Alternative Fuel Transportation Optimization Tool: Description, Methodology, and Demonstration Scenarios

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Volpe

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13. ABSTRACT (Maximum 200 words)

This report describes an Alternative Fuel Transportation Optimization Tool (AFTOT), developed by the U.S. Department of Transportation (DOT) Volpe National Transportation Systems Center (Volpe) in support of the Federal Aviation Administration (FAA). The purpose of AFTOT is to help FAA better understand the transportation needs and constraints associated with biofuel feedstock collection, processing, and fuel distribution, specifically alternative jet fuel produced from feedstocks. AFTOT uses scenarios describing potentially available feedstock production and existing transportation infrastructure to generate: locations of potentially supportable biorefineries; optimal transportation routes for moving biofuels from the point of feedstock production/pre-processing to refinement and then to fuel aggregation and storage; allocation of feedstock and fuels among biorefineries and destinations 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 AFTOT was developed and the functionality of the tool; it also demonstrates the tool's capability through the analysis of six scenarios.

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List of Abbreviations

Abbreviation[1]	Term
AFPAT	Alternative Fuel Production Assessment Tool
AFTOT	Alternative Fuel Transportation Optimization Tool
ASCENT	Aviation Sustainability Center (FAA Center of Excellence)
BTAT	Biofuel Transportation Analysis Tool (original name of AFTOT)
BTS	Bureau of Transportation Statistics
CAAFI	Commercial Aviation Alternative Fuels Initiative
CO_2	Carbon dioxide
COIN-OR	Computational Infrastructure for Operations Research project
DFSP	Defense Fuel Supply Point
DOD	Department of Defense
DOT	Department of Transportation
EPIC	Environmental Policy Integrated Climate (model)
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
GIS	Geographic Information System
NTAD	National Transportation Atlas Database
NRCS	Natural Resource Conservation Service
ONR	Office of Naval Research
PHMSA	Pipeline and Hazardous Materials Safety Administration
PuLP	Open Source Python Wrapper for Optimization Solvers
SSURGO	Soil Survey Geographic Database
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
VMT	Vehicle miles traveled

[1] Abbreviations for airports included in the AFTOT destinations layer can be found in Appendix A – Airports Abbreviations.

Executive Summary

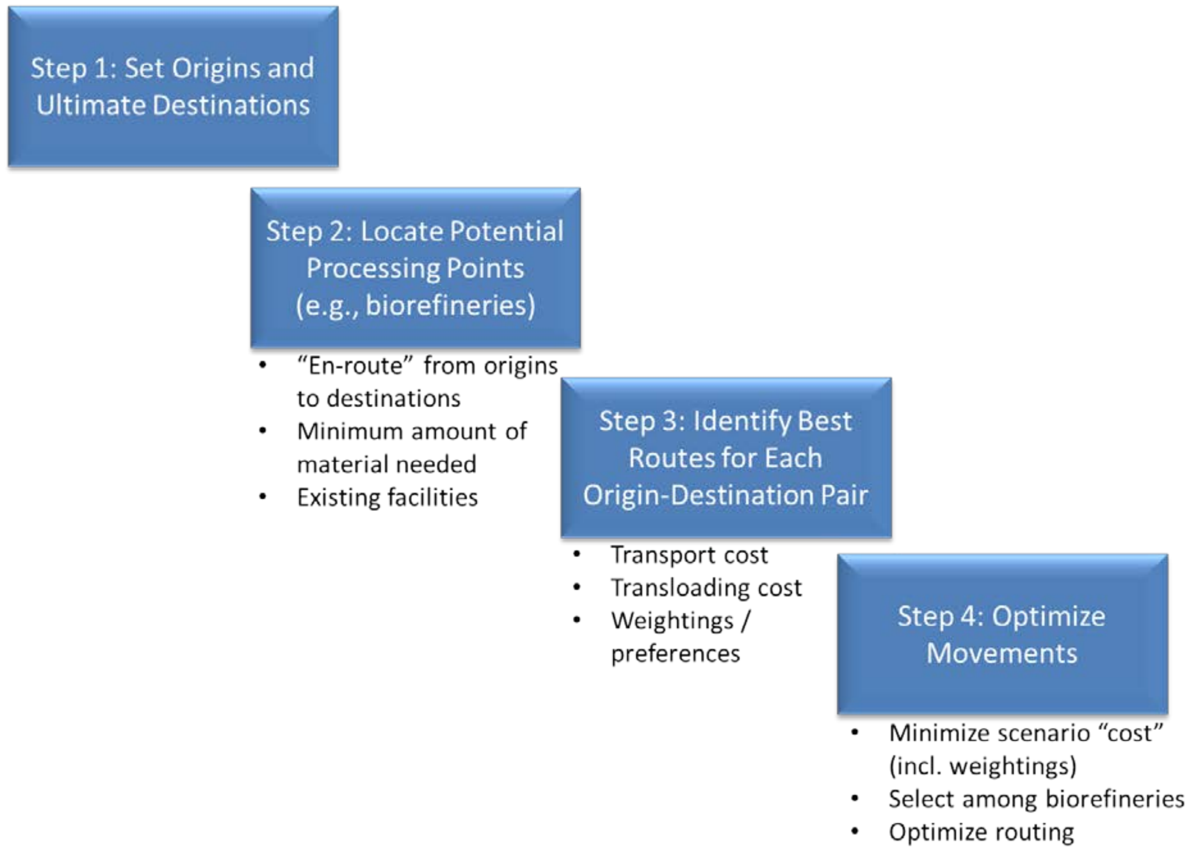
The Alternative Fuel Transportation Optimization Tool (formerly called the Biofuel Transportation Analysis Tool) has been developed by the Volpe National Transportation Systems Center (Volpe) in support of the Federal Aviation Administration's (FAA) Office of Environment and Energy and the Department of the Navy's Office of Naval Research (ONR) to evaluate scenarios of future scaled-up alternative jet fuels and feedstock production and use.

The AFTOT model is a flexible scenario-testing tool designed to analyze a variety of commodities, datasets, and assumptions associated with scenarios for alternative fuel and raw material collection, processing, and distribution in the continental United States. The tool generates potentially supportable biorefinery locations using agricultural feedstock production scenarios, transportation constraints, and existing transportation infrastructure data. The tool then performs an optimization to identify the lowest "cost" transport patterns and enable evaluation of transportation needs and constraints of local, regional and national scenarios based on raw material origins, destinations, transportation cost estimates, weightings, and parameters for converting or refining materials. Optimal routing and flows are evaluated through an optimization module and a Geographic Information System (GIS) module. The tool uses a unique multimodal network constructed from private, public, and restricted-access data sources on road, rail, waterway, and pipeline links. Outputs of optimized scenarios for transporting material include material/commodity flows, costs, CO_2 emissions, fuel burn, number of vehicle trips, and distance by mode for each link in the network, which can then be aggregated in various ways. Furthermore, in addition to generating biorefinery locations, AFTOT 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 and system costs, and GHG emissions could change based on "pioneer" facilities.

AFTOT will enable the FAA to understand the potential future patterns of movement for feedstocks and alternative fuels in order to facilitate delivery of those fuels to end users. The tool can also be used to provide general estimates of transportation costs, fuel burned, and GHG emissions relating to the transportation of feedstock and fuels for future alternative fuels scenarios. This report provides an overview of the tool's structure and capabilities and a demonstration of capabilities through the analysis of a series scaled scenarios that vary in size, complexity, and structure.

Figure ES-1 shows an overview of how AFTOT performs an analysis. Step 1 is focused on user-defined elements (input parameters and geospatial information regarding origins and production amounts as well as destinations with demand amounts). Steps 2 and 3 are performed by the GIS module and the operations-research optimization module, after which full optimization is performed by the optimization module, with outputs to the GIS module to generate tabular and geospatial reports of the results. Further detail on the elements of each module and the associated analysis components can be found in the main report.

Figure ES- 1: Overall components of AFTOT analysis



The report below gives an overview of the software tool structure, the development of the geospatially-explicit, flowable, multimodal network, the implementation of a supply chain structure that includes multimodal transport routing, pathway specific conversion factors and yields, and a biorefinery siting mechanism based on transportation costs and other constraints, and the use of the tool to analyze six different scenarios. Three of the scenarios described are test scenarios demonstrating capabilities of the tool at multiple scales (from a few counties to the national level) and three national-level scenarios focus on real analyses of interest to FAA. These three scenarios are:

- Movement of oilseeds from North Dakota (based on USDA break-even modeling) and resulting HEFA fuels to end destinations (commercial airports and DOD Defense Fuel Supply Points (DFSPs))

- Movement of wheat straw based on national wheat production scenarios from historical data (USDA National Agricultural Statistical Survey 2014), converted into jet fuel via advanced fermentation, and delivered to commercial airports and DFSPs
- Movement of multiple feedstocks (switchgrass, sorghum, and hardwoods) based on US Department of Energy's Billion Ton Study Update, converted via advanced fermentation, Fischer-Tropsch, and pyrolysis, respectively, and the resulting fuel delivered to airports and DFSPs.

The results of these scenarios are presented in the report.

1 Introduction

1.1 Overview

Alternative fuels are being developed with the hope of mitigating climate change, enhancing energy security, and reducing fuel prices. They are also seen as part of the solution to achieving the aviation sector's goal of carbon neutral growth in international aviation starting in 2020. Successful scale-up of the incipient alternative jet fuels industry requires appropriate transportation mode choice and pathway selection – and appropriate transportation planning at local, regional, and national scales – to accommodate a shift in energy transportation patterns and accommodate increased production and movement of biofuel feedstocks. The Alternative Fuel Transportation Optimization Tool has been developed by the Volpe National Transportation Systems Center (Volpe) in support of the Federal Aviation Administration's (FAA) Office of Environment and Energy and the Department of the Navy's Office of Naval Research (ONR).

