Project 001(A) Alternative Jet Fuel Supply Chain Analysis

Washington State University

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- FAA Award Number: 13-C-AJFE-WaSU-023, 026
- Period of Performance: February 5, 2020 to September 30, 2021
- Task(s):
    1. WSU 1. Design cases. Garcia-Perez, Zhang
    2. WSU 2. Evaluate the most promising biorefinery concepts for alternative jet fuel (AJF) production. Garcia-Perez, Zhang
    3. WSU 3. Supplement and maintain the current inventory of biorefinery infrastructures that are useful for the production of AJF, as identified in the conversion design cases. Wolcott
    4. WSU 4. Perform a community social asset assessment. Gaffney
    5. WSU 5. Refine and deploy facility siting tools to determine regional demand and to identify potential conversion sites to be used in regional analyses. Wolcott
    6. WSU 6. Perform a refinery-to-wing stakeholder assessment. Gaffney
    7. WSU 7. Conduct a supply chain analysis. Wolcott, Garcia-Perez
    8. WSU 8. Provide analytical support for regional Commercial Aviation Alternative Fuels Initiative (CAAFI) and U.S. Department of Agriculture (USDA) jet fuel projects. Wolcott

Project Funding Level

$1,091,455 in FAA funding and $1,091,455 in matching funds. State-committed graduate school contributions for four PhD students. Faculty time for Michael Wolcott, Manuel Garcia-Perez, and Xiao Zhang contributes to the cost share.

Investigation Team

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Project Overview

As part of an effort to realize an "aviation system in which air traffic will move safely, swiftly, efficiently, and seamlessly around the globe," the FAA has set a series of goals and supporting outcomes, strategies, and performance metrics (Hileman et al., 2013). The goal entitled "Sustaining our Future" outlines several strategies collectively aimed at reducing the environmental and energy impacts of the aviation system. To achieve this goal, the FAA set an aspirational goal for the aviation industry to utilize 1 billion gallons of AJF by the year 2018. This goal was created according to economic, emissions, and overall feasibility perspectives (Richard, 2010; Staples et al., 2014).

Current approaches to the supply chain analysis for AJF optimize the feedstock-to-refinery and refinery-to-wing transportation logistics (Bond et al., 2014). One of the greatest barriers to large-scale AJF production is the high capital of greenfield facilities, which translates to risk in the investment community (Huber et al., 2007). The cost of cellulosic ethanol plants ranges from $10 to $13 per gallon capacity (Hileman and Stratton, 2014); moreover, the additional processing steps required to convert the intermediate to a drop-in AJF could increase this cost to more than $25 per gallon capacity (Hileman, 2014).

Motivated by the realities of converting these initial commercialization efforts into second-generation AJF, researchers have considered alternative conversion scenarios, including the transitioning of existing facilities (Brown, 2013). Currently, Gevo is using retrofitting strategies for corn ethanol plants to produce isobutanol, a potential intermediate for the alcohol-to-jet (ATJ) process of producing iso-paraffinic kerosene (Pearlson, 2011; Pearlson et al., 2013). Research on approaches for achieving the FAA's aspirational goal of AJF consumption has relied on "switching" scenarios, in which the existing and planned capacity are used to produce drop-in fuel (Malina, 2012). These approaches require the identification of existing industrial assets that can be targeted for future AJF production. Thus, siting becomes not only an exercise for optimizing feedstock transportation but also a necessary task for aligning this critical factor with the existing infrastructure, markets within regions, and the appropriate social capital for developing this new industry (Henrich et al., 2007; Seber et al., 2014).

To date, all published AJF supply chain analyses have been limited to stand-alone jet fuel production technologies that do not generate bio-products. Hence, the potential techno-economic and environmental benefits of using the existing industrial infrastructure and the production of coproducts with respect to the development of jet fuel production scenarios must be considered in future studies.

Design cases of stand-alone AJF production facilities will be used in supply chain evaluations. Social asset modeling is not well developed, and efforts are likely to be hampered by difficulties in quantifying social assets when compared to improved environmental performance or reductions in AJF costs, which may be better observed by optimizing economic and environmental constraints. However, the community characteristics of a potential site must be considered when determining preferred locations for a new biorefinery. Community resistance or enthusiasm for the AJF industry can strongly influence the success or failure of a facility (Martinkus et al., 2014; Rijkhoff et al., 2017). Thus, community social asset modeling efforts conducted within this project, such as those based on the Community Asset and Attribute Model (CAAM), will inform disciplinary applications and advances. Clearly, social factors can have substantial effects, either positive or negative, on project adoption and implementation, particularly in high-technology or energy-related projects (Lewis et al., 2012; Martinkus et al., 2012; Mueller et al., 2020). The consideration of social factors in site selection and implementation decisions can maximize positive social support and minimize opposition and social negatives, thereby substantially promoting the success of a project. In this regard, the CAAM originally piloted in the Northwest Advanced Renewables Alliance (NARA) project was designed to provide a quantitative rating of select social factors at the county level (Martinkus et al., 2014).

Focusing on regional supply chains, this research aims to identify the key barriers that must be overcome to produce one billion gallons of AJF. We will address this overall goal by developing tools to support the AJF supply chain assessment performed at the Volpe Center. Our effort will provide facility siting analyses that assess conversion design cases combined with regional supply chain assets and social capacity assessments for communities to act collectively toward development goals. Finally, a refinery-to-wing stakeholder assessment will support modeling and accounting of AJF distribution for downstream fuel logistics.

