Project 001(F) Alternative Jet Fuel Supply Chain Analysis

Massachusetts Institute of Technology

Project Lead Investigators

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University Participants

Massachusetts Institute of Technology (MIT)

- P.I.: Professor Steven R. H. Barrett; co-P.I.s: Dr. Florian Allroggen, Dr. Raymond Speth
- FAA Award Number: 13-C-AJFE-MIT, Amendment Nos. 003, 012, 016, 028, 033, 040, 048, 055, 058, 067, 082, 088, and 096
- Period of Performance: August 1, 2014 to September 19, 2023
- Tasks (for reporting period October 1, 2021 to September 30, 2022):
    1. Support U.S. participation in the International Civil Aviation Organization Committee on Aviation Environmental Protection (ICAO CAEP) to enable appropriate crediting of the use of sustainable aviation fuels (SAFs) under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)
    2. Support U.S. participation in the ICAO CAEP by performing core life-cycle analysis (CLCA) to establish default values for use under CORSIA
    3. Contribute to the development of the fuel production assessment for CORSIA-eligible fuels
    4. Develop methods for probabilistic life-cycle analyses and techno-economic analyses in the context of assessing U.S.-based SAF production
    5. Support knowledge sharing and coordination across all ASCENT Project 01 universities working on SAF supply-chain analyses

Hasselt University (UHasselt, through subaward from MIT)

- P.I.: Professor Robert Malina
- Period of Performance: September 1, 2016 to August 31, 2023
- Tasks (for reporting period October 1, 2021 to September 30, 2022):

1. Support and provide leadership for U.S. participation in ICAO CAEP to enable appropriate crediting of the use of SAFs under CORSIA, particularly as it relates to feedstock classification and pathway definitions
2. Support U.S. participation in ICAO CAEP by performing CLCA to establish default values for use under CORSIA
3. Contribute to the development of fuel production assessment for CORSIA-eligible fuels

Project Funding Level

This project received $4,035,000 in FAA funding and $4,035,000 in matching funds. The sources of the match are approximately $632,000 from MIT, plus third-party in-kind contributions of $809,000 from Byogy Renewables, Inc.; $1,038,000 from Oliver Wyman Group; $1,155,000 from NuFuels, LLC; and $401,000 from Savion Aerospace Corporation. Funding is reported for the entire period of performance indicated above.

Investigation Team

Principal Investigator:	Prof. Steven Barrett (MIT) (all MIT tasks)
Principal Investigator (UHasselt Subaward):	Prof. Robert Malina (UHasselt) (all UHasselt tasks)
Co-Principal Investigator:	Dr. Florian Allroggen (MIT) (all MIT tasks)
	Dr. Raymond Speth (MIT) (Task 4)
Co-Investigators:	Dr. Sergey Paltsev (MIT) (Task 3)
	Dr. Jennifer Morris (MIT) (Task 3)
Postdoctoral Associates:	Christoph Falter (MIT) (Task 3)
	Freddy Navarro Pineda (UHasselt) (all UHasselt tasks)
Research Specialist:	Matthew Pearlson (MIT) (Tasks 2 and 4)
Graduate Research Assistants:	Tae Joong Park (MIT) (Task 1, 2 and 4)
	Sarah Demsky (MIT) (Task 4)

Project Overview

The overall objectives of ASCENT Project 01 (A01) are to (a) derive information on regional supply chains to explore scenarios for future SAF production and (b) identify supply-chain-related obstacles to commercial-scale production in the near term and to larger-scale adoption in the longer term. For the reporting period, the MIT/UHasselt team contributed to these goals by (a) providing leadership in the International Civil Aviation Organization Committee for Aviation Environmental Protection (ICAO CAEP) CLCA Task Group of the Fuels Task Group (FTG), which is mandated to calculate life-cycle greenhouse gas (GHG) emissions associated with the use of SAF, (b) performing core life-cycle GHG emissions analyses to enable the inclusion of additional SAF pathways under CORSIA or verify CLCA values calculated by other institutions, (c) contributing to SAF availability assessments, (d) analyzing U.S.-produced SAF potential and their life-cycle emissions and costs, including options to further reduce the environmental footprint of SAFs, and (e) contributing to knowledge transfer in the ASCENT 01 team.

Task 1 - Support and Provide Leadership for U.S. Participation in ICAO CAEP to Enable Appropriate Crediting of the Use of SAFs under CORSIA, Particularly as it Relates to Feedstock Classification and Pathway Definitions

Massachusetts Institute of Technology
Hasselt University

Objectives

The overall objective of this task is to provide leadership for, and support to, the FAA in its engagement with the ICAO CAEP FTG (during CAEP/12 and CAEP/13). The specific focus of the work during this reporting period was (a) to support preparation of FTG papers for submission to the CAEP/12 meeting; (b) to help define the FTG work program for CAEP/13; (c) to update feedstock classifications and the list of pathways to be considered for CLCA; and (d) to provide guidance on the inclusion of power-to-liquid (PtL) fuels in CORSIA.

Research Approach

To achieve the goals outlined above, the team continued to co-lead the CLCA Task Group of the FTG. Prof. Malina acted as a co-lead. This role ensures that Prof. Malina remains a focal point of CLCA research, so that specific research tasks can be guided efficiently and effectively. The following research has been conducted in support of the leadership role:

Prepare for CAEP/12 and define the work program for CAEP/13

The UHasselt and MIT worked closely with the FAA and other FTG members to (a) prepare FTG input to the CAEP/12 meeting and (b) to define and review the work program for the CAEP/13 cycle. The main goal of the team was to ensure that the tasks reflect the current state of the art in SAF research, are in line with existing methods and concepts of FTG, and are defined sufficiently.