The AFTOT model is a flexible scenario-testing tool designed to analyze a variety of commodities, datasets, and assumptions associated with scenarios for fuel and raw material collection, processing, and distribution in the continental United States. The tool generates potentially supportable biorefinery locations using agricultural feedstock production scenarios, transportation constraints, and existing transportation infrastructure data. The tool then performs an optimization to identify the lowest "cost" transport patterns and enable evaluation of transportation needs and constraints of local, regional and national scenarios based on raw material origins, destinations, transportation cost estimates, weightings, and parameters for converting or refining materials. Optimal routing and flows are evaluated through an optimization module and a Geographic Information System (GIS) module. This optimization includes recommended biorefinery locations taken from the candidate list. The goal of the optimization is to minimize the total annual "cost" of maximizing fulfillment of fuel demand utilizing multiple fuel-producing crops and transportation modes. The "cost" in the optimization includes dollar costs of transporting the material over each mode and transloading point, but also weightings and penalties that force the tool to favor particular desirable characteristics of the routing (e.g., prefer interstate highways over smaller roadways). The tool uses a unique multimodal network constructed from private, public, and restricted-access data sources on road, rail, water and pipeline links. Outputs of optimized scenarios for transporting material include material/commodity flows, costs, CO_2 emissions, fuel burn, number of vehicle trips, and distance by mode for each link in the network, which can then be aggregated in various ways. 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 and system costs, and GHG emissions could change based on "pioneer" facilities.

This tool builds on the original "Biofuel Transportation Analysis Tool," or BTAT, that Volpe developed for ONR and FAA (Lewis et al. 2014). The original BTAT focused on analyzing transportation flows via road and rail for oilseed movement, conversion into advanced alternative jet fuels, and downstream flow of jet fuel to Defense Logistics Agency-Energy (DLA-Energy) Defense Fuel Supply Points (DFSPs). AFTOT has been expanded to include waterway (barge) and pipeline modes, to address multiple commodity and processing options, and to incorporate time-steps and storage to enable more detailed analyses based on seasonality of harvest and flows. AFTOT also uses a set of commercial airports and DFSPs as default end destinations, but this can be changed for any scenario given a set of destination points and demand amounts. AFTOT will provide the FAA and other government agencies the ability to test various future alternative fuel transportation scenarios, explore the resulting transportation patterns, needs, and challenges, identify opportunities for alternative fuel production and distribution, and evaluate fuel burn, emissions, and costs associated with these scenarios.

1.2 Need for alternative jet fuels

Dramatic fuel cost increases (Airlines For America 2012), concerns about supply security, and concerns about greenhouse gas (GHG) emissions have led to the FAA's interest in alternative jet fuels. The FAA has set a target 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 such as the "Aviation Sustainability CENTer" (ASCENT) Center of Excellence. 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. Producing dedicated alternative energy crops, including oilseeds (such as canola, camelina, and pennycress), forage sorghum, sugar cane, lignocellulosic crops (such as perennial grasses), and others, 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. The amount of fuel burned in transporting raw feedstocks and finished fuels will influence the overall greenhouse gas (GHG) life cycle emissions of the finished fuel.

1.3 Purpose of Report

AFTOT will enable the FAA to understand the potential future patterns of movement for feedstocks and alternative fuels in order to facilitate delivery of those fuels to end users. The tool can also be used to provide general estimates of transportation costs, fuel burned, and GHG emissions relating to the transportation of feedstock and fuels for future alternative fuels scenarios. This report provides an overview of the tool's expanded structure and capabilities and a demonstration of capabilities through the analysis of a series scaled scenarios that vary in size, complexity, and structure.

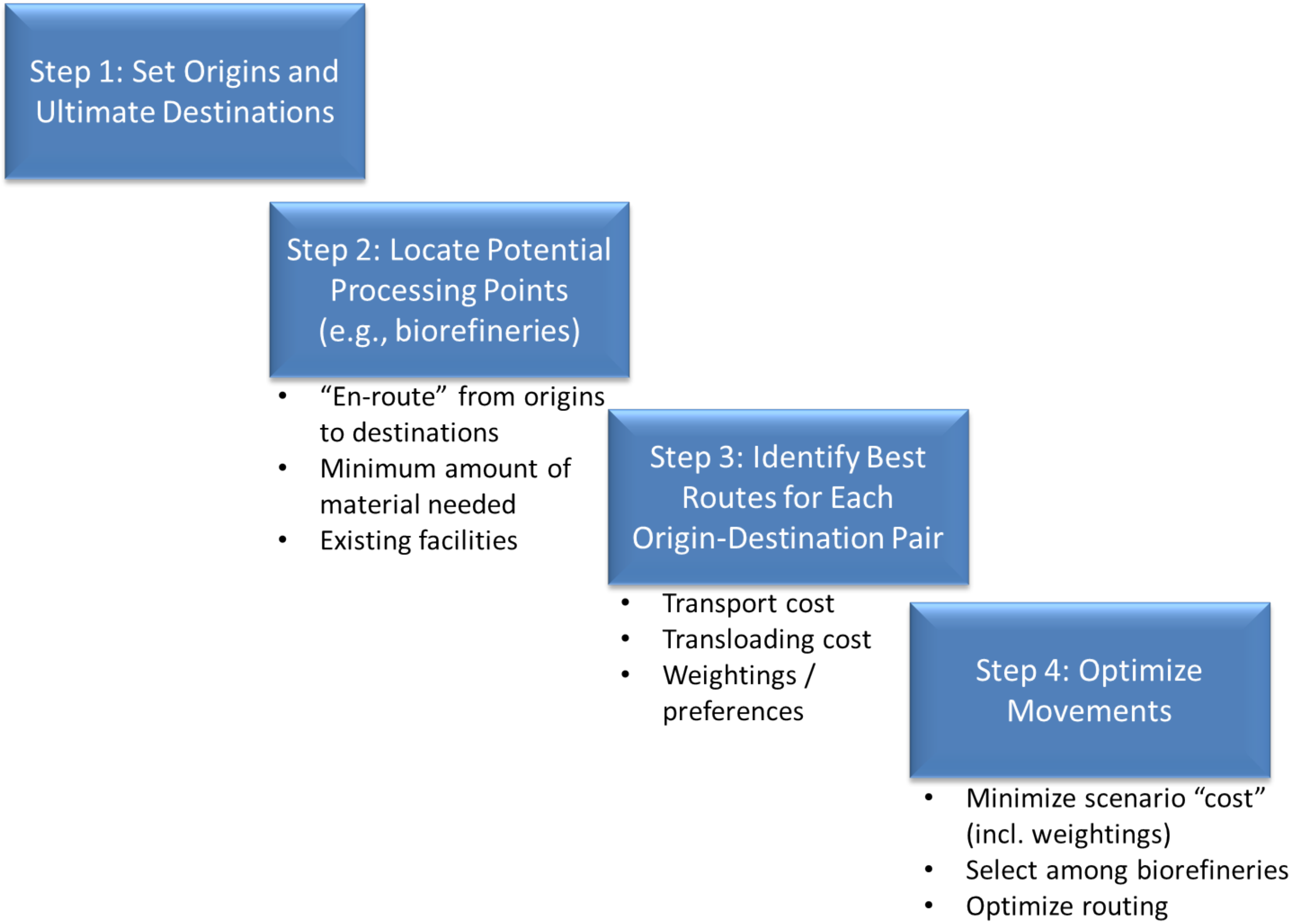
2 Model Structure

The overall goal of this project was to develop a model to translate a feedstock production/alternative fuel demand scenario into a geospatially explicit result indicating:

- How biorefineries may be sized and spatially distributed
- End-to-end route optimization over a national intermodal network
- Potential impacts of agricultural scenarios and/or transportation constraints on:
    - Material/commodity flows
    - Transportation costs associated with each movement
    - Fuel burn and CO_2 emissions associated with transport of feedstock and fuel
    - Total network distance traversed (by mode)
    - Vehicle miles traveled (VMT)
    - Number of vehicle trips (e.g., number of truck trips, rail cars, etc.)

The tool incorporates a Geographic Information System (GIS) module and an optimizer module adapted from an open source tool. The structure and function of the modules is described in more detail in the following chapter. These two modules interact to identify candidate biorefinery locations and then allocate flows among the least cost routes between each origin and destination pair, in which cost includes transportation costs per ton-mile for road, rail, and waterway; costs per origin-destination pair in pipeline; transloading costs; and any weightings or preferences incorporated. The schematic approach to this analysis is shown in Figure 1.

Figure 1: Schematic diagram of how a scenario is run in AFTOT, showing the four stages of analysis. The optimization takes into account not just transportation costs but also can incorporate preferences (weightings) for particular modes/routes or other factors.



The current supply chain model within AFTOT assumes a three-step supply chain linked via road, rail, pipeline, and/or waterway:

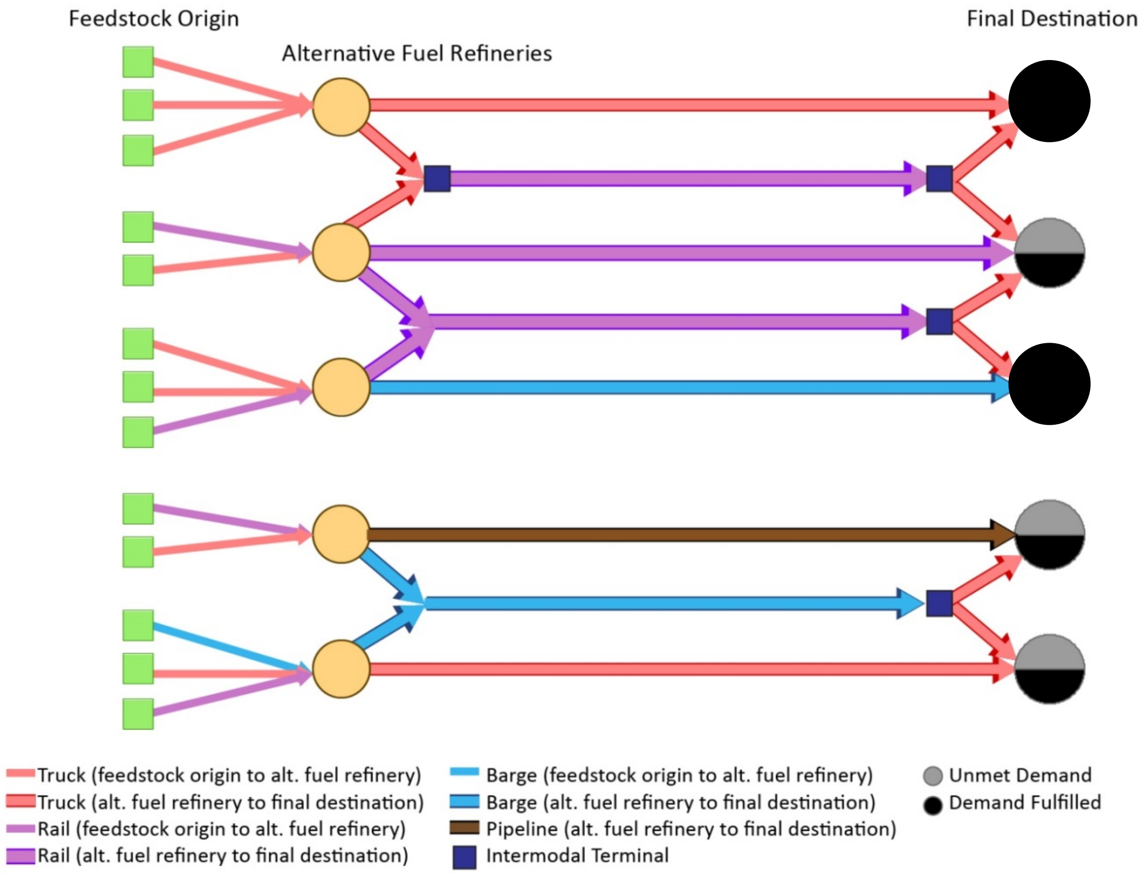
1. Agricultural production of crops and co-located preprocessor/aggregation point
2. Biorefineries, where feedstocks are converted into fuel
3. Destinations, which can be any set of locations with demand amounts for jet fuel and/or diesel (e.g., airports, DOD facilities, refineries, blending facilities, etc.)