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Task 1 - Design Cases

Washington State University

Objective(s)

In previous years, our team has worked toward completing the reviews and final reports of design cases for six stand-alone AJF technologies (Table 1) and four relevant industries (sugarcane, pulp and paper, corn ethanol, and petroleum refineries). The status of each stand-alone AJF techno-economic analysis (TEA) and report is shown in Table 1. The results on pyrolysis and ATJ pathways have been published in the referenced peer-reviewed journals. The work conducted from October 1, 2019 to September 30, 2020 focused on the following tasks:

1. Conduct a detailed analysis of a "catalytic hydrothermolysis pathway for jet fuel production"
2. Conduct a detailed analysis of a new AJF pathway for hydrothermal liquefaction (HTL) processing
3. Conduct TEA analyses on the integration of lignin coproduct technologies in the ATJ pathway to determine the potential for reducing fuel costs
4. Develop a new case report, focusing on a technology review and an evaluation of lipid conversion processes (HEFA, CH, SBI, Forge, Tyton, and decarboxylation) and new technologies for the production of alternative lipids (HTL and sugar-to-lipid)
5. Prepare manuscripts for publication

Table 1. Evaluated stand-alone AJF technologies.

	Literature review and design report date	Publications	TEA model
Pyrolysis	Literature review based on a design report, 138 pages (2017)	*Energy Fuel 33*, 4683, 2019; *Fuel Process Technology 195*, 106140, 2019	A standardized TEA is complete and available for use by university partners.
Alcohol-to-jet (ATJ)	Literature review based on a design report, 28 pages (2015)	*ChemSusChem 11*, 3728, 2018	A standardized TEA is complete and available for use by partners.
Synthetic kerosene and synthetic aromatic kerosene (SK-SKA)	Literature review based on a design report, 36 pages (2015)	Manuscript based on the case design report in preparation	This work was based on a Sasol process, on which we have not found any significant development since 2016. Because of a lack of adequate process information/data on SK-SKA production from renewable feedstock, we are not able to build a reliable TEA.
Direct sugar-to-hydrocarbon (DSHC)	Literature review based on a design report, 88 pages (2017)	Manuscript that includes DSHC submitted and under review by *Biomass and Bioenergy*	A standardized TEA is complete and available for use by partners.
Virent BioForming process	Literature review based on a design report, 46 pages (2015)	Manuscript that includes Virent submitted and under review by *Biomass and Bioenergy*	A standardized TEA is complete and available for use by partners.
Catalytic hydrothermolysis (CH)	Literature review based on a design report, 35 pages (2018)	Manuscript submitted for journal publication	A standardized TEA is complete.
Gasification Fischer Tropsch (GFT)	No literature review conducted	Manuscript that includes GFT submitted and under review by *Biomass and Bioenergy*	A standardized TEA is complete and available for use by partners.
Microchannel gasification Fischer Tropsch (microGFT)	No exhaustive literature review written; capital costs found in the open literature for microchannel FT deemed unreliable	Capital cost results deemed unreliable	A standardized microGFT TEA was completed; however, the cost information is considered unreliable.
Hydroprocessed esters and fatty acids (HEFA)	No written literature review conducted	Manuscript that includes HEFA submitted and under review by *Biomass and Bioenergy*	A standardized TEA is complete and available for use by partners.

Research Approach

Background

We have conducted a detailed literature review and prepared design case reports on six AJF pathways, including pyrolysis, ATJ, synthetic kerosene and synthetic aromatic kerosene, direct sugar-to-hydrocarbon (DSHC), Virent BioForming, and catalytic hydrothermolysis (CH). We have also collected data from the literature to conduct techno-economic analyses (TEAs) for these pathways. The results from these design cases are being applied in the development of supply chains and the identification of synergisms that may eventually lead to the construction of integrated AJF production systems that take advantage of the infrastructure in a given region. An analysis of the locations of existing infrastructure demonstrated that the United States can be divided into regions according to the dominant biomass. Thus, we believe that the generation of advanced biorefinery concepts focused on petroleum refineries, pulp and paper mills, sugarcane mills, and corn ethanol mills is a viable approach for evaluating the synergism among AJF pathways, existing infrastructure, and coproducts. We can then compare the biorefinery concepts developed for each technology to identify the most promising approach, which will then be used in supply chain analyses.

Stand-alone design case reports were generated by conducting reviews of relevant research in the academic literature and public information provided by commercial entities developing the corresponding technology. The published papers were subjected to an industrial expert review. The reports provide details regarding the processes involved in each conversion pathway and outline the technology readiness and particular barriers to implementation. Publicly available information regarding the commercial processes and research literature will provide a foundation of information to be used in modeling efforts. In cases lacking detailed process engineering information, new models will be built to estimate the parameters needed to complete assessments such as techno-economic modeling and supply chain modeling. Aspen Plus is primarily used to generate process models and details, including mass balances, energy balances, energy requirements, and equipment size and cost. These results will also provide the basis for a comparative analysis of design cases, which will identify the key advantages and markets for each technology.

Each design case has the following components:

1. Feedstock requirements
2. Companies developing/commercializing the technology
3. Current locations of units in the United States and worldwide
4. Block and flow diagram of the technology
5. Unit operations and process conditions (reactor type, separation unit type, catalysts, product yield, and jet fuel yield)
6. Properties of the produced jet fuel
7. Identification of potential intermediates
8. Current and potential uses of wastes and effluents
9. Developed coproducts
10. Potential methods for coprocessing intermediates, wastes, and coproducts by using existing infrastructure (e.g., petroleum refineries, or pulp and paper mills)
11. Preliminary TEA
12. Technological challenges and gaps

We have submitted technical reports and supplementary Microsoft Excel files with mass and energy balances and TEAs for the pathways listed below. Furthermore, we have conducted a strategic analysis to identify the overall weaknesses of the technologies under study. All files are available on shared drives for the Project 01 team members. Where indicated, the TEAs are still undergoing internal review.

