# Biofuel Transportation Analysis Tool: Description, Methodology, and Demonstration Scenarios

**Final Report - January 2014**

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13. ABSTRACT (Maximum 200 words)

This report describes a Biofuel Transportation Analysis Tool (BTAT), developed by the U.S. Department of Transportation (DOT) Volpe National Transportation Systems Center (Volpe) in support of the Department of Defense (DOD) Office of Naval Research (ONR) and the Federal Aviation Administration (FAA). The purpose of the BTAT is to help ONR and FAA better understand the transportation needs and constraints associated with biofuel feedstock collection, processing, and fuel distribution, specifically alternative jet fuel produced from oilseed feedstocks. The BTAT uses calculations of available agricultural production and existing transportation infrastructure to generate: locations of potentially supportable biorefineries; optimal transportation routes for moving biofuels from the point of oilseed feedstock production/pre-processing to refinement and finally to fuel aggregation and storage; allocation of feedstock and fuels among biorefineries and depots based on demand and efficient transport patterns; and transportation costs, $CO_2$ emissions, fuel burn, and vehicle trips and miles traveled as a result of the transportation of feedstock and fuels. This report describes how the BTAT was developed and the functionality of the tool; it also demonstrates the tool's capability through the analysis of seven scenarios.

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# Executive Summary

This report describes a Biofuel Transportation Analysis Tool (BTAT), developed by the U.S. Department of Transportation (DOT) Volpe National Transportation Systems Center (Volpe) in support of the Department of Defense (DOD) Office of Naval Research (ONR) and the Federal Aviation Administration (FAA). The purpose of the BTAT is to help ONR and FAA better understand the transportation needs and constraints associated with biofuel feedstock collection, processing, and fuel distribution, specifically alternative jet fuel produced from oilseed feedstocks. The BTAT uses calculations of available agricultural production and existing transportation infrastructure to generate:

- Locations of potentially supportable biorefinery locations;
- Optimal transportation routes for moving biofuels from the point of oilseed feedstock production/pre-processing to refinement and finally to fuel aggregation and storage;
- Allocation of feedstock and fuels among biorefineries and depots based on demand and efficient transport patterns; and
- Transportation costs, $CO_2$ emissions, fuel burn, and vehicle trips and miles traveled as a result of the transportation of feedstock and fuels.

This report describes how the BTAT was developed and the functionality of the tool; it also demonstrates the tool's capability through the analysis of seven scenarios.

The DOD's and commercial aviation's interest in alternative fuels stems from recent dramatic fuel cost increases as well as concerns about greenhouse gas (GHG) emissions and, for DOD, mission-related challenges to support and protect fuel supply chains. These and other concerns have led both the DOD and FAA to make substantial commitments regarding the use of alternative fuels. The DOD has specifically sought to explore the production and use of alternative fuels as a strategy to reduce climate change impacts, enhance mission effectiveness, address homeland security risks, and save lives.

As significant fuel consumers, both the military and commercial aviation sectors have a strong need for reliable supplies of sustainable alternative aviation fuels that can be distributed throughout supply chains in the continental United States (U.S.) and elsewhere. While there is currently some amount of biofuel production (mostly first-generation biofuels), there is little U.S. production of alternative jet fuel. As such, both the ONR and FAA have a high level of interest in exploring the production of these fuels and their distribution through a future, scaled-up supply chain.

There are unique transportation considerations and constraints associated with a scaled-up alternative fuels supply chain. For example, most petroleum-based fuel is currently produced outside the U.S.; transporting these end products typically involves moving from ports located at

the periphery of the U.S. to the country's interior regions. On the other hand, because the feedstocks used for biofuels are grown domestically, transportation of biofuel end products likely involves movement from the country's primary agricultural production areas (particularly the Midwest) to the coasts. Understanding the considerations and potential transportation constraints characterizing a scaled-up alternative fuel supply chain is critical for all participants involved, including the DOD and FAA. The BTAT will assist the DOD and FAA in these analyses.

The BTAT is a flexible, scenario-based tool designed to be adaptable with different datasets and assumptions, and it is customizable to the particular needs of a user. For the purposes of initial analysis, the tool assumed that producing alternative aviation fuels from oilseed crops involves three basic steps: 1) production of oilseeds and processing of the material to extract vegetable oil ("preprocessing"); 2) refinement of vegetable oil and conversion into fuel; and 3) aggregation and storage of fuel in fuel depots. However, the tool can accommodate potential future potential expansion including the addition of more steps or different feedstock supply chain structures.

Initial development of the tool involved several steps, summarized below:

- Generating likely locations for oilseed production based on the assumption that some amount of oilseeds would rotate in with an existing crop acreage (wheat, in the example scenarios analyzed here) and using existing oilseed yield relationships or estimates;
- Developing a transportation network using geospatial software that includes both road and rail infrastructure based on existing networks and intermodal facility lists;
- Applying an "optimizing" software tool to the transportation network to assess the lowest cost transportation routes leading from preprocessor, biorefinery, and fuel depot based on transport cost, distance, and other weighting factors; and
- Screening candidate biorefinery sites to identify those that represent the optimal locations for biorefineries (based on meeting minimum facility demand thresholds while minimizing total transportation cost).

Seven scenarios were selected to demonstrate the capabilities of the BTAT to identify optimal transportation patterns based on factors likely to be of interest to potential tool users, including ONR and FAA personnel interested in evaluating potential future demand, emissions implications, and transportation patterns of alternative fuels as well as other researchers and even alternative fuel producers and purchasers. The scenarios explored several variations characterizing the alternative jet fuel supply chain; these included changing the allowable feedstock transport distance from preprocessor to biorefinery, varying the costs involved with utilizing multiple transportation modes, applying constraints on biorefinery size, and allowing for production of the maximum amount of fuel end products (diesel and jet fuel) rather than just jet fuel.

The results from these demonstration scenarios indicate that the BTAT can accommodate a variety of inputs and constraints on the supply chain and can appropriately use those constraints to calculate optimized transportation pathways. While most results were relatively intuitive, there were a few unanticipated results. For example, Scenario 4 results showed the consolidation of biorefinery locations and an increase in average biorefinery size, when high transport costs might lead to the expectation of more, smaller biorefineries. In Scenario 5, the inclusion of a fixed biorefinery location representing a funded or existing biorefinery resulted in changes in feedstock flow throughout the transportation network. This result and others provide insights into how supply chain parameters such as specific transport costs and conversion facility characteristics (capacity, product slate) can alter transportation optimization. Furthermore, the BTAT can be used to understand how first-mover facilities may change flows of feedstock and fuel in other areas using a hybrid approach in which existing or planned facilities are included as fixed facilities, and the BTAT is used to identify the best locations for additional biorefineries. Future expansions of the tool will likely lead to additional insights. These will continue to enhance an overall understanding of the transportation considerations, constraints, and factors involved in the alternative jet fuel supply chain.

There are several opportunities to enhance the BTAT that include the following:

- Expand the tool's ability to analyze multiple feedstock types beyond oilseeds, including the ability to assess several feedstocks simultaneously, and to incorporate multiple conversion pathways and efficiencies;
- Enhance the tool's ability to optimize transportation routes and include additional transportation network capacity constraints beyond those already considered in the current version;
- Create linkages between the BTAT and existing datasets or tools such as the Department of Energy's Knowledge Discovery Framework (an online repository of alternative fuels-related geospatial data) or the AFPAT tool developed by FAA, the Massachusetts Institute of Technology, the Volpe Center, and Metron Aviation;
- Expand scenarios to include market-based considerations and industry plans for alternative jet fuel production in the U.S; and
- Obtain "finer-grained" agricultural production data to support more detailed analyses of potential production patterns and their effect on the overall alternative jet fuel supply chain. Currently, the BTAT includes agricultural inputs at the county level, but there may be future opportunities to obtain and include more detailed production data.

In the longer term, the BTAT could be transformed into a graphical user interface (GUI)-driven, turnkey tool for analyzing alternative fuel production scenarios at multiple scales. This would require development of a more sophisticated GUI for novice users and a self-contained installation package to enable novice users to install and use the tool. In addition, further expansion of tool capabilities could address barge and pipeline and possibly more detailed

aspects of the national rail system, and incorporate future capacity infrastructure and plans. For greenhouse gas accounting, the BTAT could be expanded to address multiple products in parallel and allocate GHG emissions among products according to an accepted accounting methodology. For the purposes of national-level planning, a fully expanded tool should also include tools to assess system resilience and reliability.

The current BTAT represents an important first step in assessing scenarios for advanced alternative jet fuel production from oilseed crops. Further, the tool demonstrates the ability to combine multiple datasets and knowledge of traffic flows, transportation costs by mode, and transportation emissions to provide a broad, national analysis of the most viable pathways for aviation biofuel feedstocks. Through a framework that allows for flexibility and future expansion, the BTAT supports ONR and FAA in better understanding the transportation-related needs and constraints characterizing the advanced jet fuel supply chain.

# 1 Introduction

## 1.1 Need for alternative jet fuels

Dramatic fuel cost increases, mission-related challenges to support and protect fuel supply chains, and concerns about greenhouse gas (GHG) emissions have led to substantial commitments from the Department of Defense (DOD) and the Federal Aviation Administration (FAA).

Jet fuel costs per gallon increased by 286% from 2000 to 2012 (Airlines For America 2012). Defense Logistics Agency (DLA) Energy standard pricing shows JP-8 and JA-1 jet fuels costing $3.73 per gallon for the beginning of the 2013 fiscal year, up from only $1.66/gallon in early 2009 (DLA Energy 2012b). The Congressional Research Service estimates that a dollar increase in the per-barrel cost of fuel (approximately 2.5 cents per gallon) results in a $117 million increase in DOD fuel expenditures. Such increases led to more than $3 billion in unfunded DOD costs in the 2012 fiscal year (Schwartz et al. 2012). Reallocating funds to accommodate these fuel price changes inevitably draws resources away from other military operations and equipment priorities (Starosta 2012). The DOD's dependence on petroleum-based fuels instead of locally produced fuel options also influences supply line deployment, vulnerability in forward operating theatres, and potentially mobility and maneuverability (Schwartz et al. 2012).

These cumulative factors have led DOD to identify fuel demand reduction and the use of domestically produced alternative fuels as key to enhancing mission capability and effectiveness, reducing climate change impacts, addressing homeland security risks, and saving lives (Office of the Under Secretary of Defense for Acquisition Technology and Logistics 2008). In particular, the Navy has committed to sourcing half of its energy from alternative sources by 2020 (Ewing 2009). Jet fuel is the largest component of DOD fuel use (DLA Energy 2012a).

The Federal Aviation Administration (FAA) has also set a target (including DOD's commitment) to have one billion gallons of alternative jet fuel in use in 2018 (Federal Aviation Administration 2011). To support this goal FAA has been actively working toward the development and deployment of drop-in alternative jet fuels through its sponsorship of the Commercial Aviation Alternative Fuels Initiative (CAAFI®), and other research programs.

Together the military and commercial aviation sectors have a significant need for reliable supplies of sustainable alternative aviation fuels that can be distributed throughout the DOD and commercial aviation supply chain domestically and globally. Because little U.S. alternative jet

fuel production exists, there is a high level of interest in exploring the production and distribution of a future, scaled-up alternative jet fuel supply.

The U.S. Department of Agriculture (USDA) is working extensively on modeling approaches to predict the technical and economic break-even potential for producing dedicated alternative energy crops, including both oilseeds (such as Canola, *Camelina*, and pennycress), and lignocellulosic crops (such as perennial grasses). Producing these feedstocks will lead to downstream requirements for transportation to biorefineries and fuel destinations. Furthermore, transportation costs for moving biomass feedstock and resulting fuel substantially influence economic considerations for growing bioenergy crops.

Already in the U.S., over 13 billion gallons of ethanol (mostly first-generation, corn-based ethanol, with a small but increasing percentage of cellulosic ethanol) (Renewable Fuels Association 2013) and over 1 billion gallons of biodiesel are being produced (National Biodiesel Board 2013). One of the key transportation challenges for domestic biofuel production is that biofuels and conventional fuels have nearly opposite geographic fuel distribution patterns. Since petroleum-based fuels are commonly imported and/or refined along the coasts, their transport typically begins at the periphery of the country and moves inward. On the other hand, because biofuel production capacity is located near agricultural-based feedstock production, mainly in the Midwest and Plains, biofuel product transport originates in the middle of the country and moves outward toward the coasts. This pattern of moving materials from central parts of the U.S. outward is likely to characterize a scaled-up advanced alternative fuel industry based on dedicated feedstock crops such as oilseeds and lignocellulosic bioenergy crops.

Greater diversity of feedstocks and conversion processes are likely to further decentralize the production and distribution of alternative fuels. Such diversified and decentralized expansion of the alternative fuel industry may put unanticipated strain on existing transportation infrastructure and capacity, particularly in the agricultural regions of the country. In addition, transportation contributes to the GHG emissions of final fuel from a lifecycle perspective. All participants in the alternative fuel supply chain, including the DOD and FAA, need to understand the chain's transportation requirements and constraints to achieve an efficient, cost-effective, sustainable and reliable production supply of alternative fuels. This project was funded by the DOD's Office of Naval Research (ONR) and the FAA to explore the transportation aspects of alternative jet fuel.

## 1.2 Purpose of report

This report describes a newly developed Biofuel Transportation Analysis Tool (BTAT) that allows for the exploration of scenarios for advanced alternative jet fuel production from oilseed crops. The tool generates potentially supportable biorefinery locations using agricultural feedstock production scenarios, transportation constraints, and existing transportation

infrastructure data. The system then optimizes the transport (via road and/or rail) of a) biofuel feedstocks to potential biorefinery locations, and b) the transport of produced biofuels to a set of destinations with defined annual jet fuel demand. Calculations are based on transport and transloading costs, and other prioritization factors. The BTAT reports distances, vehicle trips (truck and rail cars), transportation costs, carbon dioxide ($CO_2$) emissions, fuel burn and other information at the individual route segment level for the transport of feedstock and fuel, and this information can then be aggregated in a variety of ways.

Transportation requirements for biofuels are expected to differ from conventional fuel supply chains, while different feedstock collection, transport, and distribution patterns from traditional agricultural crops may inhibit a reliable supply of biofuels. Successful scale-up requires appropriate transportation mode choice and pathway selection, and appropriate transportation planning at local, regional and national scales, to accommodate this major shift in agricultural production from traditional crops to biofuel feedstocks. Currently no systematic methodology exists to leverage existing datasets and knowledge of traffic flows, transportation costs by mode, and transportation emissions to provide a broad, national analysis of the most viable and reliable transportation pathways for advanced aviation biofuel feedstocks and fuels. One of the key strengths of this analytical framework is that it can generate candidate biorefinery locations based on feedstock production, transportation constraints, and actual transport distances. Furthermore, in addition to generating biorefinery locations, the system can accept specific existing or planned facilities and appropriately aggregate and route feedstock to and around those facilities. This can show how the overall usage of the transportation network, system costs, and GHG emissions could change based on “first-mover” facilities.

The BTAT tool will enable the ONR and the FAA to understand the components of the transportation infrastructure that most critically determine the transportation-related constraints on biofuel feedstock collection, processing, and fuel distribution. This report demonstrates the tool’s capability through the analysis of a series of seven scenarios for supply chain structure and constraints.

# 2 Definition of Supply Chain Structure

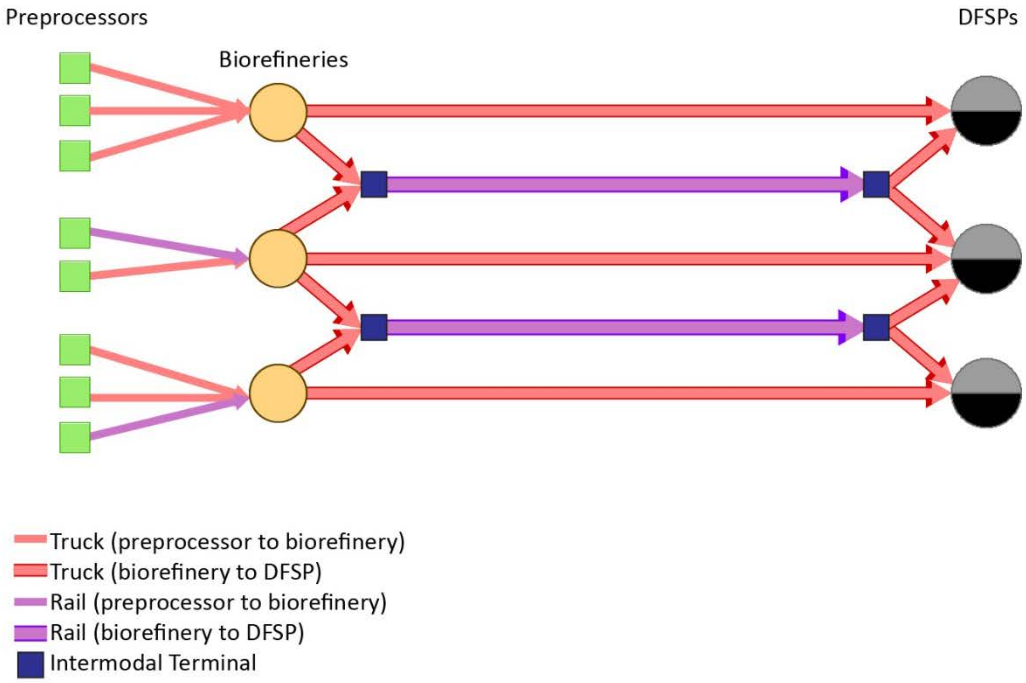
To build out the capabilities of the tool, a supply chain structure needed to be defined. The current supply chain model assumes a three-step supply chain linked via truck and/or rail:[1]

1. Agricultural production of oilseeds and co-located preprocessor (where oilseeds would be crushed to extract vegetable oil),
2. Biorefineries, where feedstocks are converted into fuel, and;
3. Destinations, which can be airports or DOD facilities; a subset of the DLA-Energy Defense Fuel Supply Points (DFSPs) were used as the destinations for the purposes of developing the tool. The DLA-Energy is the agency that procures fuel for the DOD. The DFSPs are the depots where fuel is aggregated and stored for the DOD. There are several hundred DFSPs, of which DLA-Energy was able to share the 21 largest.

While this three-step supply chain provided a basis for the current BTAT, the tool is flexible and can be expanded in the future to address multiple supply chain structures, including additional waypoints such as large-scale oilseed crushing facilities and/or fuel blending facilities, which are currently not considered separately (see Section 6 for details on potential BTAT expansions). It is not clear whether a scaled-up advanced biofuel industry based on oilseeds will include seed crushing near the production area, at the biorefinery itself, or at a third location. The BTAT currently assumes that crushing will occur within the county of production (i.e., at a "preprocessor"). In addition, it is unclear where fuel blending might occur; however, all DFSP locations provided by DLA Energy are nearly co-located with a blending facility, and therefore these two steps were combined. This structure results in a three-step, two transport leg supply chain (see Figure 1).

[1] Pipeline and barge transport are inexpensive modes for moving large quantities of fuel and are likely to be used as the industry scales up. However, for the purposes of this project, the sponsors and Volpe agreed to focus on rail and truck as the most likely initial transport modes for an incipient industry, with the intention of including pipeline and barge in future phases of BTAT development.

Figure 1: Assumed supply chain structure for BTAT optimization.




The overall goal of this project was to develop a model to translate a given agricultural scenario into a geospatially explicit result indicating:

- How preprocessors may be sized and spatially distributed,
- How biorefineries may be sized and spatially distributed,
- End-to-end route optimization over national intermodal network, and;
- Potential impacts of agricultural scenario and/or transportation constraints on:
  - Transportation costs
  - $CO_2$ emissions associated with transport of feedstock and fuel
  - Vehicle miles traveled (VMT)

# 3 Analytical Model Framework Development

The team developed an analytical framework that identifies the optimal routing of feedstock and fuel products from origin preprocessor to biorefinery and then to DFSP based on transportation costs as specified in each scenario.

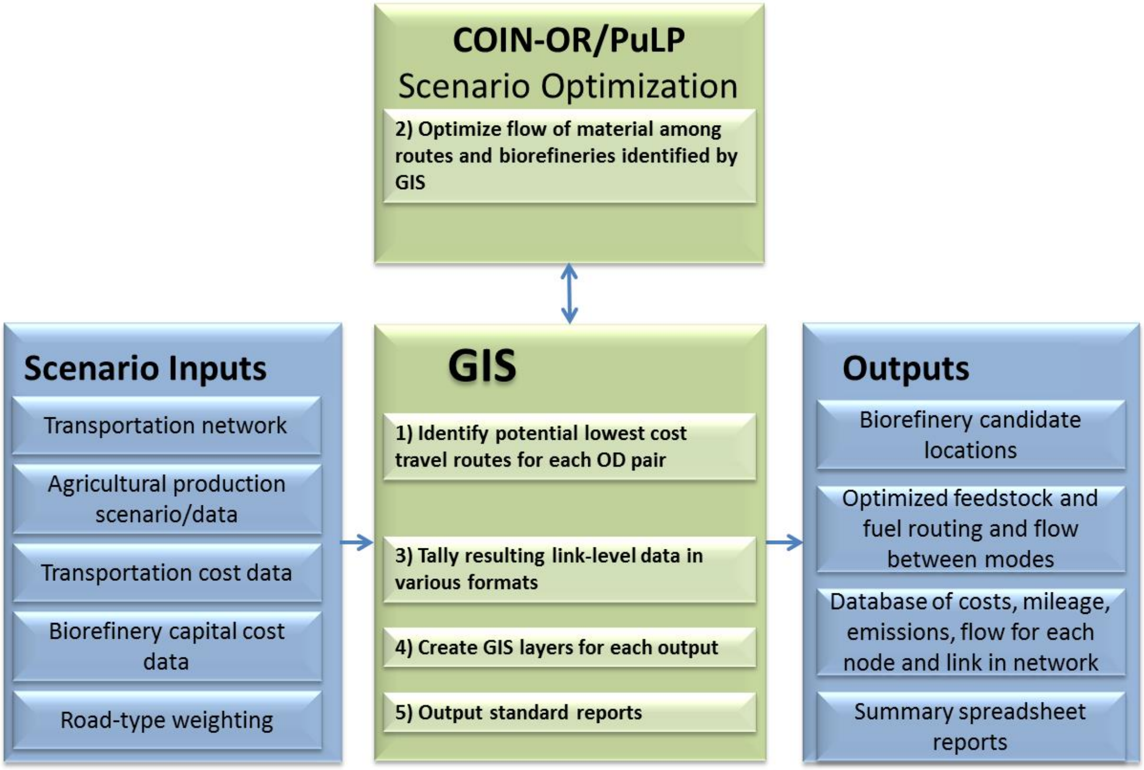
The analytical framework of the BTAT tool was built using two existing software modeling tools, described in more detail in the sections below:

- ESRI ArcMap Version 10.1 (Geospatial Analysis Program) determines the possible routes between sets of origins and destinations, assigns costs to each leg of each route, identifies the least cost paths for each mode, and identifies candidate biorefinery locations.
- PuLP Version 1.5.4 (Open Source Python Wrapper for Optimization Solvers) links the solvers in the Computational Infrastructure for Operations Research project (COIN-OR) to ESRI ArcMap. The COIN-OR project contains a number of open source optimization models, including a simplex solver (CLP) and a branch and cut solver (CBC) for mixed integer programming. These tools are used to choose biorefineries from among the candidate locations, and to optimize the assignment of feedstock or fuel to each pathway based on least cost to meet the minimum biorefinery requirements and the DFSP jet fuel demand (more details on PuLP are provided in Section 3.2.1).

Figure 2 shows the BTAT model data flow between these two tools.