AFTOT currently assumes that feedstocks are aggregated within the county of production (i.e., at a "preprocessor") which in the case of oilseeds is assumed to crush the seed for vegetable oil (which is transported downstream), but in the case of lignocellulosic or other feedstocks the preprocessors are not assumed to perform significant processing or homogenization (amount transported downstream is total raw tonnage). Addition of such functions at the preprocessor can be easily incorporated by adding a conversion factor for materials at these locations. Fuel blending facilities could be included by constructing a particular scenario with them if desired.

The overall assumptions of the current tool led to a three-step, two transport leg supply chain (see Figure 2). Each transport leg between these steps is allowed to be multimodal or single mode depending on optimal allocation, although only processed fuels are permitted to travel over the pipeline components of the network. Each transport leg can be traversed by more than one commodity type (e.g., more than one feedstock type or fuel type). Therefore, multiple feedstocks can enter a single alternative fuel refinery (if appropriate for the processing type of the facility) and multiple fuel products (currently, diesel and jet fuel) can leave the biorefinery to be transported downstream to the final destination.

While this three-step supply chain provided a basis for the current AFTOT, the tool is flexible and can be expanded to address multiple supply chain structures, including additional waypoints such as large-scale feedstock aggregation/preprocessing facilities and/or fuel blending facilities, which are currently not considered separately (see Section 6 for details on potential AFTOT expansions). It is not clear whether a scaled-up advanced biofuel industry will include feedstock aggregation/preprocessing (e.g., homogenization) near the production area, at the biorefinery itself, or at a third location.

Figure 2: Assumed supply chain structure for AFTOT optimization.



The original BTAT focused solely on annualized flows. AFTOT analyses can be focused on annual aggregate production, demand, and flows, but can also be used at a more detailed time-specific level to explore seasonal aspects of transportation patterns (e.g., due to seasonality of feedstock harvest and transport). To incorporate seasonality, the tool includes a storage option for each transport path at each time step. Currently, storage is unlimited and has zero cost, but these are variables set within AFTOT and can be modified. Storage is most likely to be suggested if production is highly seasonal, exceeding biorefinery capacity for a limited time period such that it makes sense to store the excess and process it later in the year.

To run a short-term scenario, certain parameters including minimum biorefinery size, biorefinery cost to build, demand, and/or feedstock production may need to be divided by the appropriate factor to scale annual values down to the specific time period of interest (e.g., a two-week period would require division of annual values by 26).

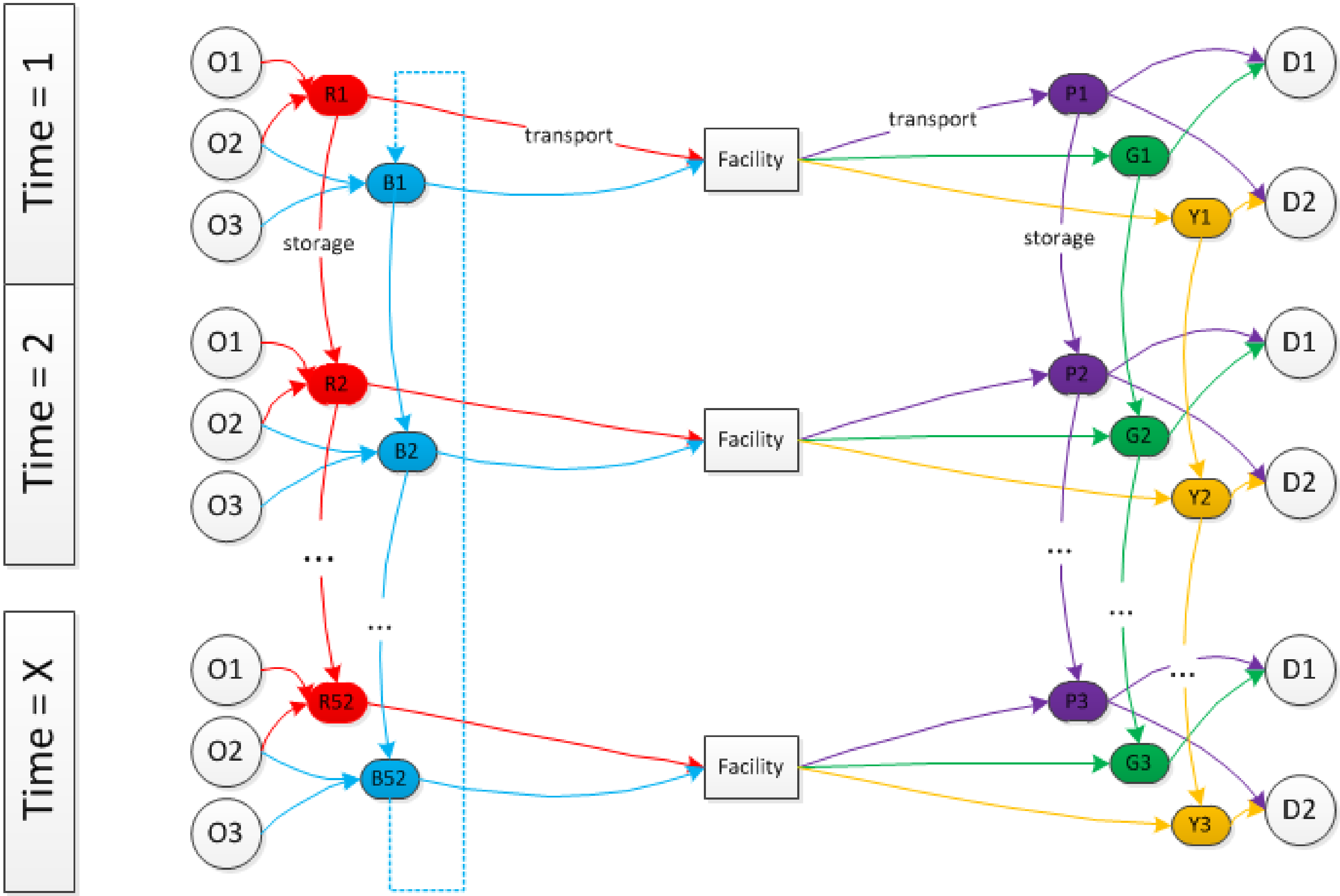


Figure 3: Storage and time schematic that looks at minimum and maximum flow constraints on transport system with each node encompassing seasonality and storage

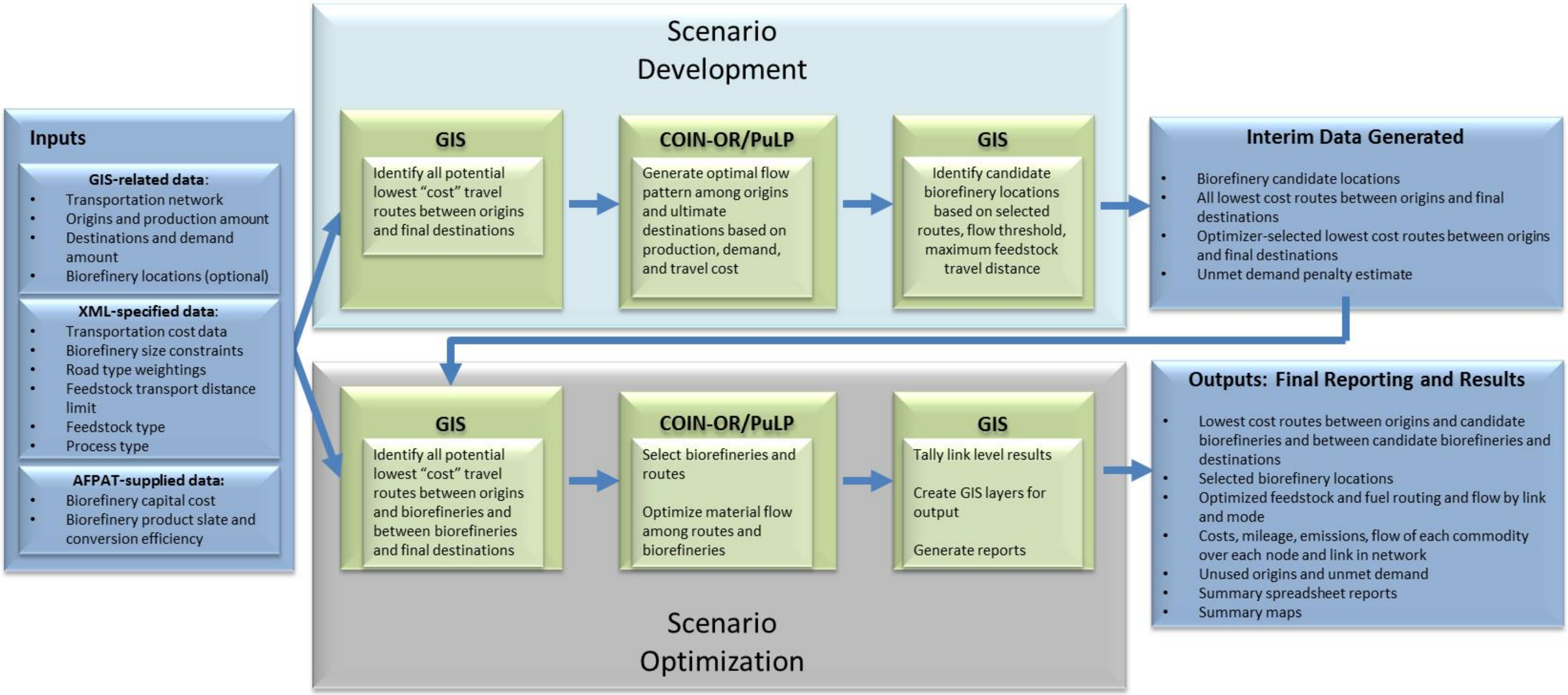
3 Analytical Model Framework

The analytical framework of AFTOT was built to accommodate the above concept and supply chain structure using two existing software modeling tools, described in more detail in the sections below:

- **ESRI ArcMap Version 10.2.2** or later (Geospatial Information System (GIS)) 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. The GIS module also turns the final optimized transportation links into a final, traversed network and then calculates and reports the results of the scenario runs.
- **PuLP Version 1.5.4** (Open Source Python Wrapper for Optimization Solvers) is a linear programming modeler written in Python. In AFTOT, PuLP is used to link 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 and maximum biorefinery requirements and the destination jet fuel demand (more details on PuLP are provided in Section 3.5.1).