- Pyrolysis-bio-oil hydro-treatment concept (hydro-treated depolymerized cellulosic jet): The TEA is complete.
- ATJ: A manuscript with information on the mass and energy balances and the TEA has been published.
- Gasification Fischer Tropsch (GFT): Two design cases have been prepared for biomass gasification. The first case focuses on microreactors, and the second design case is applicable to technology based on larger, standard reactors (reviews on the TEAs for GFT and microGFT have been completed). However, the limited reliability of the microreactor capital costs hinders the value of the practical impact of our microreactor TEA study. The TEAs are available for use by partners.
- HEFA: A stochastic TEA was created in MATLAB and was confirmed to match the completed, deterministic TEA when the assumptions and costs match (deterministic TEA review completed). The TEA is now available for use.
- CH: The TEA is complete.

We have submitted a manuscript to *Biomass and Bioenergy* comparing the economic and environmental performance of the AJF technologies discussed above and the overall weaknesses of the technologies studied. This manuscript presents a strategic analysis of the yield increases needed to achieve a minimum selling price (MSP) comparable to those of current commercial fuels. Over the past year, we have also made progress in design cases for existing industries (corn ethanol and sugarcane mills) that could be used to reduce the production cost of AJFs. The analyses are complete.

Major progress has been made on the analysis of corn ethanol, sugarcane, and petroleum refinery infrastructure that could support jet fuel production. A manuscript on the conversion of corn ethanol mills is under review by *Biomass and Bioenergy*. Two additional manuscripts using either sugarcane mills or petroleum refineries to reduce AJF production costs are under internal review.

We have worked with the Pacific Northwest National Laboratory (PNNL) and completed a case design report on HTL for AJF conversion.

A summary report on several lipid conversion pathways, including SBI, Forge, Tyton, decarboxylation, and coprocessing, has been prepared. A manuscript entitled "Techno-economic Analysis of the CH Pathway for Jet Fuel Production" was reviewed by Agrisoma (now NuSeed) and the FAA, before submission for journal publication in September 2020.

Milestone(s)

A Microsoft Excel file with TEAs for all AJF technologies has been completed, and design cases for the corn ethanol and sugarcane industries are still being reviewed by the standardization team. A detailed analysis entitled "Catalytic Hydrothermolysis Pathway for Jet Fuel Production" has been completed, and a design case report entitled "Jet Fuel Design Case: Hydrothermal Liquefaction Case Design Report" has been completed. A summary report entitled "Lipid and Bio-processing Technologies: Process Intensification and Continuous Flow-Through Reaction (PICFTR), Lipid-to-Hydrocarbon (LTH), Tyton, Decarboxylation and Co-processing" has been produced, and manuscripts have been prepared for publication.

Major Accomplishments

A manuscript entitled "Comparison of Techno-economic and Environmental Performance of Alternative Jet Fuel Production Technologies" has been prepared and reviewed. Another manuscript entitled "Economic Analysis of Catalytic Hydrothermolysis Pathway for Jet Fuel Production" has been submitted for journal publication. "Hydrothermal Liquefaction Case Design Report" has been updated in preparation for FAA review. We intend to submit these manuscripts to the FAA for review within the next four months. We are working on the construction of a TEA for lignin extraction and utilization in a biorefinery process (National Renewable Energy Laboratory [NREL] biochemical conversion, https://www.nrel.gov/docs/fy19osti/71949.pdf).

An article detailing the impact of coproducts on the financial viability of a forest-residue-based ATJ process was published in *Biofuel, Bioproducts and Biorefining*. A companion manuscript that details the combined effect of siting and repurposing industrial facilities with multiple levels of capital cost avoidance on the economic viability of AJF is being written, and submission for internal review is expected in late 2020.

We have assisted the International Civil Aviation Organization (ICAO), Committee on Aviation Environmental Protection (CAEP) through participation in the Fuel Task Group (FTG). The ASCENT HEFA, ATJ, and GFT TEAs have been revised, streamlined, and generalized for use by scientists and non-scientists worldwide. The TEAs can be modified to reflect local costs and feedstocks. The TEAs were used to develop a "Rules of Thumb" or a heuristic approach for estimating capital requirements and relative fuel costs from these technologies. This output is compiled in both a Microsoft Word document and Microsoft Excel spreadsheet formats. These documents illustrate the influence of key variables in AJF costs: yield, capital expenditure (CAPEX), feedstock price, and conversion technology maturity.

Data generated from the design cases have been made available to A01 partners to assist with supply chain analysis and techno-economic modeling by improving the conversion and cost figure database values. Evaluations of the effects of process variations on the chemical properties of the generated products are being used to provide insight into the challenges that will be faced when AJFs are blended into commercial jet fuel.

Publications

Peer-reviewed journal publications

Brandt, K.L., Wooley, R.J., Geleynse, S.C., Gao, J., Zhu, J., Cavalieri, R.P., Wolcott, M.P. (2020). Impact of co-product selection on techno-economic analyses of alternative jet fuel produced with forest harvest residuals. BioFPR, 14(4):764-775.