To develop the BTAT, the project team implemented a “sprint” development approach in which a functional but greatly simplified analytical framework was initially developed, followed by consecutive short-term “sprints” to expand the functions and add components to the analyses. Initial sprints focused on identifying data flow patterns, optimization methodologies to select among transportation pathways with a very simple array of origins and destinations, and embedding the optimization within the GIS module. Later sprints expanded the tool to address more complex aspects such as intermodal switching, biorefinery siting, and partial demand fulfillment.

Figure 2: Analytical tool data flow schematic showing the key components/roles of each component of the BTAT.




## 3.1 GIS Data, Tools and Methods

The GIS component of the tool, built on ESRI's ArcMap, takes advantage of the geospatial data processing power of this software to generate least cost routes for transportation of alternative fuel feedstock and products. In addition, the GIS module turns agricultural data into preprocessor origin locations and identifies potential biorefinery candidate locations based on volume of material being transported over given distances. The GIS module requires geospatial data for each of the nodes in the supply chain to model the complete transportation flow from origin to destination. The integration of the various components of the supply chain into the GIS module is described below.

### 3.1.1 Preprocessors

In theory, the BTAT is capable of taking in any geospatial data on potential feedstock production, but initial development of the tool focused on using USDA Agricultural Census Data (USDA 2007) to generate a feedstock production scenario based on use, rotation with, or replacement of existing crops. The tool was designed so that a user could select an existing crop (e.g., wheat) from the Agricultural Census for a given year, provide an assumption regarding

allocation of acreage to oilseed production (e.g., 10% of wheat acreage will be available in a given year for oilseed rotation) and provide either a yield value (e.g., a national average for oilseed production) or a yield relationship (e.g., a formula for relationship between existing crop such as wheat and an oilseed). The tool then calculates an estimated yield for each county in which there is production and identifies the county centroid as an origin point for feedstock. This origin point then becomes the "preprocessor" location in the supply chain. While feedstock within the county is assumed to be aggregated at this point, the aggregation itself is not currently modeled because of the lack of granularity of the agricultural production scenario data. The BTAT was designed to be easily adapted for use with other potential feedstock production data sources in the future, although more detailed data sources may require the development of local feedstock transportation analysis capability.

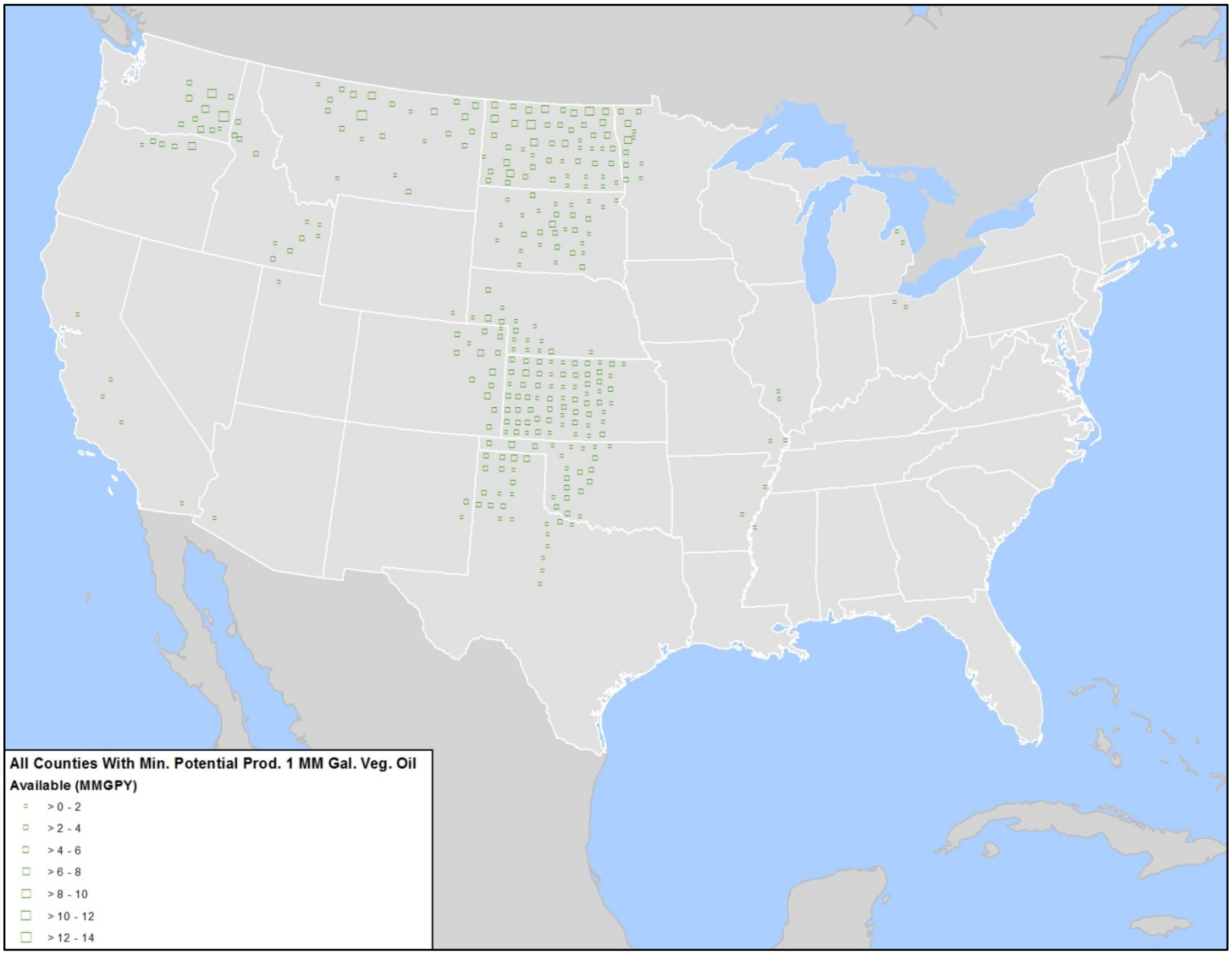
Inputs:

- USDA NASS Agricultural Census Data (or other geospatial data for feedstock production patterns)
- Percent of existing crop acreage available for oilseed production
- Oilseed yield (per acre or relationship with existing crop that will be replaced/rotated)

Outputs:

- GIS point layer and the associated data of preprocessor counties and production amounts (see Figure 3)

Figure 3: Example GIS point layer showing preprocessor counties that meet a minimum threshold of 1 million gallons of vegetable oil production per year. The size of the preprocessor symbol indicates the amount of vegetable oil available in the county.




### 3.1.2 Transportation Network

To analyze potential paths between nodes on the supply chain (e.g., between preprocessors and biorefineries and between biorefineries and DFSPs), the BTAT required inputs on both road and rail national networks. This tool uses the Freight Analysis Framework (FAF) version 3.1.1 (Federal Highway Administration 2011) for roadway data and the Class I railway network for rail data. These existing networks consist of almost 200,000 links each, which are quite complex and unnecessarily detailed for a national-level analysis. As such, the FAF and the railway network were screened to remove unnecessary links and nodes. The FAF was screened on the basis of estimated peak period speed, roadway type, Strategic Highway Network (STRAHNET) status. Roadway types and transportation modes are then prioritized for scenario analysis on the basis of the dollar cost of transportation. The cost data for transporting liquid materials over the roadway network were estimated based on personal communications with individuals involved

in shipping of biodiesel and other fuel products (e.g., McDuffie 2013). A truck was assumed to carry 8000 gallons.

To calculate $CO_2$ emissions resulting from feedstock and fuel movements in the BTAT, the project team used the U.S. Environmental Protection Agency's (EPA) Motor Vehicle Emissions Simulator 2010b model (EPA 2012). The MOVES model is an EPA tool for estimating emissions from highway vehicles based on analyses of emission test results. It provides emission factors for different types of vehicles based on different roadway types. The MOVES data correlation to the FAF roadway types used for BTAT analyses is shown in Table 1. The project team ran the MOVES model to generate values for $CO_2$ emissions (grams per mile) specifically for combination long-haul trucks.

**Table 1: Assignment of FAF roadway types to MOVES roadway categories for calculation of $CO_2$ emissions from trucks in the BTAT.**

| MOVES Roadway Categories | Assigned FAF Categories |
|---|---|
| Urban Restricted | Urban Interstate<br>Urban Freeway |
| Urban Unrestricted | Urban Principal Arterial<br>Urban Minor Arterial |
| Rural Restricted | Rural Interstate |
| Rural Unrestricted | All remaining categories |

This analysis was also restricted to Class I railroads (railroads with 2011 operating revenue of $433.2 million or more; $452.7 million is the preliminary cutoff value for 2012), which covers seven US railroads (BNSF Railway, CSX Transportation, Grand Trunk Corporation, Kansas City Southern Railway, Norfolk Southern, Soo Line Corporation, and Union Pacific Railroad) covering approximately 1.7 trillion ton miles of freight movements and nearly 70% of the freight track mileage in the United States (Association of American Railroads 2013), and approximately 94 percent of freight railroad revenue in 2011 (Association of American Railroads 2011). Extra nodes where other railway lines link to the Class I railroad were also removed. Railway costs to move a single car of vegetable oil or jet fuel were estimated based on discussions with industry participants (McDuffie 2013) as well as review of the Surface Transportation Board 2011 Waybill Sample (Surface Transportation Board 2011), which provides data on a subset of actual freight movements, including product moved, associated mileage, tonnage, and revenues. Railway emissions values were derived from EPA's estimate of 10,217 grams of $CO_2$ emitted per gallon of diesel fuel used (EPA 2009) and data on average mileage per gallon for freight cars (10.15 miles per gallon in 2012) from the Bureau of Transportation Statistics (BTS) (Bureau of Transportation Statistics 2013b). A rail car was assumed to carry 28,500 gallons.

Intermodal facilities are locations where material can be moved between truck and rail, most commonly referred to as transloading. These transloading points are also locations at which

transporters are charged additional per gallon costs. The BTS National Transportation Atlas Database (NTAD) identifies over 3000 intermodal facilities across the U.S. To develop the BTAT methodology for including intermodal facilities, a set of 102 intermodal facilities were selected based on access to Class I railroad trackage, linkage between truck and rail facilities, lack of restrictions on commodity type (or compatible commodity type allowed) and non-restricted hours of operation. The location of these facilities was then double checked with Google Earth and cross-referenced between Class I railroad facility identification and BTS NTAD facility identification. The final list of 102 intermodal facilities used in the BTAT analysis is presented in Appendix A. As with the agricultural scenario/origin points, this list can be expanded or modified as needed to run different scenarios in the BTAT. For the demonstration scenarios described below, transloading costs to move between truck and rail were estimated based on discussions with industry contacts (McDuffie 2013).

Currently, no capacity constraints are included in the BTAT, as oilseed production is small compared to other commodities, and the amount of additional annual transport is small compared to overall freight transport on truck or rail. However, transportation capacity will be much more important with other feedstocks (e.g., lignocellulosics) which can be produced at much larger volumes. The ability to address capacity constraints is recommended as part of future BTAT expansion.

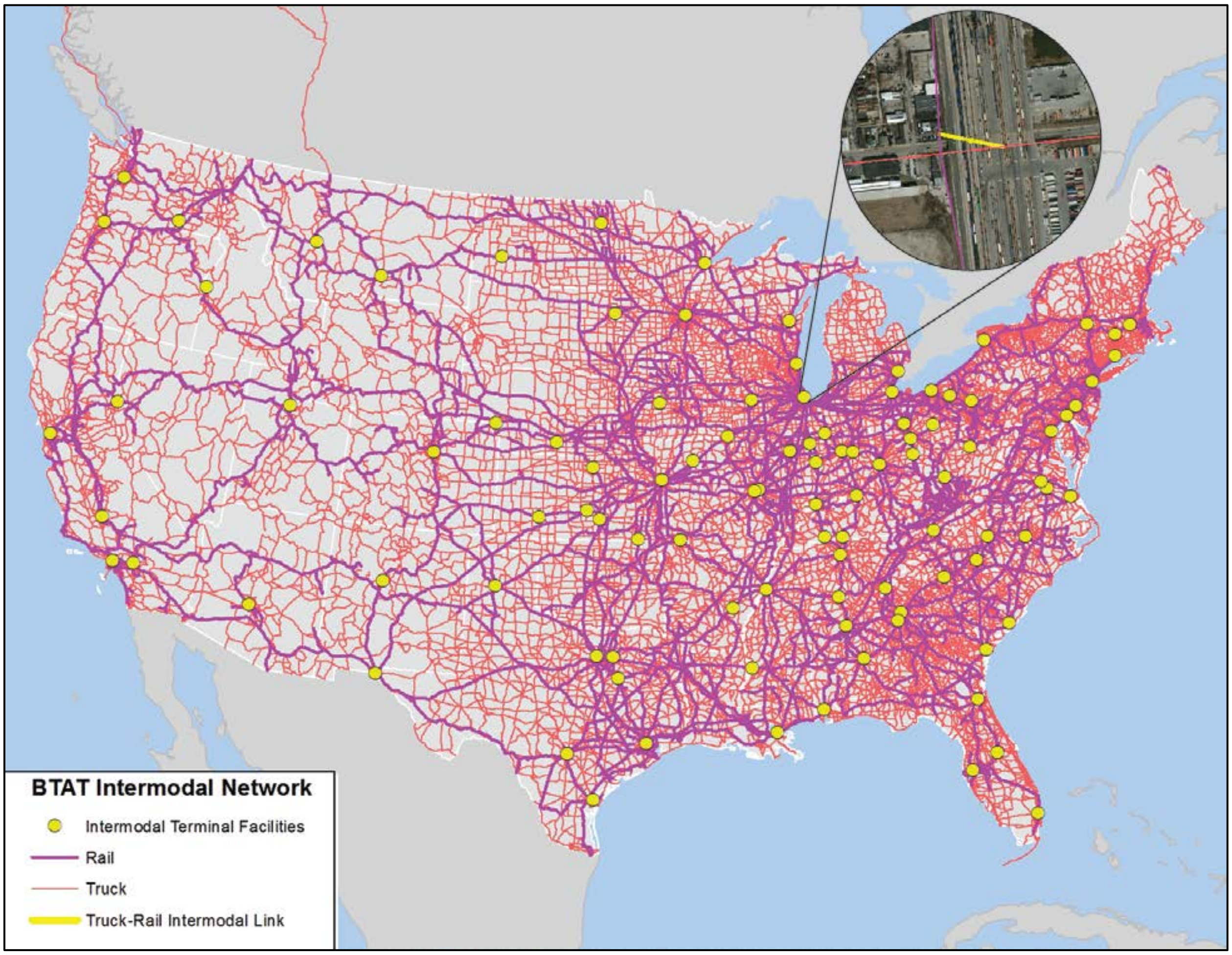
Inputs:

- Complete FAF (roadway network)
- Complete railroad network (not limited to just Class I railroads)
- BTS list of intermodal facilities
- Cost of truck transport (per ton/mi) (McDuffie 2013)
- Cost of rail transport (per ton/mi) (Surface Transportation Board 2011, McDuffie 2013)
- Cost of transloading between truck and rail (per gallon) (McDuffie 2013)
- Emissions of truck transport (per ton/mi) (EPA MOVES modeling)
- Emissions of rail transport (per ton/mi) (EPA 2009, Bureau of Transportation Statistics 2013b)

Outputs:

- Integrated, reduced-node roadway and Class I railway network, with intermodal facilities, for use in routing optimization (see Figure 4)

**Figure 4: BTAT integrated transportation network developed as basis for routing optimization**




### 3.1.3 Assigning costs

Once the preprocessor locations are established, the GIS module assigns costs to each link in the intermodal network based transport costs. The dollar costs on the GIS network are the dollar amounts required to transport 1 million gallons over each particular link. The weighting function, preferring faster/larger roadways, is based on a dollar cost per gallon-mile, e.g., \$0.00045 per gallon-mile on the interstate highways vs. \$0.00060 per gallon-mile on local roadways.[2] For each origin-and-destination (OD) pair, the GIS module then calculates all possible route (and intermodal) combinations and then identifies the route with the lowest overall cost. Thus, the GIS module develops a list of the lowest-cost routes for each preprocessor to biorefinery and biorefinery to DFSP. The GIS then passes these routes to the PuLP optimizer,

[2] Assuming that a large tanker truck holds 8000 gallons, this corresponds to a cost of \$3,60 to \$4.80 per truck-mile, depending on roadway type. Truck travel speed was calculated based on the 2007 estimated peak period speed estimated in the FAF for each link, assuming a minimum floor of 15 mph.

which resolves how much material should flow along which routes and to which biorefineries and final destinations (e.g., DFSPs) to minimize the total cost of transportation from each preprocessor to the final fuel destination(s) (see Section 3.2 below). Currently, no costs are added to pathways based on potential congestion (although this is partially addressed by roadway speed penalties), nor vulnerability (e.g., number of bridge crossings or other specific infrastructure features), although these could potentially be added in the future if data are available.

### 3.1.4 Identifying biorefinery candidate locations

The BTAT was developed to allow existing or planned biorefinery facilities to be entered into the system. Location and capacity are all that is needed to incorporate a biorefinery into the model. However, the BTAT is also able to generate potential candidate biorefinery locations based on preprocessor and DFSP locations, transport costs, distance constraints, and total agricultural feedstock supply, using the following steps:

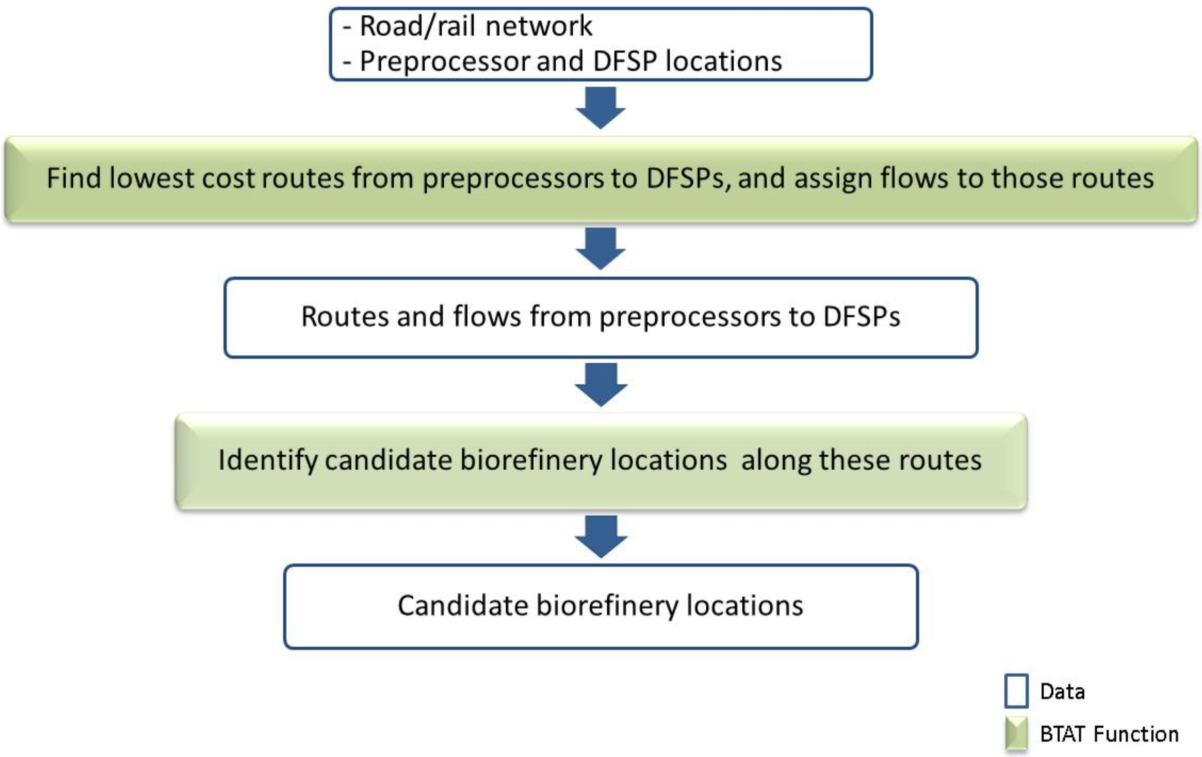
1. Identify routes and flow directly from preprocessors to DFSPs, since a well-located biorefinery is likely to be "on the way" from a preprocessor to a DFSP.
2. Identify candidate biorefinery sites that include points on the path from preprocessor to DFSP and reach a user-specified minimum annual flow (e.g., 10 million gallons of flow in the demonstration scenarios).
3. Consider as a candidate site every node on the transportation network at which further flow increases occur.

As a secondary screening for biorefinery locations, the BTAT uses an inverse distance weighting (IDW) to rank biorefinery locations based on the amount of feedstock available within a radius of the candidate location. This distance is set as a radius equal to the maximum allowed actual transport distance for feedstocks (e.g., if the user sets the maximum transport distance of feedstock as 250 miles over the transportation network, then the screening would calculate feedstock availability within a mapped radius of 250 miles.) IDW ranks highest the candidate biorefinery locations with the most feedstock available at the lowest total transport distance; those candidates with a low amount of feedstock available and/or high total transport distances are ranked lower. This IDW ranking allows the user to drop the worst performing and least feasible biorefinery candidates from consideration. In the interest of preserving as many candidate locations as possible, the scenarios were run with only the bottom 10% of the candidate locations removed from consideration. The number of candidates to eliminate from consideration is set by the user and can range from 0%, which would preserve all candidates, to 100%, leaving only any pre-funded locations. The decision of how many candidates to eliminate, if any, is based on run-time, as each biorefinery candidate location exponentially adds to the computation time, and efficiency, because the greater the number of candidates the greater

the likelihood of having redundant candidates located within close proximity of each other. The IDW formula is as follows: IDW Score = Total Feedstock Available * (1/(Total Transport Distance$^2$)).

This secondary screening has the effect of keeping the biorefineries relatively close to the preprocessors and allows the BTAT to choose from a wide number of candidate locations to find the optimal locations for biorefineries, while reducing run times in the final analysis. In the seven demonstration scenarios presented below, the number of candidate biorefineries resulting from this two step candidate identification process varied from 51 to 107.

**Figure 5: Flow of process to identify candidate biorefinery locations.**




To select among the biorefinery candidate locations identified by the process described above, the candidate biorefinery sites are then passed to the GIS module, which identifies the routes and costs from preprocessors to biorefineries, and then from biorefineries to DFSPs (see Figure 5). The routes and candidate biorefinery sites are then passed to the PuLP optimizer, which allocates flow of material along the transportation network (see Section 3.2 below) and chooses the biorefinery candidate locations that best utilize the available feedstock and the lowest cost pathways. The optimization steps to select among biorefinery candidate locations and allocate feedstock among them are described in greater detail in Section 3.2.

In the case where a particular biorefinery or set of biorefineries either exist or are planned and the user would like to see how inclusion of the fixed biorefinery locations and demand might

alter future development (compared to the baseline case), the BTAT can handle set inputs of location and processing capacity. These fixed biorefineries are flagged within the biorefinery GIS shapefile with the value of 1 in the “required” field. All unfunded biorefineries will have a value of zero. As with the candidate biorefineries, the GIS module then calculates the optimal pathways to the fixed biorefineries from the preprocessors and from the biorefineries to the DFSPs. The routes to/from all biorefineries, fixed and candidate locations, is then passed to the PuLP optimizer for processing.

