Project 001(A) Alternative Jet Fuel Supply Chain Analysis

Washington State University

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- 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 CAAFI and USDA jet fuel projects. Wolcott

Project Funding Level

$510,918 FAA funding and $510,918 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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- Manuel Garcia-Perez, WSU, Co-Project Director/Co-PI
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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 a number of strategies that are 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 from an economic, emission, and overall feasibility perspective (Richard, 2010; Staples et al., 2014).

Current approaches to 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 over $25 per gallon capacity (Hileman, 2014).

Motivated by the realities of converting these initial commercialization efforts into second-generation AJF, researchers have considered alternate conversion scenarios, including the transitioning of existing facilities (Brown, 2013). Currently, Gevo is employing retrofit 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 aspirational FAA goal of AJF consumption has relied upon "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 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).

Thus far, 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 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 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). 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 a significant effect – positive or negative – on project adoption and implementation, particularly in high technology or energy-related projects (Lewis et al., 2012; Martinkus et al., 2012). The consideration of social factors in site selection and implementation decisions can maximize positive social support and minimize opposition and social negatives, which can significantly promote the success of a project. In this regard, the CAAM originally piloted in the 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 1 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.

References

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Task 1 - Design Cases

Washington State University

Objective(s)

In previous years, our team has worked towards 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 updated statuses of each stand-alone AJF techno-economic analysis (TEA) and report are shown in Table 1. The results from pyrolysis and ATJ pathways have been published in peer-reviewed journals, while the work conducted from October 1, 2018 to September 30, 2019 has 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 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, 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	Standardized TEA complete.
Alcohol-to-jet (ATJ)	Literature review based on a design report, 28 pages (2015)	ChemSusChem 11:3728, 2018	A core ATJ model, from ethanol and butanol to final fuel, was developed and analyzed. This manuscript was reviewed by LanzaTech and Gevo. Standardized TEA.
Synthetic kerosene and synthetic aromatic kerosene (SK-SKA)	Literature review based on a design report, 36 pages (2015)	Due to a lack of further development (Sasol process), this activity is on hold	N/A
Direct sugar-to-hydrocarbon (DSHC)	Literature review based on a design report, 88 pages (2017)	Manuscript in preparation, which includes a DSHC summary (draft to be completed in 2020)	Standardized TEA in progress.
Virent BioForming process	Literature review based on a design report, 46 pages (2015)	Manuscript in preparation	Standardized TEA complete.
Catalytic hydrothermolysis (CH)	Literature review based on a design report, 35 pages (2018)	Manuscript completed, under internal review	CH based on the ARA process. Four feedstocks were analyzed (soybean oil, carinata, yellow grease, and brown grease). This manuscript was reviewed by Agrisoma.
Gasification Fischer Tropsch (GFT)	No literature review conducted		A GFT techno-economic model was completed. Standardized TEA.
Microchannel gasification Fischer Tropsch (microGFT)	No literature review conducted		A standardized GFT techno-economic model was completed.
Hydroprocessed esters and fatty acids (HEFA)	No literature review conducted		A standardized HEFA techno-economic model is now available.

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 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 based on 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 have been subjected to an industrial expert review, and 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. Where detailed process engineering information is lacking, new models will be built to estimate the parameters needed to complete assessments such as techno-economic modeling, lifecycle analysis, 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 between 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 location 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, 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 ways to coprocess intermediates, wastes, and coproducts using existing infrastructure (petroleum refineries, pulp and paper mills, etc.)
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. 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)
- Synthetic kerosene and synthetic aromatic kerosene
- ATJ- A manuscript with information regarding the mass and energy balances and the TEA was recently published (an internal review of the DSHC TEA is in progress).
- 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 large standard reactors (reviews on the TEAs for GFT and microGFT have been completed).
- HEFA mass and energy balances and TEA- A stochastic TEA was created in MATLAB and was confirmed to match the completed, deterministic TEA when assumptions and costs match (deterministic TEA review completed).
- TEA of CH pathway for jet fuel production

We are currently preparing a manuscript comparing the economic and environmental performance of the AJF technologies discussed above. This manuscript will also present a strategic analysis of the yield increases needed to achieve an MSP comparable to those of current commercial fuels. Over the last year, we also made progress in design cases for existing industries that could be used to reduce the production cost of AJFs.

