agricultural residues
	Forestry residues

The source of the submitted data also must be credible, such as a study published in a peer-reviewed journal, an appropriate state agency, or direct submission of a study carried out by a State agency, intergovernmental agency, non-profit or NGO, or private entity.

The data submitted to AFTF must also be transparent and replicable, and the data must be accessible such that the LCA values can be re-calculated and verified.

Aggregation analyses
In order to carry out the calculation of default core LCA values in line with the agreed upon methodology, AFTF will have to decide on the appropriate level of feedstock, conversion technology and geographical aggregation to consider. In order to support this decision, MIT has carried out a number of analyses to quantify the impact of differing levels of aggregation on

the LCA results. In preparation for the face-to-face meeting of AFTF in October 2016, an analysis of regional variation in lifecycle GHG emissions for a number of pathways was carried out. This was done by leveraging pathways that are already modeled in GREET, and augmenting the parameter values to better reflect LCA results of other world regions. These results are shown in Figure 8.



	Tallow	UCO	Canola	Soybean	Corn Oil	Palm	Jathropa	Camelina
USA	29.8	19.4	53.9	36.3	25.8	37.5	44.4	46.5
EU	28.8	18.9	52.7	36.6	24.5	38.0	38.9	
Canada			50.0	35.2	25.6	33.1	38.9	50.8
SE Asia	28.6	18.7				37.2	47.2	
Latin America	27.7	18.3		34.8			44.7	

Figure 8: Aggregation analysis results for regional variation

The findings indicate that regional variation may be less important than initially expected for many of the pathways

Milestone(s)

The major milestones of this task were presentation of the Guidance Document summarizing the agreed upon LCA methodology to AFTF in the fall of 2016, and the presentation of aggregation analyses to AFTF in May, June and September of 2016.

Major Accomplishments

By drafting and agreeing upon the Guidance Document described here, MIT has contributed to setting up AFTF for success in accomplishing the tasks it has been given by CAEP. The Guidance Document will be used to solicit LCA data from interested parties for the establishment of default values, and the aggregation analyses establish the reasoning for the level of resolution at which the default value calculation must be carried out.

Publications

This work is carried out in support of an international negotiation. As such, the methodology and results have not be published in scientific journals or presented at conferences, in order to respect the sensitive nature of the negotiation.

However, the work carried out by MIT in this reporting period is contained in the following AFTF papers: CAEP/11-AFTF/1-IP/14 and CAEP/11-AFTF/2-WP/2 include general information about the LCA task carried out by MIT, CAEP/11-AFTF/2-IP/4 summarizes the pathway aggregation study carried out by MIT, and CAEP/11-AFTF/2-IP/03 contains a draft of the Guidance Document put together by MIT.

Outreach Efforts
A preliminary version of this work was presented at the AFTF meeting Montreal in June 2016. In addition, the Guidance Document and aggregation analyses were presented via telecon to AFTF in September 2016, in preparation for the face-to-face meeting in Montreal in October 2016.

Awards
None.

Student Involvement
Mark Staples drafted the Guidance Document, presented it to AFTF members and made revisions as necessary. Mark also wrote the corresponding information papers. He completed his PhD at MIT in December 2016.

Cassandra Rosen carried out the aggregation analysis in co-operation with Argonne National Laboratory. Cassandra also presented the work and drafted the information paper. She is a continuing Masters student at MIT.

Plans for Next Period
For the next period, one of the main areas of work will be the development of an initial set of core default LCA emission values. In order to do this, we will make a proposal on the level of resolution of data to be used under AFTF, both geo-spatially and in terms of feedstock and technology groupings. In addition, we will develop an initial list of core LCA values to be brought forward to AFTF. Finally, we will work towards a proposal for a petition process, by which eligible entities could prove lower LCA values of a fuel under consideration.

In the coming period we will also assist Purdue University in the development of ILUC emission factors by, for example, providing input on scenario assumptions. We will also help in the development of an appropriate definition of carbon-hotspot areas, the usage of which would make the related aviation fuel ineligible for a credit under the GMBM.

AY 2015/2016 Task 5 & AY 2016/2017 Tasks 2 and 6 – Support of the US FAA at ICAO AFTF for development of sustainability criteria, policy and feasibility assessment of ICAO climate change goals, including in person support at meetings of ICAO CAEP AFTF

Massachusetts Institute of Technology

Objective(s)

The objective of this task is to support the US FAA's engagement with ICAO CAEP AFTF in a number of additional areas, including the development of sustainability criteria and policy and feasibility assessment of ICAO's climate change goals.

Research Approach

Alternative jet fuels might have to satisfy some sustainability considerations other than CO_2 reductions, which are to be defined by AFTF during CAEP/11. MIT will assist to identify the environmental, social and economic aspects that should be taken into account. In addition, we will contribute to this effort over the coming year by collaborating on a review and comparison of existing sustainability frameworks.

MIT will also contribute to the task group working on developing guidance for policies to encourage deployment of alternative jet fuels.

Finally, MIT will carry out an analysis to put international aviation emissions, including emissions from alternative jet fuels, into the context of international climate change goals. These goals may include keeping average global temperature change below some threshold, such as 2°C, or a global carbon budget of 1,000 billion tonnes. This task is particularly relevant because, while alternative jet fuels may reduce aviation's contribution to climate change, the technologies may also shift some of the emissions burden to other sectors or industries, such as agriculture or fuel production. This is an important feedback that has not yet been considered for aviation in the context of global climate change targets.