Figure 4 shows AFTOT model data flow between these two tools.

Figure 4: Analytical tool data flow schematic showing the key components/roles of each component of AFTOT.



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 build an intermodal network, import origins and ultimate destinations, and 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 Intermodal Network

The foundation of AFTOT is its intermodal network, as the network determines the flow pathways available between each origin and destination in the scenario. The network includes the following elements:

- Roadway network from the Federal Highway Administration's (FHWA) Freight Analysis Framework (FAF version 3.4 (Federal Highway Administration 2013)
- Railway network developed by the Federal Railroad Administration (FRA). AFTOT uses both Class I and non-Class I rail by default, but the user can subset the network input data when building the network (e.g., Class 1 railroads only).
- Waterway network from the Navigable Waterway Links data developed by the United States Army Corps of Engineers and the US DOT Bureau of Transportation Statistics (BTS) and available in the 2011 National Transportation Atlas Database (Bureau of Transportation Statistics 2011).
- Pipeline origin-destination pairs from a proprietary pipeline dataset provided by Levine Associates.
- Intermodal Terminal Facilities – AFTOT uses an adapted, corrected subset of the Intermodal Terminal Facilities data developed by the BTS and available in the 2011 National Transportation Atlas Database (Bureau of Transportation Statistics 2011). Mode shifts in the AFTOT network can only occur and be modeled at these intermodal terminal facility locations.

Each of these networks was maintained in its own GIS layer, with interfaces between layers occurring at the intermodal facilities. These layers are used to construct a new intermodal network at the beginning of a scenario run. Thus, the user can also replace layer(s) to create a custom network.

The pipeline network was developed with origin-destination pairs (OD pairs) in a privately acquired dataset from Leonard B. Levine Associates that lists OD pairs, specific product movements, and associated tariffs. Pipeline data repair in the current AFTOT development phase focused on pipeline systems of at least 150 miles in length. Ten full pipeline systems and 20 partial pipeline systems were incorporated into the AFTOT network during this phase of work, with finalization of the full pipeline network anticipated in summer of 2015.

Intermodal facilities are locations where material can be moved through intermodal networks (road, rail, pipeline, and waterway), most commonly referred to as transloading. These transloading points are also locations at which transporters are charged additional per gallon or per ton costs. The BTS National Transportation Atlas Database (NTAD) identifies over 3000 intermodal facilities across the U.S. However, this list has not been updated since 2003, and many of the data points are either in incorrect locations, clustered together, or not relevant to the AFTOT network for various reasons. Therefore, Volpe created a subset of this facility list using specific criteria and visual review of satellite imagery to eliminate excess facility points and correct facility locations. Criteria for elimination included: lack of nearby significant intermodal facility in satellite imagery, proximity to other, more accurate intermodal points, points that did not have complete data and/or points that were not applicable to the AFTOT network (e.g., made at least one linkage among road, rail, waterway, and pipeline). Rail intermodal points were added to the remaining list based on movements of specific, feedstock-relevant commodity types in the Railway Waybill Sample to identify potential railway entry points for agricultural commodities, which are likely to enter the system at smaller facilities than the main intermodal terminals identified by BTS. The commodity-specific origins were incorporated into the GIS layer and duplicates eliminated. The final intermodal facilities layer for AFTOT includes 383 unique intermodal facilities tagged specifically for the different modes that interface at each point. As with the agricultural scenario/origin points, this list can be expanded or modified as needed to run different scenarios in AFTOT.

For routing efficiency, the roadway, rail, and waterway networks were simplified using an "unsplitting" procedure to eliminate nodes between adjacent segments of network that have the same characteristics (e.g., peak period speed (road) or inclusion in Strategic Rail Corridor Network (STRACNET)) and where there is no intersection. This technique does not alter the route options along the network, simply reduces the computational requirements and analysis run times.

Currently, no capacity constraints are included in AFTOT. However, transportation capacity will become more important as the alternative fuel industry expands. The ability to address capacity constraints is recommended as part of future AFTOT expansion, which may also require more detailed networks and other data sources.

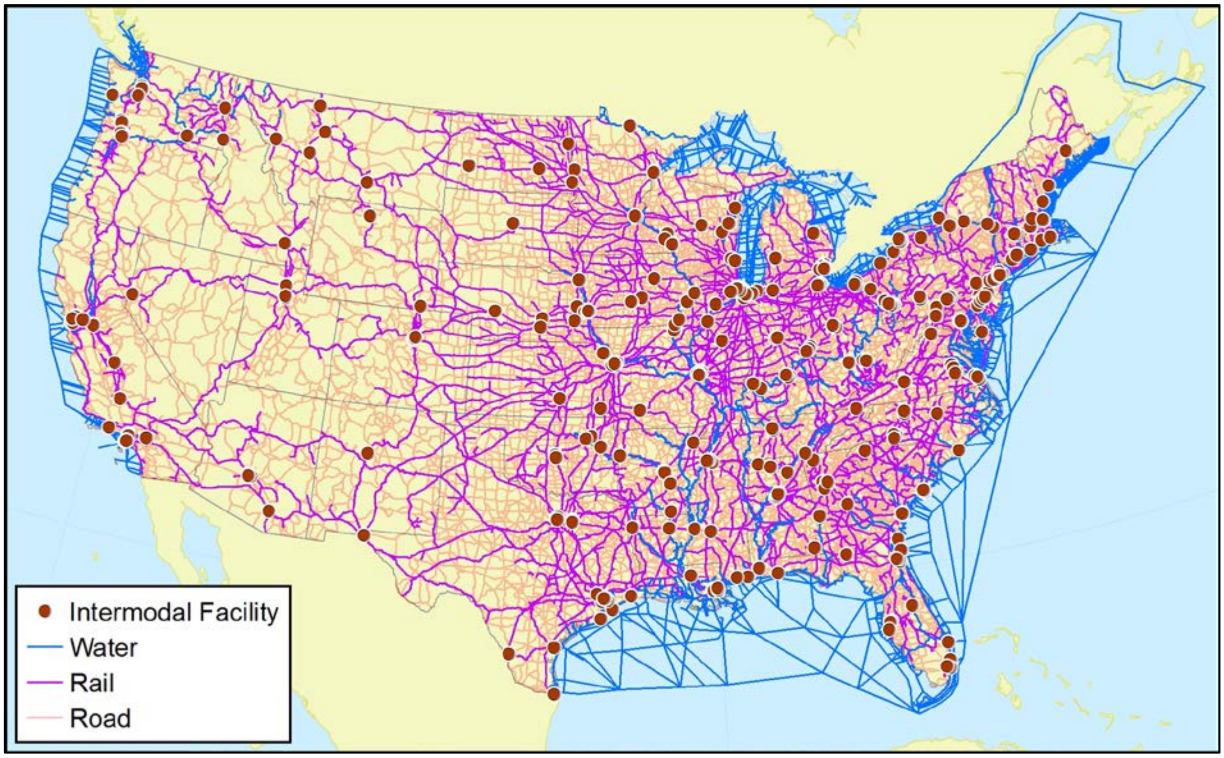
3.1.2 Origins

AFTOT is capable of accepting gridded, county-level, or other geospatial data describing feedstock origins and production amounts.

In BTAT, 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 crop production (e.g., 10% of wheat acreage will be available in a given year for crop rotation). 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.

AFTOT can also take in gridded data for feedstock production, and currently assigns an average production value to the county centroid in which the grid cell occurs to identify starting points for the feedstock movement. In each case, AFTOT generates a GIS point layer and the associated data of preprocessor counties and production amounts (see Figure 5). The tool can also take in an existing point layer with production amounts as well, for example if a known set of preprocessors, oilseed crushing facilities, or other origins were used.

Figure 5: Example GIS point layer showing origins for a scenario in which county centroids are used as aggregation points for feedstock produced in the county. The user can set a minimum threshold amount of feedstock production below which origins are eliminated. The size of the preprocessor symbol indicates the amount of feedstock available in the county. Note that the pipeline network is included in the multimodal network but is not shown on this graphic because it is based on origin/destination pairs from a private dataset. AFTOT Phase 3 will likely incorporate a publicly viewable pipeline dataset.



3.1.3 Destinations

AFTOT is capable of using any set of geospatially defined destinations as the endpoints for the analysis. Due to the project focus on alternative jet fuels in particular, AFTOT includes two default GIS layers of destinations for commercial aviation (airports) and the DOD (Defense Fuel Supply Points, or DFSPs). The airports layer is not exhaustive, but includes 79 airports and their current demand based on approximate (rounded) values provided by Airlines for America (A4A). The current default year is 2014. For the DOD, DLA-Energy shared with the project team the top 52 DFSPs that are the dominant recipients of fuels for the DOD and their annual throughput of jet fuel.