Update feedstocks and pathways

The UHasselt and MIT team worked with the CLCA subgroup to update and prioritize the list of feedstock-to-fuel pathways, and to assign lead modeling groups for each of the pathways that were set to be the priority. The team also provided support to FTG regarding feedstock classification, including guidance for CORSIA-approved sustainability certification schemes. Guidance has been made publicly available through CORSIA online ("Frequently Asked Questions," 2023). Finally, the team worked with other FTG experts in agreeing upon a definition for PtL fuels (see below).

Guidance on including PtL fuels

During CAEP/13, FTG was tasked with developing an actual-value method for PtL fuels. The MIT and UHasselt team are co-leading this effort through collaboration among the CLCA, Sustainability, and induced land-use change (ILUC) subgroups within FTG. During the reporting period, the team worked toward capturing a range of potential conversion technologies which use electricity as a significant input (Figure 1). The definition covers not only "pure PtL" pathways, which use hydrogen made from low-carbon electricity and CO_2 captured from the atmosphere or from industrial point sources, but also more conventional SAF production pathways using hydrogen from electrolysis.

Because electricity is a major input in the production of CORSIA-eligible fuels, its characteristics must be assessed. Most importantly, the source of electricity can substantially influence the life-cycle GHG emissions of the fuel (Figure 2). At the same time, electricity produced from low-carbon and high-carbon sources cannot physically be distinguished, particularly if the fuel production facility is connected to an electricity grid fed by multiple sources. Therefore, an approach for tracing the electricity used for fuel production is required. In addition, electric power generation, particularly from low-carbon sources, can be intermittent, thus prompting questions regarding how electricity sourcing or storage strategies can meet the demand of a fuel production process at a particular time, despite meeting annual average electricity requirements (Figure 3). Finally, because electricity is used in substantial quantities for SAF production, concerns regarding competing uses of electricity and a need for load balancing must be considered.

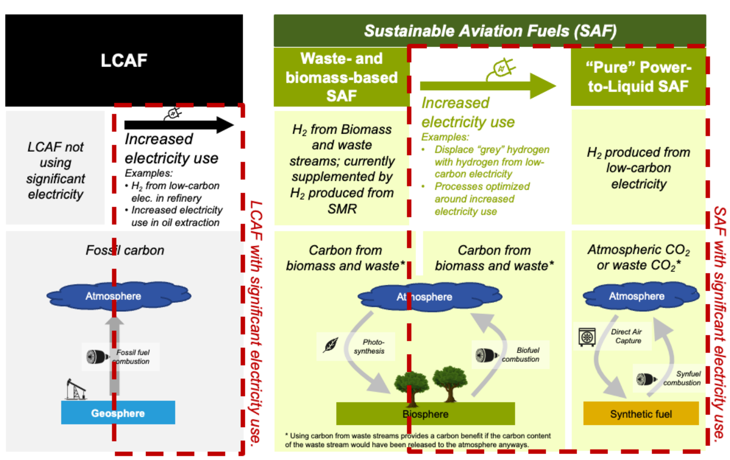

Figure 1. Production of CORSIA-eligible fuels using significant electricity inputs.

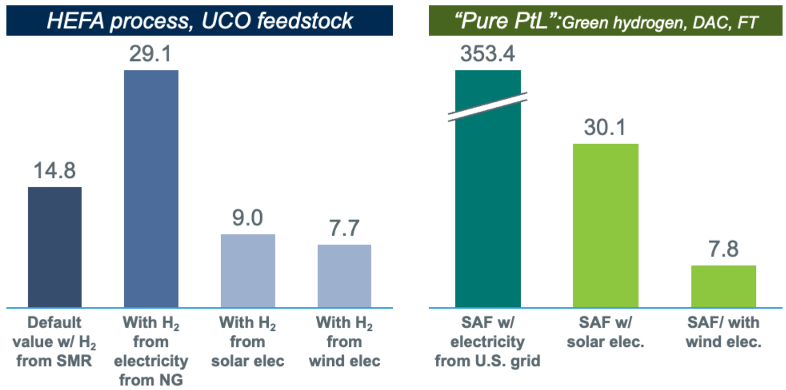

Figure 2. Electricity-based SAF production using a hydroprocessed esters and fatty acids (HEFA) pathway with used cooking oil (UCO) (left) or a "pure PtL" pathway using electrolytic hydrogen, CO_2 from direct air capture and Fischer–Tropsch conversion (right). Different hydrogen sources include steam methane reforming (SMR) and electrolytic hydrogen using different electricity sources, including natural gas (NG), solar photovoltaic, and wind electricity.

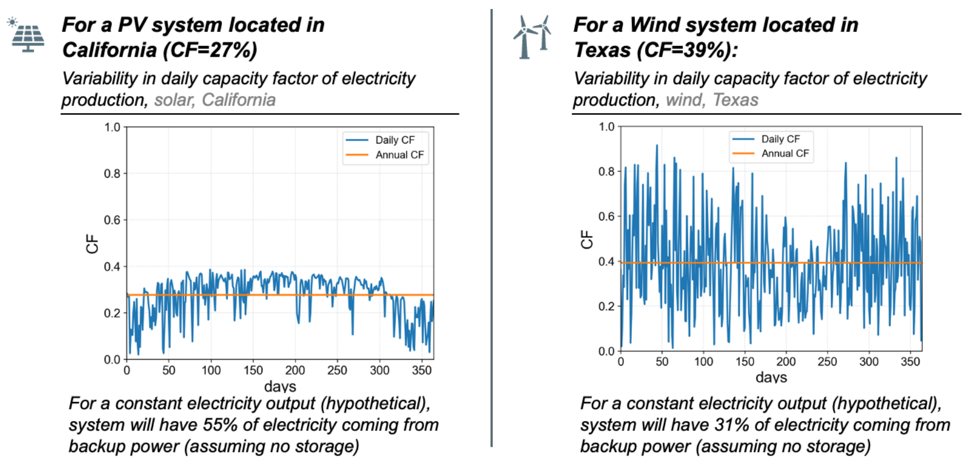

Figure 3. Impact of intermittency in solar- and wind-based electricity production on electricity availability in Texas and California. CF is the capacity factor, which reflects the availability of electricity.