Geleynse, S., Jiang, Z., Brandt, K., Garcia-Perez, M., Wolcott, M., Zhang, X. (2020). Fuel Processing Technology 201:106338

Tanzil, A.H., X. Zhang, M. Wolcott and M. Garcia-Perez, Strategic Assessment of Sustainable Aviation Fuel Production Technologies: Yield Improvement and Cost Reduction Opportunities (*Submitted to Biomass and Bioenergy, 2020*)

Outreach Efforts

During the preparation of design case reports, we have closely interacted with industrial companies, including Gevo, LanzaTech, and Agrisoma (now NuSeed). These companies have also helped us review reports and draft manuscripts. Our results have been presented to the FAA, the Washington State Academy of Science, and specialized conferences (TCS 2020). We have also made several presentations to graduate and undergraduate students.

Malina, R., Wolcott, M., Brandt, K. Update on TEA tool development. CAEP/12 Fuels Task Group, TPP subgroup. 20 May 2020.

Awards

None

Student Involvement

Several graduate students (Senthil Subramaniam, Sudha Eswaran, Kelly Nguyen, Tanzil Hossain, Anamaria Paiva, and Lina Martinez) and one undergraduate student (Kitana Kaiphanliam) participated in the creation, editing, and updating of the design cases for stand-alone AJF technologies, relevant existing infrastructure, and lignin coproducts.

Plans for Next Period

We intend to submit three to five manuscripts on the lignin coproduct analyses and other manuscripts on the AJF analyses. The following are the proposed manuscripts to be completed this project year:

1. Methodology of Quantifying the Impact of Repurposing Existing Manufacturing Facilities: Case Study using Pulp and Paper Facilities for SPORL Sustainable Aviation Fuel Facility
2. Lipid and Bio-processing Technologies: Process Intensification and Continuous Flow-Through Reaction (PICFTR), Lipid-to-Hydrocarbon (LTH), Tyton, Decarboxylation and Co-processing
3. Economic Analysis of Catalytic Hydrothermolysis Pathway for Jet Fuel Production
4. The Potential of SK-SKA for Production of Sustainable Aviation Fuel
5. The Opportunity for Lignin Co-Products to Improve the Economics of Sustainable Aviation Fuel Production

Task 2 - Evaluation of the Most Promising Biorefinery Concepts for AJF Production

Washington State University

Objective(s)

Continuation from previous years

During the upcoming year, we will complete our evaluation of biorefinery scenarios for AJF production using corn ethanol, sugarcane, pulp and paper mills, and petroleum refineries. Over the past year, we have advanced our analyses for corn ethanol and pulp and paper mills, and in the coming year, we aim to complete our analyses for sugarcane and petroleum refineries.

We will conduct detailed TEAs on the integration of lignin coproduct technologies and the ATJ pathway to determine the potential for reducing fuel costs.

Research Approach

Background

In this task, we will utilize the design cases for existing infrastructure, AJF production technology, and identified coproducts to generate new biorefinery concepts for petroleum refineries, pulp and paper mills, sugarcane mills, and corn ethanol mills. The results from this effort will allow us to identify and select the most commercially feasible biorefinery concepts. Major technical gaps or barriers to the commercialization of each biorefinery concept will also be determined from the results of this study.

The integration of process technologies will be assessed with an approach similar to that for the stand-alone design cases. The integration concepts will be developed by pairing stand-alone cases with these concepts to evaluate the economic and environmental advantages of the integration approaches. Over this period, we have conducted detailed analyses of ATJ conversion and integration with pulp mill operations. We have also investigated the potential contribution of lignin coproducts to the overall process economy.

A dry-grind corn ethanol mill (DGCEM) with a capacity of 80 million gallons of ethanol per year was studied to evaluate potential biorefinery scenarios for AJF production. Similarly, we used a sugarcane mill with a sugarcane processing capacity of 12,444 million tons per day (MTD) that produces raw sugar, molasses, surplus bagasse, and surplus electricity. The petroleum refinery used as the base case processes 120,000 barrels per day of crude oil. Five AJF technologies were studied: Virent's BioForming, ATJ, DSHC, fast pyrolysis, and GFT. A standardized methodology was adopted to compare the biorefinery concepts DGCEM, sugarcane mill, and petroleum refinery in several integration scenarios with six jet fuel production scenarios. For all cases, we estimated the minimum fuel selling price and greenhouse gas emissions.

A manuscript on the integration of ATJ technologies in the pulp mill infrastructure was published. Three new manuscripts will be published with the results for corn ethanol mills, sugarcane mills, and petroleum refineries.

Major Accomplishments

Building on the ATJ pathway analyses, we have analyzed the integration of the ATJ process in a pulp mill infrastructure. A manuscript entitled "Pulp Mill Integration with Alcohol-to-Jet Conversion Technology" has been published in *Fuel Processing Technology*. Economic models and life cycle assessments have been applied to select the most promising biorefinery concepts for corn ethanol, sugarcane, pulp and paper, and petroleum refineries. The manuscript on corn ethanol was submitted to *Biomass and Bioenergy*. The other two manuscripts (on sugarcane and petroleum refineries) are under internal review.

Publications

Written reports under peer review

Brandt, K.L., Wooley, R.J., Geleynse, S.C., Gao, J., Zhu, J., Cavalieri, R.P., Wolcott, M.P. (2020). Impact of co-product selection on techno-economic analyses of alternative jet fuel produced with forest harvest residuals. BioFPR, 14(4):764-775

Geleynse, S., Jiang, Z., Brandt, K., Garcia-Perez, M., Wolcott, M., Zhang, X. (2020). Fuel Processing Technology 201:106338

Tanzil, A.H., Zhang, X., Wolcott, M., Garcia-Perez, M. Evaluation of Biorefinery Alternatives for the Production of Sustainable Aviation Fuels in a Dry Grind Corn Ethanol Mill (*Submitted to Biomass and Bioenergy*)

Tanzil, A.H., Zhang, X., Wolcott, M., Garcia-Perez, M. Evaluation of Biorefinery Alternatives for the Production of Sustainable Aviation Fuels in a Sugarcane Mill (*Internal review*)

Tanzil, A.H., Zhang, X., Wolcott, M., Garcia-Perez, M. Evaluation of Biorefinery Alternatives for the Production of Sustainable Aviation Fuels in a Petroleum Refinery (*Internal review*)

Outreach Efforts

None

Awards

None

Student Involvement

Graduate students (Senthil Subramaniam, Kelly Nguyen, Abid Tanzil Hossain, Lina Martinez Valencia, and Anamaria Paiva) have received training in this project. An undergraduate student, Kitana Kaiphanliam, funded under a National Science Foundation Research Experience for Undergraduates (NSF-REU) grant, assisted in building techno-economic models for coproduct production scenarios.