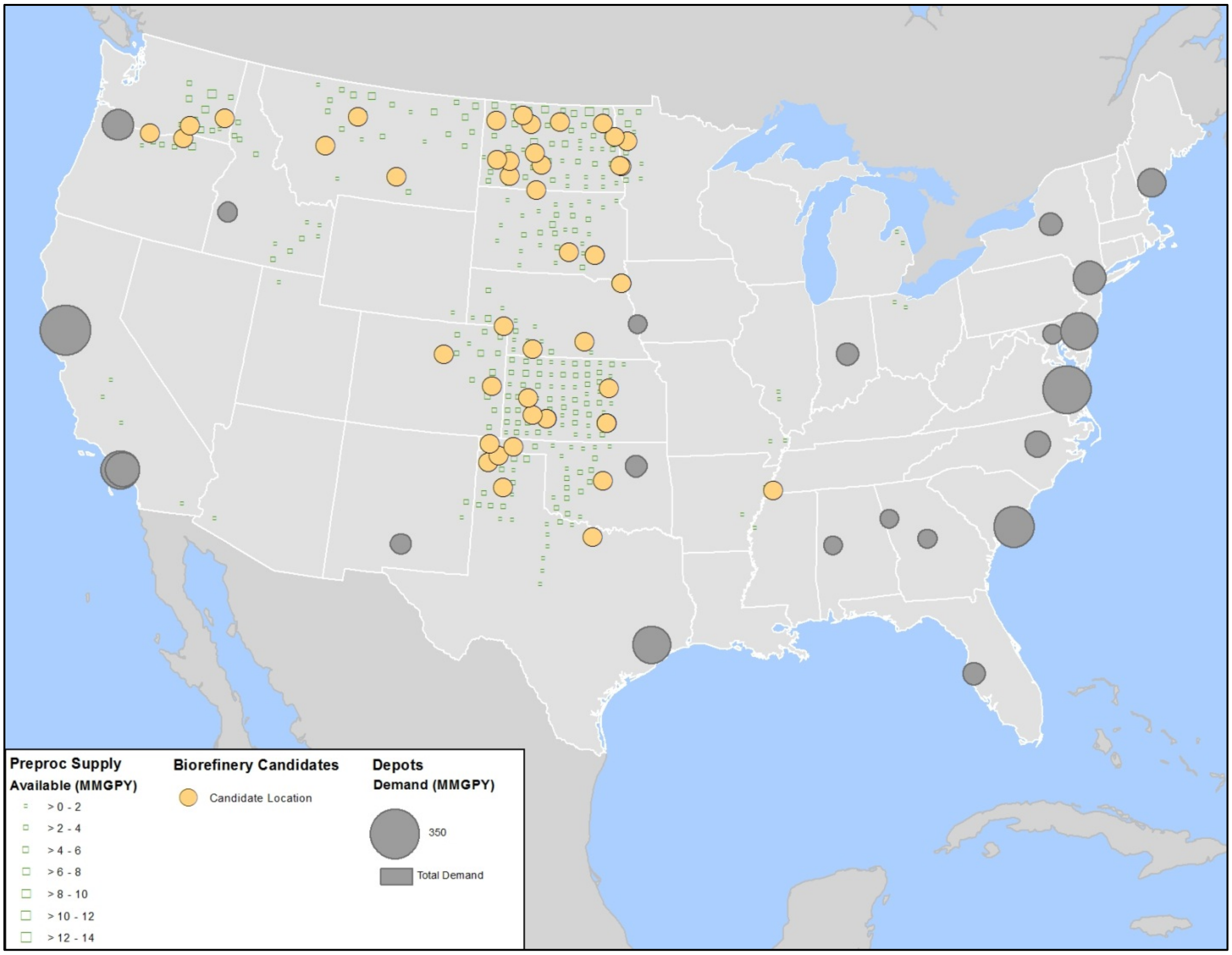
Inputs:

- Preprocessor locations
- Destination locations (e.g., DFSPs)
- Planned or existing biorefinery locations and capacity (optional)
- Threshold for aggregation of material

Outputs:

- Candidate biorefinery locations layer (see example in Figure 6)

**Figure 6: Generic example of candidate biorefinery location map generated from agricultural scenario, minimum aggregation threshold information along the transportation network, and optimized routes to final destinations.**




### 3.1.5 Destination

As with other inputs, the BTAT is capable of using any set of geospatially defined destinations as the endpoints for the analysis. However, for the purposes of developing the initial version of the tool for ONR and FAA, incorporating a set of DOD endpoints was a logical approach. DLA-Energy shared with the project team the top 21 DFSPs that are the dominant recipients of fuels for the DOD. These locations were used as the destinations for the alternative fuels transported by the BTAT. As no demand data were available, the tool currently estimates demand for jet fuel at each DFSP by assuming that 80% of the total DOD demand for jet fuel (based on the 2012 value of DLA Energy jet fuel purchases) (DLA Energy 2012a) is sent to the top 21 DFSPs. The BTAT then allocates that demand based on storage capacity at each facility (see Appendix B). These endpoints could just as easily be a set of commercial airports with their associated annual jet fuel demand, or some combination thereof.

Inputs:

- Location and demand (or basis for generating demand) for a set of destinations such as airports or fuel depots. In our demonstration scenarios, the destinations are the DLA-Energy DFSPs (top 21 facilities), and the total demand is provided by total DOD jet fuel demand (2012) (DLA Energy 2012a)

Outputs:

- Estimated demand for each destination; in the seven demonstration scenarios, these are the DFSPs (Figure 6 in the preceding section shows DFSP locations, in gray, scaled by estimated demand).

## 3.2 Description of optimization tools and methods

### 3.2.1 PuLP optimizer – problem definition

The PuLP optimizer is a Python-based tool that identifies a maximum or minimum value (in this case, total cost and weighting) using a mathematical description of the problem at hand. In its application for the BTAT, the PuLP optimizer takes all of the origins, destinations, waypoints, and the transportation network as defined by the GIS module (described in Section 3.1) and optimizes the paths among all components. The goal of the optimization is to minimize the total annual "cost" of moving all the material in the sample from the possible origins to one or several optimal destinations. The "cost" in the optimization includes not only actual dollar costs of transporting the material, but also weightings and penalties that force the tool to favor particular desirable characteristics of the routing. This analysis included factors for:

1) Actual transportation costs
    a. Rail transport: dollars per gallon-mile. This is configurable; in most of our scenarios we assumed 0.00012 $ / gallon-mile
    b. Trucking costs: dollars per gallon-mile, assigned according to roadway type as described below
    c. Transloading costs

2) Capital costs
    a. Amortized annual capital expenses for biorefinery construction

3) Weightings and penalties
    a. Roadway type. The preference for different roadway types is achieved by assigning varying dollar costs per gallon-mile. For example, in many of the

demonstration scenarios presented herein, the cost was $0.00045 per gallon-mile on interstate highways vs. $0.00060 per gallon-mile on local roadways.

b. Unmet demand penalty: each DFSP has a desired quantity of jet fuel to receive annually. For each gallon of demand that is not met (total, for all DFSPs) the optimization adds five dollars to the cost of that "solution;" the magnitude of this penalty is configurable as part of the optimization, so that one can prioritize transportation costs versus the possibility of not meeting all demand. This penalty is required for the optimizer to function; if there is no penalty for not meeting demand, the lowest cost solution is always to transport nothing at all. In general, it may be necessary to raise this penalty when any other cost (e.g. rail transport) is raised, or else the optimizer will conclude that it is more optimal to transport less material. As a general guide, the unmet demand penalty will likely work best if set to be 10-50 times the average actual transportation cost. This ensures that feedstock and fuel will be transported even over long routes. It should be noted that at very low flows, one may see non-intuitive results such as reduced utilization of feedstock that is available. This is due to the optimizer electing the less expensive option of reducing flow overall instead of accumulating high transport costs in addition to a large unmet demand penalty for a given route. Likewise, a very high unmet demand penalty may force the flow of materials in unanticipated ways.

c. Minimum flow requirements: for a biorefinery to be used, it must process at least a certain amount of feedstock (minimum provided by the user). In the demonstration scenarios, the project team used 40 million gallons of vegetable oil per year under the baseline formulation. For a preprocessor to be included, it must produce enough oilseed to create a certain annual amount of degummed vegetable oil (in the demonstration scenarios, this value was 1 million gallons per year (with a raw vegetable oil to clean, degummed vegetable oil assumed to have a processing ratio of 0.9622).

These costs and weightings are translated to mathematical decision variables and coefficients as follows:

| **Variable** | **Explanation** |
|---|---|
| $x_{ij}$ | Flow, in gallons / year, from preprocessor i to biorefinery j |
| $x_{jd}$ | Flow, in gallons / year, from biorefinery j to DFSP d |
| $u_d$ | Unmet demand at DFSP d, in gallons / year |
| $y_j$ | 0 – 1 variable: 1 if biorefinery j is used, 0 otherwise |

| **Coefficient** | **Explanation** |
|---|---|

| Coefficient | Explanation |
|---|---|
| $U_{Pi}$ | Upper bound on flow out of preprocessor i, in gallons / year |
| $C_{ij}$ | Transportation cost, in $ / gallon, to flow product from preprocessor i to biorefinery j |
| $F_{Bj}$ | Fixed cost, converted to $ / year, to build the biorefinery j |
| $U_{Bj}$ | Upper bound on flow into biorefinery j, in gallons / year |
| $L_{Bj}$ | If biorefinery j is used, lower bound on flow into biorefinery j, in gallons / year |
| $C_{jd}$ | Transportation cost, in $ / gallon, from biorefinery j to DFSP d |
| $S_B$ | Conversion factor at the biorefinery: inbound gallons x $S_B$ = outbound gallons |
| $U_d$ | Penalty ($ / gallon) for not meeting demand at DFSP d |
| $D_d$ | Demand, in gallons / year, at DFSP d |

Then the problem for BTAT analysis is mathematically stated as follows:

Minimize **annual cost** = $\sum_{ij} C_{ij}\, x_{ij} + \sum_j (F_{Bj}\, y_j) + \sum_{jd} C_{jd}\, x_{jd} + \sum_d (U_d\ u_d)$

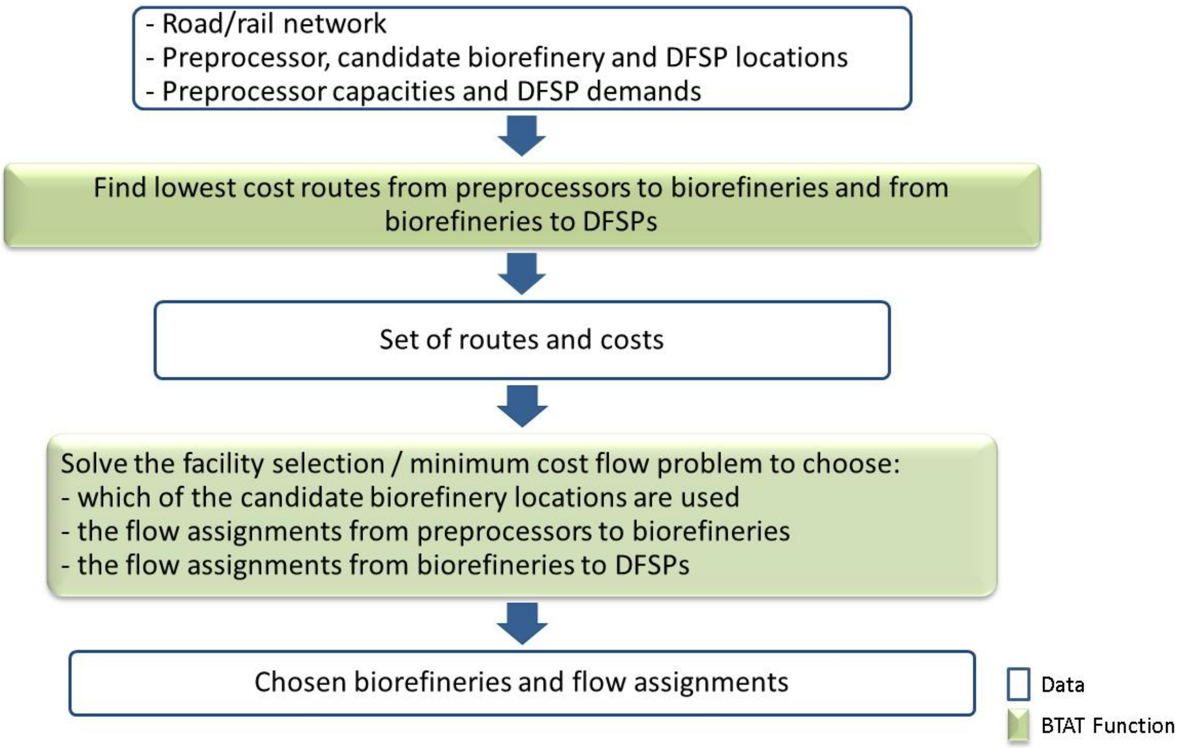
Subject to the following:

| Constraint | Explanation |
|---|---|
| (1) For each biorefinery j, $S_B \sum_{ij} x_{ij} - \sum_{jd} x_{jd} = 0$ | Flow must be conserved at each stage (with the appropriate conversion factors) |
| (2) For each biorefinery j, $y_j\, U_{Bj} - \sum_{ij} x_{ij} \geq 0$ | If a biorefinery is used, flow cannot exceed the upper bound. Note that if the biorefinery is not used ($y_j = 0$), this constraint requires the flow into the biorefinery be 0. |
| (3) For each biorefinery j, $y_j\, L_{Bj} - \sum_{ij} x_{ij} \leq 0$ | If a biorefinery is used, the flow into it must exceed the lower bound. |
| (4) For each preprocessor i, $\sum_{ij} x_{ij} \leq U_{Pi}$ | Flow out of each preprocessor does not exceed the preprocessor upper bound |
| (5) For each d, $\sum_{jd} x_{jd} + u_d = D_d$ | Unmet demand plus flow into a DFSP is equal to that DFSP's demand |
| (6) The y variables are binary (0 or 1) | A biorefinery is used, or it isn't. |
| (7) The x and u variables are non-negative | No negative flows are permitted |

The PuLP optimizer takes in the various options for building routes between origins and destinations from the GIS module. The optimizer then uses standard linear optimization techniques such as a revised simplex algorithm to solve the mathematical description of the problem to move material from origin to destination by selecting among paths and biorefinery options for each unit of vegetable oil or fuel. The specific choice of algorithm is made by the COINMP_DLL solver, as implemented by PuLP. The allocation of vegetable oil/fuel among routes, biorefineries, and DFSPs is based on meeting maximum demand while minimizing the total cost, without violating the constraints on minimum and maximum flow. Figure 7 shows

the process of optimization in BTAT where the GIS tool identifies the routes and the PuLP solver allocates flow to solve the problem statement.

Figure 7: Flow optimization process in BTAT.




### 3.2.2 Inclusion of Fixed Biorefineries – "Hybrid Scenario" Optimization

In the case where a particular biorefinery or set of biorefineries either exist or are planned and the user would like to see how inclusion of the pre-existing biorefinery locations and demand might alter future development (compared to the baseline case), the BTAT takes in location and processing capacity for existing or planned facilities and incorporate them into the optimization. In this case, the biorefinery construction cost for the pre-existing locations is set to zero, which makes it more attractive for the optimization to select these biorefineries rather than incurring the capital expense of selecting a "new" biorefinery candidate location. Thus, unless the transportation cost involved in using the pre-existing locations is extremely high, the pre-existing biorefineries are used before any other biorefineries are allocated feedstock. The optimizer allocates feedstocks among biorefinery locations based on the minimum cost to move at least the minimum required feedstock amount to the biorefinery and then to the DFSPs.

## 3.3 Scenario file input approach

The BTAT is a flexible analytical tool that can be used to process a variety of scenarios based on different geospatial data sources, costs, cost functions, and agricultural production scenarios.

Initially, the Volpe Center project team began developing a simple graphical user interface (GUI) of dialogue boxes to allow a user to enter information into the BTAT. However, due to the desire to input many different variables, and to facilitate running of multiple scenarios, the team eventually chose to develop a "scenario file" input approach using an XML-based document. This document tags each potential data source (as a file source, a function, or a specific set value) for functions within the BTAT. The XML file is essentially a text-based file that can be modified in a text editor (e.g., Notepad or Wordpad), and viewed in a browser or text editor. The XML file uses tags corresponding to the BTAT software code to indicate the presences of variables that should be read by the BTAT to fill in particular values. For example, to designate a restriction on feedstock transportation, the opening tag <Maximum_Raw_Material_Travel_Distance_Miles> is used before the value designated for that variable and the ending tag </Maximum_Raw_Material_Travel_Distance_Miles> afterward.

Thus, the line of the XML file that designates the maximum feedstock transportation distance to BTAT would read:

> <Maximum_Raw_Material_Travel_Distance_Miles>**250**</Maximum_Raw_Material_Travel_Distance_Miles>

Because the tags are readable as plain text, even a novice user can easily modify the values in an XML file using a text editor and then run that scenario through the BTAT tool with essentially no additional GIS or Python experience. This approach allows users to modify scenarios, rerun or run scenarios in batches with many scenarios defined by a series of files; it also captures all inputs for the scenario in a single location that can be easily reviewed. Furthermore, it is much easier to develop an XML -based input approach than a full-blown GUI with all the graphics, options, and guidance required. An example Scenario Input File (representing the baseline scenario presented in Section 4) appears in Appendix C. A user can create multiple XML files and run a set of scenarios at one time using a set of command line prompts within a batch file.

## 3.4 Reporting Outputs

Once the optimization is complete, the GIS module takes the data generated by the optimizer and develops maps and spreadsheet data reports showing flow along specific routes to and from various origins and destinations. It also reports summary statistics by biorefinery, by DFSP, and

by scenario. Further, the BTAT reports unmet demand (i.e., at the DFSPs) and unused production (at the preprocessors).

As outputs, the BTAT generates several reports as follows:

- Mode, mileage and dollar cost for every possible route combination (arcs.txt)
- Met and unmet demand for all DFSPs (depotDemand.txt)
- Roll-up of costs, flows and statistics by destination (destinationData.txt)
- Amount of green diesel produced at each biorefinery (greendieselProduction.txt)
- County (or city for DFSPs) and State lookup table for each preprocessor county, biorefinery and DFSP (locationInformation.txt)
- Roll-up of costs, flows and statistics by origin (originData.txt)
- Scenario summary report (scenarioSummary.txt)
- Roll-up of costs, flows and statistics by optimal route (singleRunReport.txt)
- Available and used vegetable oil for all preprocessors in the scenario (unusedProduction.txt)

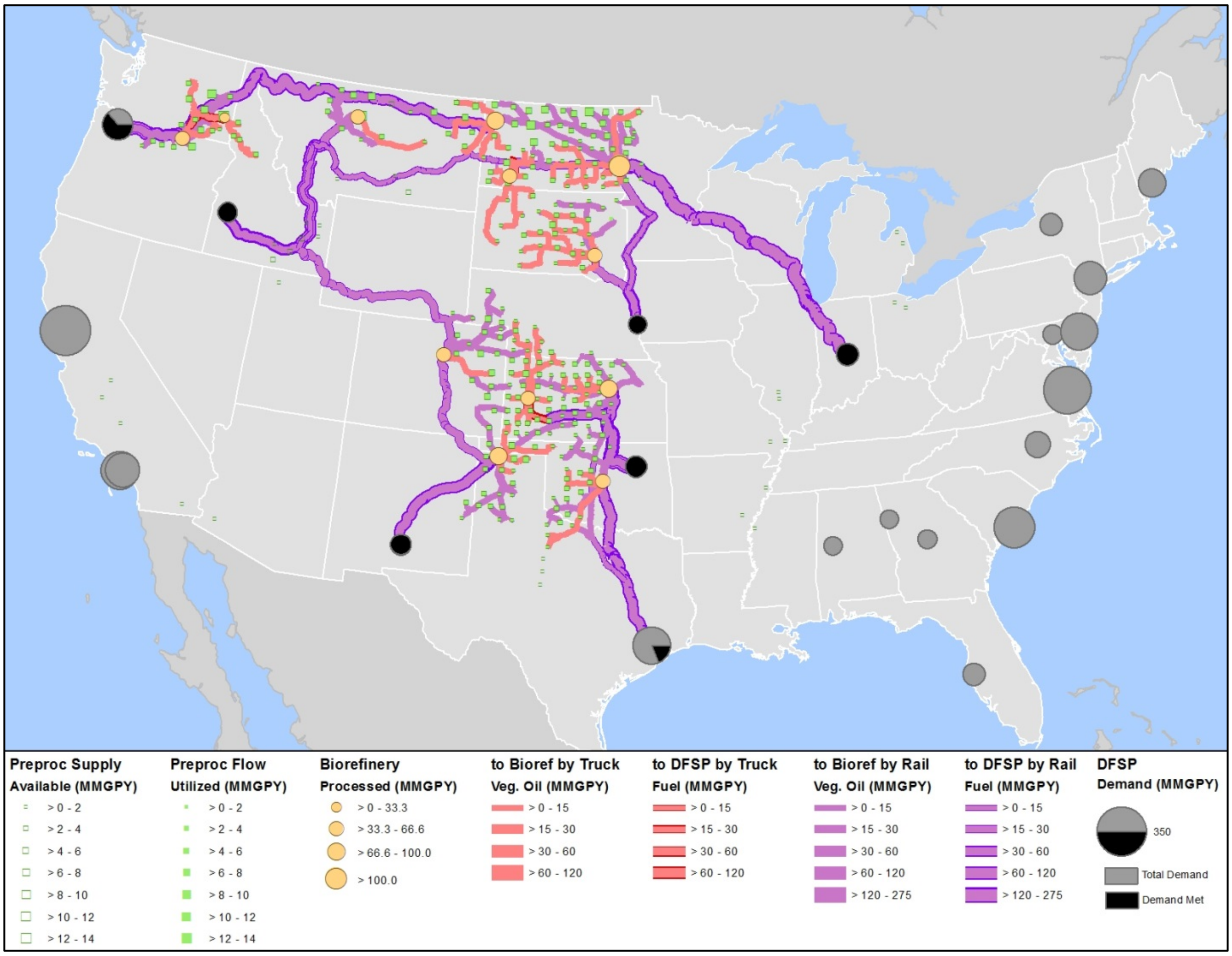
## 3.5 Map Outputs

For each scenario, the BTAT also generates a multilayered GIS map (see example in Figure 8) that shows:

- Preprocessor locations (green square symbol scaled by production amount; the available production is represented by the dark green outline and the optimized amount to use is represented by the lighter green fill)
- Biorefinery locations used (orange symbol scaled by feedstock volume processed)
- DFSPs (symbol scaled by jet fuel demand and demand fulfillment designated by the proportion of the symbol that is filled with black (i.e., all black = all demand met, half black and half gray = 50% of demand met)
- Flow of vegetable oil from preprocessor to biorefinery by truck (red, no outline) or rail (purple, no outline), with thickness indicating volume of flow
- Flow of fuel from biorefinery to DFSP by truck (red, with darker red outline) or rail (purple, with darker purple outline), with thickness indicating volume of flow

Each of these layers can be turned on and off to facilitate visual exploration of the results.

Figure 8: Example map output from a BTAT scenario visualizing the scenario results and demonstrating symbology.