Milestones

UHasselt and MIT have brought forward analyses to support progress in the areas outlined above. The results have been presented to FTG during FTG meetings and numerous subgroup and expert meetings. Most importantly, UHasselt and MIT experts participated in, and contributed to, numerous FTG meetings, including CAEP12_FTG/11 (October 2021), CAEP13_FTG/01 (May 2022), and CAEP13_FTG/02 (October 2022) (see manuscripts below).

Major Accomplishments

The MIT and UHasselt team accomplished the following under this task:

1. As co-lead of the FTG CLCA Task Group, Prof. Malina drafted CLCA progress reports for FTG meetings, where CLCA topics were discussed. In addition, Prof. Malina co-led several Task Group meetings.
2. The team helped shape preparation of the CAEP/12 meeting and contributed to the preparation of the CAEP/13 work program for FTG.
3. The MIT team led the development of CORSIA life-cycle analysis (LCA) methods for fuels requiring significant electricity input. The team worked with technical experts on identifying the fuel pathways, which rely on electricity input. Furthermore, the key issues for analysis have been identified, and further work has been scoped accordingly.

Publications

CAEP/12-FTG/11-WP/05. Summary of the work on the core LCA group since FTG/03, October 2021.
CAEP/13-FTG/01-WP/04: Core LCA approach for the tasks of the CAEP/13 cycle, May 2022.
CAEP/13-FTG/02-WP/03: Summary of the progress of the core LCA subgroup on Task S.06 and S.17, October 2022.
CAEP/13-FTG/02-WP/04: Proposed path forward on CORSIA eligible fuels (CEF) using significant electricity inputs, October 2022.
CAEP/13-FTG/02-WP/14: Actual value method for CORSIA eligible fuels (CEF) using Significant electricity inputs, October 2022.
CAEP/13-FTG/02-FL/02: Core LCA pathway discussions, October 2022.
CAEP/13-FTG/02-FL/03: Flowchart threshold, October 2022.

Outreach Efforts

Progress on these tasks was communicated during weekly briefing calls with the FAA and other U.S.-delegation members to FTG, as well as during numerous FTG teleconferences between meetings. In addition, UHasselt and MIT experts participated in, and contributed to, FTG meetings, including CAEP12_FTG/11 (October 2021), CAEP13_FTG/01 (May 2022), and CAEP13_FTG/02 (October 2022).

Student Involvement

During this reporting period, the MIT graduate student involved in this task was TJ Park.

Plans for Next Period

In the coming year, the MIT/UHasselt ASCENT Project 01 team will continue its work in FTG. Default CLCA values will be calculated and proposed for additional pathways. Prof. Malina will continue to lead the CLCA Task Group. A particular focus will be on helping to develop the actual-value method for calculating the LCA values for fuels requiring substantial electricity inputs. Close collaboration with technical experts in the ILUC and Sustainability subgroups will be pursued.

References

Frequently asked questions. (n.d.). Retrieved February 7, 2023, from
https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-FAQs.aspx

Task 2 - Support U.S. Participation in ICAO CAEP by Performing CLCA to Establish Default Values for Use Under CORSIA

Massachusetts Institute of Technology
Hasselt University

Objective

During the CAEP/11 and CAEP/12 cycle, the MIT ASCENT Project 1 team took leadership in applying the agreed-upon CLCA method to establish default CLCA values for CORSIA-eligible fuels. However, the list of pathways is not exhaustive, and further CLCA analysis is required to enable the inclusion of SAF technologies nearing commercialization. During the current reporting period, the team supported (a) an in-depth analysis of the impact of biomass-based process fuels on default CLCA values; and (b) initial analyses toward the establishment of CLCA values for Fischer–Tropsch co-processing of lipid bio-feedstocks, catalytic thermolysis, and hydroprocessed hydrocarbon (HC)–hydroprocessed esters and fatty acids (HEFA)–synthetic paraffinic kerosene (SPK).

Research Approach

Analysis of the impacts of biomass-based process fuels on CLCA values

The GHG-emission mitigation potential of the inclusion of biomass-based energy to meet the heat and power requirements of SAF conversion was explored. For this purpose, the team modeled the GHG emissions associated with heat and electricity production in a range of SAF conversion stages. For the replacement scenarios, the life-cycle inventory for the cultivation and transportation of poplar was used, with emissions from the combustion of poplar taken from the Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) model. Although the emissions do not depend on how the resulting energy from the biomass combustion is harnessed, they are adjusted according to conversion efficiencies. Heat generation and power generation were assumed to have 90% and 40% efficiency, respectively, thus depicting scenarios using highly efficient technologies. Biomass-based heat and energy production was then implemented with SAF conversion processes by using the CORSIA calculation tool based on GREET v2.8 (2019). The electricity required in other stages of SAF production was assumed to be provided by the grid with a GHG-emission intensity factor equal to that for the United States. In total, four energy scenarios were defined, representing the different combinations for integrating biomass-based energy into the SAF conversion process (Table 1). The first scenario represents the current baseline and does not consider any inclusion of biomass-based energy. In contrast, Scenario 4 represents the full inclusion of biomass-based energy to meet power and heat requirements. Scenarios 2 and 3 capture biomass-based heat or electricity use, respectively.

Table 1. Definition of the short-term SAF production scenarios.