A paper detailing the impact of coproducts on the financial viability of the ATJ process has been submitted to *BioFPR* and is currently under review.

A preliminary technical report containing information on the mass and energy balances and the TEA of the petroleum refinery is being developed for the corn ethanol and sugarcane design cases. Major progress has been made on the analysis of corn ethanol and sugarcane biorefineries for jet fuel production. Two papers in this area are under internal review.

We are working with the Pacific Northwest National Laboratory (PNNL) to complete a case design report on HTL for AJF conversion. This work involves the collection of primary data, the establishment of process flow diagrams for several feedstocks including municipal wastewater (primary and secondary sludge), algae, and tall oil, and a detailed TEA. We have discussed the draft report with PNNL. We will also work with PNNL to identify methods for improving the HTL conversion efficiency.

A summary report on several lipid conversion pathways, including SBI, Forge, Tyton, decarboxylation, and coprocessing, has been prepared. We have also revised the design case for CH and have prepared a manuscript entitled "Techno-economic analysis of the CH pathway for jet fuel production." This manuscript reviews the technological development and commercialization of the CH pathway and assesses the advantages of the CH pathway in utilizing a wider range of feedstock, including edible and inedible vegetable oils and fats, oils, and greases (FOGs), and generating a broader mix of hydrocarbons. Potential cost savings for the use of low-cost feedstock such as FOGs have been assessed, with a consideration of the added costs for preconditioning and feedstock availability. A draft manuscript has been reviewed by Agrisoma. We plan to revise and submit the manuscript in 2020.

Milestone(s)

An 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 prepared and sent to Agrisoma and our internal team for review. The revised manuscript will be submitted for FAA review. We have also updated the "Lipid-to-Biofuel Conversion Pathways" manuscript in preparation for its publication. In addition, we are drafting a manuscript entitled "Oleaginous yeast/fungi for jet fuel production" with PNNL scientists and are updating the "Hydrothermal liquefaction case design report" manuscript as preparation for publication. We intend to submit these manuscripts to the FAA for review within the next four months. We have also initiated 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).

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

Pires, A.P.P., Arauzo, J., Fonts, I., Domine, M.E., Fernanzed, Arroyo, A., Garcia-Perez, M.E., Montoya, J., Chejne, F., Pfromm, P., & Garcia-Perez, M. (2019). Challenges and opportunities for bio-oil refining: A review. Energy & Fuels, 33(6):4683-4720.

Yinglei Han, Mortaza Gholizadeh, Chi-Cong Tran, Serge Kaliaguine, Chun-Zhu Li, Mariefel Olarte, Manuel Garcia-Perez. (2019). Hydrotreatment of pyrolysis bio-oil: A review. Fuel Processing Technology, 195:106140.

Outreach Efforts

During the preparation of design case reports, we have closely interacted with industrial companies, including Gevo, LanzaTech, and Agrisoma. These companies have also helped us review reports and draft manuscripts.

Awards
None.

Student Involvement
Several graduate students (Senthil Subramaniam, Sudha Eswaran, Kelly Nguyen, Tanzil Hossain, Anamaria Paiva, 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 complete the manuscript submission process (3–4 papers), complete the lignin coproduct analyses, and prepare additional manuscripts based on the AJF analyses.

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

Objective(s)
Continuation from previous years
During this 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 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 TEA analyses 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/barriers toward the commercialization of each biorefinery concept will also be determined from the results of this study.

The integration of process technologies will be assessed using 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 in order to evaluate potential biorefinery scenarios for AJF production. Five AJF technologies were studied: Virent's BioForming, Gevo ATJ, DSHC, fast pyrolysis, and GFT. A standardized methodology was adopted to compare DGCEM and AJF technologies in 12 integration scenarios in terms of the minimum fuel selling price and greenhouse gas emission. We are currently conducting similar analyses for petroleum refineries and are comparing sugarcane biorefinery concepts for aviation fuel production.