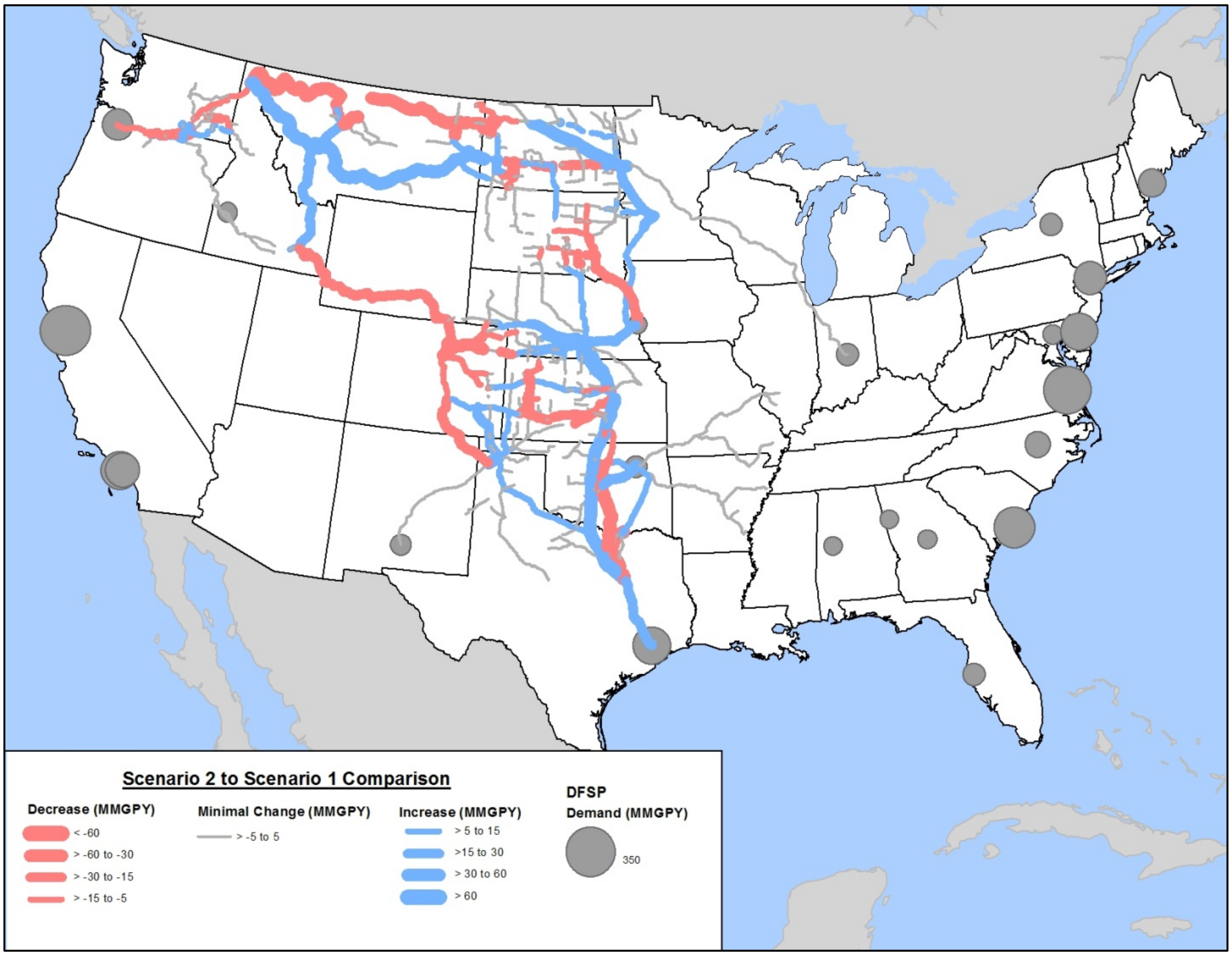



## 3.6 Compare tool

Detailed results from any given scenario run are persisted by the BTAT, which allows for scenario-to-scenario comparisons. While resources did not permit the development of a formal scenario compare tool, someone familiar with ArcMap can take the results from two different scenarios and create a map that displays significant increases and decreases between scenarios (Figure 9). This type of map-based comparison provides a relatively easy way to understand the effects of different scenarios. The map shows:

- Increased flow along routes (blue), with thickness of the line commensurate with flow volume change
- Decreased flow along routes (red), with thickness of the line commensurate with flow volume

**Figure 9: Example comparison map showing increases and decreases in flow along all transportation routes between a baseline scenario and a modified scenario.**




## 3.7 Testing and Verification of Model Functions

The team performed a variety of tests on model performance as part of model development to ensure that the tool executes its calculations and optimization properly and that the tool's modules are internally consistent with one another. When using two different software tools, one must exercise particular care to ensure that nothing is lost in the transfer of data among units of the model. The following tests and verification procedures were used to ensure the accuracy and performance of the tool and the validity of the results:

1) During coding, a logging process was implemented to track performance time for various steps and check interim calculations in the model. Files produced by the program included
    - An overall logfile providing timestamps for key point in the process.
    - A logfile of assumptions (parameter settings) for that particular scenario.

- A human and machine readable file of the mixed integer optimization problem that is solved by the PuLP optimization, listing all variables, constraints and coefficients.
- A human and machine readable file of the solution (values of each variable) produced by the optimization.

2) The team performed detailed end-to-end audits of a small number of routes within executed scenarios, where the total flow of material and transportation / transloading costs were calculated by hand for individual links in the network and then checked against the reported totals in the model outputs. The hand-calculated transportation costs for selected routes were also compared with the GIS module's calculated route transportation costs that were fed into the PuLP optimization to ensure correct transfer of information between modules at both the beginning and end of the optimization process.

3) For selected scenarios, the team compared the output reports with each other and with the detailed mixed integer program solution produced by PuLP, to ensure internal consistency and correct transfer of information between PuLP and GIS after the optimization.

4) After code was finalized, the same scenarios were run on multiple machines and by multiple people to check for consistency and stability of the tool. All scenario results came out identically on different machines.

5) The final analysis presented herein includes comparisons of scenarios with the baseline to ensure the differences were in the directions expected. For example, if a constraint is relaxed, the total cost should stay the same or decrease, whereas if additional constraints are imposed, costs should stay the same or increase.

# Demonstration of Model Capabilities

Seven scenarios were selected to demonstrate the capabilities of the BTAT to identify optimal transportation patterns based on factors that are likely to be of interest to potential users of the tool. The baseline scenario uses the supply chain structure described in Section 2, including preprocessors at the counties of production, transport of vegetable oil to biorefineries, and transport of jet fuel product to the DFSPs. In the baseline scenario, feedstock transport is assumed to be constrained to within 250 miles of actual transportation distance by road or rail (rather than a simple radius) of the county in which it was produced. While in actuality, oilseeds may be cost-effectively transported much longer distances, for other types of feedstocks shorter distances might be considered optimal for cost and emissions reasons due to the low density of the feedstocks. Therefore, this capability to constrain feedstock transport travel distance was included in the model and the baseline scenario. Each of the seven demonstration scenarios are described in more detail below.

**The baseline scenario** includes a floor of 1 million gallons per year for preprocessing facilities and a minimum threshold for building a biorefinery of 40 million gallons of vegetable oil supply per year. Biorefineries were assumed to cost approximately $100 million to build and therefore to have an amortized annual capital cost of $6 million (approximate annual cost for a $65 million loan, 15 year term, and 5% interest). Transloading costs were assumed to be relatively low ($0.02/gal) and rail transport cost was assumed to be much lower than trucking costs (with the actual values based on the data sources described in Section 3.1.3). In all cases the roadway types were weighted to favor interstate highway, then major arterials, then minor arterials and small roads. A complete XML input file example showing the baseline scenario inputs is provided in Appendix C.

**Scenario 2** varies from the baseline in feedstock transport distance, in that this Scenario doubles the allowed feedstock transport distance to 500 miles. This demonstrates the ability of the tool to adjust the optimization calculation for feedstock production constraints or lack thereof.

**Scenario 3** varies from the baseline in transloading costs, which are doubled. This demonstrates the robustness of the tool's ability to respond to changes in transloading costs.

**Scenario 4** varies from the baseline in rail costs, which are set to $0.00040 per gallon mile (instead of the baseline $0.00012) compared to $0.00045-$0.00060 per gallon mile for trucking, depending on roadway type. This value is set simply to make truck and rail more comparable to demonstrate the tool's ability to optimize among modes even when costs are similar.

**Scenario 5** is a hybrid case that demonstrates how the BTAT behaves when two fixed biorefinery facilities are included in the scenario. It also demonstrates changes in both candidate

biorefinery location selection and transportation patterns in response to the incorporation of fixed facilities into the optimized scenario solution. The two facility locations were placed within zones of high feedstock production but not at any of the candidate locations identified by the BTAT in the baseline scenario.

**Scenario 6** is distinguished from the baseline scenario by including an upper bound on biorefinery size (90 million gallons a year (MGY)). This demonstrates the BTAT's ability to handle cases in which technological or other constraints limit the size of biorefineries.

**Scenario 7** repeats the baseline scenario but shows how different the outputs and patterns would be if the product slate were tuned to produce the maximum amount of distillate (diesel and jet) as opposed to being tuned to maximize jet fuel production (volume-to-volume fuel production values relative to feedstock input from Matthew Pearlson (Pearlson 2013). This demonstrates the BTAT's ability to handle multiple product slate options.

The table below describes the differences among the seven scenarios and highlights the values that vary, but does not list all inputs for the scenarios.

| **Scenario** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
|---|---|---|---|---|---|---|---|
| Description | **Baseline** | **High feedstock transport distance** | **High trans-loading costs** | **High rail transport costs** | **Hybrid scenario (2 fixed bio-refineries)** | **Upper bound on biorefinery capacity** | **Maximum distillate case** |
| Class I railroad cost ($ per gallon-mile) | $0.00012 | $0.00012 | $0.00012 | $0.00040 | $0.00012 | $0.00012 | $0.00012 |
| Truck-to-Rail Transloading cost ($/gallon) | $0.02000 | $0.02000 | $0.04000 | $0.02000 | $0.02000 | $0.02000 | $0.02000 |
| Maximum Raw Material Travel Distance (Miles) | 250 | 500 | 250 | 250 | 250 | 250 | 250 |
| Maximum Biorefinery Size (million gallons) | | | | | | 90 | |
| Product Slate Approach | Max Jet | Max Jet | Max Jet | Max Jet | Max Jet | Max Jet | Max distillate |

## 3.8 Results

### 3.8.1 Agricultural Production

As previously noted, all of the seven demonstration scenarios assumed oilseed rotation on 10% of existing wheat acreage, distributed evenly across the wheat growing locations. The BTAT assumed that no switching to oilseed would occur in counties where this would result in less than 1 million gallons of vegetable oil produced. Given this projected rate of agricultural production, the BTAT calculated a maximum potential vegetable oil production of 802 million gallons from 306 candidate preprocessor locations. The actual amount of potential production used depended on access to nearby biorefinery locations and varied by scenario.

### 3.8.2 Scenario Results

Scenario results are presented below in detail; maps demonstrating the results of each scenario are presented in figures 8-14. Table 1 presents detailed results of each scenario. Figure 15 shows and compares variation among scenarios key results. Figures 16-21 are comparison maps showing changes in flow volume along individual routes for each scenario compared to the baseline scenario (Scenario 1).

#### *3.8.2.1 Scenario 1*

In Scenario 1 (baseline scenario), 51 candidate biorefinery locations were identified, 12 of which were actually used (Figure 10). These 12 facilities combined processed 752 million gallons of vegetable oil into 421 million gallons of jet fuel (as well as 203 million gallons of diesel, the transport of which was not modeled). The average biorefinery produced 35.1 MGY of jet fuel in this scenario. The average distance that feedstock traveled to reach a biorefinery was 127 miles, suggesting that many pre-processors are much closer to the biorefineries than the upper limit. The average distance from biorefinery to DFSP was 629 miles. The pattern of short feedstock travel distances (shorter than the feedstock transport distance constraint of 250 miles) and long biofuel travel distances is attributed mainly to the production footprints of the assumed agricultural scenario (10% rotation with wheat crops, centered in the Midwestern regions or Pacific Northwest) as well as the spatial distribution of DFSP locations.

Vegetable oil and fuel travel over a total of 45,071 road and rail miles in this scenario, of which 74% (33,441) were rail miles. 38,954 truck trips and 32,917 rail cars would be required to actually move vegetable oil and fuel produced over this many miles, resulting in 3.85 million truck vehicle miles traveled (VMT) and 11.1 million rail VMT. Given there were nearly 2.5 million combination trucks registered in the U.S. in 2011 (Bureau of Transportation Statistics 2013a) and 1.36 million freight cars in 2009 (Bureau of Transportation Statistics 2011), this is

only a small fraction of the rolling capacity or trips that occur annually. The vast majority of the truck trips (79%) occurred on the preprocessor-to-biorefinery leg of travel (i.e., the feedstock transport leg). The fact that so much vegetable oil is moved by truck suggests that at short distances, transloading costs and/or rail access are substantial barriers to rail transport.

Interestingly, the vegetable oil feedstock was only responsible for 40% of total transport costs in spite of the higher truck usage, whereas the produced biofuel was responsible for 60% despite the lower per unit transport costs of rail (the dominant mode of transport). This is due to the much greater average distances traveled by the biofuel compared to the vegetable oil. The end result of this scenario is that 7 DFSPs were served – 5 received total demand fulfillment, and 2 received partial demand fulfillment (see Figure 10). Total transport costs per gallon of final biofuel delivered totaled $0.114/gallon for this particular delivery pattern, presumably a very small cost contributor to the final price of the fuels. Scenario 1 results in the lowest overall cost, and the lowest dollar cost per gallon of jet fuel transported of the scenarios except for the maximum distillate case (Scenario 7), in which the cost of feedstock transport is allocated mainly to diesel and therefore not captured by the results.

The amount of fuel used to transport the vegetable oil and fuels in this scenario was 1.75 million gallons, or about 0.4% of the amount of biofuel delivered by the system. In total, 7.58 million kg of $CO_2$ would be emitted by the transportation of the feedstock and fuel in this scenario.

#### *3.8.2.2 Scenario 2*

In Scenario 2, the feedstock transport distance maximum is double that of Scenario 1 (500 miles instead of 250), which one would expect would increase the availability of feedstock for alternative jet fuel production. In Scenario 2, 52 candidate biorefinery locations were identified, only 6 of which were used, compared to 12 used in the baseline scenario (see Figure 11). These facilities processed 777 million gallons of vegetable oil into 435 million gallons of jet fuel and 210 million gallons of diesel. Thus, the doubling of allowable feedstock transport distance increased feedstock use, jet fuel, and diesel production by 5% over the baseline scenario. The average distance between preprocesors and biorefineries increased to 217 miles (from 127 in Scenario 1) indicating that cases where feedstock transport distance is constrained will likely affect overall scenario cost and optimal alternative production.

Vegetable oil and fuel travel over a total of 70,437 road and rail miles in this scenario, 82% (58,019) of which were rail miles. Rail VMT increased by over 2 million, to 13.2 million, while truck VMT increased only by 0.3 million, to 4.1 million. Thus, almost all of the transport distance increase over the baseline resulted from increases in rail mileage. The average transport distance for the feedstock in this scenario was 217 miles – higher than the 127 miles in Scenario 1, indicating that constraining feedstock distance does alter how much feedstock is used and where. The average distance from biorefinery to DFSP is 546 miles, compared to 619 miles in Scenario 1. All biorefinery to DFSP trips occurred via rail in this scenario, indicating that when

feedstock transport distance is less constrained, biorefineries should be sited along rail lines to minimize transport costs.

Scenario 2 is the only scenario in which the number of rail car trips was greater than the number of truck trips. Scenario 2 would result in approximately 24,515 truck trips (compared to nearly 39,000 in the Scenario 1) and over 37,000 rail car trips (up from approximately 33,000 rail cars in Scenario 1). Transloading events between truck and rail more than doubled (from 6 to 13). Thus, it appears that the main effect of increasing feedstock transport distance is that transloading costs are outweighed by the benefit of lower rail costs in more cases due to longer distances traveled. Additionally, in this scenario it is found beneficial to build fewer biorefineries (7, rather than 12 in Scenario 1). If a higher maximum transport distance is permitted, the additional transportation cost of moving material a longer distance between biorefineries and preprocessors is outweighed by the cost savings from not building five biorefineries.

The doubling of allowable feedstock transport distance resulted in more feedstock being transported (both higher total vegetable oil flows and feedstock acreage used) and larger average biorefinery jet fuel production (63MGY, compared to 35 MGY for Scenario 1. There is also a shift in transport from the lower Midwestern states toward the south rather than the west (see Figure 18). Total transport costs per gallon of final fuel totaled $0.117/gallon, slightly higher than the Scenario 1 Baseline, probably due to overall distance increases.

The end result of this scenario is that 7 DFSPs were served –5 received total demand fulfillment, and 2 received partial demand fulfillment (see Figure 11).

The amount of fuel used to transport the vegetable oil and fuels in this scenario was 2 million gallons, about 0.45% of the amount of fuel delivered by the system (similarly to Scenario 1). In total, 8 million kg of $CO_2$ would be emitted by the transportation of the feedstock and fuel in this scenario, an increase of 7% over the baseline.

#### *3.8.2.3 Scenario 3*

In Scenario 3, the transloading costs are doubled over Scenario 1, from $0.0.02 to $0.04 per gallon. One would expect this scenario to show fewer transloadings and possibly more truck travel, as greater rail travel distance would be required to outweigh the cost of shifting from truck tor rail. In Scenario 3, 53 candidate biorefinery locations were identified, 12 of which were used. This is the same number as the baseline scenario, although the exact placement of the biorefineries and their sizes differed in some cases differ (see Figure 12). These facilities processed 752 million gallons of vegetable oil into 421 million gallons of jet fuel, which are nearly the same volumes as in Scenario 1.

Vegetable oil and fuel travel over a total of 45,687 road and rail miles in this scenario, of which 74% (33,755) were rail miles. 32,646 truck trips and 38,257 rail cars would be required, a slight

reduction in both truck (2% less) and rail (1% less) trips compared to Scenario 1. VMT were similar to those in Scenario 1, but demonstrating a slight shift from rail to truck travel (3.97 million truck VMT and 11.0 rail VMT). As with Scenario 1, the vast majority of truck trips (80.4%) occurred in the feedstock transport phase. Transloading events decreased only by one event (from 6 to 5), and transport flows changed very little in location or volume in this scenario (see Figure 19), suggesting that the transloading costs at $0.04 per gallon are outweighed by the benefit of transferring to rail in most cases, likely due to the distance traveled on rail as a result of each transloading event.

Total transport costs per gallon of final fuel totaled $0.116/gallon, slightly higher than Scenario 1, likely due to the actual transloading cost change.

The end result of this scenario is that 7 DFSPs were served – 5 received total demand fulfillment, and 2 received partial demand fulfillment (see Figure 12)

The amount of fuel used to transport the vegetable oil and fuels in this scenario was 1.77 million gallons, still about 0.4% of the amount of fuel delivered by the system (similarly to Scenario 1). In total, 7.8 million kg of $CO_2$ would be emitted by the transportation of the feedstock and fuel in this scenario, a 35% increase over the baseline.

#### *3.8.2.4 Scenario 4*

In Scenario 4, the cost of transport by rail is set just below the cost of trucking in order to show the system's ability to distinguish paths even at low cost differentials. One would expect this scenario to show fewer transloadings, possibly more truck travel, greater overall scenario costs and greater per gallon costs of transporting the fuel. In this Scenario, 107 candidate biorefinery locations were identified (over double the number of candidate locations compared to Scenario 1 due to the increase in trucking routes, which tend to have more frequent intersections where candidate biorefinery locations would be identified given suitable flow). Of these candidate locations, 10 were used (see Figure 13). These facilities processed 763 million gallons of vegetable oil into 428 million gallons of jet fuel (and 206 million gallons of green diesel), which are within 0.2% of Scenario 1.

Vegetable oil and fuel travel over a total of 44,088 road and rail miles in this scenario, of which only 40.5% (17,885) were rail miles. Approximately 77,014 truck trips and 10,178 rail cars would be required. Truck VMT increased by over fourfold, from 3.85 million in Scenario 1 to 16.2 million in Scenario 4, while rail VMT dropped from 11.1 to 7.2 million. These numbers reflect the greatly reduced advantage of moving by rail, which results in more truck miles and trips compared to Scenario 1. As anticipated, transloadings dropped from 6 events in Scenario 1 to zero events in this scenario, a much greater effect than doubling the transloading costs.

Total transport costs per gallon of final fuel totaled $0.304/gallon, 2.7 times the cost per gallon in Scenario 1, because of the higher number of truck trips and the higher cost of rail transport.

The increase in fuel costs resulted in a reduction of biorefineries from 12 to 10, with consolidation and concomitant shifting of all biorefinery locations occurring in the upper Midwest, centered around the Dakotas (from five to four biorefineries) and in the Kansas region (five to four biorefineries) (see Figure 13) and changes in the associated feedstock and fuel flow patterns (Figure 20). Average biorefinery output increased to 43 MGY, which is somewhat counter to anticipated results, as one might expect increases in travel cost would make it more economical to use more, smaller biorefineries.

The end result of this scenario is that 7 DFSPs were served – 5 received total demand fulfillment, and 2 received partial demand fulfillment (see Figure 13). In particular, a reduction in flow of jet fuel to the Washington State/Oregon border DFSP occurs in conjunction with changes in transportation patterns through Montana (see Figure 20). A shift from rail to truck is also evident in Kansas and Oklahoma.

The amount of fuel used to transport the vegetable oil and fuels in this scenario was 3.5 million gallons, over 0.8% of the amount of fuel delivered by the system (compared to 0.4% in Scenario 1). Thus, the return on energy invested in the transport of the feedstock and fuel has dropped by approximately 50%. In total, 31.5 million kg of $CO_2$ would be emitted by the transportation of the feedstock and fuel in this scenario, three times the amount from Scenario 1.

#### *3.8.2.5 Scenario 5*

Scenario 5 is a hybrid scenario that demonstrates the tool's capability to route through and around fixed biorefinery locations. For example, if specific facilities were already built or planned, the tool can be used to identify optimized feedstock transport routes and flow to those facilities and identify candidate biorefinery locations taking the fixed facilities into account. This scenario included two fixed biorefinery locations near feedstock production areas in Kansas and South Dakota, for which capital cost was set at zero. In many cases, such facilities will be included in the optimized solution because the savings on capital costs makes those locations more attractive for the GIS module and optimizer to route feedstock through (Figure 14). In this demonstration scenario, facility capacity was not capped, even for the pre-existing facilities – this capability is demonstrated in Scenario 6. One would expect Scenario 5 to include one or both fixed biorefinery locations in the optimal solution, and to show a change in selected, internally-generated biorefinery candidate locations based on feedstock routing patterns to accommodate the fixed location(s). In this Scenario, 67 candidate biorefinery locations were identified, of which 11 were used, including the fixed facility location in Kansas (see Figure 14). The fixed facility location in South Dakota was not selected, indicating that nearby candidate locations met the demand more cost-effectively, even with the capital cost of building a new biorefinery instead of using the fixed facility.[3] The average facility jet fuel production increased

[3] One can modify the unmet demand penalty to make it more likely the system will utilize the fixed biorefineries (see Section 3.2.1). Running Scenario 5 with an unmet demand penalty of $1 resulted in both fixed biorefineries

from 35 to 38.5 million gallons per year, and these facilities have shifted locations, particularly in the region near the pre-existing facilities, to accommodate altered feedstock availability and flows. These facilities processed 755 million gallons of vegetable oil into 423 million gallons of jet fuel (and 204 million gallons of green diesel), which are within 0.1% of Scenario 1.

Vegetable oil and fuel travel over a total of 45,295 road and rail miles in this scenario, of which 71% (32,370) were rail miles. Approximately 43,748 truck trips and 31,677 rail cars would be required. This indicates a 12% increase in truck trips (approximately 4,000) and about 1,200 fewer rail cars (4% decrease), suggesting that the fixed biorefinery locations are not optimally located for transport of feedstock and fuel by rail. This is corroborated by the VMT results, which show a19% increase in truck trips (to 4.6 million VMT) and a 2% increase in rail trips (to 11.3 million VMT). While the greatest changes in flow patterns occur near the fixed biorefinery location, there are impacts on flow patterns and volumes even in the portions of the system furthest from the fixed biorefinery (Figure 21), suggesting that there may be unanticipated effects of "first-mover" facilities on the overall optimization of the feedstock and fuel transport.