Energy scenario	Use of electricity from the grid	Use of natural gas	Remarks
1	Yes	Yes	Reference scenario (default LCA values without ILUC)
2	No	Yes	Effect of natural gas
3	Yes	No	Effect of electricity from the grid
4	No	No	Combined biomass-based energy integration

The avoided GHG emissions associated with the inclusion of biomass-based energy into the conversion stage are shown in Table 2. Because the Fischer-Tropsch (FT) and Synthesized Isoparaffins (SIP) pathways are self-sufficient in terms of energy requirements, they are not affected by the inclusion of biomass-based energy. For all other pathways, the GHG mitigation potential of the inclusion of the biomass-based electricity is <3 g CO_{2e}/MJ_{SAF}, with the exception of ethanol alcohol-to-jet (ATJ)- or isobutanol ATJ-based SAF production using corn grain (GHG mitigation potential of 6–7 g CO_{2e}/MJ_{SAF}). In comparison, the GHG-emission reduction potential of biomass-based heat production is high for almost all SAF production pathways, reaching 30 g CO_{2e}/MJ_{SAF}.

Table 2. Avoided GHG emissions due to the inclusion of biomass-based energy in the SAF conversion stage. Data are in g CO_2e/MJ_{SAF}.

	Fossil energy source	1	2	3	4
	Electricity	💡	🌲	💡	🌲
	Natural gas	🔥	🔥	🌲	🌲
Pathway	**Feedstock**				
HEFA	*Brassica carinata*	0.00	1.40	7.13	8.53
	Corn oil	0.00	0.50	4.66	5.16
	Palm fatty acid distillate	0.00	1.00	5.60	6.60
	Palm oil	0.00	0.87	4.70	5.57
	Rapeseed/canola	0.00	1.45	7.60	9.05
	Soybean	0.00	1.53	7.67	9.19
	Tallow	0.00	0.60	6.97	7.58
	Used cooking oil (UCO)	0.00	0.60	6.97	7.58
Ethanol ATJ	Agricultural residues	0.00	2.96	19.37	22.34
	Corn grain	0.00	6.78	24.03	30.81
	Forest residues	0.00	2.57	14.13	16.71
	Miscanthus	0.00	2.57	11.59	14.16
	Switchgrass	0.00	2.57	11.59	14.16
	Sugarcane	0.00	0.00	0.00	0.00
Isobutanol ATJ	Agricultural residues	0.00	0.01	5.87	5.88
	Corn grain	0.00	6.18	20.84	27.01
	Forest residues	0.00	0.01	3.04	3.05
	Miscanthus	0.00	0.58	9.89	10.47
	Sugarcane	0.00	0.00	1.33	1.33
	Switchgrass	0.00	0.02	9.31	9.32
FTJ	Corn Stover	0.00	0.00	0.00	0.00
	Forest residues	0.00	0.00	0.00	0.00
	Miscanthus	0.00	0.00	0.00	0.00
	MSW	0.00	0.00	0.00	0.00
	Switchgrass	0.00	0.00	0.00	0.00
	Wheat Straw	0.00	0.00	0.00	0.00
SIP	Sugarcane	0.00	0.00	0.00	0.00
	Sugarbeet	0.00	0.00	0.00	0.00

Evaluation of Fischer–Tropsch co-processing, catalytic thermolysis, and HC-HEFA-SPK
Work has been initiated to obtain the necessary data for the modeling of these pathways from producers. For the catalytic hydrothermolysis pathway, a first-order LCA was conducted.

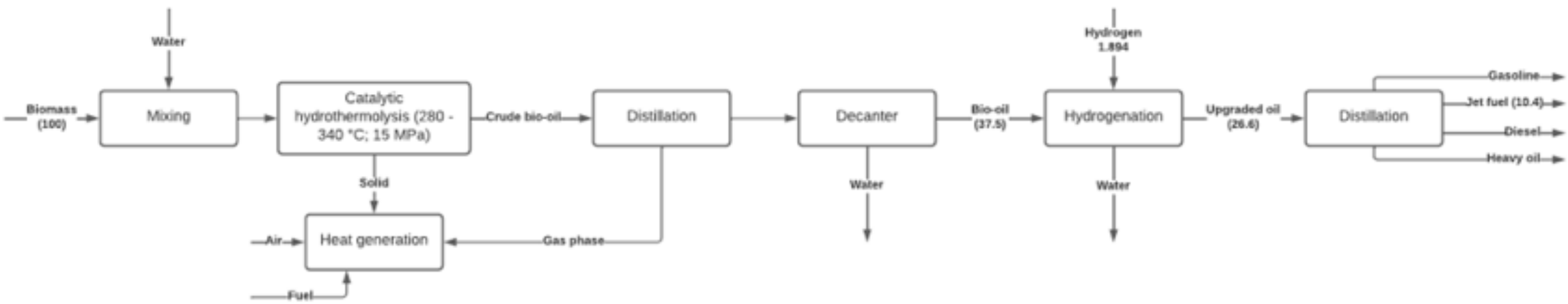

Figure 4. Flowchart of the catalytic hydrothermolysis pathway.

As shown in Figure 4, the catalytic hydrothermolysis pathway transforms biomass into bio-oil by using hot pressurized water (at 280–340˚C and 15 MPa). Publicly available data are limited regarding the mass and energy balances of the process. The life-cycle GHG emissions of SAF production via catalytic hydrothermolysis have been estimated to fall between 17 and 43 g CO_2eq/MJ_{SAF}.

Milestones
The work described above has been documented in working papers and information papers submitted to FTG. Furthermore, the team discussed the work outlined above with various technical experts. UHasselt and MIT experts participated in, and contributed to, the FTG meetings held during the reporting period, including CAEP12_FTG/11 (October 2021), CAEP13_FTG/01 (May 2022), and CAEP13_FTG/02 (October 2022).

Major Accomplishments
The MIT and UHasselt team accomplished the following under this task:

1. The team finished a comprehensive assessment of the quantitative impact of the inclusion of process biomass fuels on life-cycle GHG emissions of different SAFs.
2. The team developed a first assessment of new pathways to be considered for CLCA analysis in the future.
3. The team published a journal publication on the CORSIA default values (see below).