We will complete a manuscript on the integration of ATJ technologies in pulp mill infrastructure during this coming year. We will then apply this methodology to analyze another advanced fermentation technology (DSHC by Amyris) for use in a pulp mill during the next year. We will also expand the lignin coproduct analysis to all other AJF pathways.

Major Accomplishments
Building upon 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 submitted to *Fuel Processing*

Technology. Following the reviewer's input, a revised manuscript has been submitted. Economic models and life cycle assessments have been applied to select the most promising biorefinery concepts for corn ethanol, sugarcane, and pulp and paper, and manuscripts on jet fuel production using corn ethanol, sugarcane, and pulp and paper biorefineries will be submitted shortly. We are currently working on methods for utilizing petroleum refineries as part of biorefineries.

Publications

Written reports under peer review

Impact of co-product selection on techno-economic analyses of alternative jet fuel produced with forest harvest residuals. (2019). In revision, BioFPR.

Pulp Mill Integration with Alcohol-to-Jet Conversion Technology. (2019). In revision, Fuel Process Technology.

Outreach Efforts

Scott Geleynse, Xiao Zhang. Techno-Economic Assessment of Pulp Mill Infrastructure Integration with the Alcohol-to-Jet Pathway for Aviation Fuel Production. International Bioenergy & Bioproducts Conference, October 30, 2018

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.

Plans for Next Period

During the next period, Dr. Garcia-Perez's team will focus on potential cost reductions that can be achieved by integrating AJFs with a petroleum refinery.

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 an annual evaluation of the database to add or eliminate new and closed facilities in each category such 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 value of different 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 a 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 articulate 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 are evaluating the database to add or eliminate new and closed facilities in each category to ensure that the geospatially specific assets are current.

Geospatially specific facility databases, waste feedstock estimates, and forest residual inventories have been developed and prepared in conjunction with the Volpe Center. FTOT analyses of specific scenarios are compared to similar analyses reported by the NREL Biomass Scenario Model to assess the adoption of AJF technologies and to determine potential national targets.

Major Accomplishments

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

Publications

Peer-reviewed journal publications

Lewis, K. C., Newest, E. K., Peterson, S. O., Pearlson, M. N., Lawless, E.A., Brandt, K., Camenzind, D., Wolcott, M. P., English, B. C., Latta, G. S., Malwitz, A., Hileman, J. I., Brown, N. L., Haq, Z. (2019). US alternative jet fuel deployment scenario analyses identifying key drivers and geospatial patterns for the first billion gallons. Biofuels, Bioproducts and Biorefining, 13(3):471-485. Doi:10.1002/bbb.1951

Outreach Efforts

N/A

Awards

None; these are shared assets for later analyses.

Student Involvement

Dane Camenzind, a Master's student in Civil Engineering, validated the operating status of previously identified production facilities, compiled and geolocated MSW incinerators and landfill gas-to-energy facilities, and assisted in assembling and updating all county-level feedstock information. Dane Camenzind graduated in September 2019 and is currently working for WSU as an operations research engineer.

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)

Expand and refine social asset decision tools for biorefinery plant siting (CAAM) through the addition of political capital. Prepare for national extension and replication for Canada and select E.U. countries.

Research Approach

Based on key measures of social, cultural, human, and political capitals, WSU has developed and finalized CAAM. The first tool 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 sub-regions of NARA. An initial measure of political capital has now been added to the CAAM, which can be used across the continental United States. The refined CAAM (excluding political capital) has been used to assess social capacity for biorefinery siting in two separate studies, including the retrofitting of paper mill facilities in the Pacific Northwest. Ground-truthing analysis was used to assess the role of social, cultural, and human capitals in the success or failure of AJF-related projects in both the NARA and BANR regions. This ground-truthing analysis supported the role of CAAM measures of project success and highlighted opportunities for further improving the CAAM. The final CAAM includes measurements of political capital, and the manner in which capital is measured varies for each capital type. We have also completed a strategic application model that combines the final CAAM and supplementary data, providing strategic community engagement recommendations to increase the likelihood of project success. The strategic application model was validated with case studies of biorefineries in the Pacific Northwest, and a manuscript describing this validation was submitted to the *Community Development Journal*. Additional efforts are currently underway to validate the final CAAM and to implement strategic applications that involve the BANR region and the Inland Northwest.