Total transport costs per gallon of final fuel totaled $0.12/gallon, slightly higher than in Scenario 1.

The end result of this scenario is that 7 DFSPs were served – 5 received total demand fulfillment, and 2 received partial demand fulfillment (see Figure 14).

The amount of fuel used to transport the vegetable oil and fuels in this scenario was 1.9 million gallons, approximately 0.4% of the amount of fuel delivered by the system (similarly to Scenario 1). In total, 8.97 million kg of $CO_2$ would be emitted by the transportation of the feedstock and fuel in this scenario, an 18% increase from Scenario 1, again suggesting that the pre-existing biorefinery location was not efficiently located for the purposes of feedstock and fuel transport. One would expect greater changes in optimal feedstock transport patterns as more fixed facilities are added to the system.

#### *3.8.2.6 Scenario 6*

Scenario 6 places a cap on biorefinery processing capacity at 90 million gallons per year. One would expect this scenario to show an increase in biorefinery numbers and/or a decrease in the amount of feedstock processed if many biorefineries were processing more than this cap in the baseline scenario. If only a few biorefineries were operating above the 90 million gallon cap, one would expect to see subtler changes as no new biorefineries are built, but existing biorefineries that had been operating significantly under capacity absorb the displaced flow. In this Scenario, 51 candidate biorefinery locations were identified, of which 12 were used – this represents no

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being used, with associated changes in the biorefinery locations and capacities in the Dakotas. All the scenarios presented in detail used a $5 unmet demand penalty in order to compare among scenarios and to achieve reasonable flow levels in Scenario 7, in which overall jet fuel flow is low.

change from Scenario 1 (see Figure 15). The biorefineries in this scenario processed 752 million gallons of vegetable oil into 421 million gallons of jet fuel (and 203 million gallons of green diesel), which are within 0.1% of Scenario 1. Interestingly, the average biorefinery size did not change in this scenario, suggesting that biorefinery sizes are already constrained by feedstock availability under the selected agricultural scenario. However, one of the biorefineries in Scenario 1 does exceed 90 MGY, and setting a maximum facility size does redirect flow to other facilities as anticipated (Figure 22).

Vegetable oil and fuel travel over a total of 46,891 road and rail miles in this scenario, of which 74% (34,810) were rail miles. Approximately 40,679 truck trips and 32,883 rail cars would be required. This indicates a slight increase in truck trips (approximately 1500) and VMT (3.98 million) and essentially no change in rail car number (but a slight increase in VMT to 11.2 million).

Total transport costs per gallon of final fuel totaled $0.116/gallon, slightly higher than in Scenario 1.

The end result of this scenario is that 7 DFSPs were served – 5 received total demand fulfillment, and 2 received partial demand fulfillment (see Figure 15).

The amount of fuel used to transport the vegetable oil and fuels in this scenario was 1.79 million gallons, approximately 0.4% of the amount of fuel delivered by the system (similarly to Scenario 1). In total, 7.8 million kg of $CO_2$ would be emitted by the transportation of the feedstock and fuel in this scenario, an increase of about 3% compared to the amount from Scenario 1.

#### *3.8.2.7 Scenario 7*

Scenario 7 applies a different product slate output to each biorefinery compared to Scenario 1. In a HEFA (hydroprocessed esters and fatty acids) facility that is trying to maximize the production of jet fuel, the output of jet fuel is about 56% of the volume of vegetable oil entering the facility, and diesel output is about 27% of the volume. In a case where a facility is maximizing total distillate output (diesel + jet fuel), the amount of jet fuel drops to approximately 15% and diesel output volume is approximately 78% that of vegetable oil coming in. One would expect this scenario to show a reduction in jet fuel production and a concomitant reduction in total transport of jet fuel, total cost to transport jet fuel, and associated fuel use and greenhouse gases, although it should be noted that these changes would result in corresponding increases in the same areas for diesel production and transport, which is not modeled here except in terms of total diesel production that would be expected.

In this Scenario, 51 candidate biorefinery locations were identified, of which only 10 were used (see Figure 14). The biorefinery locations are similar to Scenario 1 in the Montana, North and South Dakota, but in Washington State there is only one biorefinery, which is larger than the two in Scenario 1, and in Kansas and the surrounding states, there are only four biorefineries, which

tend to be larger than in Scenario 1 and are shifted in location (Figure 16). These facilities processed only 742 million gallons of vegetable oil into 111 million gallons of jet fuel (and 579 million gallons of green diesel), a 74% reduction in jet fuel production and nearly a threefold increase in diesel production, as expected. This results in an average jet fuel output per biorefinery of 11.1 MGY. Feedstock acreage was within 1% of the usage in Scenario 1.

Vegetable oil and fuel travel over a total of 40,236 road and rail miles in this scenario, of which 70% (28,290) were rail miles. Approximately 33,718 truck trips (3.7 million truck VMT) and 21,777 rail cars (4.0 million rail VMT) would be required to transport the feedstock and jet fuel components. The reductions in rail car numbers and in VMT are due to the reduction in jet fuel transported from biorefinery to DFSP. The reduction in flow from biorefineries to DFSPs is shown in Figure 23.

Total transport costs per gallon of final fuel totaled $0.096/gallon, lower than the $0.117 in Scenario 1, most likely due mainly to the reallocation of most of the feedstock transport cost to diesel production.

The end result of this scenario is that one DFSP was fully supplied and four were partially served with regard to their jet fuel demand (see Figure 16).

The amount of fuel used to transport the vegetable oil and fuels in this scenario was 1.0 million gallons, approximately 0.9% of the amount of jet fuel delivered by the system (approximately double the percentage from Scenario 1). In total, 7.2 million kg of $CO_2$ would be emitted by the transportation of the feedstock and jet fuel in this scenario, a reduction of about 5% compared to the amount from Scenario 1. Given the large reduction in jet fuel transport, it is somewhat surprising that the $CO_2$ was not reduced further, given that the tool does not model the associated increase in jet fuel demand. This suggests that most of the $CO_2$ emissions are associated with feedstock transport (which are not split by product in this calculation). This demonstrates the need to better allocated $CO_2$emissions among products within the transport flow in the next iteration of the BTAT.

Table 2: Summary of selected results for Scenarios 1-7.

| Scenario Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| **Scenario Description** / **Result** | **Baseline** | **High feedstock transport distance** | **High trans-loading costs** | **High rail transport costs** | **Hybrid scenario (2 fixed bio-refineries)** | **Upper bound on bioref. capacity** | **Maximum distillate case** |
| **Scenario Results** | | | | | | | |
| Number of Biorefineries to Build | 12 | 7 | 12 | 10 | 11 | 12 | 10 |
| Total flow from Preprocessors to Biorefineries (MMGPY) | 752 | 787 | 752 | 763 | 755 | 752 | 742 |
| Total flow from Biorefineries to Depots (MMGPY) | 421 | 441 | 421 | 428 | 423 | 421 | 111 |
| Total cost to Build Biorefineries excluding already funded -- total annualized CapEx (MM $) | 72 | 42 | 72 | 60 | 60 | 72 | 60 |
| Total transportation cost from Preprocessors to Biorefineries (MM $) | 20.90 | 33.05 | 21.31 | 44.58 | 22.29 | 21.11 | 22.27 |
| Total transportation cost from Biorefineries to DFSP (MM $) | 33.69 | 28.96 | 34.48 | 99.97 | 36.11 | 34.77 | 7.08 |
| Total Scenario Cost, as calculated by PuLP -- includes unmet demand penalty (MM $) | 12,120.34 | 12,000.00 | 12,121.53 | 12,166.63 | 12,102.96 | 12,121.62 | 13,632.54 |
| Total Miles of Road/Rail, not vehicle-miles | 45,071 | 70,437 | 45,687 | 44,088 | 45,295 | 46,891 | 40,236 |
| Average Speed, truck only (miles/hour) | 51 | 50 | 51 | 48 | 49 | 50 | 49 |
| Total Transportation Cost (MM $) | 54.60 | 62.01 | 55.79 | 144.55 | 58.40 | 55.88 | 29.35 |
| Total Vegetable Oil (MMGPY) | 752 | 787 | 752 | 764 | 755 | 752 | 742 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Dollar Cost Per Gallon of Jet Fuel ($) | 0.1135 | 0.1163 | 0.1160 | 0.3042 | 0.1209 | 0.1164 | 0.0959 |
| Interstate Miles | 3,017 | 2,658 | 3,463 | 5,358 | 2,143 | 2,617 | 2,913 |
| Non-Interstate Miles | 8,610 | 9,758 | 8,467 | 20,844 | 10,779 | 9,461 | 9,031 |
| STRAHNET Miles (truck) | 3,108 | 2,572 | 3,547 | 6,041 | 2,294 | 2,708 | 3,160 |
| GHGs CO2 (total tonnes) | 7,576 | 8,074 | 7,797 | 31,457 | 8,970 | 7,829 | 7,223 |
| Rail Miles | 33,441 | 58,019 | 33,755 | 17,885 | 32,370 | 34,810 | 28,290 |
| Truck Miles | 11,627 | 12,417 | 11,930 | 26,202 | 12,923 | 12,078 | 11,945 |
| STRACNET Miles (rail) | 12,916 | 19,141 | 13,282 | 5,459 | 11,643 | 14,360 | 8,281 |
| Rail Vehicle Miles Traveled (millions) | 11.05 | 13.17 | 11.01 | 7.16 | 11.30 | 11.19 | 4.05 |
| Truck Vehicle Miles Traveled (millions) | 3.85 | 4.10 | 3.97 | 16.20 | 4.57 | 3.98 | 3.71 |
| Number of Transloadings | 6 | 13 | 5 | - | 5 | 7 | 6 |
| Total Jet Fuel Amount (MMGPY) | 421 | 441 | 421 | 428 | 423 | 421 | 111 |
| Total Acres of Feedstock (Millions) | 36.15 | 37.63 | 36.15 | 36.76 | 36.33 | 36.15 | 35.73 |
| Total Fuel Used for Transportation (millions of gallons) | 1.75 | 2.01 | 1.77 | 3.50 | 1.90 | 1.79 | 1.04 |
| Number of Truck Trips | 38,954 | 24,515 | 38,247 | 77,014 | 43,748 | 40,679 | 33,718 |
| Number of Rail Cars | 32,917 | 37,369 | 32,646 | 20,178 | 31,677 | 32,883 | 21,777 |
| Total Green Diesel Amount (MMGPY) | 203 | 213 | 203 | 206 | 204 | 203 | 579 |
| Number of Preprocessors Used | 274 | 294 | 274 | 280 | 275 | 274 | 270 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Number of Depots Supplied | 7 | 7 | 7 | 7 | 7 | 7 | 5 |
| Available Preprocessors | 306 | 306 | 306 | 306 | 306 | 306 | 306 |
| Average Annual Biorefinery Jet Fuel Output (MMGPY) | 35.10 | 62.96 | 35.10 | 42.75 | 38.46 | 35.10 | 11.13 |