Publications
Peer-reviewed journal publications
Prussi, M., Lee, U., Wang, M., Malina, R., Valin, H., Taheripour, F., Velarde, C., Staples, M. D., Lonza, L., & Hileman, J. I. (2021). CORSIA: The first internationally adopted approach to calculate life-cycle GHG emissions for aviation fuels. *Renewable and Sustainable Energy Reviews*, *150*, 111398. doi: 10.1016/j.rser.2021.111398

Written reports
CAEP/12-FTG/11-WP/05. Summary of the work on the core LCA group since FTG/03, October 2021.
CAEP/13-FTG/01-WP/04: Core LCA approach for the tasks of the CAEP/13 cycle, May 2022.

Outreach Efforts
Progress on these tasks was communicated during weekly briefing calls with the FAA and other U.S.-delegation members to FTG, as well as during numerous FTG teleconferences between meetings. In addition, UHasselt and MIT experts participated in, and contributed to, FTG meetings, specifically CAEP12_FTG/11 (October 2021), CAEP13_FTG/01 (May 2022), and CAEP13_FTG/02 (October 2022). Professor Malina also presented the default CLCA values at the 2022 FAA AEC Emissions Roadmap meeting in May 2022.

Plans for Next Period

The team will continue to perform attributional CLCA to establish default values for use under CORSIA. More specifically, the team expects to support efforts to determine CLCA values for mixed animal fat HEFA, mixed animal fat co-processing, and FT co-processing. The team will also conduct a comprehensive local sensitivity analysis to understand the sensitivity of the CLCA default values to changes in input parameters. This process will guide FTG in defining requirements for different types of SAF to qualify under a certain default value.

Task 3 - Contribute to the Development of the Fuel Production Assessment for CORSIA-eligible Fuels

Hasselt University
Massachusetts Institute of Technology

Objective

The team aimed to contribute to the development of the fuel production assessment for CORSIA-eligible fuels to the year 2035, on the basis of detailed information gathered in a fuel production database. The data were further extrapolated to the year 2050. During the reporting period, the team worked jointly with researchers from Washington State University to finalize fuel production estimates for the long-term aspirational goal (LTAG) report, including the availability of fuels from biomass and waste streams, as well as waste CO_2 sources and atmospheric CO_2 (direct air capture). For the latter pathways, detailed modeling was developed under ASCENT Project 52.

Research Approach

The research team maintains a short-term projection database of publicly available production announcements from companies planning to produce SAFs over the next 5 years. Using this database, and a set of criteria and assumptions, the team modeled a short-term SAF production ramp-up under five production scenarios (low, moderate, high, high+, and max). These scenarios differed with respect to the types of companies included, the maturity of the production plans, and the assumptions concerning product slate and the success rates of the announced production plans. The resulting ramp-ups from each scenario were taken as a starting point to forecast SAF production to 2035, assuming a diffusional approach, which was then extended to 2050. For fuels that leverage waste CO_2 sources from industrial installations and from direct air capture, electricity-based SAF production via the Fischer–Tropsch process with hydrogen produced from low-carbon electricity via electrolysis was considered. The availability of renewable electricity and CO_2 sources are modeled as factors limiting the availability of these SAFs.

The scenarios were combined to obtain insights into the scale-up curves for SAF production. The results (Figure 5) indicate that, even in the most favorable scenarios, neither biofuels nor PtL alone could fully displace conventional jet fuel by 2050. In contrast, a combination of both technologies would enable full replacement by 2045 (in the most optimistic case). Regarding total emissions, using either technology alone would leave the aviation industry with annual emissions of at least 300 Mt/year because of limited scale-up potentials and residual emissions. A combination of both fuel pathways with emphasis on PtL production could minimize emissions. We note that the combined potential of biofuels and PtL exceeds the maximum jet fuel demand in 2050 under the moderate and high scenarios. If preference were given to biomass-based SAFs (covering the remaining volumes with PtL-based SAFs), the net emissions would reach 265–709 Mt CO_2eq. In contrast, if preference were given to PtL-based SAFs, the net emissions would reach 218–350 Mt CO_2eq.

