Project 001(C) Alternative Jet Fuel Supply Chain Analysis

Purdue University

Project Lead Investigator: October 1, 2018–August 15, 2019

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University Participants: October 1, 2018–August 15, 2019

Purdue University

- PI: Wallace E. Tyner, James and Lois Ackerman Professor
- FAA Award Number: 13-C-AJFE-PU
- Period of Performance: July 14, 2014 to August 15, 2019
- Task(s):
  1. **Lead: Tyner; supported by graduate students** – Develop stochastic techno-economic models for relevant pathways and identify key stochastic variables to be modeled for assessing risk in conversion pathways. This work will lead to a capability to compare pathways and their expected economic cost, plus the inherent uncertainty in each pathway.
  2. **Lead: Tyner; supported by Taheripour, Sajedinia, and Malina (Hasselt University)** – Life-cycle analysis (LCA) of alternative jet fuel pathways, in coordination with the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) Alternative Fuels Task Force (AFTF) and Fuels Task Group (FTG). Work with the CAEP/AFTF/FTG LCA group on issues such as system boundaries, induced land-use change (ILUC), LCA methodology, and pathway greenhouse gas (GHG) emissions assessment.
  3. **Lead: Tyner; supported by Taheripour, and Sajedinia** – Develop estimates of emissions associated with land-use change for alternative jet fuels for the ICAO AFTF. This task is closely related to Task #2,
  4. **Lead: Tyner** – **P**rovide support for the other ASCENT universities on analysis of aviation biofuel policy.
  5. **Lead: Tyner** – Provide support for the Farm to Fly initiative as needed.

University Participants: August 16, 2019–September 30, 2019

Purdue University

- PI: Farzad Taheripour, Research Associate Professor
- FAA Award Number: 13-C-AJFE-PU
- Period of Performance: July 14, 2014 to September 30, 2019
- Task(s):

1. **Lead: Farzad Taheripour; supported by Chepeliev and graduate student** – Develop stochastic techno-economic models for relevant pathways and identify key stochastic variables to be modeled for assessing risk in conversion pathways. This work will lead to a capability to compare pathways and their expected economic cost, plus the inherent uncertainty in each pathway.
2. **Lead: Taheripour; supported by Sajedinia, Aguiar, and Malina (Hasselt University)** – LCA of alternative jet fuel pathways, in coordination with ICAO CAEP/FTG. Work with the CAEP/FTG LCA group on issues such as system boundaries, ILUC, LCA methodology, and pathway GHG emissions assessment.
3. **Lead**: **Taheripour; supported by Sajedinia and Aguiar** – Develop estimates of emissions associated with land-use change for alternative jet fuels for the ICAO AFTF. This task is closely related to Task #2,
4. **Lead: Taheripour** - Provide support for the other ASCENT universities on analysis of alternative jet fuel policy.

Project Funding Level

- Amendment 3: $250,000
- Amendment 6: $110,000
- Amendment 10: $230,000
- Amendment 15: $373,750
- Amendment 19: $400,000
- Amendment 29: $400,000

Current cost sharing for this project year was from Oliver Wyman.

Investigation Team

Wallace E. Tyner: PI until August 15, 2019, James and Lois Ackerman Professor, Purdue University
Farzad Taheripour: PI since August 16, 2019, Research Associate Professor, Purdue University; involved in several aspects of the project, particularly LCA and land-use change
Xin Zhao: PhD student, Purdue University (graduated and left Purdue); stochastic techno-economic analysis (TEA) and Global Trade Analysis Project (GTAP) ILUC analysis
EhsanReza Sajedinia: PhD student, Purdue University; stochastic TEA and GTAP ILUC analysis
Jeremiah Stevens: MS student, Purdue University (graduated December 2019 and will continue to work for the project as a consultant); stochastic TEA
Maksym Chepeliev: PhD Research Associate, GTAP Center, Purdue University (collaborates part time in the project)
Angel H. Aguiar: PhD Research Associate, GTAP Center, Purdue University (collaborates part time in the project)
Note: Wallace E. Tyner passed away August 17, 2019