Milestone(s)
The CAAM model has been tested and is available for use. The CAAM dataset and a codebook for its use are available for incorporation in regional projects.

Major Accomplishments
A strategic application model has been created using completed CAAM measures and supplementary data to provide engagement recommendations for improving the likelihood of success when making initial contacts with communities. A paper explaining the development of the final model and strategic application recommendations for three case studies of refineries in the Pacific Northwest was submitted to the *Community Development Journal* and is currently being revised for resubmission. We presented this paper at the Pacific Northwest Political Science Conference in November 2018. Significant research collaborations have been organized to further test the CAAM's effectiveness, including areas beyond aviation AJF and refinery site selection (namely, climate change resiliency and community vulnerability to climate change). We are currently working on an additional manuscript for BANR on an application of the CAAM in Colorado and Wyoming.

Publications
Written report under peer review

Mueller, D., Hoard, S., Roemer, K., Rijkhoff, S., Sanders, C. "Quantifying the Community Capitals Framework: Strategic Application of the Community Assets and Attributes Model." In revision, Community Development.

Outreach Efforts
Boglioli, M., Strauss, S., Hoard, S., Mueller, D., Budowle, R., Beeton, T. & Jensen-Ryan, D. Searching for culture in 'cultural capital': The case for a mixed-methods approach to production facility siting. CSU Energy.

Gaffney, M., Sanders, C., Hoard, S. & Mueller, D. Community capitals: Strategic application of the CAAM. Commercial Aviation Alternative Fuels Initiative (CAAFI) Annual Meeting. Washington DC.

Mueller, D., Hoard, S., Roemer, K., Rijkhoff, S. & Sanders, C. Quantifying the community capitals framework: Strategic application of the community assets and attributes model. Pacific Northwest Political Science Association. Bend, OR.

Mueller, D., Hoard, S., Roemer, K., Sanders, C., & Rijkhoff, S.A.M. Quantifying the community capitals framework: Strategic application of the community assets and attributes model, WSU Academic Showcase, Pullman, WA.

Mueller, D., Hoard, S., Sanders, C., & Gaffney, M. From field to flight: Using community capitals to predict sustainable aviation biofuel scale-up, WSU Academic Showcase, Pullman, WA.

Awards
None

Student Involvement
Daniel Mueller graduated with a PhD in political science at WSU in May 2019 and continued as a research assistant on this project until August 2019.

Plans for Next Period

The final CAAM and strategic application will be validated in the Inland Northwest and BANR regions. This approach will include the incorporation of multi-method decision-making tools and appropriate weighting of the capital types based on their correlations.

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

Develop readiness level tools for regional projects.

Research Approach

Developed under the NARA project and refined for ASCENT applications, the CAAM provides county-level data collected from national datasets to conduct a preliminary assessment of community characteristics for four (cultural, social, human, and political) of the seven "Community Capitals" developed by Emery and Flora (2006).

To improve facility siting tools, prior CAAM models (focusing on three assets: social, cultural, and human capital) were added to economic assets to assess the suitability of communities in the Pacific Northwest for biorefineries. Expanding on these analyses, our CAAM measures have been added to a decision support tool to assess the repurpose potential of pulp mills in the Pacific Northwest for biorefineries. An additional manuscript has been written on the effectiveness of this tool and will be submitted for review. These approaches have been utilized for cellulosic ATJ supply chains in the Pacific Northwest, and we will demonstrate the application of this tool in supply chain siting analyses for AJF production using HEFA conversion technology and FOGs as feedstock in the Inland Northwest.

Concepts from the decision support tool have been applied to inform a new siting tool that uses general types of geospatial data to find and rank candidates for supply chain optimization. These candidates can then be further analyzed or used in a supply chain optimization model that will select one or multiple candidates.