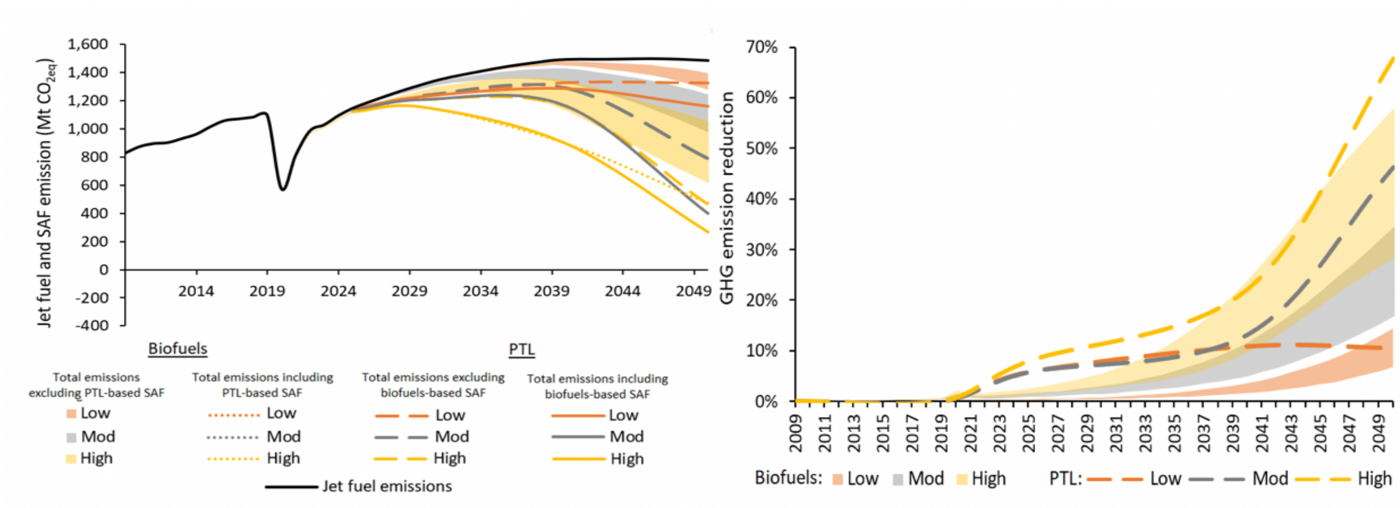

Figure 5. GHG emissions of the aviation industry (left) using SAFs, and SAF decarbonization potential (right) under the analyzed scenarios.

Milestone
Both the SAF production scenarios and the fuel production scenarios for fuels produced from waste CO_2 and atmospheric CO_2 provide the scientific basis for the fuel availability assessments under LTAG.

Major Accomplishments
The team developed comprehensive scenarios of future availability of SAFs and provided the data as input to LTAG. The results were included in the LTAG report.

Publications
Written reports

ICAO (2022). *Report on the Feasibility of a Long-term Aspirational Goal (LTAG) for International Civil Aviation CO_2 Emission Reductions*. https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx

Outreach Efforts
Progress on these tasks was communicated during weekly briefing calls with the FAA and other U.S.-delegation members to FTG, as well as during numerous FTG and LTAG teleconferences. Results have been included in the LTAG report and are regularly presented as part of the results.

Plans for Next Period
The team will continue to update scenarios and projections as needed.

Task 4 - Develop Methods for Probabilistic Life-cycle Analyses and Probabilistic Techno-economic Analyses of SAFs
Massachusetts Institute of Technology

Objective
Analysis of the potential for U.S.-based SAF production

Work conducted under this project in previous reporting periods has shown that the availability of biomass may limit biomass-based SAF production in the United States. During the current reporting period, the team aimed to understand pathways for increasing SAF supply, including expanding land use for biomass production, rerouting existing biomass production, and decoupling SAF production from bioenergy supply through PtL pathways. The rerouting of biomass production was specifically considered for ethanol. As electric cars are adopted in the United States, the demand for ethanol from the road sector is expected to decrease, thereby offering additional potential for SAF production.

Analysis of approaches for reducing the carbon footprint of U.S.-based SAF production

Under the SAF Grand Challenge, the minimum reduction in life-cycle GHG emissions for SAF volumes to be counted against the goals of the challenge is a 50% (89 gCO_2e/MJ to 44.5 gCO_2e/MJ) (DOE, 2022). As shown in the current CORSIA default life-cycle emissions assessments, many fuels might not meet this target (Figure 6). The team analyzed potential levers for reducing the life-cycle GHG emissions of different pathways and worked toward understanding the maximum decarbonization potential of SAFs while considering process innovation. Such an analysis not only is important for the SAF Grand Challenge but also supports the long-term ambitions of the aviation sector to reach net-zero CO_2 emissions.

Research Approach

Analysis of potentials of U.S.-based SAF production

Previous studies performed by this team have shown that the United States might not be able to produce sufficient biomass for meeting 2035 U.S. jet fuel demand with bio-based SAFs through expanding agricultural land use, because of limited land availability and suitability. During this reporting period, the team analyzed whether additional pastureland conversion could mitigate these concerns. According to the analysis, approximately 40% of existing pastureland in the United States would need to be converted to cropland to produce sufficient energy crops. Such a conversion is possible under aggressive assumptions for pastureland requirements.

Another approach for meeting the demand could rely on rerouting ethanol from road transportation into SAF production. In the most optimistic biomass availability scenario, an additional 10.5 billion gallons of ethanol would be needed to meet 2035 jet fuel demand. In 2021, the United States produced a total of approximately 17.5 billion gallons of ethanol; therefore, approximately 60% of the total ethanol production would be needed to close the gap in SAF production.

The team also assessed how PtL-based SAFs could help increase SAF supply. According to a preliminary assessment assuming current technology, the cost of such a scenario would be very high. However, future process innovation could make such a strategy more realistic.

Analysis of approaches for reducing the carbon footprint of U.S.-based SAF production

Because the SAF Grand Challenge focuses on the United States, the team initially analyzed SAF production by using feedstocks grown in North America, specifically soybean, rapeseed/canola, camelina, carinata (*Brassica carinata*), and corn. Figure 6 shows the considered pathways as well as their associated CLCA, ILUC, and total life-cycle emissions (LSf) CO_2e values published under the CORSIA default values. As shown, SAFs from HEFA soybean and rapeseed, and from ATJ and ethanol-to-jet (ETJ) corn grain currently may not qualify for the SAF Grand Challenge target of 44.5 gCO_2e/MJ. SAFs from HEFA camelina and carinata already meet the SAF Grand Challenge target because of negative ILUC values. Similarly, HEFA corn has an ILUC value of zero, because the corn oil from DDGS is considered a by-product (ICAO, 2022B). We note that the default values presented here reflect default assumptions; individual producers might have implemented innovations to reduce the life-cycle GHG emissions of their processes.