Project Overview

This project has five main components. First is the advancement of stochastic TEA for aviation biofuel pathways. Second is LCA and production-potential analysis of alternative jet fuel pathways in coordination with ICAO/AFTF/FTG. The third component also involves working with ICAO/AFTF/FTG, specifically on estimating the emissions associated with land-use change for alternative jet fuels. The fourth component is to provide support for the policy subgroup in AFTF/FTG and to bridge the existing TEA for alternative jet fuels with partial and general equilibrium economic models to develop alternative scenarios for including alternative jet fuels in the mixed fuel used by the industry and to provide policy guidelines to facilitate expansion of the use of sustainable aviation fuels. The fifth component is providing support for Farm to Fly 2.0, a collaboration between government and industry to enable commercially viable, sustainable alternative jet fuel supply chains in the United States at the state and regional levels that are able to support the goals of an alternative jet fuel production capacity of 1 billion gallons and use by 2019. To support this effort, Purdue provides necessary analytical support in this process.

Task 1 - Develop Stochastic Technoeconomic Models for Relevant Pathways and Identify Key Stochastic Variables for Assessing Risk in Conversion Pathways

Purdue University

Objective(s)
Develop stochastic techno-economic models for relevant pathways and identify key stochastic variables to be modeled for assessing risk in conversion pathways. This work will lead to a capability of comparing pathways and their expected economic cost, plus the inherent uncertainty in each pathway.

Research Approach
For each fuel pathway being evaluated, we developed a stochastic model covering the entire pathway, to allow for use in both TEA and LCA. Over this period, we evaluated alcohol-to-jet and catalytic hydrothermolysis processes. We have also developed some new approaches to stochastic TEA.

Milestone(s)
We developed a new a stochastic TEA for a plant designed to use catalytic hydrothermolysis technology to produce renewable diesel fuel, renewable jet fuel, and renewable naphtha from pennycress oilseed. Beyond the standard stochastic practices, this TEA takes uncertainty in biofuel policies into account and highlights the existing policies that can be altered to support production of alternative jet fuels. This research shows that with proper policies in place, producing alternative jet fuels could be commercially viable in the near future. This research has been fully and successfully conducted, and we continue to publish the related results.

Beyond the TEAs, we are now collecting and reviewing the existing TEAs on alternative jet fuels to summarize and synthesize their findings, advantages, and limitations. The results of this work will help us bridge the TEA approach with a modeling framework that aims to develop a supply schedule for alternative jet fuels. We developed a template to collect information from the existing TEAs, and we are in the process of filling in this template. We collected data from the literature and the ASCENT experiments and are awaiting information from the MIT TEA cases.

Major Accomplishments
See the Publications section below.

Publications
Written Reports

Two papers are under development from the TEA of pennycress to jet fuel:

1. Stevens, J., Taheripour, F., & Tyner, W.E. A stochastic techno-economic analysis of aviation biofuel production from pennycress oilseed.
2. Stevens, J., Taheripour, F., & Tyner, W.E. Policy recommendations to expand production of aviation biofuels: lessons from a TEA.

Outreach Efforts
Tyner attended a meeting of the Civil Aviation Alternative Fuels Initiative (CAAFI) and made presentations on the economic availability of feedstock for alternative jet fuels. The meeting was in Washington, DC on December 3–7, 2018.

Awards
None.

Student Involvement
Jeremiah Stevens: MS student, Purdue University; graduated in December 2019 and will collaborate with the project until August 2020

Plans for Next Period
We plan to continue the work on the case of producing alternative jet fuels from pennycress oilseed for the following reasons, with the aim of publishing the results of this research. We will repeat the new stochastic TEA method in analysis of the case of carinata to determine the sensitivity of this approach with respect to feedstock. We will study the existing TEAs to summarize and synthesize their findings, advantages, and limitations, and will use them to develop an aviation supply function. Finally, the review of the existing TEAs will help us determine the gaps in this research area and define priorities for future research in this field.

Task 2 - LCA of Alternative Jet Fuel Pathways in Coordination with ICAO-AFTF-FTG

Purdue University

Objective(s)

- Provide required data and analysis to support the low-land-use-change risk practices adopted in CAEP
- Provide required data and analysis to support the core LCA group with respect to ILUC for coprocessing of esters and fatty acids in petroleum refineries and other tasks as needed

Research Approach

There are many varied assignments and components in this task. For LCA, working with other team members, we use standard approaches for consequential LCA. For system boundaries, we have investigated the consequences of different approaches to defining system boundaries. For estimating ILUC, we use the GTAP-BIO model and have modified it to improve land allocation and represent more jet fuel pathways. We have developed new data sets to rank countries according to their likely ILUC potentials. We have collaborated with the Technology, Policy, and Production (TPP) subgroup as well.