Milestone(s)

The CAAM has been updated with four capitals, and readiness level tools for regional projects have been developed.

Major Accomplishments

During this reporting period, a manuscript combining the CAAM with economic and environmental indicators to assess site selection in Western Oregon and Western Washington was submitted to *Biomass and Bioenergy*, which recommended a revision and resubmission.

Publications

Peer-reviewed journal publications

Martinkus, N., Latta, G., Rijkhoff, S.A.M., Mueller, D., Hoard, S., Sasatani, D., Pierobon, F., & Wolcott, M. (2019). A multi-criteria decision support tool for biorefinery siting: Using economic, environmental, and social metrics for a refined siting analysis, Biomass and Bioenergy, 128, 105330.

Outreach Efforts

N/A

Awards

None.

Student Involvement

Daniel Mueller completed his PhD in political science at WSU in May 2019 and continued as a research assistant on this project until August 2019.

Plans for Next Period
During the upcoming year, the latest iteration of the CAAM will be applied for the Inland Northwest and BANR regions.

Task 6 - Refinery-to-Wing Stakeholder
Washington State University
This is a shared task led by Penn 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
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, 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)
A manuscript on perceptions in the Pacific Northwest was published by the *International Journal of Aviation Management* in 2018, and a national survey has been completed. Due to low response rates, the national data are being assessed for appropriate analysis for potential manuscripts.

Major Accomplishments
Data collection for the national survey has been completed, and the data are currently being assessed for potential analysis and manuscripts.

Publications
Peer-reviewed journal publications

Mueller, D., Hoard, S., Smith, P. M., Sanders, C., & Gaffney, M. (2018). Airport management perspectives on aviation biofuels: Drivers, barriers, and policy requirements in the U.S. pacific northwest. International Journal of Aviation Management. https://doi.org/10.1504/IJAM.2019.098380

Outreach Efforts
N/A

Awards
None.

Student Involvement
Daniel Mueller completed his PhD in political science at WSU in May 2019 and continued as a research assistant on this project until August 2019.

Plans for Next Period
The team will begin drafting a manuscript based on the national survey 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 plan to develop a framework for assessing the resilience of a sustainable aviation fuel (SAF) supply chain subjected to multiple uncertain hazards and conditions and will prepare for the application of the proposed framework to hypothetical SAF supply chains in the Pacific Northwest region.

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 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.

Resiliency

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, tsunamis) and man-made (e.g., terrorist attacks, cyber-attacks, 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, most existing studies have focused on negative consequences induced by a single type of natural hazard, which often leads to the under- or overestimation of potential risks. Moreover, previous studies have assessed supply chain resilience in a more qualitative manner, utilizing either conceptual or empirical analysis. To address these deficiencies in the existing literature, the proposed framework quantitatively assesses the effect 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 dimensions of resilience.

In this task, we have developed a multi-dimensional resilience assessment framework for a supply chain system subjected to multiple uncertain hazards and conditions. The framework consists of three stages: risk identification, hybrid risk assessment, and resilience assessment.

1. Risk identification: In the first stage of the framework, potential events and conditions that may affect supply chain performance are identified and categorized based on their characteristics. In this study, eight risk categories are identified: natural hazards, man-made hazards, government assistance, market, supply, technology, finance, and human/organizational behavior. Because most risk factors classified into the abovementioned categories are site- and problem-specific, each supply chain is subjected to a distinct combination of risk factors.
2. Hybrid risk assessment: Each risk factor has unique properties, and its effect on supply chain performance should be assessed using an appropriate risk assessment methodology. For example, while quantitative risk assessment has emerged as a widely accepted tool for quantifying uncertainties and managing risks associated with natural hazards, a purely probability-based approach to uncertainty and risk analysis can be problematic when dealing with low-probability, high-consequence man-made hazards. The knowledge and information needed to characterize such hazards are invariably limited. Additionally, changes in market demand and capacity are often forecasted based on prior knowledge and historical data. As such, each risk factor is incorporated by using an appropriate methodology based on its characteristics, and the realizations of all risk factors are layered to generate a single scenario over the

projection horizon. The scenario generation process is repeated until a sufficiently large set of plausible future scenarios is generated. At each time step for each scenario, the combined effects of multiple hazards and conditions on supply chain performance are assessed using supply chain analysis.