3.1.4 Identifying biorefinery candidate locations

AFTOT is 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:

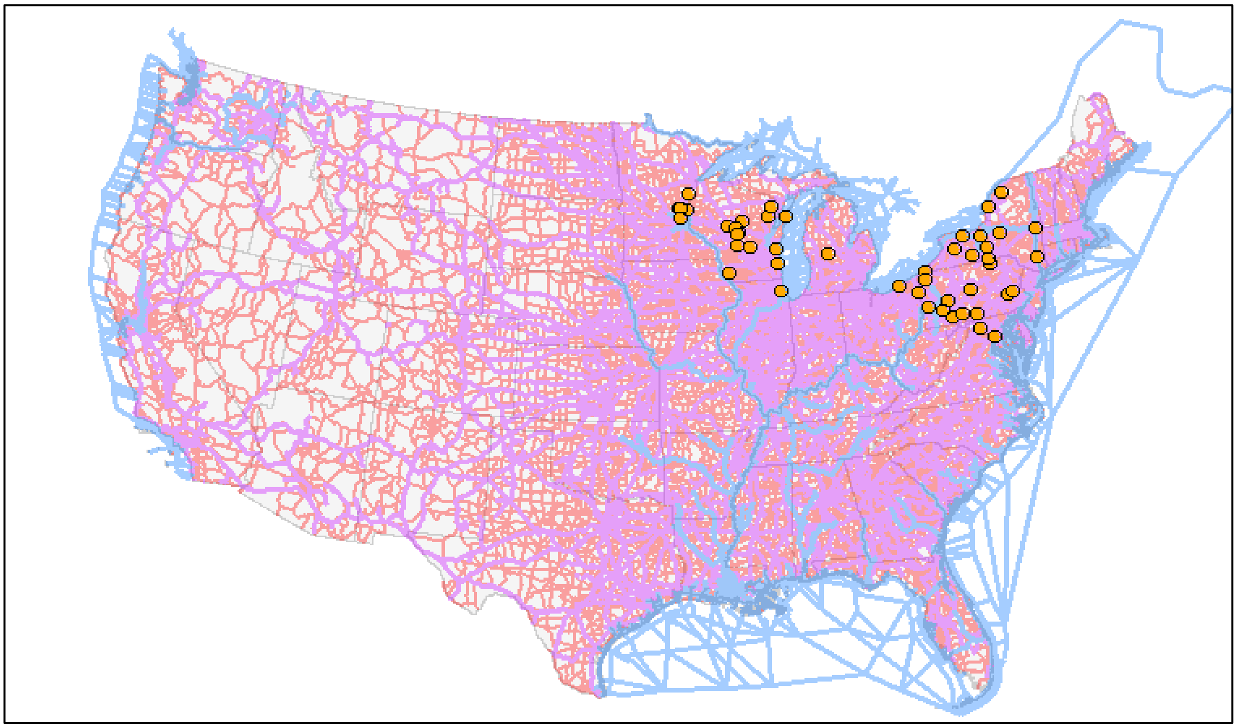
1. Identify routes and flow directly from origins to ultimate destinations.
2. Identify candidate biorefinery sites that occur at points on the path from origin to destination where there is potential for sufficient raw material flow to support a biorefinery (value can be set in the scenario XML configuration file and is usually lower than the actual minimum biorefinery size threshold, as additional feedstock may be available to be reallocated to a biorefinery candidate location during optimization).
3. Consider as a candidate site every node on the transportation network at which further flow increases occur up to the maximum raw material flow distance.

As a secondary screening for biorefinery locations, AFTOT uses an inverse distance weighting (IDW) (ESRI undated) to rank potential biorefinery locations based on the distance from preprocessors and the amount of feedstock available within the user-specified distance limit. The IDW formula is as follows: IDW Score = Total Feedstock Available * (1/(Total Transport Distance^2)), which is based on a common structure and exponent value for such weightings (Shepard 1968, ESRI undated).

The user can set limits on the actual travel distance feedstock is permitted to travel to reach a biorefinery – this can be constrained due to, for example, trucking regulations related to moving agricultural products, other regulations, policies or incentives, preference for a particular region, or economic considerations. The user sets the maximum transport distance of feedstock over the transportation network in the scenario input file (described in more detail in Section 3.2). The biorefinery candidate siting algorithm checks for sufficient availability of feedstock for a given candidate location based on that distance limit. 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 least feasible biorefinery candidates from consideration. This secondary screening has the effect of keeping the biorefineries relatively close to the preprocessors and allows AFTOT to choose from a wide number of candidate locations to find the optimal locations for biorefineries, while reducing run times in the final analysis. The percentage of candidates to eliminate from consideration is set by the user in the code 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 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.

In the interest of preserving as many candidate locations as possible, the scenarios were run with the bottom 25% of the candidate locations removed from consideration Prefunded facilities are not removed from consideration by the IDW ranking process. The candidate biorefinery sites are incorporated into the GIS network for the scenario.

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. Note this map does not show the pipeline element of the multimodal network.



3.1.5 Known Biorefineries

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, AFTOT can handle a point layer of such facilities. Location, capacity, and facility name are all that is needed to incorporate fixed biorefinery locations into the model. These fixed biorefineries are flagged within the biorefinery GIS shapefile with the value of 1 in the “prefunded” field. All prefunded biorefineries will have a construction cost of zero. These biorefineries do not have a lower bound on their annual processing because existing production could be adjusted; the lower bound is primarily associated with the decision to invest in building a new biorefinery. 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 along with the other routes for candidate locations generated by AFTOT (as described in the preceding section).

3.2 XML Defined Parameters

AFTOT uses 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 AFTOT.

The user is able to specify a number of scenario parameters in the XML input file, including the transportation costs and weightings that will be allocated across the network, the biomass feedstocks and fuel conversion pathways, minimum production floor for agricultural production to be considered, the maximum feedstock transport distance over the network, the size (minimum and maximum) biorefineries, the feedstock and process designation (to enable capital cost, conversion efficiency and product slate to be pulled from the Alternative Fuels Production Assessment Tool (AFPAT) – see Section 3.3) , and the unmet demand penalty, among other variables. The XML file is validated against an XML schema file. An example XML file is shown 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.

3.2.1 Assigning Costs to the Network

AFTOT allows the user to define costs to be assigned to each mode, to transloading, and as penalties for particular paths. The cost parameters are summarized in Table 1.

The GIS module assigns costs to each link in the intermodal network based on transport costs entered into the XML file. The dollar costs on the GIS network are the dollar amounts required to transport 1,000 gallons or one ton (depending on the commodity moved) over each particular link.

Table 1: Modal cost units and default values in AFTOT.

Transport mode	Units	Default Value (used in demonstration scenarios)
Roadway/Trucking	$/kgal-mile[2]| $/metric ton-mile	$0.45 | $0.15
Railway/Rail car	$/kgal mile \|$/metric ton-mile	$0.12 | $0.04
Waterway/Barge	$/kgal mile | $/metric ton-mile	$0.05 |$0.017
Pipeline	$/1000-gal-OD-pair	Actual tariffs (2013) from proprietary dataset - $4.27-$482 per movement, mean cost is $147.52
Transloading cost	$/kgal | $/metric ton	$40.00 | $13.00

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).

Following in Table 2 are the default values for capacity of different types of vehicles by commodity type (liquid/solid).

Table 2: Default vehicle capacities for solids and liquids in AFTOT

Vehicle Type	Default Load Capacity Value
Truck – Hopper (solid)	26 tons/7,865 gallons
Truck – Tanker (liquid)	8000 gallons (jet)
Railcar (solid)	90 tons/4000 bushels; 33,870 gallons
Railcar – Tanker (liquid)	28,500 gallons (jet)
Barge (solid)	1,500 tons/52,500 bushels/453,600 gallons
Barge (liquid)	400,000-1,000,000 gallons (10-25,000 bbl)

*Sources: (McDuffie 2013, USDA Agricultural Marketing Service 2014)

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

[2] Cost per metric tonne of feedstock is about 1/3 that of fuel transport cost per 1000 gallons

provides data on a subset of actual freight movements, including product moved, associated mileage, tonnage, and revenues.

For the demonstration scenarios described below, transloading costs to move between truck and rail were estimated based on discussions with industry contacts (McDuffie 2013).

In addition to actual dollar costs, the tool can incorporate weighting functions/penalties as well. Currently the tool contains one weighting option as a default, which is weighting to favor particular roadway types (e.g., larger/faster roadways). The weighting function is a multiplication factor (e.g., 1.3) that adjusts the dollar cost per gallon-mile, e.g., $0.45 per 1000-gallon-mile on the interstate highways vs. $0.60 per 1000-gallon-mile on local roadways.[3]

3.2.2 Assigning Emissions to Movements

AFTOT can potentially contribute to screening level GHG life cycle analysis calculations for future alternative fuels by estimating transportation fuel burn and associated emissions. Currently the tool is capable of calculating CO_2 only but could be modified to calculate life cycle CO_2e emissions.

To calculate CO_2 emissions resulting from feedstock and fuel movements in AFTOT, the project team used two sources of emissions factors. Rail, barge, and pipeline emissions factors were provided by Argonne National Laboratory from the current version of the Greenhouse Gases, Regulated Emissions, and Energy use in Transportation model(Argonne National Laboratory 2014) and are shown in Table 3. The GREET team provided CO_2 combustion emissions values. In the final reporting step in AFTOT, the ton-mileage for each link is multiplied by the appropriate modal value to get CO_2 emissions associated with transportation over that link.

Table 3: CO_2 per ton-mile combustion emissions intensities for various transportation modes, generated with GREET1_2014 (CO_2 only)

		Diesel Freight Rail	Ocean Tanker	Barge	Pipeline
CO_2 Intensity, g CO_2/ton-mile	**End use combustion**	21.3	2.9	29.5	0.0

For roadway, the tool uses emissions results for CO_2 only from the U.S. Environmental Protection Agency's (EPA) Motor Vehicle Emissions Simulator 2010b model (EPA 2012). The

[3] 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.

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 AFTOT analyses is shown in Table 4. The project team ran the MOVES model to generate values for CO_2 emissions (grams per mile) specifically for combination long-haul trucks (these can be either tanker or hopper trucks).

Table 4: Assignment of FAF roadway types to MOVES roadway categories for calculation of CO_2 emissions from trucks in AFTOT.