Senthil Subramaniam, who has been supported by this project, has graduated with a PhD degree from WSU (December 2020).

Kelly Nguyen, who has been supported by this grant, has graduated with a Master's degree from WSU (May 2020).

Abid Tanzil submitted and defended a PhD dissertation during the fall 2020 semester.

Plans for Next Period

During the next period, Dr. Garcia-Perez's team will focus on publications.

Task 3 - Supplement and Maintain the Current Inventory of Biorefinery Infrastructures that are Useful for AJF Production, as Identified in the Conversion Design Cases

Washington State University

Objective

This task requires periodic evaluation of the databases to add new facilities or update the status of closed facilities in each category to ensure that the geospatially specific assets are current.

Research Approach

The use of existing infrastructure assets is a key component of retrofit approaches for advances in this industry. To differentiate between the relative values of various options, the specific assets must be valued with respect to their potential use within a conversion pathway. Regional databases of industrial assets that might be utilized by a developing AJF industry have been assessed on the national level. These baseline databases are compiled from a variety of sources, including industry associations, universities, and news outlets. These databases will be expanded, refined, and validated as the conversion design cases indicate additional needs for the regional analyses.

Milestone(s)

National databases have been compiled, geolocated, validated, and shared for biodiesel, corn ethanol, energy pellet, pulp and paper, and sugar mill production. We evaluated the databases as necessary to add new facilities or change the status of closed facilities in each category, to ensure that the geospatially specific assets are current.

The geospatial infrastructure data were converted for use in the supply chain resiliency models. Tools were updated for transportation cost modeling, which should lead to future improvements.

Major Accomplishments

National databases have been compiled, validated, and shared with the A01 teams. All metadata are available for use in regional analyses.

Publications

None

Outreach Efforts

N/A

Awards

None

Student Involvement

None

Plans for Next Period

N/A

Task 4 - Continue Work on Social Asset Decision Tools Developed in Phase 1 for Plant Siting (CAAM), Including Additional Validation and Incorporation of Multi-decision-making Tools; Extend Applications to Another U.S. Region in Coordination with Other Team Members (Inland Northwest, Appalachian Region); Prepare for National Extension and Replication in Select Countries

Washington State University

Objective(s)

The objective of this task is to update CAAM with available data and strategically apply it to additional U.S. regions.

Research Approach

Based on key measures of social, cultural, human, and political capital, WSU finalized the CAAM for strategic application to communities to determine appropriate outreach to aid in project development and implementation. The first tool with only three community assets—social, human, and cultural—was initially applied to the NARA region in the Pacific Northwest, and a refined tool that added more complete measures of social, cultural, and human capital was deployed in two subregions of NARA. The model was updated in 2019 to include political capital and was further refined through factor analysis to capture more parsimonious measures of each capital by using factor analysis. The 2019 updated model was strategically applied to case studies of biorefineries in the Pacific Northwest and Montana to provide community engagement recommendations and increase the likelihood of project success. The case study analysis was used to validate the strategic application model, which has been published online in *Community Development*. Additional efforts to apply the final CAAM in the Bioenergy Alliance Network of the Rockies (BANR) region and the Inland Northwest are ongoing.

Milestone(s)

The CAAM dataset and codebook are available and were shared with FAA ASCENT colleagues in Tennessee. CAAM benchmark measures have been developed for two additional regions: BANR and the Inland Northwest.

Major Accomplishments

A strategic application model has been created by using completed CAAM measures and supplementary data to provide engagement recommendations for improving the likelihood of success when making initial contacts with communities. A manuscript that explains the development of the new CAAM and applies the model to case studies in the Pacific Northwest and Montana has been published online with *Community Development*. The manuscript will be available in an upcoming issue of *Community Development* in 2020. Two additional manuscripts for the BANR on an application of the CAAM in Colorado and Wyoming are still underway.

Publications

Written report under peer review

Mueller, D., Hoard, S., Roemer, K., Rijkhoff, S., Sanders, C. (2020). Quantifying the Community Capitals Framework: Strategic Application of the Community Assets and Attributes Model. Community Development. DOI: 10.1080/15575330.2020.1801785

Outreach Efforts

None

Awards

None

Student Involvement

None

Plans for Next Period

We plan to update the model with new data (where available) and complete the application to the BANR and Inland Northwest regions.

Task 5 - Refine and Deploy Facility Siting Tools to Determine Regional Demand and Potential Conversion Sites to be Used in Regional Analyses

Washington State University

Objective

This task's objective is to develop tools to site potential conversion facilities. Two primary needs exist: a generalized tool to site initial locations that meet the needs of a specific conversion facility type and a second tool to select optimal conversion facility sites from the initial set of locations.