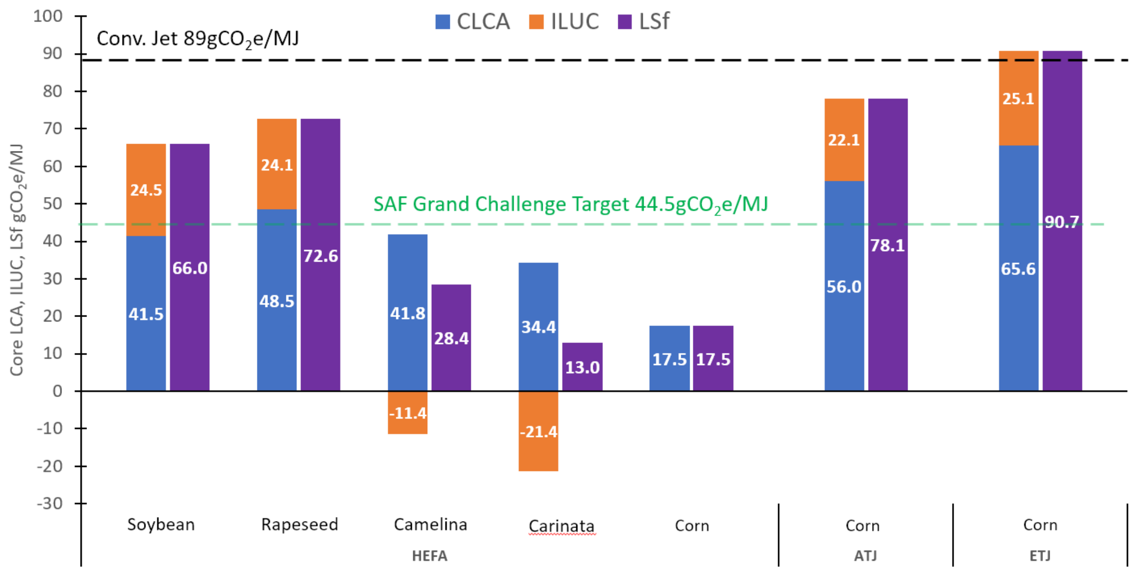

Figure 6. CORSIA default values for CLCA, ILUC, and LSf for HEFA, ATJ, and ETJ fuels from North American agricultural feedstocks. Note that individual producers might have introduced process innovations to reduce life-cycle GHG emissions.

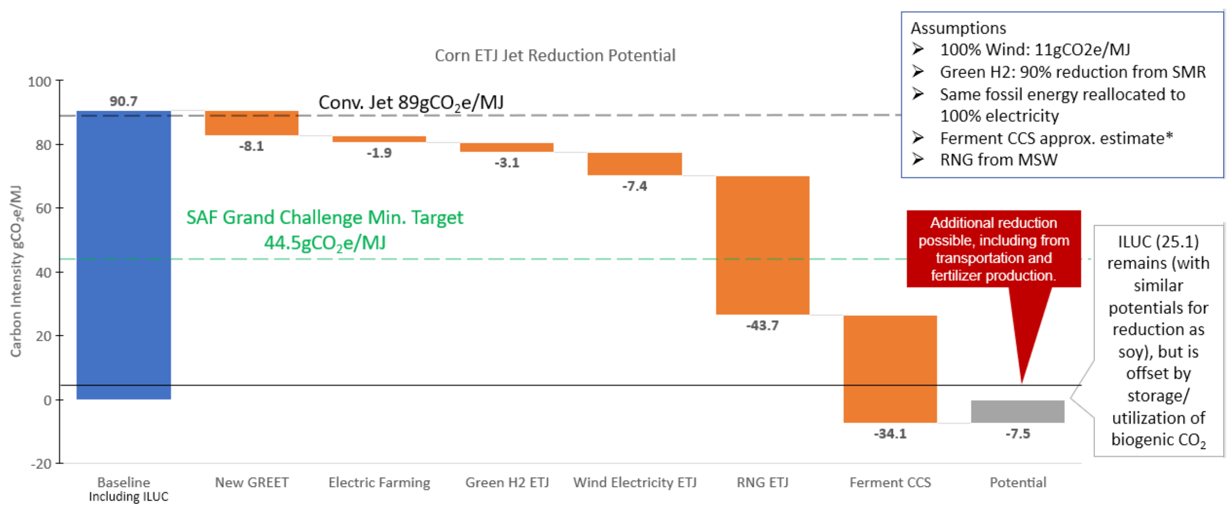

Figure 7. Corn grain ethanol-to-jet potential CO_2 reductions from the current CORSIA LSf value.

The team then analyzed how the soybean- and corn-based processes could be optimized to reduce GHG emissions. The corn grain ETJ process and the HEFA soybean process were considered for that purpose.

Through detailed analysis, the following approaches for GHG emissions savings were identified for the corn ETJ process (Figure 7):

1. Natural gas combustion: The default values for the corn ETJ process were calculated with GREET 2011. Assuming improved technology, lower emission factors for natural gas handling and combustion (Argonne National Laboratory, 2022) can be used, thus leading to an emissions saving of 8.1 gCO_2e/MJ.
2. Electric farming: If all fossil fuel use in farming is replaced with electric energy (e.g., electric tractors), a 1.9 gCO_2e/MJ reduction can be achieved if the electricity is sourced from 100% wind energy (emissions factor of 11 gCO_2e/MJ).

3. Hydrogen use: If all H_2 used in the fuel conversion process is sourced from electrolysis using 100% wind electricity (instead of steam methane reformation), a 3.1 gCO_2e/MJ life-cycle GHG emissions reduction can be achieved.
4. Electricity use: If the U.S. grid electricity used in the fuel conversion step is replaced by 100% wind electricity, 7.4 gCO_2e/MJ can be eliminated from the life-cycle GHG emissions.
5. Heat production: If all fossil natural gas use in the fuel conversion stage is replaced with renewable natural gas sourced from municipal solid waste, a savings of 43.7 gCO_2e/MJ is achievable.
6. Carbon capture: If biogenic CO_2 emissions from the ethanol fermentation step is captured and permanently stored, the life-cycle GHG emissions of the fuel can be reduced by 34.1 gCO_2e/MJ reduction (Spaeth, 2021).