- Tyner was co-chair of the AFTF/FTG ILUC group.
- Tyner was working with Dr. Brad Saville on low risk for ILUC.
- Tyner was working with the TPP and other subcrops.
- Taheripour will co-chair the FTG ILUC group.
- Taheripour will work with Dr. Brad Saville on low risk for ILUC.
- Taheripour will work with other FTG/TPP and other subgroups

Milestone(s)

Tyner participated in the FTG1 meetings in Montreal in May 2019. Taheripour, Chepeliev, and Aguiar participated in the FTG2 meeting in Montreal in September 2019. Tyner and Taheripour have been involved in many tasks and document-preparation activities for the meetings. They responded to other subgroups' requests for help and collaboration. They led the efforts on ILUC modeling efforts and the ILUC-related tasks associated with other subgroups. We developed a framework to examine regional ILUC and to rank countries according their land-use-change determinants. We collected data on land-use-change determinants and developed a primary analysis.

Major Accomplishments

Helped design the next-step properties of the TPP subgroups.

Publications

See the list for Task #3.

Outreach Efforts

Taheripour attended the CRC meeting and made a presentation on regional land-use-change values. The meeting was in Argonne National Laboratory, Lemont, IL on October 15–17, 2019.
Taheripour attended the ASCENT Advisory Group Meeting and made a presentation on limiting deforestation from palm oil in Malaysia and Indonesia. The meeting was in Washington, DC on October 22–23, 2019.

Awards

None.

Student Involvement

EhsanReza Sajedinia: PhD student, Purdue University.

Plans for Next Period

- We will continue to support TPP, LCA, and other subgroups,
- See Plans for Next Period for Task 3.

Task 3 - Develop Estimates of Emissions Associated With Land-Use Change for Alternative Jet Fuels for the ICAO Alternative Fuels Task Force

Purdue University

Objective(s)

- Compute ILUC emissions of alternative jet fuels for use in CORSIA
- Improve the GTA-BIO model and its database and make proper modifications in the AEZ-EF emissions model
- Define and implement a method to determine regional ILUC values and rank countries according to their land-use-change determinants.

Research Approach

We modify, update, and use the GTAP-BIO model to produce estimates of ILUC for AFTF/FTG. We also collaborate with IIASA and Hugo Valin to evaluate the outcomes of GTAP-BIO and GLOBIOM models. We collect data and develop new approaches to assess issues related to ILUC emissions due to production of alternative jet fuels.

Milestone(s)

We added several new pathways to the GTAP-BIO model. We examined new regional ILUC values. We developed primary analyses to rank countries according to their land-use-change determinants.

Major Accomplishments

Most of the accomplishments under this task are in the form of work progress of ICAO/CAEP/AFTF. Some of the working papers and information papers that we have produced over this period are listed in this section and in the overall publication list at the end of this report.

Publications

Written Reports

Several working papers and information papers have been produced for the AFTF/FTG work. Below, we present only a few items produced in recent months, since August 15, 2019. We have not included reports submitted by late professor Wallace E. Tyner from October 2018 to August 15, 2019.

- CAEP/12-FTG/02-IP/03: Land Use Change Emission Accounting in GLOBIOM and GTAP-BIO. Montreal, September 2019.
- CAEP/12-FTG/02-WP/08: Progress Report from the ILUC Subgroup. Montreal, September 2019.
- CAEP/12-FTG/02-WP/15: ILUC Permanence. Montreal, September 2019.
- CAEP/12-FTG/02-WP/09: Potential Methodology for the Fuel Production Evaluation Task. Montreal, September 2019.
- CAEP/-SG/20191-WP/09: Progress on Development of LCA Values. Johannesburg, December 2019.
- Comments on: CAEP-SG/20194-WP Indonesia Observations on Result of LCA. Johannesburg, December 2019.