Milestone(s)

These specific tasks fall under the work plan for AY 2016/2017. Therefore, the major milestones for this work will occur in the next period.

Major Accomplishments

These specific tasks fall under the work plan for AY 2016/2017. Therefore, the major accomplishments for this work will occur in the next period.

Publications

None.

Outreach Efforts

None.

Awards

None.

Student Involvement

This work will be carried out by Mark Staples and Cassandra Rosen. Mark completed his PhD at MIT in December 2016, but will continue working on this project as a post-doctoral researcher. Cassandra is a continuing masters student at MIT.

Plans for Next Period

Please see the task description above under "Research Approach".

AY 2016/2017 Task 4 – Long-term production and GHG emissions' reduction potential of alternative jet fuel in the US

Massachusetts Institute of Technology

Objective(s)
The objective of this task is to assess the long-term production potential of alternative jet fuel in the US.

Research Approach
This research will use a three step analysis that considers: the availability of primary bioenergy constrained by the physical limits of agro-climatic conditions, bio-productivity, environmental sustainability and socio-economic conditions; the proportion of potentially available bioenergy that could actually be produced on the basis of feedstock economics; and the proportion of produced bioenergy dedicated to the production of alternative jet fuels as opposed to other potential uses. This analysis will leverage the modeling framework developed for the Fuel Production Assessment carried out during CAEP/10. Whereas the previous modeling and analysis was carried for a global scope, the work carried out during the coming year will be focused on the US.

In addition to fuel volumes, this analysis will also provide a high-level estimate of the greenhouse gas (GHG) emissions reductions associated with different scenarios of alternative jet fuel deployment in the US context, including both attributional life cycle GHG emissions and emissions from land use change (LUC). The analysis will use an additional approach for the quantification of LUC emissions, meaning that all bioenergy feedstock cultivation is assumed to be additional to future projected land uses in the US, and therefore there are LUC emissions associated with all alternative jet fuels derived from cultivated energy crops. This was the method employed for the CAEP/10 AFTF Fuel Production Assessment, and the advantage of this approach is that it can be used to quantify the trade-off between increased alternative jet fuel volumes, and increased emissions from LUC.

Milestone(s)
This task falls under the work plan for AY 2016/2017. Therefore, the major milestones for this work will occur in the next period.

Major Accomplishments
These specific tasks fall under the work plan for AY 2016/2017. Therefore, the major accomplishments for this work will occur in the next period.

Publications
None.

Outreach Efforts
None.

Awards
None.

Student Involvement
This work will be carried out by Timothy Galligan. Timothy is a continuing masters student at MIT.

Plans for Next Period
Please see the task description above under "Research Approach".

AY 2016/2017 Task 5 – Economic and environmental assessment of alternative jet fuels accounting for the potential for technology maturation

Massachusetts Institute of Technology

Objective(s)

The objective of this task is to provide an assessment of the economic and environmental viability of alternative jet fuels, accounting for time- and path-dependency of technology maturation.

Research Approach

This is an important aspect to consider because a number of long-term trends suggest that the economic and environmental performance of alternative jet fuels, relative to petroleum-derived jet fuels, may change over time. For example, a growing proportion of non-conventional crude oil production is anticipated to be required to meet new demand for liquid fuels (ExxonMobil 2014), and jet derived from non-conventional crude oil has a higher GHG footprint than conventional petroleum-derived jet fuel: 19% and 39% higher for jet fuel derived from Canadian oil sands and oil shale, respectively (Stratton et al. 2011). As a result, alternative jet fuels' GHG footprint may become smaller relative to petroleum-derived jet fuels.

In addition, empirical data from the Brazilian sugarcane ethanol industry indicate that learning-curve effects contributed to a 29% reduction in cost for every doubling of cumulative production (Goldemberg et al. 2004), implying the potential for similar effects for analogous alternative jet fuel production processes. Some of these cost reductions are likely attributable to improved process efficiencies, which also imply the potential for improvements in life cycle GHG performance of alternative jet fuels as a function of cumulative fuel production.

In order to achieve these learning-curve effects some rate of alternative jet fuel production is required in order to accumulate experience, and this suggests endogeneity and path-dependence associated with the development and performance of alternative jet fuels production technologies. This research project will use a system dynamics modeling approach to quantify the changes in the environmental and economic performance of alternative jet fuels, taking into account the time- and path-dependence of technology development and maturation. This task will include an assessment of alternative jet fuel adoption rates and associated emissions impacts that are required to get from 2020 to 2050 estimates of alternative jet fuel use generated by AFTF under CAEP/10.

Milestone(s)

This task falls under the work plan for AY 2016/2017. Therefore, the major milestones for this work will occur in the next period.

Major Accomplishments

These specific tasks fall under the work plan for AY 2016/2017. Therefore, the major accomplishments for this work will occur in the next period.

Publications

None.

Outreach Efforts

None.

Awards

None.

Student Involvement

This work will be carried out by Mark Staples. Mark completed his PhD at MIT in December 2016, and will continue to work on this as a post-doctoral researcher.

Plans for Next Period

Please see the task description above under “Research Approach”.

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