Figure 10: Scenario 1 - Baseline

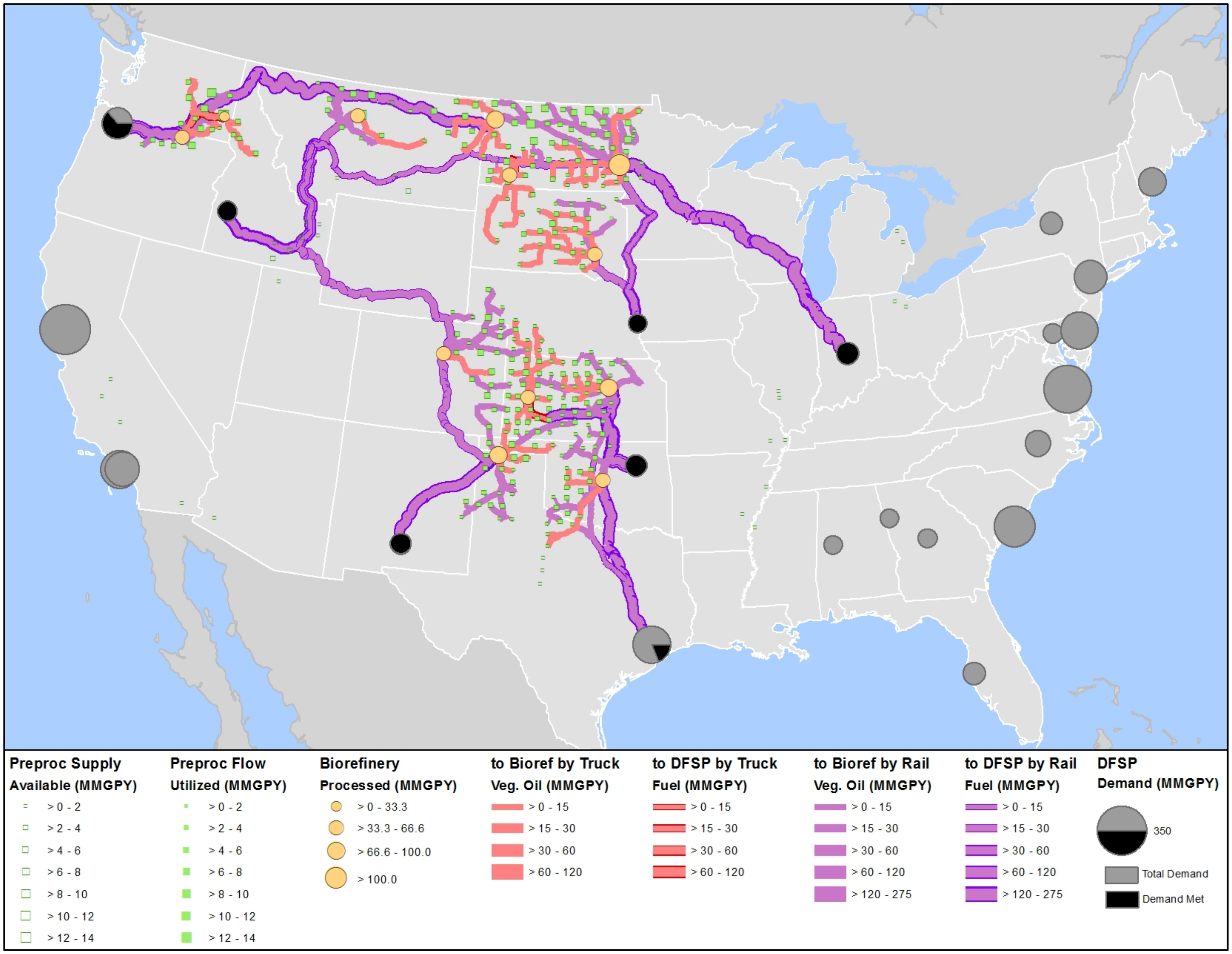


**Figure 11: Scenario 2 – 500 Mile Distance**

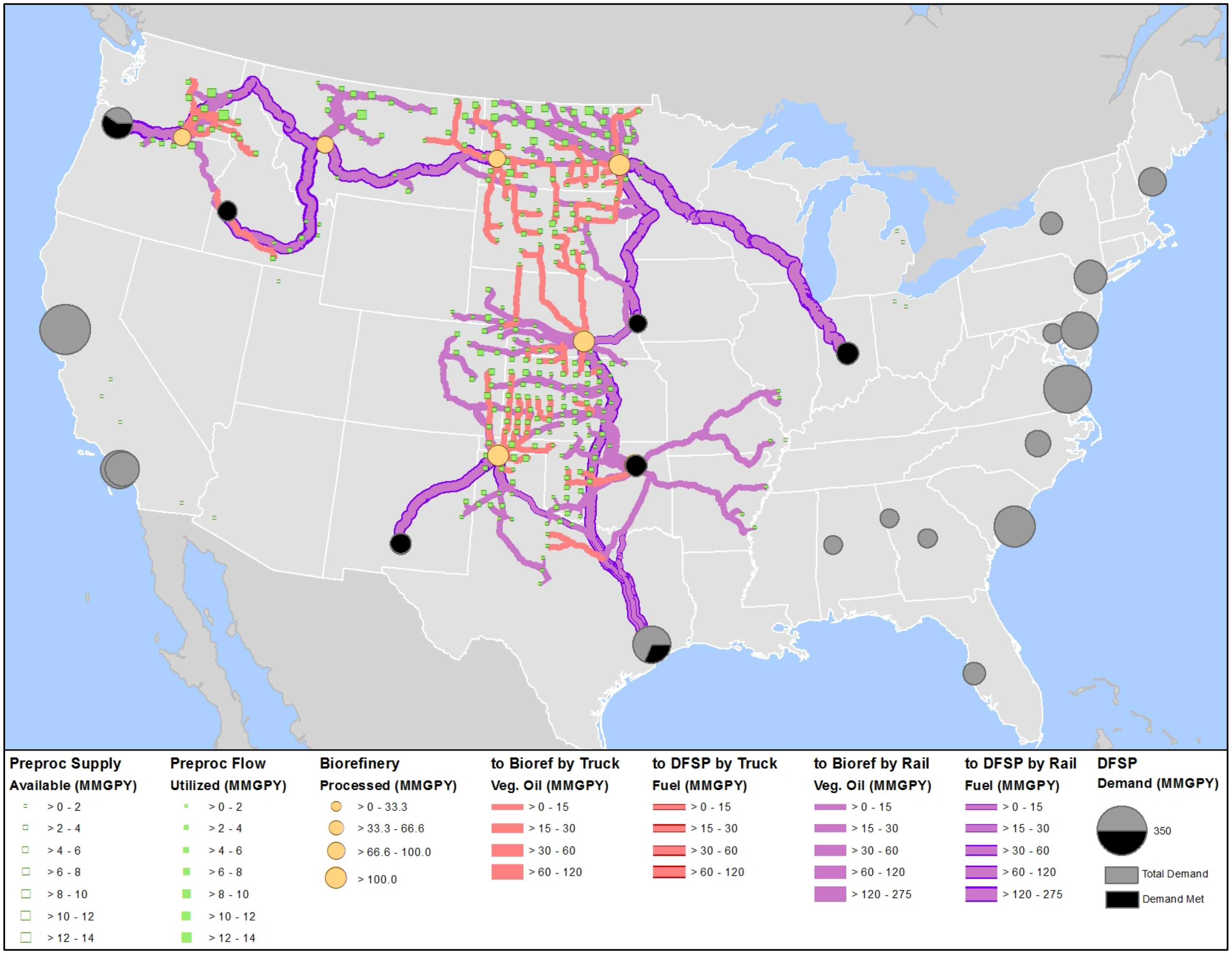


Figure 12: Scenario 3 – High Transloading

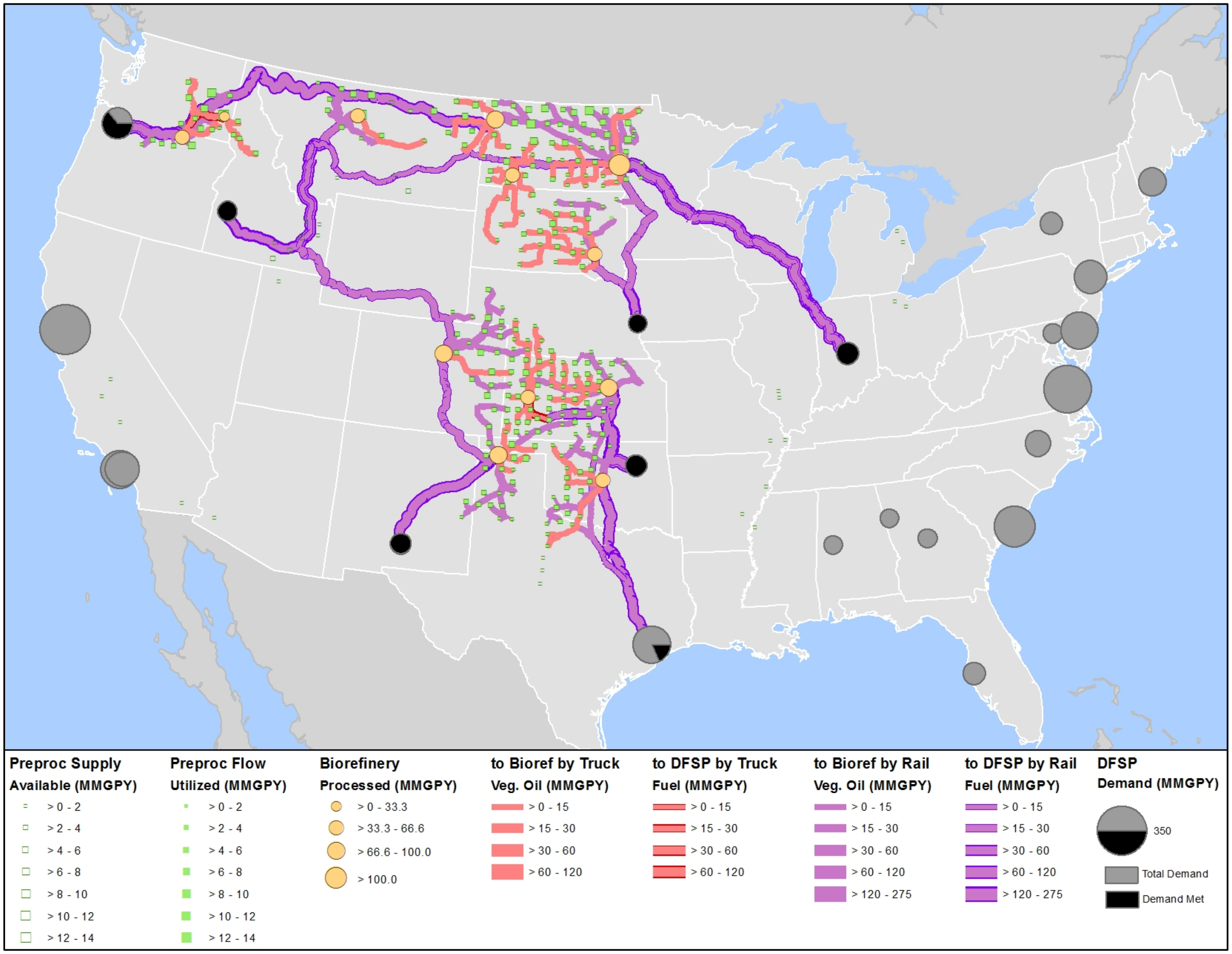


Figure 13: Scenario 4 – High Rail Cost

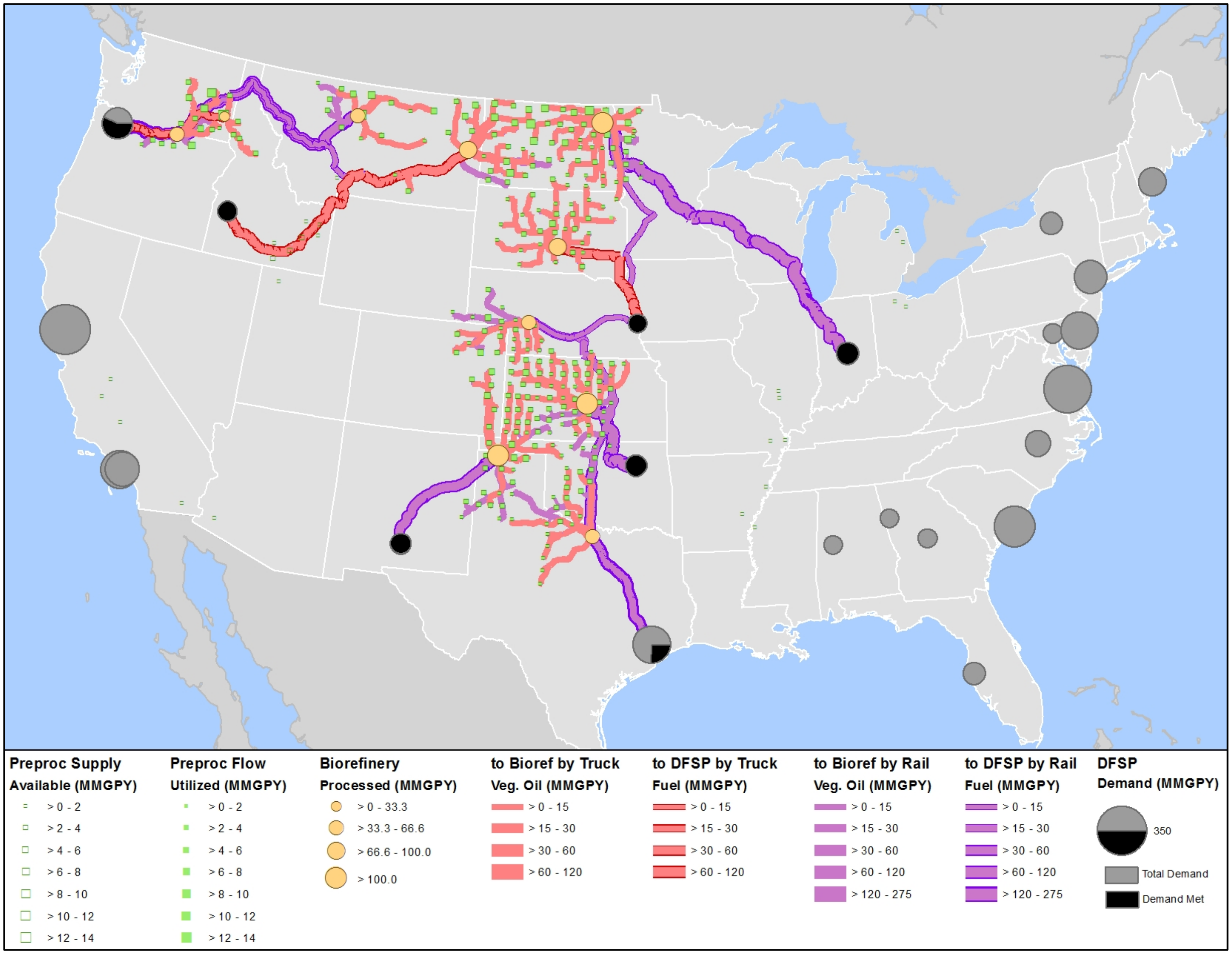


**Figure 14: Scenario 5 – Hybrid Case**

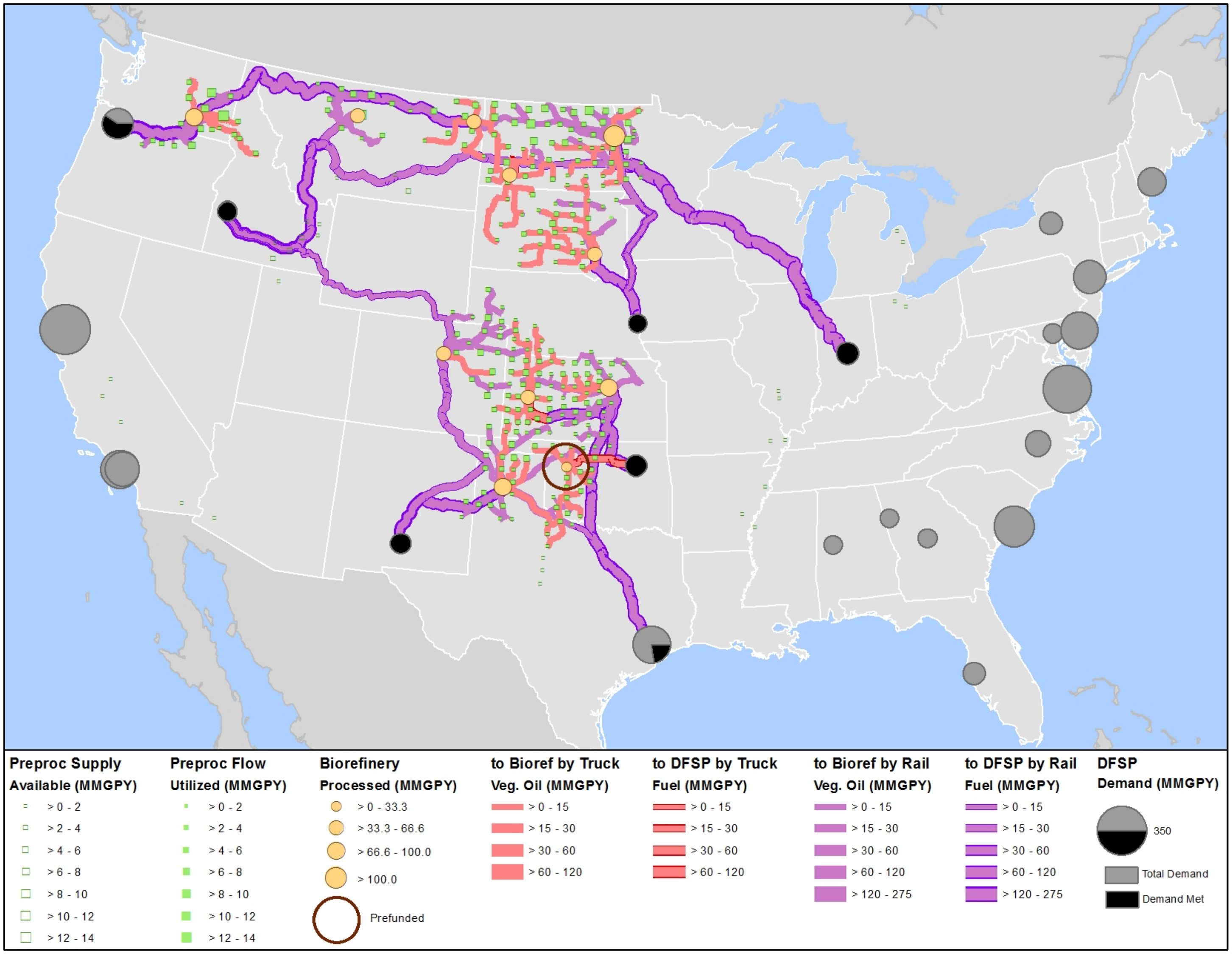


**Figure 15: Scenario 6 – Baseline with Biorefinery Upper Bound**

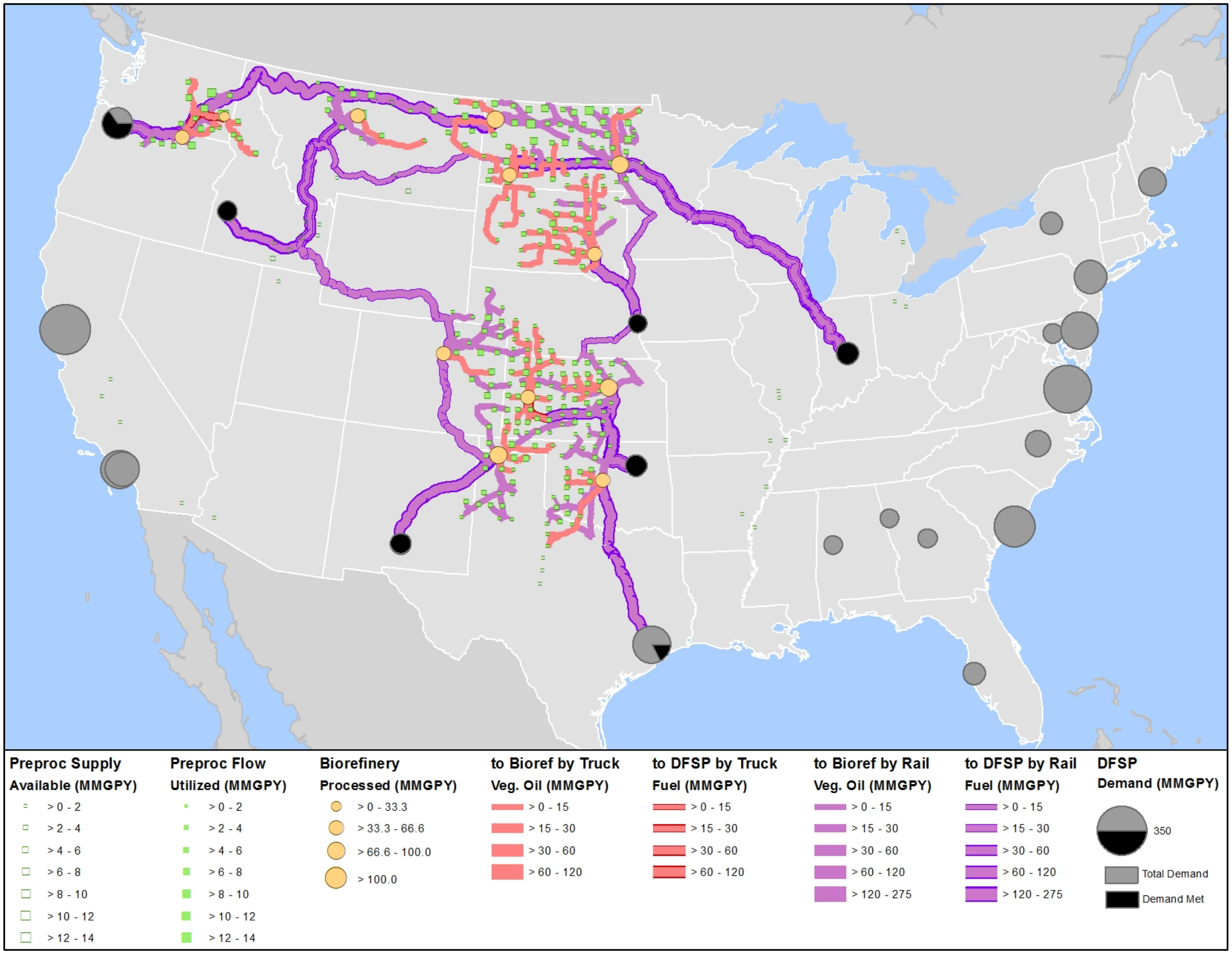


Figure 16: Scenario 7 – Max Distillate

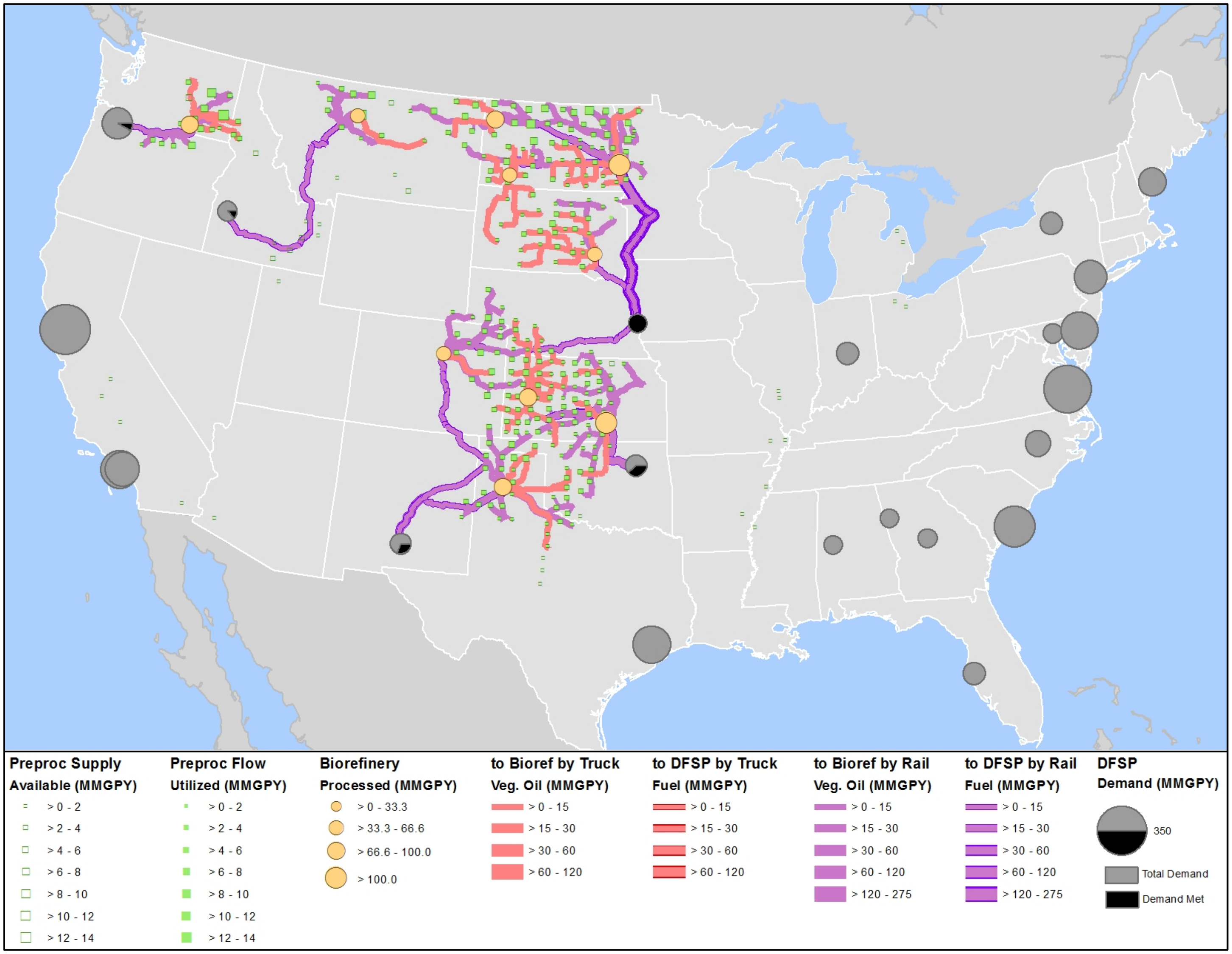


**Figure 17: Comparison showing variation among scenarios for selected results of interest.**

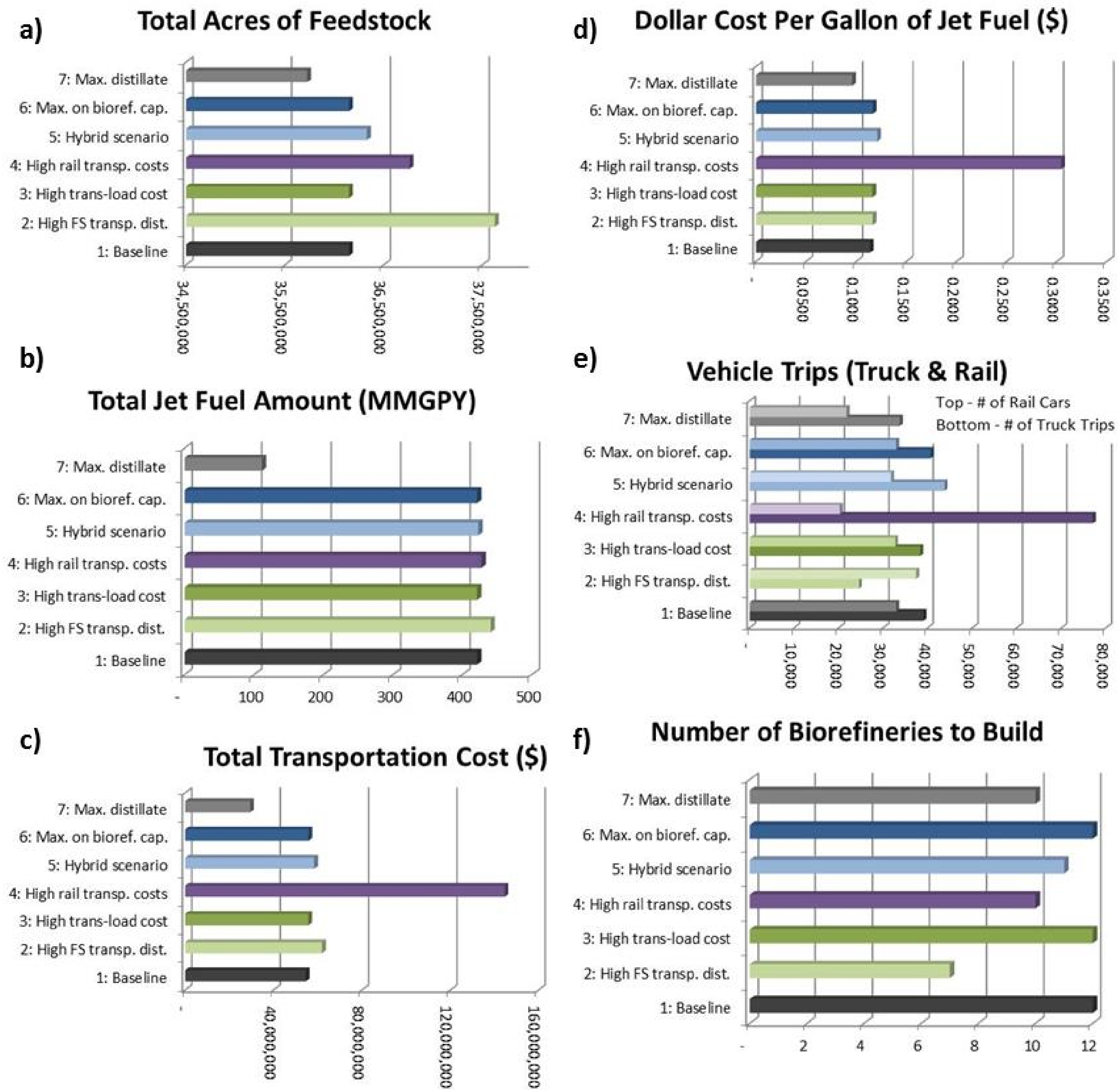


**Figure 18; Comparison map showing increased and decreased flow patterns in Scenario 2 compared to Scenario 1.**

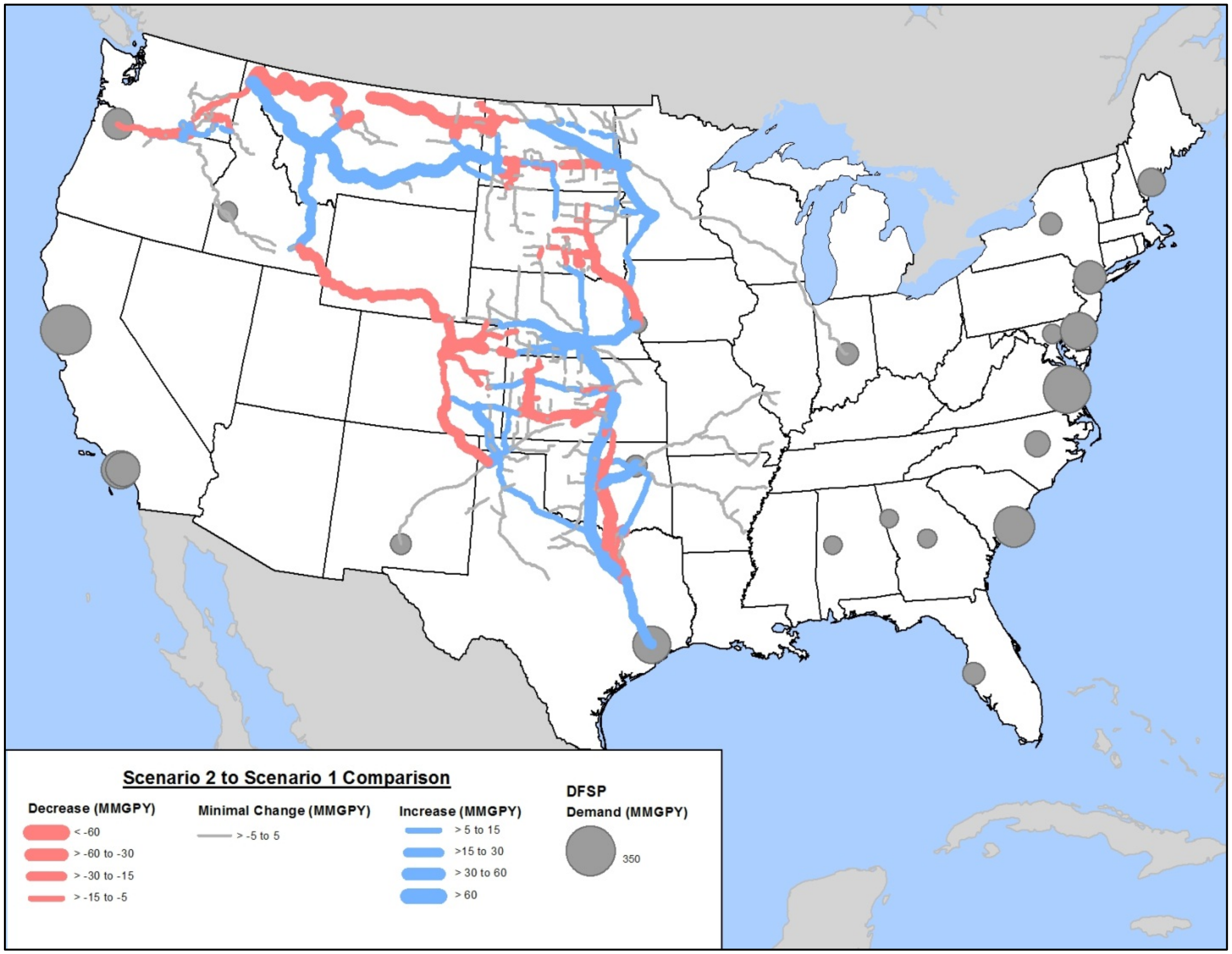


**Figure 19: Comparison of Scenario 3 to Scenario 1.**

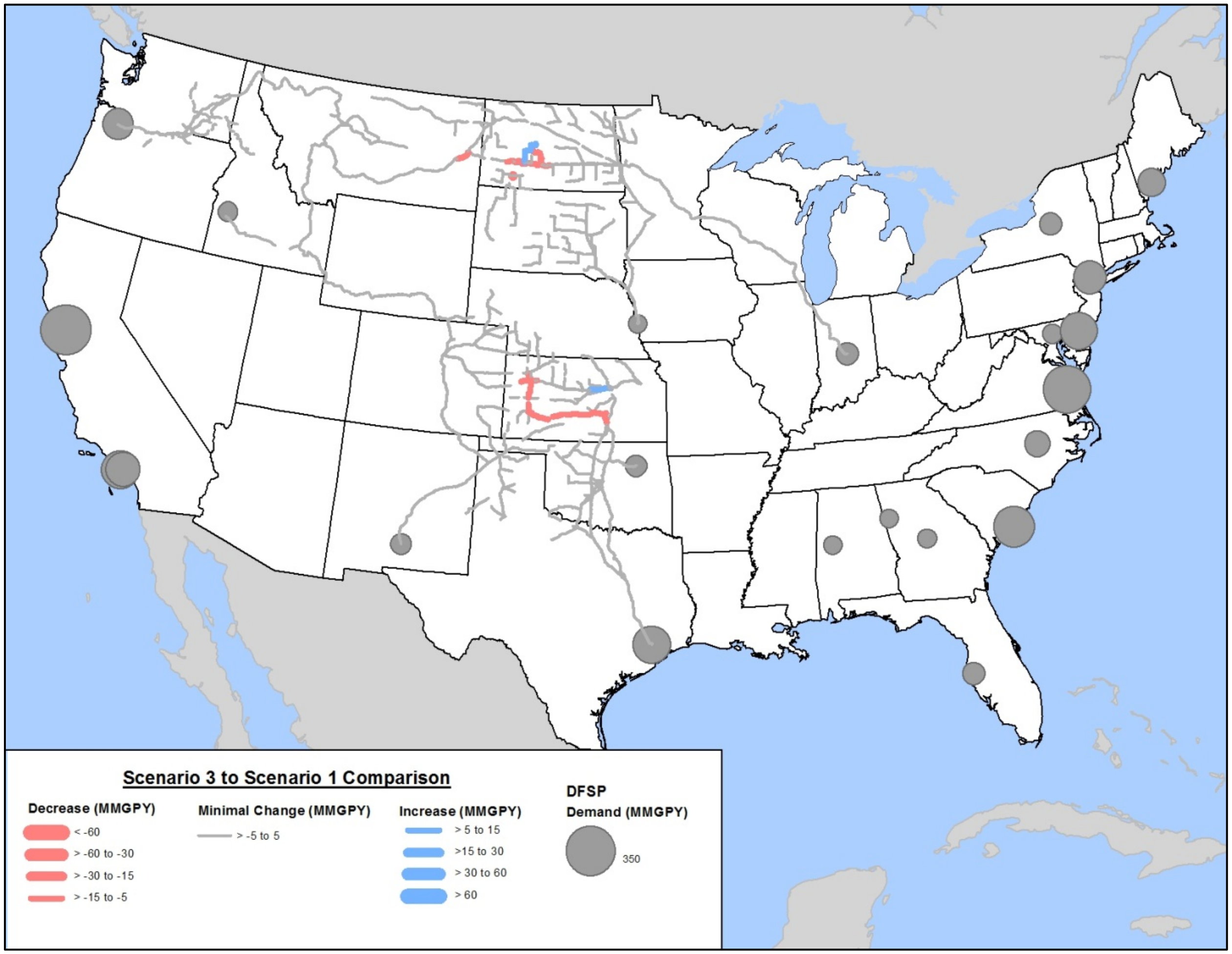


**Figure 20: Comparison of Scenario 4 to Scenario 1.**

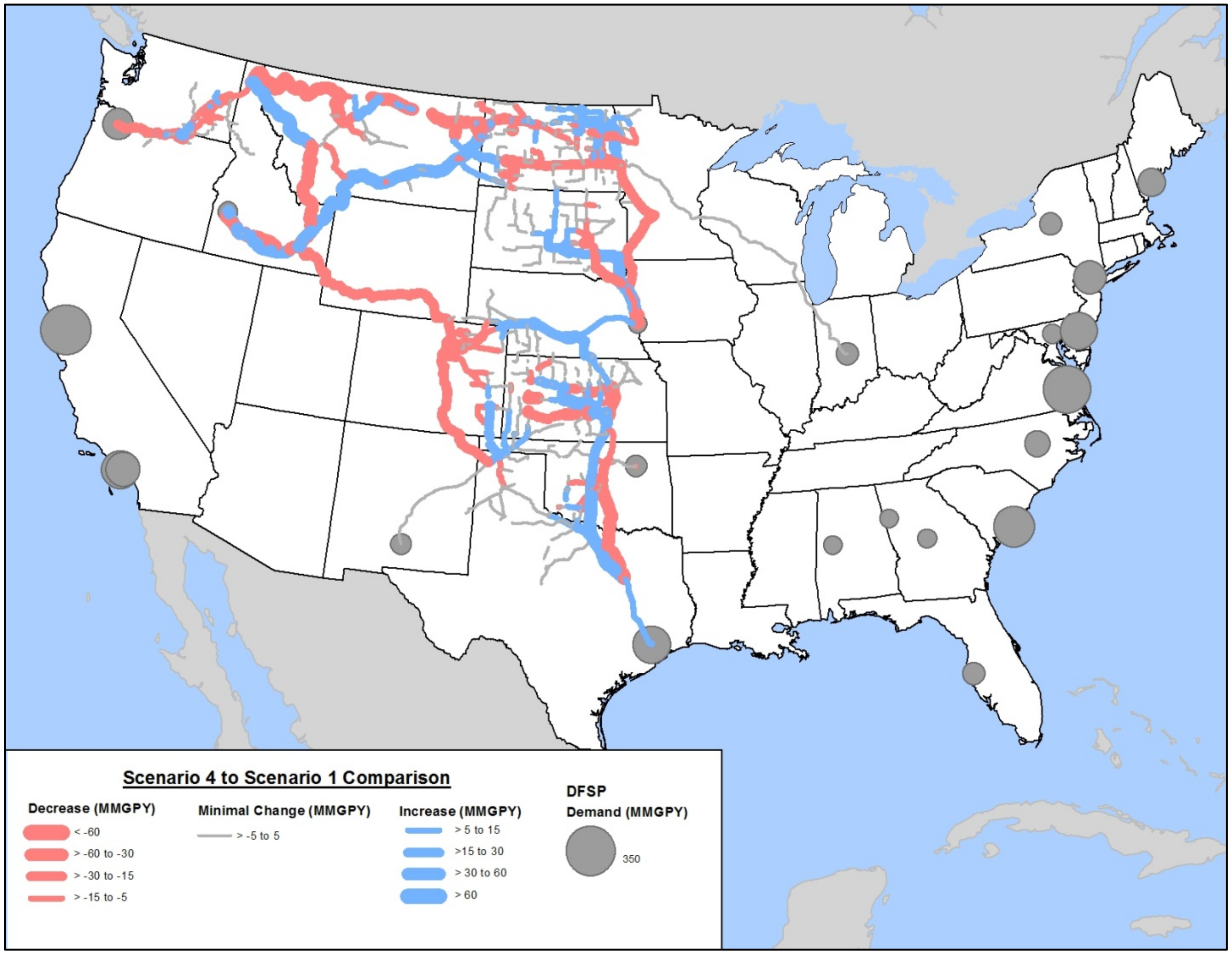


**Figure 21: Comparison of Scenario 5 to Scenario 1.**

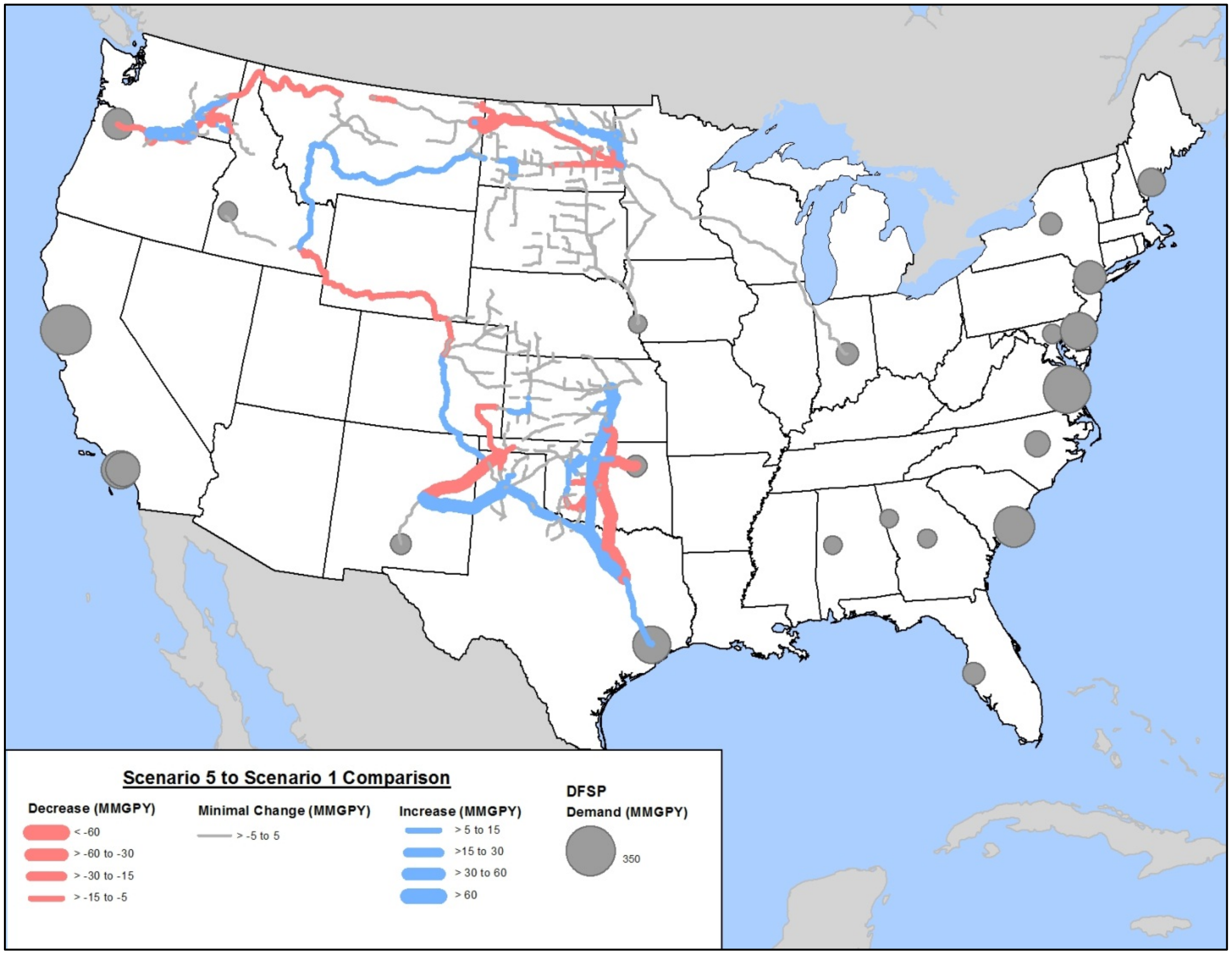


**Figure 22: Comparison of Scenario 6 to Scenario 1.**

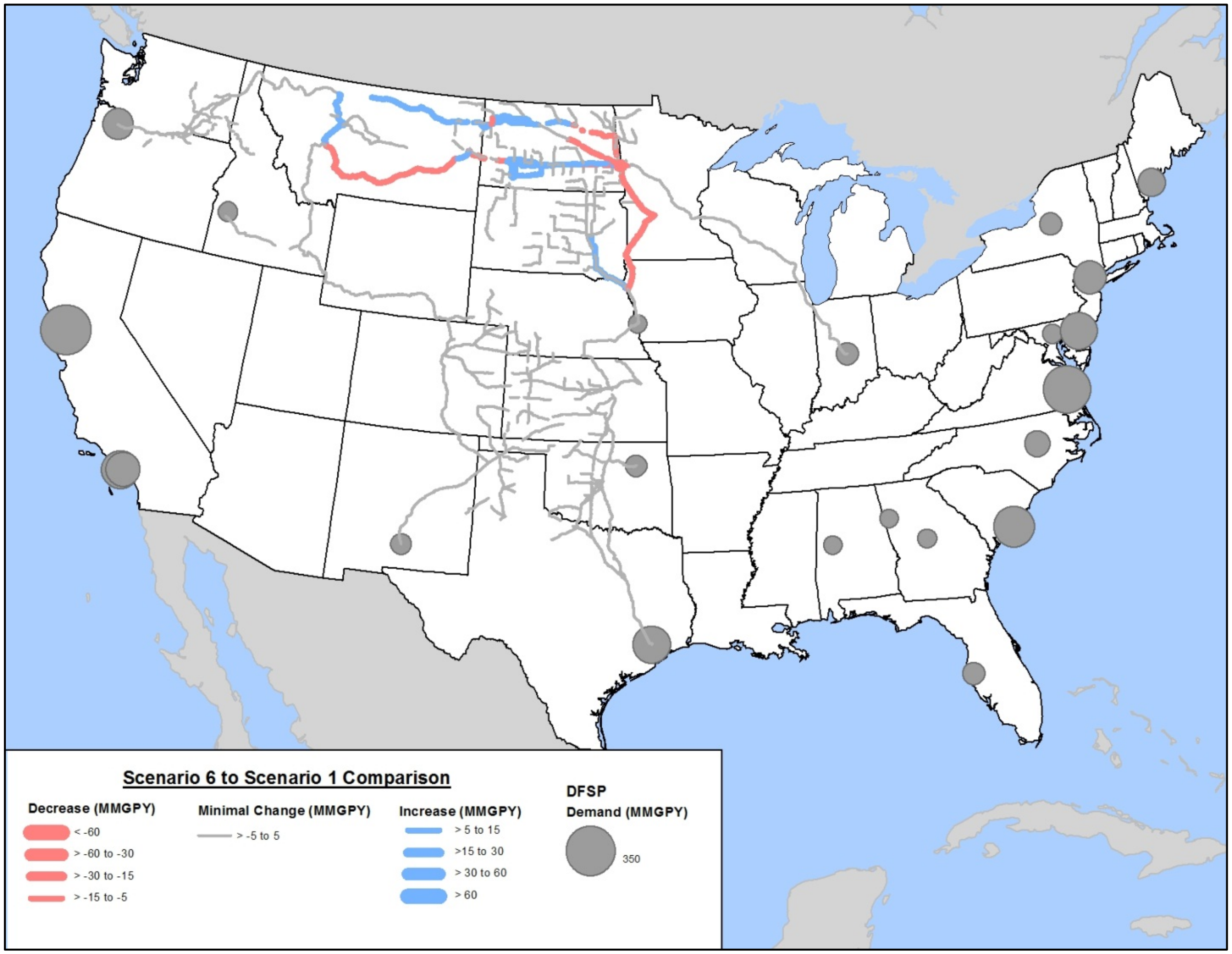
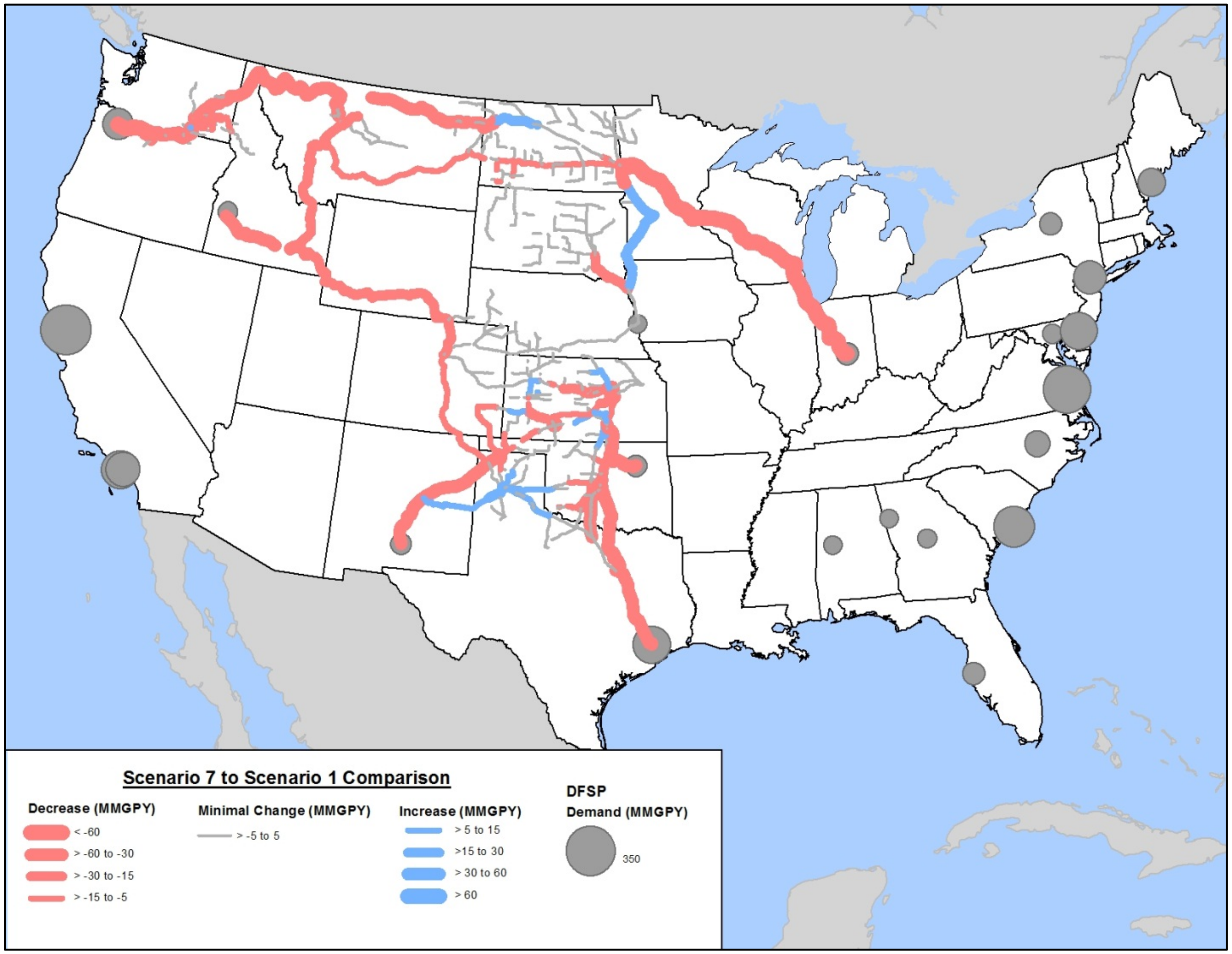


**Figure 23: Comparison of Scenario 7 to Scenario 1.**



# 4 Conclusion

This report sought to demonstrate the capabilities of the BTAT and explain the process used to develop it for ONR and FAA. The current BTAT is the first generation of a scalable, expandable tool that was designed to assess oilseed feedstock and alternative jet fuel production scenarios, identify candidate biorefinery locations, optimal (lowest cost) patterns of feedstock, and fuel flow across the road and rail networks, and to calculate the potential transportation-related costs, energy-return-on-energy-invested (EROI), transportation requirements, and $CO_2$ footprint of each scenario. The Volpe Center project team also developed a scenario comparison tool that allows for rapid analysis of differences in transportation flow and patterns across scenarios.

The results from the seven demonstration scenarios show that the BTAT can accommodate a variety of inputs and constraints on the supply chain and can appropriately use those constraints to calculate optimized transportation pathways. Most patterns of change across scenarios are in the direction anticipated, although there were a few unanticipated results. For example, Scenario 4 results showed the consolidation of biorefinery locations and an increase in average biorefinery size, when high transport costs might lead to the expectation of more, smaller biorefineries. In Scenario 5, the inclusion of a fixed biorefinery location representing a funded or existing biorefinery resulted in changes in feedstock flow throughout the transportation network. Overall, the BTAT, and the specific set of demonstration scenarios presented in this report provide insight into how supply chain parameters such as specific transport costs and conversion facility characteristics (e.g., capacity, product slate) can alter transportation optimization. Furthermore, using the "hybrid scenario" capability, a BTAT user can better understand how first-mover facilities may change flows of feedstock and fuel in other areas.

There are several opportunities to develop the BTAT further – as described in the following section focusing on recommendations for future work.