In addition to the above reports, the following papers are already published or in press:

- Taheripour, F., & Tyner, W. (in press). US biofuel production and policy: Implications for land use changes in Malaysia and Indonesia. *Biotechnology for Biofuels*.
- Taheripour, F., Zhao, X., Horridge, M., Farrokhi, F., & Tyner, W. (in press). Modeling land use in computable general equilibrium models: preserving physical area of land. *Journal of Global Economic Analyses*.
- Zhao, X., van der Mensbrugghe, D., Keeney, R., & Tyner, W. (2020). Improving the way land use change is handled in economic models. *Economic Modeling*, 84,13-26. https://doi.org/10.1016/j.econmod.2019.03.003

Taheripour also published the following related paper with no reference to FAA support:

- Taheripour, F., Hertel, T., & RamanKutty, N. (2019). Market-mediated responses confound policies to limit deforestation from oil palm expansion in Malaysia and Indonesia. *PNAS*, 1903476116.

Outreach Efforts

Tyner attended a CAAFI meeting and made presentations on ILUC values for alternative jet fuels. The meeting was in Washington, DC on December 3–7, 2018.

Taheripour attended several meetings to present the research outcomes on ILUC values, including the following:

- National Biodiesel Conference & Expo, San Diego, California, January 21–24, 2019
- GTAP 22nd Annual Conference on Global Economic Analysis, University of Warsaw, Warsaw, Poland, June 2019
- 2019 AAEA Annual Meeting, Atlanta, July 2019

Awards
None.

Student Involvement
EhsanReza Sajedinia: PhD student, Purdue University

Plans for Next Period
We will continue working with ICAO on ILUC emission estimates including the following highlights:

- The current model uses a database representing the world economy in 2011. We plan to update this database to 2014. This is a major task and new development.
- We will work to develop regional ILUC values.
- We are in the process of developing a method to rank countries according to their land-use-change-determinant factors.
- We are now working on values for direct land-use change.

Task 4 - Provide Support for the Other ASCENT Universities on Alternative Jet Fuel Policy Analysis
Purdue University

Objective
Provide support for the other ASCENT universities on alternative jet fuel policy analysis.

Research Approach
We are developing spreadsheet models of various pathways incorporating risk analysis. The output of the risk analysis is the distribution of net present value, the internal rate of return, and the probability that the investment will lose money. Being able to provide a distribution of financial outputs is immensely valuable to private-sector investors and other parties. The analysis outputs can also be used to help target future research to areas in which the research outcomes could be expected to have high payoff. We have been working with WSU on stochastic TEA and expect in the next year to work with WSU, PSU, and universities in Hawaii and Tennessee on stochastic TEA and risk analysis. More recently, we made several efforts to harmonize the TEA across the active research groups on TEA for alternative jet fuels, including their components and underlying assumptions. We have developed a new approach to take uncertainty in biofuel policies into account.

Any of the stochastic TEAs can be used with policy overlays to conduct evaluations of alternative policy options. The stochastic models can also be used to examine the effects of alternative feedstock contracting mechanisms for feedstocks without effective hedging alternatives available, such as the cellulosic feedstocks or new lipids such as those from pennycress oilseed. We have worked with the ICAO/AFTF policy subgroup to develop such policy case studies.

Milestone(s)
See Task 1.

Major Accomplishments
See Task 1.

Publications
N/A

Outreach Efforts
N/A

Awards
None.

Student Involvement
Jeremiah Stevens: MS student, Purdue University; graduated in December 2019 and will collaborate with the project until August 2020

Plans for Next Period
In collaboration with ASCENT, we are collecting and reviewing the exiting TEAs on alternative jet fuels and their feedstocks. This effort will help us evaluate what we have learned to date and what we need to accomplish in the future. It also will help us develop a supply schedule for alternative jet fuels by feedstock and conversion technology, and to define and outline alternative policies that can be used to encourage expansion of alternative jet fuels.

Task 5 - Provide Support for the Farm to Fly Initiative as Needed
Purdue University

Objective
Provide support for the Farm to Fly initiative as needed.

Research Approach
This activity is a general support for other initiatives. Our main role is to consult with researchers involved in other projects and activities and provide assistance as needed.

Milestone(s)
There has been little activity under this task in this reporting period.

Major Accomplishments
N/A

Publications
N/A

Outreach Efforts
N/A

Awards
None.

Student Involvement
None.

Plans for Next Period
We will continue to be available to support other projects and universities as needed in regional and national analysis related to Farm to Fly.