Research Approach

The geospatial siting pre-selection tool (GSP) began development in early 2019. It is a Python-based script that automates ArcGIS to produce points representing locations that suit the needs of a conversion facility. The GSP uses a combination of buffer and cost datasets. Buffer datasets ensure that a candidate is sited in proximity to the necessary infrastructure, such as roads, rails, and natural gas pipelines. Because the set of candidates generated by using only buffers would be very large, cost datasets have been added to distinguish candidates from each other. Cost datasets represent geospatially variable costs including electricity, natural gas, and transportation. An additional script has been developed to model the input transportation costs for the GSP by taking a feedstock point dataset and using it to develop an equation relating feedstock density to the average cost to supply a set amount of feedstock to that location. In early 2020, a graphic user interface was added to the GSP to make it more user friendly.

The Many Step Transshipment Solver (MASTRS) is another Python-based script that models large supply chains across multiple levels by building and solving mixed integer linear programming problems. The model starts with feedstock spread across many locations and then models the distribution and conversion of feedstock into biofuels and other coproducts through multiple levels of intermediate facilities that may include temporary storage, pre-treatment, and fuel production, before sending the new products to their destinations. Intermediate facilities may include existing facilities or new candidate facilities that are generated by the GSP. Output from MASTRS shows the flow of materials throughout the supply chain and the most cost-efficient capacities and locations of new facilities.

The modeling combination of GSP and MASTRS scripts has been implemented on several regional supply chains. MASTRS was first implemented with the Pacific Northwest oilseed-to-jet-fuel supply chain in 2018. Since 2019, GSP and MASTRS scripts have been used together for two supply chain models for both the production of jet fuel from forest residuals and lumber production byproducts in the Pacific Northwest. The first uses single-stage conversion at integrated biorefineries, and the second is a multi-stage model with distributed pre-processing facilities.

Milestone(s)

GSP and MASTRS have undergone continual progress to become much more practical tools. Along with the expansion of tool capabilities, substantial improvements have been made to tool accessibility for new potential users.

Major Accomplishments

None

Publications

None

Outreach Efforts

None

Awards

None

Student Involvement
None

Plans for Next Period
We plan to begin the process to publish papers that define GSP and MASTRS. We will continue implementation of GSP and MASTRS in regional supply chain analyses and will complete the BANR supply chain analysis.

Task 6 - Refinery-to-Wing Stakeholder
Washington State University
The report is provided in Award No. 13-C-AJFE-PSU-002.

Objective(s)
We will extend the stakeholder assessment to a limited sample of informed stakeholders in the remaining sections of the country to provide insight into market and industry dynamics, with the aim of optimizing successful outcomes.

Research Approach
In 2019, the team collected primary data via surveys to better understand the awareness, opinions, and perspectives of key aviation fuel supply chain stakeholders regarding the potential impacts and key factors for an economically viable biojet fuel production industry in the United States. These aviation fuel supply chain stakeholders include airport management, fixed base operators (FBOs), aviation fuel handlers, relevant airlines, and CAAFI personnel. Data were collected to assess the opinions, awareness, and perceptions of aviation fuel supply chain stakeholders regarding factors impacting the adoption and diffusion of AJF. A national survey of aviation management and FBOs was distributed to several hundred stakeholders across the United States and was completed in the summer of 2019.

Milestone(s)
Data have been assessed for potential manuscripts due to low response rates and potential publication identified.

Major Accomplishments
None

Publications
None

Outreach Efforts
N/A

Awards
None

Student Involvement
None

Plans for Next Period
We plan to complete an updated publication based on national results.

Task 7 - Supply Chain Analysis

Washington State University-Volpe

Objective(s)

Washington State University and Volpe have each developed modeling tools that apply trans-shipment optimization to model the geospatial layout of developing supply chains. A comparison of these tools would be useful to identify the strengths and weaknesses of each.

We have developed a framework for assessing the resilience of a sustainable aviation fuel (SAF) supply chain subjected to multiple uncertain hazards and conditions, and we have modified the Freight and fuel Transportation Optimization Tool (FTOT) for extensive utilization in a continuous re-optimization process. The team has applied the proposed resilience assessment framework to a forest-residue-based SAF supply chain in the Pacific Northwest (PNW) region to demonstrate its feasibility.

Research Approach

Focusing on the use of woody-biomass-to-jet-fuel conversion via fast pyrolysis and the upgrading of a supply chain centered in the Northern Rockies, a series of comparison studies was conducted by using optimization tools from Volpe and Washington State University. Each modeling approach was required to determine sites for new pyrolysis depots and upgrading refineries. Forest production data were provided by the LURA model from the University of Idaho. Pyrolysis depot locations were selected by candidate generation tools included in each approach, and existing petroleum refineries were used as candidates for upgrading refineries. Cities, ports, and airport hubs throughout the U.S. West Coast and Rocky Mountain regions were used as markets for road transportation fuel, bunker fuel, and jet fuel.

Resilience

A supply chain can be exposed to multiple unpredictable events and conditions over the medium- to long-term horizon. These events and conditions include natural (e.g., earthquakes, hurricanes, floods, wildfires, or tsunamis) and man-made (e.g., terrorist attacks, cyber-attacks, or industrial accidents) hazards, climate change, technology development, evolving customer preferences, dynamic changes in government regulation, and political circumstances, etc., which may have negative or positive impacts on supply chain performance. Although supply chain resilience assessments should address the combined effects of multiple negative and positive events and conditions that may occur over the planning horizon, most existing studies have focused on the negative consequences induced by a single type of natural hazard, which often leads to the under- or over-estimation of potential risks. Moreover, previous studies have assessed supply chain resilience in a qualitative manner through either conceptual or empirical analysis. To address these deficiencies in the existing literature, the proposed framework quantitatively assesses the effects of both negative and positive events and conditions on the performance of a supply chain and supports resilience-enhancing strategies that minimize negative impacts while capitalizing on opportunities. Furthermore, in contrast to conventional resilience assessments, which focus on a single type of hazard and provide a snapshot of the resilience index immediately following a hazardous event, the proposed resilience assessment considers the medium- to long-term performance of a supply chain, thereby providing the resilience index as a function of time over the planning horizon. In this way, the time-dependent performance-based supply chain resilience index enables the quantification of multiple components of resilience.