3. Resilience assessment: At each time step for each scenario, the performance of each node and link in a supply chain is adjusted, and the optimal routes are recalculated to maximize the system performance, based on the given conditions. In this study, the resilience of a supply chain, which is expressed as a function of time over the planning horizon, has three dimensions: (a) nonhazardous-event-induced resilience, reflecting the adaptability of a system; (b) hazardous-event-induced resilience, primarily indicating the robustness, rapidity, and resourcefulness of a system; and (c) opportunity-induced resilience, representing the redundancy of a system. Because each scenario has different values for the three dimensions of resilience, the expected values of each dimension are calculated over the entire set of plausible scenarios and then combined to compute a single resilience index. The main advantages of the proposed resilience index are as follows: (a) it can consider multiple types of uncertain hazards and conditions and can better address the associated uncertainties by considering a large set of scenarios, (b) it enables supply chain managers to assess the relative effect of each risk factor on the overall resilience to facilitate effective budget/resource allocation, and (c) it captures both opportunities and disruptions affecting the performance of a supply chain, which allows supply chain managers to design resilience-enhancing strategies that reduce negative impacts while taking advantage of opportunities in the decision-making stage.

To examine the feasibility and practicability of the proposed framework, the team has prepared to apply the framework to hypothetical oilseed-to-AJF supply chains in the PNW region. Some of the supply chains are adopted from the Master's thesis of Dane Camenzind, in which the locations of three oilseed crushers are determined using the many-step trans-shipment solver (MASTRS). The team has identified four risk factors, including earthquakes, drought conditions induced by climate change, intelligent attacks on airports, and increasing HEFA conversion rates. During the upcoming year, our team will compute a resilience index for each supply chain to determine which supply chain is the most resilient to current and future changes and conditions.

Milestone(s)

The proposed multi-dimensional resilience assessment framework provides two novel contributions. First, hybrid risk assessment can address uncertainties associated with each risk factor and can uniquely combine all risk factors to generate a set of plausible scenarios. Second, this new resilience index has three dimensions of resilience corresponding to multiple attributes (i.e., adaptability, robustness, rapidity, resourcefulness, and redundancy) of a supply chain in response to current and future events and conditions.

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-dimensional resilience assessment. As part of this development, we also investigated stochasticity in various input parameters for TEA, which was incorporated in the analysis. The team has prepared case studies to apply the proposed framework to potential oilseed-to-AJF supply chains in the PNW region. The team has also been working on a journal paper primarily focused on the development of a multi-dimensional resilience assessment framework and plans to submit this paper in February 2020.

Publications

N/A

Outreach Efforts

N/A

Awards

None.

Student Involvement
Dane Camenzind, MS Environmental Engineering, Washington State University – graduated in September 2019; currently employed by WSU as an operations research engineer
Jie Zhao, PhD candidate, Civil Engineering, Washington State University
Fangjiao Ma, PhD candidate, Civil Engineering, Washington State University

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

The team will submit a manuscript on a multi-dimensional resilience assessment framework in February 2020. We will continue working on case studies to demonstrate how the proposed framework enables comparisons between alternative supply chain designs based on their resilience indices and how the framework supports the most resilient design under given conditions and constraints. The case studies will require an extensive utilization of either MASTRS or FTOT in a continuous reoptimization process, a thorough investigation of the total cost function, and more practical applications to decision-making problems.

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 AJF 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.

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 be focused on the use of softwood forest salvage feedstock in a thermochemical conversion process to produce fuels and coproducts.

Milestone(s)
We are progressing on 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.

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.

Publications
N/A

Outreach Efforts
N/A

Awards
None.

Student Involvement
Dane Camenzind, M.S. Environmental Engineering, Washington State University - graduated in September 2019; 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 within the project year.