Together, if all these measures are implemented, the corn ETJ process could be brought to negative life-cycle GHG emissions at −7.5 gCO_2e/MJ of SAF. Further reductions could be achieved, for example by including green fertilizer, by decarbonizing feedstock and fuel transportation, or by applying agricultural practices that decrease ILUC emissions. These reductions would allow SAFs from the ETJ process to not only meet the SAF Grand Challenge qualification target but also be compatible with the aviation sector's long-term decarbonization ambitions.

A similar analysis was conducted for the HEFA soybean process (Figure 8). The analysis shows that the LSf value of the process could be reduced to 35.9 gCO_2e/MJ (including ILUC), thereby meeting the SAF Grand Challenge qualification target. Again, additional reductions would be possible from green fertilizer, decarbonized transport of feedstock and fuel, and low land use change farming practices. However, the emissions reductions of this process are inherently limited, partly because of the emissions associated with the growing cycle of the soybean plant itself.

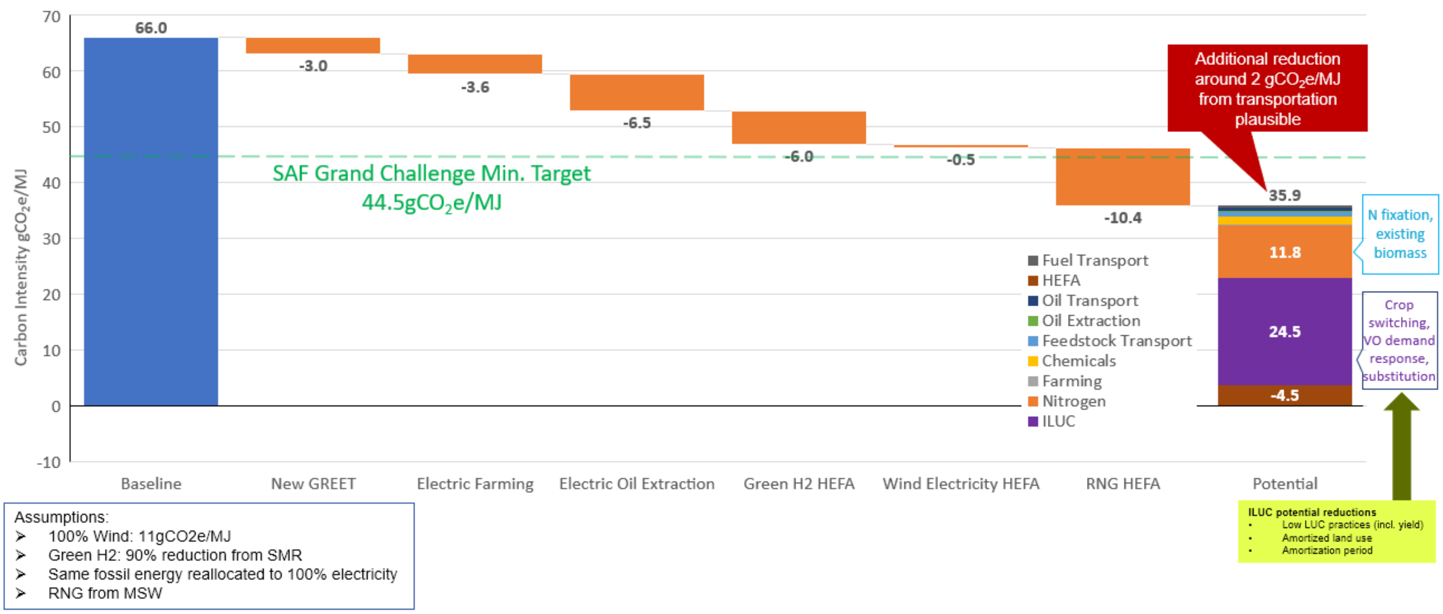

Figure 8. HEFA soybean SAF potential CO_2 reductions from the current CORSIA LSf value.

Milestone

A baseline analysis has been completed and is being prepared for publication in the scientific literature. The SAF Grand challenge analysis of life-cycle emissions has been completed.

Major Accomplishments

First presentation of results and discussion with stakeholders.

Publications

None.

Outreach Efforts
MIT presented the work under this task to the ASCENT 1 Team meeting in May 2022 and to the ASCENT Fall meeting in October 2022.

Student Involvement
The MIT graduate students involved in this task were Sarah Demsky and TJ Park.

Plans for Next Period
MIT will continue to apply and refine the regional stochastic modeling, specifically focusing on PtL as well as cover crops and double-cropping. In addition, together with WSU, MIT will assess the costs of optimized SAF production pathways.

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Task 5 - Support Coordination of All A01 Universities' Work on SAF Supply Chain Analyses
Massachusetts Institute of Technology

Objective
The objective of this task is to provide support for coordination of all ASCENT Project 1 (A01) universities' work on SAF supply chain analysis. The sharing of methods and results decreases the replication of A01 universities' work on similar topics.

Research Approach
The MIT A01 team performed several functions to accomplish this task. Specifically, the team:

- Participated in the bi-weekly A01 coordination teleconferences, which served as a venue to discuss progress in various grant tasks and learn about the activities of other ASCENT universities, and also presented current research on co-processing to the A01 universities
- Contributed to efforts for developing a special journal issue on SAFs, based on the research conducted under A01

Milestone
The MIT ASCENT A01 team presented current research to other ASCENT universities.

Major Accomplishments
The major accomplishments associated with this task include participation in bi-weekly A01 coordination teleconferences; presentation of current research to other ASCENT universities; and contribution to the development of a journal special issue.

Publications
None.

Outreach Efforts
See above.

Awards
None.

Student Involvement
None.

Plans for Next Period
Continued engagement in bi-weekly teleconferences and other events to disseminate MIT's A01 work.