In the previous period of performance (October 2018–September 2019), we developed a multi-component resilience assessment framework for a supply chain system subjected to multiple uncertain hazards and conditions. During this period (October 2019–September 2020), our task consisted of two parts: (a) the modification and utilization of FTOT and (b) the application of the resilience assessment framework to a forest-residue-based SAF supply chain system in the PNW region. We have investigated the utilization of FTOT in solving re-routing problems following a major disruption and computing time-dependent supply chain system performance. First, we studied the FTOT Python package and scenarios thoroughly to identify the implicit assumptions and methodologies adopted in FTOT. Then, we communicated with the Volpe FTOT team from March to August of 2020 through bi-weekly meetings and FTOT GitHub to incorporate the risk and resilience assessment process into the current FTOT framework. We have made major modifications to FTOT, including the following: (a) a separate Python package that simulates multiple risk factors, (b) modifications of the main objective function and constraints, and (c) a new iterative structure embedded in the existing codes to enable the continual evaluation of system performance over the planning horizon.

To facilitate the Volpe team's understanding of the incorporation of risk and resilience assessment into the current FTOT framework, we have utilized a simple supply chain system. Specifically, quick scenario 2 from the FTOT package was used for communication purposes. Subsequently, the newly added modules and modified FTOT codes were validated with this example. After the initial validation was completed, we utilized a more realistic forest-residue-based SAF supply chain system distributed over the PNW region to identify any challenges that might arise from the application of the modified and/or newly added modules to a larger-scale supply chain system and demonstrate the feasibility and practicability of the proposed framework. We have identified multiple risk factors that may potentially affect the supply chain system. Among them, seismic hazards may induce the greatest negative impact on the system performance, because some parts of the system are located in high-seismic-hazard zones. While seismic risk assessment of civil infrastructure and regional transportation system has been well investigated in the past decades, their concern has focused on a city- or county-scale risk assessment. However, the supply chain system is distributed over a much larger geographical region, including three states (Washington, Idaho, and Oregon), and a new approach has been developed to generate a finite set of stochastic seismic events for the study region that can appropriately represent all possible events. An importance sampling technique has been used to sample large-magnitude seismic events while improving computational efficiency. In the next quarter, all risk factors will be combined to assess their effects on supply chain system performance and resilience to complete the case study.

Milestone(s)

The team has developed risk and resilience modules that are compatible with the FTOT to incorporate the resilience assessment framework into the current FTOT package.

The proposed assessment framework has been illustrated with a forest-residue-based SAF supply chain system distributed over the PNW region, to demonstrate its feasibility and practicability.

Major Accomplishments

The WSU MASTRS and Volpe FTOT were compared for siting analyses in the BANR region. Similar and differing modeling assumptions were identified, and the appropriate model for a given objective was determined.

The team has developed a theoretical framework for multi-component resilience assessment. The Python-based risk and resilience modules and the supporting documentation have been shared with the Volpe FTOT team. A manuscript describing the resilience assessment framework and its illustration with a forest-residue-based SAF supply chain system has been prepared and will be submitted to *Transportation Research Part E: Logistics and Transportation Review*. A conference abstract on this topic (but with a case study of transportation system) has been accepted, and we have been invited to submit a full paper to the *13th International Conference on Structural Safety & Reliability*.

We have performed a preliminary study on wildfire risk assessment of a supply chain system to investigate the potential effects of wildfire on a forest-residue-based SAF supply chain system.

Publications

None

Outreach Efforts

N/A

Awards

None

Student Involvement

Dane Camenzind, MS Environmental Engineering, Washington State University, graduated in September 2019 and is currently employed by WSU as an operations research engineer.

Jie Zhao, PhD candidate, Civil Engineering, Washington State University

Plans for Next Period

We will utilize regional supply chain tools to assess forest residuals for SAF using pyrolysis methods, as described in Task 8 below.

The team will submit a manuscript on a multi-component resilience assessment framework for a supply chain system in January 2021 and another manuscript on wildfire risk assessment of a forest residual-based SAF supply chain system in December 2020. During the upcoming year, we will extend this study to determine the most resilient supply chain layout among alternatives and support cost-effective resilience-enhancing activities. Moreover, we will also investigate various negative effects of wildfires on supply chain performance, including forced closedown of several facilities; delayed delivery schedules due to health risk; and closures of essential transit routes due to landslides, rock falls, etc.