# 5 Recommendations for Development of Turn-key Biofuel Feedstock and Fuel Transportation Modeling Tool

## 5.1 Next Steps

The current BTAT can assess the transportation features, conversion efficiencies/process, and costs associated with a single feedstock type (oilseeds); it also took into account movement by truck and rail. However, oilseeds are unlikely to be the only feedstock available for conversion to jet fuel. Therefore, to maximize the utility of the BTAT, the Volpe team suggests expanding the tool's scope to increase its capacity to assess multiple feedstocks and conversion processes at the same time. Such expansion would necessitate the evaluation of transportation capacity in greater detail due to the much greater potential alternative fuel volumes that could be produced by additional feedstocks.

Furthermore, the Volpe Center and FAA have identified opportunities for synergy with existing FAA-funded projects and the BTAT to enable testing of future scenarios identified through the FAA's AFPAT tool (for feedstock production) and the aggregation of industry plans for alternative fuel production (for conversion capacity). These opportunities would enhance the realism of BTAT scenarios and provide useful insight into how the industry may develop and optimal deployment patterns. This would also allow the Volpe Center to feed the resulting scenarios into USDA's break-even analyses for feedstock production as well as detailed aviation fuel burn and emissions-related modeling studies using the Aviation Environmental Design Tool (AEDT)[4] and associated models. The Volpe Center project team also sees an opportunity to disseminate this information broadly to stakeholder communities and the public through publishing GIS layers on the DOE's Knowledge Discovery Framework (KDF). This effort would raise the visibility of alternative jet fuel efforts. A scope of work for these efforts is currently being developed by Volpe and FAA's Office of Environment and Energy.

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[4] AEDT is an integrated aviation modeling tool for calculating noise impacts, fuel burn and emissions at the single flight up to global levels.

## 5.2 Phase 3 Needs - Additional Future Tasks Necessary to Create a Turnkey Model

The longer term opportunity to turn BTAT into a user-friendly, easily accessible tool would require the implementation of more functions within the tool itself, as well as specific user interface capabilities to allow a novice user without extensive GIS experience to work with the tool and test scenarios. Additional future tasks that might be required to create a turnkey version of the BTAT that could be easily disseminated to a wide user audience include:

- Create user interface to enable novice user to run system and enter inputs
- Develop user interface for regional capacity screening
- Create self-contained installation package
- Address barge and pipeline transportation options, including incorporation of intermodal facilities, current routes, costs, and emissions.
- Expand the rail component of the tool beyond Class 1 railroads
- Expand the tool to calculate transportation costs and GHGs for multiple products (e.g., green diesel, jet fuel, other) and allocate those costs and GHG emissions in accordance with accepted life cycle methodologies.
- Work with other organizations (e.g., national labs, USDA researchers) to identify needs for scenario runs
- Incorporate future capacity/infrastructure plans/projections
- Address system resilience/reliability – e.g., identify locations where excess capacity could allow for system redundancy, identify biorefinery or DFSP supplies that are vulnerable to disruption from single route disruptions.