MOVES Roadway Categories	Assigned FAF Categories	Default CO_2 Value (g/truckload-mi)
Urban Restricted	Urban Interstate Urban Freeway	1993.25
Urban Unrestricted	Urban Principal Arterial Urban Minor Arterial	2393.08
Rural Restricted	Rural Interstate	1930.87
Rural Unrestricted	All remaining categories	1922.52

3.3 Interface with Alternative Fuel Production Assessment Tool (AFPAT)

The Alternative Fuels Production Assessment Tool (AFPAT) was developed by the Massachusetts Institute of Technology (MIT), the FAA, Volpe, and Metron Aviation, and has since been updated by MIT and Volpe, with input on data values (e.g, feedstock yields) from researchers at Washington State University, Pennsylvania State University, Idaho National Laboratory, and Oak Ridge National Laboratory. The current version of the tool collates peer reviewed data on typical yields for various feedstocks, associated conversion pathways, conversion efficiencies for particular crops and pathways, and product slate information, as well as notional capital costs for small, medium, and large facilities of each conversion process type.

To enable better calculation of costs for optimization, AFTOT imports capital costs from AFPAT for a given refinery type. AFTOT also uses conversion efficiencies and product slates from AFPAT to calculate resulting fuel volumes from feedstock flows into biorefineries. The user specifies the feedstock and process from a detailed default list in the XML, which AFTOT uses to look up the appropriate capital cost, conversion efficiency, and product slate information.

3.4 GIS route identification step

Once all the data have been fed into the tool via the GIS layers and network generation, the XML, and the interface with AFPAT, the GIS module then identifies the routes and costs from preprocessors to biorefineries, and then from biorefineries to destinations. For each origin-and-destination (OD) pair, the GIS module uses the values above to calculate all possible route (and intermodal) combinations and then identifies the route with the lowest overall cost. The GIS passes these routes and candidate biorefinery locations to the PuLP optimizer, which resolves how much material should flow along which routes and to which biorefineries and final destinations (e.g., airports) to minimize the total cost of transportation from each preprocessor to the final fuel destination(s).

3.5 Optimization tools and methods

3.5.1 PuLP optimizer – problem definition

The PuLP optimizer is a Python-based tool that identifies a maximum or minimum value (in this case, minimizing total cost and weighting) using a mathematical description of the problem at hand. In its application for AFTOT, the PuLP optimizer takes all of the origins (and crop production information), destinations (and fuel demand information), waypoints, list of candidate biorefinery locations, and the transportation network as defined by the GIS module (described in Section 3.1) and optimizes the paths among all components. This optimization includes recommended biorefinery locations taken from the candidate list. The goal of the optimization is to minimize the total annual "cost" of meeting as much fuel demand as possible by utilizing multiple fuel-producing crops and transportation modes. 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 (as outlined in Section 3.2.1)
    a. Mode specific transport costs
    b. Transloading costs
2) Capital costs
    a. Amortized annual capital expenses for biorefinery construction (from AFPAT)
3) Weightings and penalties

a. Roadway type. The preference for different roadway types is achieved by assigning varying dollar costs per gallon-mile.
b. Unmet demand penalty: each destination has a desired quantity of fuel to receive annually. For every thousand gallons of demand not met during the scenario timeframe (total, for all destinations and fuel types) the optimization adds a penalty 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 works 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. A very low unmet demand penalty may result in little or no flow as transportation costs exceed the penalty, whereas an excessively high unmet demand penalty may force the flow of materials. The tool includes a mechanism to estimate the unmet demand penalty based on the scenario demand, maximum feedstock transport distance, and assuming the highest cost mode of transport. The estimate provides a lower limit on the demand penalty, but the user may wish to increase the penalty to ensure that the tool will be driven to flow material.
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). For a preprocessor to be included, it must produce enough crop to create a certain annual amount of feedstock as specified by the user.

These costs and weightings are translated to mathematical decision variables and coefficients as follows in Table 5.

Table 5: PuLP optimizer problem variables and coefficients.

Variable	**Explanation**
x_{iabjab}	Flow, in units[4] / week, from preprocessor i_{ab} to preprocessor storage j_{ab}, where a is the crop produced and b is the week of production
$x_{jabja(b+1)}$	Storage of crop a at preprocessor storage location j from week b to week b+1, in units/week
x_{jabkab}	Flow, in units/week from preprocessor storage j_{ab} to biorefinery k_{ab} where a is the crop being transported and b is the current week
$x_{kabmabc}$	Flow, in thousand gallons /week from biorefinery k_{ab} to destination storage m_{abc} where a is the crop that was processed, b is the current week, c is the fuel being transported
$x_{mabcma(b+1)c}$	Storage at destination storage location m from week b to week b+1 of fuel type c, produced from crop a, in thousand gallons/week
$x_{mabcnbc}$	Flow, in thousand gallons/week from destination storage m_{abc} to destination n_{bc} where a is the crop that was processed, b is the current week, c is the fuel being transported
u_{nc}	Unmet demand of fuel type c at destination n, in thousand gallons / year
E_{kabc}	Excess fuel remaining at biorefinery k_{ab} of fuel type c, where a is the crop that was processed, b is the current week. Non-negative. Counts toward upper and lower bounds on production, but is not used to fulfill demand.
y_k	0 – 1 variable: 1 if biorefinery j is used, 0 otherwise

Coefficient	**Explanation**
U_{Piab}	Upper bound on flow of crop a out of preprocessor i_{ab} during week b, in thousand gallons or tons / week
C_{iabjab}	Transportation cost, in $ / thousand gallons or ton, to flow crop a during week b from preprocessor storage j_{ab} to biorefinery k_{ab}
F_{Bk}	Fixed cost, converted to $ / year, to build the biorefinery k
U_{Bk}	Upper bound on flow out of biorefinery k, in thousand gallons / week
L_{Bk}	If biorefinery j is used, lower bound on flow out of biorefinery j, in thousand gallons / year
$C_{kabmabc}$	Transportation cost, in $ / thousand gallon, from biorefinery k to destination storage m, of fuel c in week b processed form crop a
S_{Bac}	Conversion factor at the biorefinery: inbound thousand gallons or tons of crop a x S_{Bac} = outbound thousand gallons of fuel type c
U_{nc}	Penalty ($ / thousand gallon) for not meeting demand at destination n for fuel c
D_{nc}	Demand, in thousand gallons / year, at destination n of fuel c

[4] "units" are either thousand gallons or tons, depending on whether the feedstock is solid or liquid

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

Minimize **annual cost** = $\sum_{jabkab} C_{jabkab}\, x_{jabkab} + \sum_{k} (F_{Bk}\, y_k) + \sum_{kabmabc} C_{kabmabc}\, x_{kabmabc} + \sum_{nc} (U_{nc}\, u_{nc})$

Subject to the following constraints show in Table 6.

Table 6: PuLP Optimizer Constraints

Constraint	Explanation
(1) For each biorefinery k_{ab}, $S_{Bac} \sum_{jabkab} x_{jabkab} - \sum_{kabmabc} x_{kabmabc} = E_{kabc}$	Flow must be conserved at each stage relative to time, crop, and fuel type (with the appropriate conversion factors) ; any excess is tracked.
(2) For each biorefinery k_{ab}, $y_k U_{Bk} - \sum k_{abmabc}\, x_{kabmabc} - E_{kabc} \geq 0$	If a biorefinery is used, flow cannot exceed the upper bound during any week, across all crops and fuel types, including excess. 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 k_{ab}, $y_k L_{Bk} - \sum k_{abmabc}\, x_{kabmabc} - E_{kabc} \leq 0$	If a biorefinery is used, the flow out of it over a year must exceed the lower bound, summing all crops and fuel types.
(4) For each preprocessor i_{ab}, $\sum_{iabjab} x_{iabjab} \leq U_{Piab}$	Flow out of each preprocessor does not exceed the preprocessor upper bound, for each week and crop
(5) For each destination n_c, $\sum_{mabcnbc} x_{mabcnbc} + u_{nc} = D_{nc}$	Unmet demand plus flow into a destination is equal to that destination's demand, for each fuel type
(6) The y variables are binary (0 or 1)	A biorefinery is used, or it isn't.
(7) The x, E, 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 feedstock or fuel. The specific choice of algorithm is made by the COINMP_DLL solver, as implemented by PuLP. The allocation of crops and fuel among routes, biorefineries, and destinations is based on meeting maximum demand while minimizing the total cost, without violating the constraints on minimum and maximum flow.

3.6 Reporting Outputs

Once the optimization is complete, the GIS module takes the data generated by the optimizer and develops maps and spreadsheet data reports. The spreadsheet data report lists all of the xml input parameters, the source data, the version of AFTOT used, the preliminary calculations done by AFTOT, interim results, and final outputs for cost, mileage, vehicle miles traveled, number of loads, and CO_2 emissions. It also reports the destinations, the amount of demand fulfilled, and the total demand fulfilled for the scenario. Additional outputs can include information aggregated for a given biorefinery or destination, or by route.

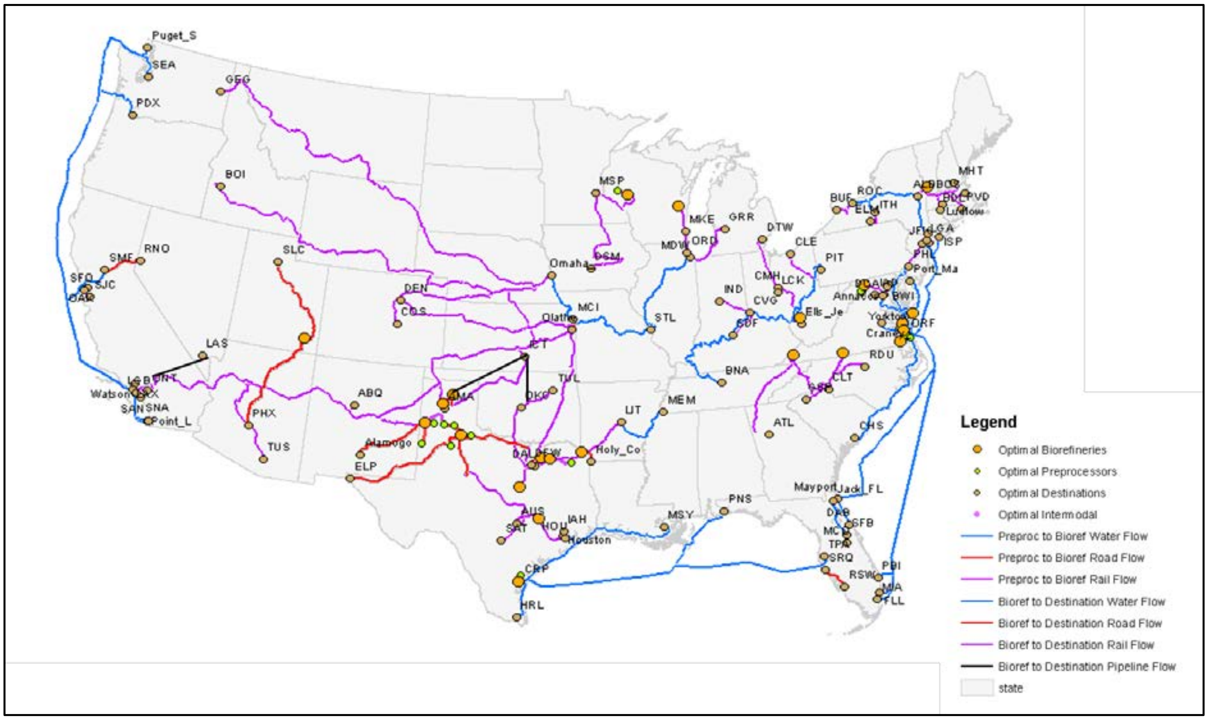
3.7 Map Outputs

For each scenario, AFTOT also generates a multilayered GIS map (see example in Figure 7) that shows:

- Preprocessor locations are located at the centroid of a county. Preprocessors used in the optimal solution are presented by a green circle.
- Biorefinery locations used in the optimal solution are represented by an orange circle.
- Destinations, such as DFSPs and airports, used in the optimal solution are represented by a brown circle". Airports are labeled with their three letter code as used throughout the aviation sector. DFSPs are labeled with their city/town of location.
- Intermodal facilities (not shown) are represented by a pink circle. There are 383 intermodal facilities which can obscure the routes and locations of preprocessor, biorefineries, and destinations and are not displayed by default, although this layer can be turned on if needed.
- The network segments used in the optimized solution are shown. Each mode in the optimized solution is represented by a dark color:
    - Water – blue
    - Pipeline – black – NOTE: pipeline has been represented by a manually drawn straight line between approximate origins and destinations on the graphics presented herein due to restrictions on geospatial representation of pipeline. Actual network data were used to calculate routes and costs
    - Rail - pink
    - Road - red

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

Figure 7: Example map output from an AFTOT scenario visualizing the scenario results and demonstrating symbology. Pipeline in this map is an overlain straight line between selected origins and destinations and does not reflect underlying geospatial network data used in the calculations for the analysis.



3.8 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
    - A logfile for each processing step and individual timestamps for each subroutine 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. Scenario results came out identically on different machines.

3.9 Known Issues and Limitations

As with any software tool under ongoing development, AFTOT has known bugs and limitations, which are briefly summarized here.

1) Pipeline – currently the tool contains approximately 75% of the OD pairs that exist in the pipeline systems. Phase 3 development will entail completion of the full pipeline system in the network.

2) Pipeline – certain included pipeline routes do not contain base rate data and therefore costs associated with movements along these routes are not currently included in overall cost or per gallon cost estimates for scenarios that use them. These will be updated in Phase 3 as well.
3) Pipeline – in rare cases in which feedstock production occurs within 5 miles of an origin point in the pipeline database, an artificial link may be created that would erroneously allow feedstock to flow over pipeline. While the distances involved under such circumstances are very small, this can introduce a small additional error into the final calculations. This issue will be addressed in Phase 3.

4) Zero-flow solution / No optimal solution found – in some cases AFTOT will return the error "no optimal solution found" even with a properly specified scenario. In this case, PuLP calculates the lowest cost option is to have zero-flow over the network. The following variables can be adjusted in the scenario XML configuration file in order to force flow: lowering the cost and/or size of biorefineries, increasing destination demand, increasing biomass production, increasing unmet demand penalty.
5) Single pathway scenarios – currently the tool can address one biorefinery type in a given scenario (e.g., pyrolysis or HEFA or Fischer-Tropsch). Therefore, for complex scenarios involving more than one pathway type, the user must run a scenario for each pathway/feedstock combination and collate the results at the end. In cases where demand centers are shared, this means that the user must either allocate demand among pathways in advance or prioritize pathways and adjust demand downward for each successive run until the demand centers are filled. An approach to managing this internally will be investigated in Phase 3.

4 Demonstration of Model Capabilities

Six scenarios were selected to demonstrate the capabilities of AFTOT to identify optimal transportation patterns based on factors that are likely to be of interest to potential users of the tool. The three test scenarios (Test Scenarios 1-3) described below demonstrate the capabilities of the tool, increasing from a single origin, destination, and biorefinery in a geographic scale covering a couple of counties (Test Scenario 1) to a Gulf Coast regional scale showing local pipeline integration (Test Scenario 2) to a Gulf Coast regional scale extending up the East Coast demonstrating greater pipeline integration (Test Scenario 3).

The full scenarios (Scenario 4-6) were defined based on discussions with FAA. Scenario 4 analyzes the downstream transportation and refining optimization based on a USDA break-even analysis for oilseed production. The scenario presented herein uses first-run dataset for North Dakota and delivers the resulting HEFA fuels to airports and DFSPs. Scenario 5 demonstrates the ability to use existing materials such as crop residues (e.g., wheat straw) in the most efficient processing option for that feedstock (advanced fermentation) and deliver the resulting fuels to airports and DFSPs. Scenario 6 uses a highly cited biomass feedstock dataset from the DOE "Billion Ton Study Update" (Perlack and Stokes 2011) as a mixed feedstock scenario, with the feedstocks processed by the most efficient technology available and then delivered to airports and DFSPs. These scenarios are summarized in Figure 8.

For all of the scenarios described, the same default set of costs and weightings were used. These are shown in Table 5. Selected scenario level details of inputs and results are provided in Table 6 and described in the following sections.

Figure 8: Feedstock source, processing type, and destinations for demonstration Scenarios 5-7.

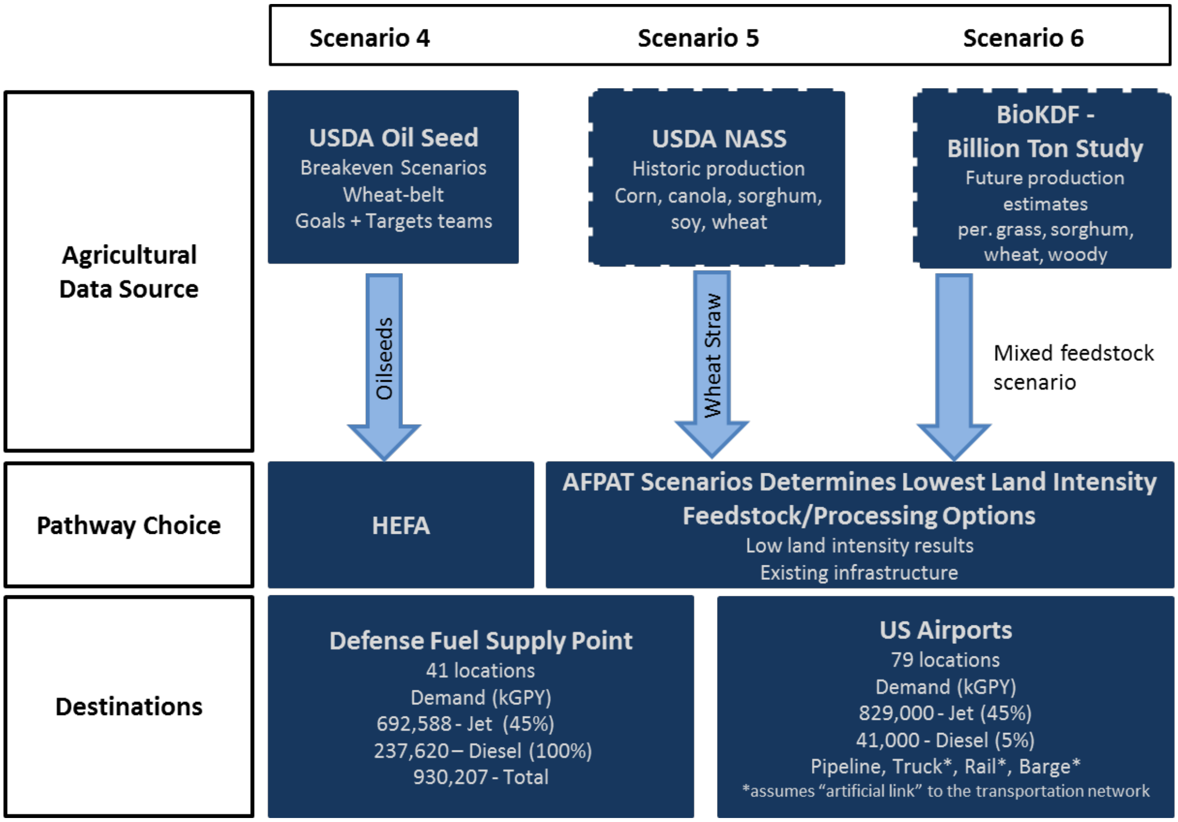


Table 7: Key input parameters common to all demonstration scenarios described in this report.