In the following year, the research team will incorporate the proposed resilience assessment framework into FTOT to (a) assess the integrated effects of multiple types of hazards/conditions on long-term supply chain performance and (b) quantify the overall resilience of a supply chain system under a wide range of plausible future scenarios. To make FTOT compatible with the proposed resilience assessment framework, several modifications of the FTOT Python file package are required. For example, the framework has an iterative structure to measure supply chain performance at each time step, which generates a set of future scenarios. This structure is necessary to capture the dynamic nature of supply chain performance over a planning horizon under diverse scenarios and thus should be included in FTOT. Moreover, FTOT needs to be modified to incorporate the restoration costs and processes following a hazard event to quantify the restorative capacity of a supply chain, which is one of the three resilience components. In addition to the modifications to the FTOT simulation structure and procedure, minor modifications to variables and constraints in FTOT will be required. Although the unmet-demand ratio in FTOT can be either 0 or a positive value, the resilience assessment framework considers the positive effects of risk factors on supply chain performance and allows for redundancy of the system. Accordingly, the lower bound of the unmet-demand ratio should be changed from 0 to negative infinity. Furthermore, additional Python files need to be developed for generating the realizations of each type of risk factor and integrating the factors in supply chain analysis. To maintain the consistency between the proposed framework and FTOT, this work will involve active collaboration with the U.S. Department of Transportation Volpe Center. The incorporation of resilience assessment into FTOT will provide supply chain managers and stakeholders with information on (a) the key risk factors that should be mitigated to enhance supply chain resilience and (b) which supply chain design is the most resilient among alternative designs in the future. Such information could be further used to determine cost-effective resilience-enhancing solutions.

Task 8 - Analytical Support for Regional CAAFI and USDA Jet Fuel Project

Washington State University

Objective(s)

We will develop a readiness-level tool to assess the status of regional SAF production projects and will use supply chain and stand-alone design cases to support the USDA BANR project in TEA and supply chain analysis. This regional CAP project focuses on the use of softwood forest salvage feedstock for fuels via a catalyzed pyrolysis conversion pathway.

We will assess the regional feedstock, conversion pathways and the fuel MSP for SAF manufactured in the Northwest United States. The focus of this work requested by the Port of Seattle is to determine whether the Seattle-Tacoma International Airport can attain its 10% SAF goal by using SAF manufactured in the region from regional feedstock.

Research Approach

We will develop readiness-level tools for regional projects to assess the status of developing fuel projects and to identify critical missing components. This tool will be similar in form to the CAAFI Feedstock and Fuel Readiness Levels and will be used to assist CAAFI in understanding the stage of development for projects of interest and to assess critical gaps. In addition, we will assist the regional USDA BANR team in deploying TEA and supply chain analysis for their project. This effort will focus on the use of softwood forest salvage feedstock in a thermochemical conversion process to produce fuels and coproducts.

The facility siting tools discussed in Task 5, GSP and MASTRS, have been implemented on the BANR supply chain and Port of Seattle project. The most recent model runs included feedstock and markets in an 11-state region including the West Coast and intermountain regions. Feedstocks include forest residue from logging operations and mill residues from lumber production. A future expansion will also include beetle-killed timber. The model run results generated by MASTRS will help determine the relationships between facility location, fuel MSP, and conversion facility revenue.

The Port of Seattle project required a detailed feedstock survey for forest residuals, municipal solid waste (MSW) and lipids. Forest residuals were quantified with the LURA model for Oregon, Washington, Idaho, and Montana. Regional landfills were identified and located, scales were determined, and the remaining lifetime was assessed to determine the most viable biorefinery location. The composition of MSW in the region was determined, as was a method and the related costs of sorting the material to match the SAF conversion pathway. Lipids were separated into two major categories: (a) waste fats, oils, and greases and (b) vegetable oil. Each feedstock was quantified and then paired with a compatible SAF conversion pathway to determine SAF MSP by using ASCENT-developed TEAs.

Milestone(s)

We are making progress in the use of supply chain and stand-alone design cases to support the USDA BANR project in TEA and supply chain analysis. Additionally, we have supported the BANR team in creating TEAs for the technologies under consideration.

The Port of Seattle analysis and report have been completed, submitted, and presented.

Major Accomplishments

We have collaborated with the USDA BANR project and attended their annual meeting to coordinate analysis. We currently await their completion of dead wood estimates to complete the supply chain analysis. Moreover, analyses with previous forest-residue data have been successfully modeled.

The Port of Seattle feedstock and SAF assessment was completed, presented to the Port of Seattle, and released to the public.

Publications

Public Reports

Potential Northwest Regional Feedstock and Production of Sustainable Aviation Fuel: 2019 Report form the Port of Seattle and Washington State University. Prepared February 2020. https://www.portseattle.org/sites/default/files/2020-08/PofSeattleWSU2019updated_appendix.pdf

Outreach Efforts

Wolcott, M., Holladay, J. Supply chains for sustainable aviation fuels: Why, What, Who? CleanTech Alliance Breakfast. 11 December 2019. Seattle, WA.

Wolcott, M., Brandt, K., Camenzind, D. Potential Northwest Regional Feedstock and Production of Sustainable Aviation Fuel. Energy and Sustainability Committee – WSU Briefing. 12 February 2020. Seattle, WA.

Wolcott, M., Brandt, K., Camenzind, D., Meyn, S._Potential Northwest Regional Feedstock and Production of Sustainable Aviation Fuel: Port of Seattle. ASCENT Spring Meeting. 31 March 2020.

Wolcott, M.P., K. Brandt, and D. Camenzind. Potential Northwest Regional Feedstock and Production of Sustainable Aviation Fuel: Port of Seattle. Washington State Aviation Biofuels Work Group. Virtual Meeting held on June 3, 2020.

Wolcott, M. Potential Northwest Regional Feedstock and Production of Sustainable Aviation Fuel: Port of Seattle. Washington Clean Fuel Forum: 2021 Industry and Policy Forecast. 22 October 2020.

Awards

None

Student Involvement

Dane Camenzind, MS Environmental Engineering, Washington State University, graduated in September 2019 and is currently employed by WSU as an operations research engineer.

Lina Martinez, PhD candidate, Biosystems Engineering, Washington State University

Plans for Next Period

Analysis of the BANR region is underway and will be completed in 2021.

The Port of Seattle report will be adapted for peer-reviewed publication.