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# Appendix A – Intermodal Facility List

| NAME | MODE_TYPE | CITY | STATE | ZIP | ASSOC |
|---|---|---|---|---|---|
| TRANSFLO-BIRMINGHAM-AL | RAIL & TRUCK | BIRMINGHAM | AL | 35217 | CSXT |
| PORT OF DECATUR | RAIL & TRUCK | DECATUR | AL | 35602 | CSXT, NS |
| BNSF-MOBILE-AL | RAIL & TRUCK | MOBILE | AL | 36602 | |
| TRANSFLO-MONTGOMERY-AL | RAIL & TRUCK | MONTGOMERY | AL | 36117 | CSXT |
| Producer Rice Mill Inc. | RAIL & TRUCK | Stuttgart | AR | 72160 | UP |
| BNSF-PHOENIX INTERMODAL FACILITY | RAIL & TRUCK | GLENDALE | AZ | 85301 | |
| BNSF-BAKERSFIELD-CA | RAIL & TRUCK | BAKERSFIELD | CA | 93308 | |
| BNSF-LOS ANGELES-CA | RAIL & TRUCK | LOS ANGELES | CA | 90023 | |
| CSX-OAKLAND-CA-INTERMODAL FACILITY | RAIL & TRUCK | OAKLAND | CA | 94607 | CSX |
| A AND R TRANSPORT, INC.-SAN BERNARDINO-CA | RAIL & TRUCK | SAN BERNARDINO | CA | 92410 | BNSF |
| BNSF-DENVER-CO | RAIL & TRUCK | DENVER | CO | 80216 | |
| FARMERS GRAIN CO. | RAIL & TRUCK | JULESBURG | CO | 80737 | UP |
| TRANSFLO-NORTH HAVEN-CT | RAIL & TRUCK | NORTH HAVEN | CT | 6473 | CSXT |
| NS INDEPENDENT BULK TRANSFER TERMINAL-NEWARK-DE | RAIL & TRUCK | NEWARK | DE | 19711 | NS, CSXT |
| TRANSFLO-FT. LAUDERDALE-FL | RAIL & TRUCK | FT. LAUDERDALE | FL | 33312 | CSXT |
| CSX INTERMODAL-JACKSONVILLE-FL | RAIL & TRUCK | JACKSONVILLE | FL | 32219 | |

| | | | | | |
|---|---|---|---|---|---|
| CSX INTERMODAL-ORLANDO-FL | RAIL & TRUCK | ORLANDO | FL | 32824 | |
| TRANSFLO-TAMPA-FL | RAIL & TRUCK | TAMPA | FL | 33605 | CSXT |
| TRANSFLO-ATLANTA-GA | RAIL & TRUCK | ATLANTA | GA | 30318 | CSXT |
| NS THOROUGHBRED BULK TRANSFER TERMINAL-DALTON-GA-2 | RAIL & TRUCK | DALTON | GA | 30720 | NS |
| COLONIAL TERMINAL INC. (PLANT 1)-SAVANNAH-GA-101 N | RAIL & TRUCK | SAVANNAH | GA | 31415 | NS |
| FARMERS COOPERATIVE-BAYARD-IA | RAIL & TRUCK | BAYARD | IA | 50029 | BNSF |
| PEAVEY GRAIN COS.-CLINTON-IA | RAIL & TRUCK | CLINTON | IA | 52732 | UP |
| MERSHMAN SEEDS, INC.-FORT MADISON-IA | RAIL & TRUCK | FORT MADISON | IA | 52627 | BNSF |
| MATHEWS GRAIN AND STORAGE-WEISER-ID | RAIL & TRUCK | WEISER | ID | 83672 | UP |
| BEMENT GRAIN CO.-BEMENT -IL | RAIL & TRUCK | BEMENT | IL | 61813 | UP |
| CSX INTERMODAL-CHICAGO-IL | RAIL & TRUCK | CHICAGO | IL | 60636 | |
| CSXT, NS, UP, BUNGE LAUHOFF GRAIN CO. | RAIL & TRUCK | EAST ST. LOUIS | IL | 62201 | |
| CSX-EAST ST. LOUIS-IL | RAIL & TRUCK | EVANSVILLE | IN | 47712 | |
| CSX INTERMODAL-EVANSVILLE-IN | RAIL & TRUCK | INDIANAPOLIS | IN | 46221 | CSXT, IU, CR, NS |
| NATIONAL STARCH AND CHEMICAL CO.-INDIANAPOLIS-IN | RAIL & TRUCK | LAFAYETTE | IN | 47620 | CSXT |
| TRANSFLO-LAFAYETTE-IN | RAIL & TRUCK | MORRISTOWN | IN | 46161 | CSXT |
| MORRISTOWN GRAIN CO.-MORRISTOWN-IN-120 EAST B | RAIL & TRUCK | TERRE HAUTE | IN | 47802 | CSXT |

| | | | | | |
|---|---|---|---|---|---|
| GRAHAM GRAIN CO.-TERRE HAUTE-IN | RAIL & TRUCK | CONCORDIA | KS | 66901 | BNSF |
| BNSF, UP, S E K GRAIN-COFFEVILLE-KS | RAIL & TRUCK | DODGE CITY | KS | 67801 | BNSF |
| CLOUD COUNTY COOPERATIVE ELEVATOR-CONCORDIA-KS | RAIL & TRUCK | HUTCHINSON | KS | 67504 | BNSF |
| DODGE CITY COOPERATIVE EXCHANGE-DODGE CITY-KS | RAIL & TRUCK | WICHITA | KS | 67204 | WTA, BNSF, UP |
| FARMLAND GRAIN-HUTCHINSON-KS | RAIL & TRUCK | FRANKLIN | KY | 42135 | CSXT |
| GARVEY ELEVATORS, INC.-WICHITA-KS | RAIL & TRUCK | LOUISVILLE | KY | 40219 | CSXT |
| KENTUCKY TENNESSEE GRAIN-FRANKLIN-KY | RAIL & TRUCK | PEMBROKE | KY | 42266 | CSXT |
| TRANSFLO-LOUISVILLE-KY | RAIL & TRUCK | NEW ORLEANS | LA | 70126 | |
| CHRISTIAN  CO. GRAIN CO., INC.-PEMBROKE-KY | RAIL & TRUCK | WEST SPRINGFIELD | MA | 1089 | |
| CSX INTERMODAL-NEW ORLEANS-LA | RAIL & TRUCK | WORCESTER | MA | 1607 | |
| CSX INTERMODAL-WEST SPRINGFIELD | RAIL & TRUCK | BALTIMORE | MD | 21224 | |
| CSX INTERMODAL-WORCESTER-MA | RAIL & TRUCK | DETROIT | MI | 48209 | |
| CSX INTERMODAL-BALTIMORE-MD | RAIL & TRUCK | Duluth | MN | 55802 | BNSF, SOO |
| CSX INTERMODAL-DETROIT | RAIL & TRUCK | ST. PAUL | MN | 55104 | |
| AGP Grain Limited | RAIL & TRUCK | Aurora | MO | 65605 | BNSF |
| BNSF-ST. PAUL-MN | RAIL & TRUCK | Brookfield | MO | 64628 | BNSF |
| MFA Grain Operations-Aurora | RAIL & TRUCK | VICKSBURG | MS | 39180 | KCS |

| | | | | | |
|---|---|---|---|---|---|
| AG-Land, Inc. | RAIL & TRUCK | BILLINGS | MT | 59101 | |
| BNSF,KCS,UP Bartlett & Co., Grain | RAIL & TRUCK | HELENA | MT | 59601 | BNSF |
| BUNGE CORPORATION-VICKSBURG-MS | RAIL & TRUCK | CHARLOTTE | NC | 28208 | |
| BNSF-BILLINGS-MT | RAIL & TRUCK | RALEIGH | NC | 27603 | CSXT |
| CAPITAL TRANSFER AND STORAGE-HELENA-MT | RAIL & TRUCK | WINSTON-SALEM | NC | 27107 | CSXT |
| CSX INTERMODAL-CHARLOTTE-NC | RAIL & TRUCK | Forest River | ND | 58233 | BNSF,SOO,NP,RR |
| TRANSFLO-RALEIGH-NC | RAIL & TRUCK | Taylor | ND | 58656 | BNSF |
| TRANSFLO-WINSTON-SALEM-NC | RAIL & TRUCK | Holdrege | NE | 68949 | BNSF |
| Farmers Elevator Co. of Forest River | RAIL & TRUCK | ELIZABETH | NJ | 7201 | CR |
| Southwest Grain Cooperative | RAIL & TRUCK | ALBUQUERQUE | NM | 87102 | |
| Agri Co-Op | RAIL & TRUCK | ALBANY | NY | 12205 | CSXT |
| NS CONNECTING LINE BULK TRANSFER TERMINAL-ELIZABET | RAIL & TRUCK | BUFFALO | NY | 14212 | CSXT |
| BNSF-ALBUQUERQUE-NM | RAIL & TRUCK | CHILLICOTHE | OH | 45601 | CSXT |
| TRANSFLO-ALBANY-NY | RAIL & TRUCK | CINCINNATI | OH | 45214 | |
| TRANSFLO-BUFFALO-NY | RAIL & TRUCK | CLEVELAND | OH | 44113 | CSXT |
| TRANSFLO-CHILLICOTHE-OH | RAIL & TRUCK | COLUMBUS | OH | 43207 | CSXT |
| CSX INTERMODAL-CINCINNATI-OH | RAIL & TRUCK | Prospect | OH | 43342 | CSXT |

| | | | | | |
|---|---|---|---|---|---|
| TRANSFLO-CLEVELAND-OH | RAIL & TRUCK | WARREN | OH | 44481 | CSXT |
| TRANSFLO-COLUMBUS-OHIO | RAIL & TRUCK | BUTLER | PA | 16001 | CSXT |
| CSXT, NS Coshocton Grain Co. | RAIL & TRUCK | PHILADELPHIA | PA | 19145 | CSXT |
| Prospect Farmers Exchange | RAIL & TRUCK | GREENVILLE | SC | 29601 | CSXT |
| CR, CSXT, GTW, NS Anderson Marine River Elevator | RAIL & TRUCK | N. CHARLESTON | SC | 29405 | |
| TRANSFLO-WARREN-OH | RAIL & TRUCK | LABOLT | SD | 57246 | BNSF |
| TRANSFLO-BUTLER-PA | RAIL & TRUCK | KINGSPORT | TN | 37660 | |
| TRANSFLO-PHILADELPHIA-PA | RAIL & TRUCK | MEMPHIS | TN | 38109 | CSXU |
| TRANSFLO-GREENVILLE-SC | RAIL & TRUCK | NASHVILLE | TN | 37204 | |
| CSX INTERMODAL-CHARLESTON-NC | RAIL & TRUCK | AMARILLO | TX | 79107 | BNSF |
| LABOLT FARMERS GRAIN | RAIL & TRUCK | CORPUS CHRISTI | TX | 78402 | BNSF |
| CSX INTERMODAL-KINGSPORT-TN | RAIL & TRUCK | CORSICANA | TX | 75110 | BNSF |
| CSX INTERMODAL-MEMPHIS | RAIL & TRUCK | DALLAS | TX | 75228 | |
| CSX INTERMODAL-NASHVILLE-TN | RAIL & TRUCK | EL PASO METRO AREA | TX | 79922 | BNSF |
| AMARILLO WAREHOUSE COMPANY-AMARILLO-TX | RAIL & TRUCK | FORTH WORTH | TX | 76179 | BN |
| BERKSHIRE COLD STORAGE-CORPUS CHRISTI-TX | RAIL & TRUCK | HOUSTON | TX | 77020 | |
| CORSICANA GRAIN AND ELEVATOR, INC. | RAIL & TRUCK | SAN ANTONIO | TX | 78204 | UP |

| | | | | | |
|---|---|---|---|---|---|
| KANSAS CITY SOUTHERN-DALLAS-TX | RAIL & TRUCK | SALT LAKE CITY | UT | 84119 | |
| AMRAIL SERVICES, INC.-EL PASO METRO AREA-TX | RAIL & TRUCK | HOPEWELL | VA | 23860 | NS, CSXT |
| MONTGOMERY TANK LINES-FORT WORTH-TX-700 EAST M | RAIL & TRUCK | PORTSMOUTH | VA | 23707 | |
| CSX INTERMODAL-HOUSTON-TX | RAIL & TRUCK | RICHMOND | VA | 23227 | CSXT |
| BIG TEX GRAIN CO. | RAIL & TRUCK | PASCO | WA | 99301 | BNSF |
| UP-SALT LAKE CITY-UT-650 DAVIS | RAIL & TRUCK | TACOMA | WA | 98421 | |
| NS INDEPENDENT BULK TRANSFER TERMINAL-HOPEWELL-VA- | RAIL & TRUCK | GREEN BAY | WI | 54307 | CN |
| CSX INTERMODAL-PORTSMOUTH-VA | RAIL & TRUCK | MILWAUKEE | WI | 53207 | UP, SOO |
| TRANSFLO-RICHMOND-VA | RAIL & TRUCK | CLARKSBURG | WV | 26301 | CSXT |
| AMERICOLD LOGISTICS, INC.-PASCO-WA-5805 INDUS-PASC | RAIL & TRUCK | SOUTH CHARLESTON | WV | 25303 | CSXT |
| CSX INTERMODAL-TACOMA-WA | RAIL & TRUCK | TACOMA | WA | 98421 | CSXT |
| WAREHOUSING OF WISCONSIN-GREEN BAY-WI-2275 CENTU | RAIL & TRUCK | GREEN BAY | WI | 54307 | |
| CHICAGO & ILLINOIS RIVER MARKETING LLC | RAIL & TRUCK | CHICAGO | IL | 60636 | |
| TRANSFLO-CLARKSBURG-WV | RAIL & TRUCK | CLARKSBURG | WV | 26301 | |
| TRANSFLO-SOUTH CHARLESTON-WV | RAIL & TRUCK | SOUTH CHARLESTON | WV | 25303 | |
| BNSF Atlanta (Fairburn) Intermodal Facility | RAIL & TRUCK | ATLANTA | GA | 30318 | BNSF |
| BNSF Portland Intermodal Facility | RAIL & TRUCK | PORTLAND | OR | | BNSF |

| | | | | | |
|---|---|---|---|---|---|
| BNSF St. Louis Intermodal Facility | RAIL & TRUCK | ST LOUIS | MO | | BNSF |
| UP Sparks, Nevada | RAIL & TRUCK | SPARKS | NV | | UP |

# Appendix B – DLA-Energy DFSPs (subset) with Storage Capacity and Associated Estimated Demand

| PROD | MODE | LOCATION | MAX_STOR_B | CITY | STATE | LONGITUDE | LATITUDE | DEMAND | NAME |
|---|---|---|---|---|---|---|---|---|---|
| JAA | PL | DFSP BALTIMORE, MD | 114855 | Baltimore | MD | -76.6121893 | 39.2903848 | 56.164095 | Baltimore |
| JAA | BG | DFSP PORT MAHON, DE | 404449 | Port Mahon | DE | -75.40103 | 39.1853907 | 197.775561 | Port_Mahon |
| JAA | TK | DFSP CHARLESTON, SC | 479100 | Charleston | SC | -79.9309216 | 32.7765656 | 234.2799 | Charleston |
| JP8 | PL | WILLIAMS PL CO. (OMAHA), NE | 100878 | Omaha | NE | -95.9308475 | 41.2513875 | 49.329342 | Omaha |
| JP8 | PL | DFSP BREMEN, GA | 101909 | Bremen | GA | -85.1455036 | 33.7212179 | 49.833501 | Bremen |
| JP8 | PL | DFSP MACON, GA | 104408 | Macon | GA | -83.6324022 | 32.8406946 | 51.055512 | Macon |
| JP8 | PL | DFSP MOUNDVILLE, AL | 100589 | Moundville | AL | -87.6300075 | 32.9976242 | 49.188021 | Moundville |
| JP8 | PL | DFSP INDIANAPOLIS, IN | 141871 | Indianapolis | IN | -86.1580423 | 39.7683765 | 69.374919 | Indianapolis |
| JP8 | BG | DFSP HOUSTON, TX | 408017 | Houston | TX | -95.3632715 | 29.7632836 | 199.520313 | Houston |
| JP8 | PL | DFSP TULSA, OK | 134799 | Tulsa | OK | -95.992775 | 36.1539816 | 65.916711 | Tulsa |
| JP8 | PL | DFSP YORKTOWN, VA | 661360 | Yorktown | VA | -76.5096731 | 37.2387556 | 323.40504 | Yorktown |
| JP8 | BG | DFSP JACKSONVILLE, NJ | 310094 | Jacksonville | NJ | -74.3298722 | 40.9525982 | 151.635966 | Jacksonville |
| JP8 | BG | DFSP PORTLAND, ME | 229513 | Portland | ME | -70.2553259 | 43.661471 | 112.231857 | Portland |
| JP8 | TK | DFSP PT TAMPA, FL | 147156 | Port Tampa | FL | -82.5267625 | 27.8636354 | 71.959284 | Port_Tampa |
| JP8 | PL | DFSP VERONA, NY | 147366 | Verona | NY | -75.5707345 | 43.1381247 | 72.061974 | Verona |
| JP8 | PL | DFSP SELMA, NC | 188993 | Selma | NC | -78.2844435 | 35.5365485 | 92.417577 | Selma |
| JP8 | TK | DFSP VANCOUVER, WA | 274353 | Vancouver | WA | -122.6614861 | 45.6387281 | 134.158617 | Vancouver |
| JP8 | PL | HOLLY TERMINAL, ID | 110952 | Holly Terminal | ID | -116.237651 | 43.613739 | 54.255528 | Holly_Terminal |
| JP8 | TK | DFSP SAN PEDRO, CA | 419074 | San Pedro | CA | -118.2922934 | 33.7358518 | 204.927186 | San_Pedro |
| JP8 | PL | ALAMOGORDO, NM | 122212 | Alamogordo | NM | -105.960265 | 32.8995325 | 59.761668 | Alamogordo |
| JP8 | PL | DFSP SELBY, CA | 731072 | Selby | CA | -122.2438579 | 38.0565876 | 357.494208 | Selby |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| JP8 | TK | DFSP CARSON TERMINAL, CA | 338000 | Carson Terminal | CA | -118.195617 | 33.768321 | 165.282 | Carson_Terminal |

# Appendix C – XML-based Scenario Input File for Scenario 1 (Baseline)

This sample input file shows the variables that can be modified by a user of the analytical tool, with sample inputs from Scenario 1 (the Baseline Scenario).

```xml
<?xml version="1.0" encoding="utf-8"?>

<Scenario xmlns="http://example.com" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:schemaLocation="http://example.com Master_ONR_Schema.xsd">
    <!--These are the scenario inputs-->
    <Scenario_Name>S011_Baseline</Scenario_Name>

    <Scenario_Inputs>

        <Preprocessor_Location_Layer>Preprocessor</Preprocessor_Location_Layer>

        <Network_Layer>Network</Network_Layer>

        <Biorefinery_Candidates_Layer>Biorefinery</Biorefinery_Candidates_Layer>

        <Base_Data_Directory>C:\ONR_Runs\Program\BASE</Base_Data_Directory>

        <Product_Slate>

            <!--Maximum Jet: 56% Jet, 27% Diesel; Maximum Distillate: 15% Jet, 78% Diesel-->

            <Jet_Percentage>56</Jet_Percentage>

            <Diesel_Percentage>27</Diesel_Percentage>

        </Product_Slate>

    </Scenario_Inputs>




    <Assumptions>

        <Jet_Fuel_Density_kg_per_liter>0.757</Jet_Fuel_Density_kg_per_liter>

        <Fuel_CO2_Emissions_per_MJ>70.4</Fuel_CO2_Emissions_per_MJ>

        <Vegetable_Oil_gallons_per_kg>0.28714</Vegetable_Oil_gallons_per_kg>

        <Truck_Fuel_Efficiency_MilesPerGallon>5.8</Truck_Fuel_Efficiency_MilesPerGallon>

        <Rail_Fuel_Efficiency_MilesPerGallon>10.15</Rail_Fuel_Efficiency_MilesPerGallon>

        <Atmos_CO2_Urban_Unrestricted>2393.08</Atmos_CO2_Urban_Unrestricted>

        <Atmos_CO2_Urban_Restricted>1993.25</Atmos_CO2_Urban_Restricted>

        <Atmos_CO2_Rural_Unrestricted>1922.52</Atmos_CO2_Rural_Unrestricted>

        <Atmos_CO2_Rural_Restricted>1930.87</Atmos_CO2_Rural_Restricted>

        <Railroad_C02_Emissions_kg_per_gal>10.217</Railroad_C02_Emissions_kg_per_gal>

    </Assumptions>




    <!--These are the input parameters to run all of the scripts.-->
    <scriptParameters>

        <!--Updates the network with the cost functions defined by the user.
        CREATE NETWORK SCRIPT -->

        <Create_Network_Layer_Script>

            <Network_Costs>

                <Intermodal_Costs_Per_Gallon_Mile>

                    <Railroad>

                        <Railroad_Class_I>0.00012</Railroad_Class_I>

                    </Railroad>

                    <Truck>
                        <!--Truck Interstate includes FAF Function Classes 1,11,12-->
```

```
                        <!--Truck_Interstate includes FAF Function Classes 1,11,12-->
                        <Truck_Interstate>0.00045</Truck_Interstate>
                        <!--Truck_Principal_Arterial includes FAF Function Classes 2,14-->
                        <Truck_Principal_Arterial>0.00050</Truck_Principal_Arterial>
                        <!--Truck_Minor_Arterial includes FAF Function Classes 6,16-->
                        <Truck_Minor_Arterial>0.00055</Truck_Minor_Arterial>
                        <!--Truck_Local includes all other FAF Functions Classes (excluding those above)-->
                        <Truck_Local>0.00060</Truck_Local>

                    </Truck>
                    <!--<Barge>
                        <Barge_Shallow_And_Deep_Draft>$0.85</Barge_Shallow_And_Deep_Draft>
                    </Barge>-->

                </Intermodal_Costs_Per_Gallon_Mile>

                <Intermodal_Transloading_Costs>

                    <Truck_Rail_Transloading>0.02</Truck_Rail_Transloading>
                    <!--<Rail_Barge_Transloading>$1</Rail_Barge_Transloading>
                    <Truck_Barge_Transloading>$1</Truck_Barge_Transloading>-->
                </Intermodal_Transloading_Costs>

            </Network_Costs>

        </Create_Network_Layer_Script>




        <!--Calculate the preprocessor locations and fuel production.  This assumes that a county shapefile with the crop yield data has already been created.
        CREATE PREPROCESSOR LOCATIONS SCRIPT -->
        <Create_Preprocessor_Location_Script>

            <Crops_to_Use>

                <Crop>

                    <Crop_type>Wheat</Crop_type>

                    <Replacement_Percentage>10</Replacement_Percentage>

                </Crop>
                <!--<Crop>
                        <Crop_type>Soybean</Crop_type>
                        <Replacement_Percentage>10</Replacement_Percentage>
                </Crop>-->
            </Crops_to_Use>

            <!--Minimum production floor is in millions of gallons per county.  This step is not required, but is useful for limiting preprocessors to decrease run-time-->
            <Minimum_Production_Floor>1</Minimum_Production_Floor>

            <Raw_Vegetable_Oil_Processing_Ratio>0.9622</Raw_Vegetable_Oil_Processing_Ratio>

        </Create_Preprocessor_Location_Script>




        <!--Create a shapefile with the biorefinery candidate locations.  This step requires that the user create the network dataset in ArcCatalog.
        Right click on the geodatabase, select New, Feature Dataset.  Right click on the feature dataset, select New, Network Dataset.  Follow the wizard prompts to create the Network Dataset.  The cost basis is named "cost_" + the scenario name, e.g., if the scenario name is called "subset", the cost basis is "cost_subset".  You will need to update this XML file with the correct path to the Network Dataset.  The tag is at the top in the "Scenario_Inputs" section.
        CREATE BIOREFINERY CANDIDATES SCRIPT -->
        <Create_Biorefinery_Candidates_Script>

            <Maximum_Raw_Material_Travel_Distance_Miles>250</Maximum_Raw_Material_Travel_Distance_Miles>

            <Minimum_Millions_of_Gallons_Biorefinery_Feasibility>40</Minimum_Millions_of_Gallons_Biorefinery_Feasibility>

            <Maximum_Biorefinery_Capacity_Millions_of_Gallons>99999999</Maximum_Biorefinery_Capacity_Millions_of_Gallons>

            <Biorefinery_Building_Fixed_Cost_Dollars>6000000</Biorefinery_Building_Fixed_Cost_Dollars>

            <Currently_Funded_Biorefineries>
```

```xml
                <Biorefinery>

                    <Name>Null</Name>

                    <Latitude>Null</Latitude>

                    <Longitude>Null</Longitude>

                    <Capacity_Millions_of_Gallons>Null</Capacity_Millions_of_Gallons>

                </Biorefinery>

            </Currently_Funded_Biorefineries>

        </Create_Biorefinery_Candidates_Script>




        <!--inputNetworkDataset as first input, costLayer is networkLayer, costField is cost_to_use, origins_fc is preproc,
        ROUTE OPTIMIZATION SCRIPT -->
        <Route_Optimization_Script>

            <Max_Artificial_Link_Distance_Miles>25</Max_Artificial_Link_Distance_Miles>

            <Penalty_For_Not_Fulfilling_Depot_Demand>1000000</Penalty_For_Not_Fulfilling_Depot_Demand>

            <Output_Optimal_Routes_Feature_Class>Routes</Output_Optimal_Routes_Feature_Class>

            <Output_Route_Data>Traversed_Routes</Output_Route_Data>

            <Cache_Directory>Null</Cache_Directory>

        </Route_Optimization_Script>




        <!--Data reporting
        DATA REPORTING SCRIPT -->
        <Data_Reports_Script>


        </Data_Reports_Script>

    </scriptParameters>

</Scenario>
```