Input Parameter	Value Common to Scenarios Below
Trucking base cost (per 1 kgal-mi / per tonne mi)	$0.45 per kgal-mi / $0.15 per tonne-mi
Rail cost (per 1 kgal-mi / per tonne mi)	$0.12 per kgal-mi / $0.04 per tonne-mi
Barge cost (per 1 kgal-mi/ per tonne mi)	$0.05 per kgal-mi / $0.0167 per tonne-mi
Pipeline cost	Based on OD pair tariffs
Transloading cost (per 1 kgal or metric ton)	$40/$13.3
Trucking interstate weighting	1
Trucking principal arterial weighting	1.10
Trucking minor arterial weighting	1.20
Trucking local weighting	1.30
Maximum artificial link distance (to join network – in miles)	5
Time steps	1 (annual results)

Table 8: Summary of selected inputs and results for Test Scenarios 1-3

	Test Scenario 1	Test Scenario 2	Test Scenario 3
Crop and Primary conversion Process:	Corn, AFx	Wheat_Straw, AFx	Wheat_Straw, AFx
Minimum Biorefinery Size (kgal/yr)	30,000	30,000.00	30,000.00
Maximum Biorefinery Size (kgal/yr)	200,000	150,000.00	150,000.00
Minimum preprocessor production floor (metric tons per time period)	10,000	10,000.00	10,000.00
Unmet demand penalty ($)	2,000	4,000.00	4,000.00
Total preprocessors above production floor	1	2.00	2.00
Number of Destinations	1	8.00	17.00
Maximum Raw Material Transport Distance (miles)	100	250.00	250.00
Total Potential Production from Preprocessors (metric tons/ time period)	508,024	74,926,285	74,926,284,840
Total OD pairs	1	16	34
Estimated Maximum Potential Fuel Production from Feedstock Conversion (kgal/time period)	45,806	2,896,186	2,896,186,053
Maximum Number of New Biorefineres Supported	2	97	96,540
Total Demand from Destinations (kgal/time period)	98,586	2,996,347	732,820
Biorefineries Candidate Locations (after IDW ranking)	177	5	1
Total Jet Demand (kgal/year)	49,293	2,723,952	666,200
Total Diesel Demand (kgal/year)	49,293	272,395	66,620

	Test Scenario 1	Test Scenario 2	Test Scenario 3
Total Demand (kgal/year)	98,586	2,996,347	732,820
Scenario Unmet Demand Penalty ($/kgal)	2,000	4,000	4,000
Number of Optimal Biorefineries	1	4	1
Cost to Build Optimal Biorefineries:	6,000,000	12,000,000	6,000,000
Total Unmet Demand Jet (kgal/year)	19,295	2,355,734	546,128
Total Unmet Demand Diesel (kgal/year)	41,816	180,615	36,692
Total Unmet Demand Fuel Product (kgal/year)	61,111	2,536,348	582,820
Total Unmet Demand Jet Cost ($/year)	38,590,600	9,422,934,084	2,184,513,720
Total Unmet Demand Diesel Cost ($/year)	83,631,908	722,459,100	146,766,272
Total Unmet Demand Fuel Product Cost ($/year)	122,222,508	10,145,393,184	2,331,279,992
Total Movements	25,852	624,992	216,438
Total Feedstock Flow	508,024	14,546,310	4,743,362
Total Jet Flow	29,998	368,219	120,072
Total Diesel Flow	7,477	91,781	29,928
Percent of Potential Feedstock Used	100%	19%	0.01%
Percent of Jet Fuel Demand Met	61%	14%	18%
Percent of Diesel Demand Met	15%	34%	45%
Total Cost ($)	888,580.00	574,793,934.00	46,028,090.00
Trucking Cost ($)	888,580.00	574,413,047.00	46,028,090.00
Rail Cost ($)	-	-	-

	Test Scenario 1	Test Scenario 2	Test Scenario 3
Barge Cost ($)	-	-	-
Pipeline Cost ($)	-	380,887.00	-
Cost per Gallon of Fuel Delivered	0.02	1.25	0.31
Total Vehicle Miles Traveled (VMT)	89,405	47,209,961	5,658,281
Truck VMT	89,405	47,209,961	5,658,281
Railcar VMT	-	-	-
Barge VMT	-	-	-
Truckloads	25,852	624,846	216,390
Railcar Loads	-	-	-
Barge Loads	-	-	-
Pipeline Movements	-	146	48
Total Miles of Network Used	11	3,835	1,274
Road Network Miles Used	11	570	193
Rail Network Miles Used	-	-	-
Water Network Miles Used	-	-	-
Pipeline Network Miles Used	-	3,265	1,081
Total CO_2 Combustion Emissions	171,882,050	93,280,428,969	11,043,634,165
Total Rail CO_2 Emissions	-	-	-
Total Truck CO_2 Emissions	171,882,050	93,280,428,969	11,043,634,165
Total Barge CO_2 Emissions	-	-	-
Total Pipeline CO_2 Emissions	-	-	-

4.1 Test Scenario 1 – Small geographical area test case

4.1.1 Objective

This scenario is the simplest test case of one origin, one biorefinery candidate location, one destination and one mode (road only) in a single county. The scenario demonstrates the tool's capability to run and solve scenarios in a small geographic area, allowing for simple comprehension and rapid auditing of results. This test scenario also demonstrates the geographic scope that would be used to explore options for an individual airport, biorefinery, etc.

4.1.2 Geographical Scope

This scenario focuses on a sub-regional scope encompassing one county, one origin, one biorefinery, and one destination, allowing travel only by road (truck).

4.1.3 Key Input Parameter Values

Test Scenario 1 used a subset of the AFTOT intermodal network surrounding a particular county and airport, specifically the DFSP in Omaha, Nebraska. The feedstock data for the arbitrarily selected county came from a gridded dataset developed by MIT on future bioenergy potential with corn as a potential feedstock, but this scenario is not intended to suggest that corn is likely to be used for advanced biofuels; the feedstock data simply provide a hypothetical county production level to enable tool testing. The advanced fermentation pathway in AFPAT can be tuned to predominantly produce jet fuel. Jet fuel and diesel demand were both set at 49 million gallons per year. The biorefinery size was set at a minimum of 30 million gallons per year.

4.1.4 Run Summary

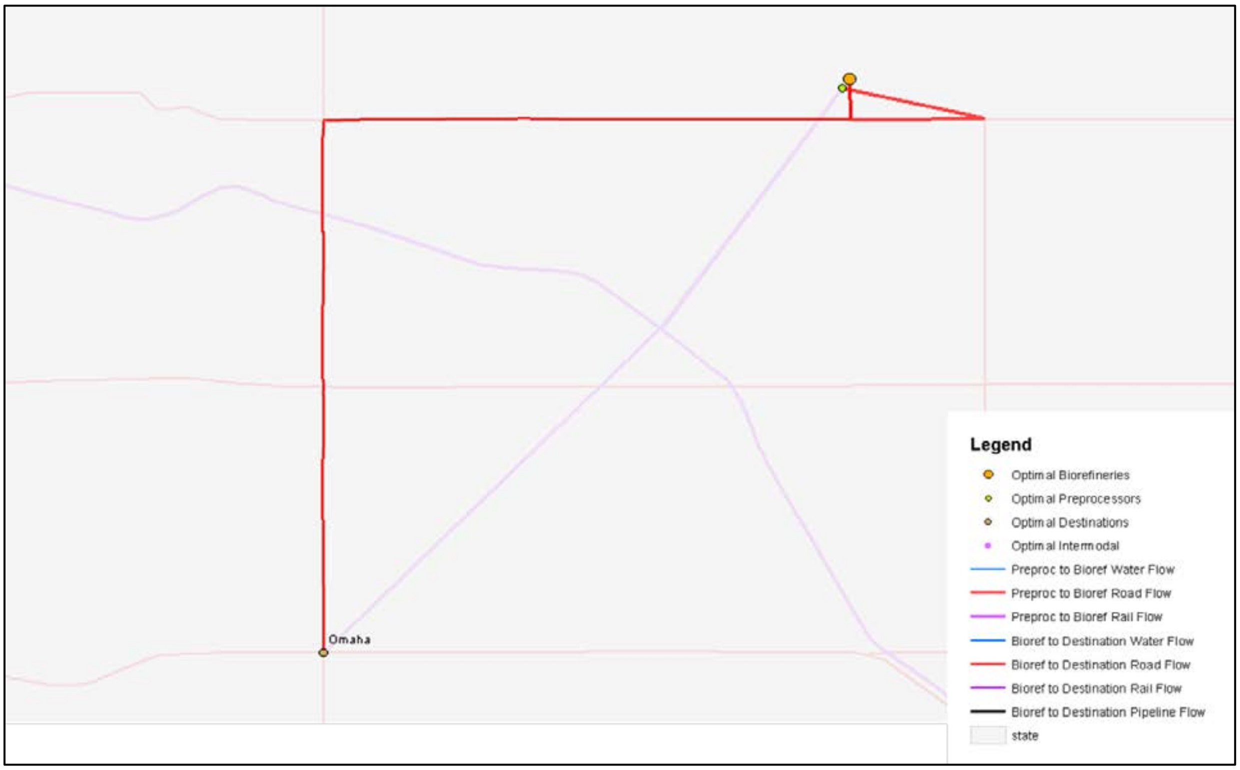
AFTOT processed Test Scenario 1 in approximately 5 minutes. Given the narrow scope of the scenario, only one route was generated. AFTOT generated two candidate biorefinery, of which one was used. Potential feedstock production was 508,024 metric tons annually, with the possibility of producing up to 45.8 million gallons of fuel products per year.

4.1.5 Results/Conclusions

In Test Scenario 1, 100% of the potential feedstock production (508,024 metric tons) was used to make fuel in the single candidate biorefinery location selected during the optimization by AFTOT. This amount of feedstock produced 30 million gallons of jet fuel and 7.5 million gallons of diesel.

The total cost to move this material was $51,500 to move nearly 26,000 truckloads over 89,405 vehicle miles. All of those vehicle miles traveled (VMT) occurred on only 11 miles of roadway. The average per gallon cost of moving the fuels was approximately $0.02 per gallon, which is low because of the very short distances involved. This produced 172 metric tons of CO_2.

Figure 9: Map of Test Scenario 1 showing single origin, biorefinery and destination and demonstrating ability of AFTOT to perform a simple, geographically constrained analysis.



4.2 Test Scenario 2 – Regional geographical area test (Gulf Coast)

4.2.1 Objective

Test Scenario 2 demonstrates the tool's capability to run and solve scenarios in a mid-sized/regional geographic area, such as an analysis of a few closely spaced biorefineries and/or delivery to a few airports in one or several states. This scenario also verifies pipeline network integration. It includes roadway and pipeline modes to ensure travel over pipeline and verify connectivity and performance.

4.2.2 Geographical Scope

Test Scenario 2 focuses on the Gulf Coast region. The road network within approximately a 200-mile radius of Houston is included. The entire pipeline network is also included.

4.2.3 Key Parameter Values

Test Scenario 2 uses a small geographic subset of the USDA NASS wheat straw data, which is converted to fuels by advanced fermentation (AFx), as this is the most efficient conversion technology AFPAT identifies for this feedstock. The advanced fermentation pathway (conventional fermentation to ethanol with dilute acid pretreatment), in AFPAT predominantly produces jet fuel through an ethanol oligomerization process. The unmet demand penalty was set at $4,000 per thousand gallons.

4.2.4 Run Summary

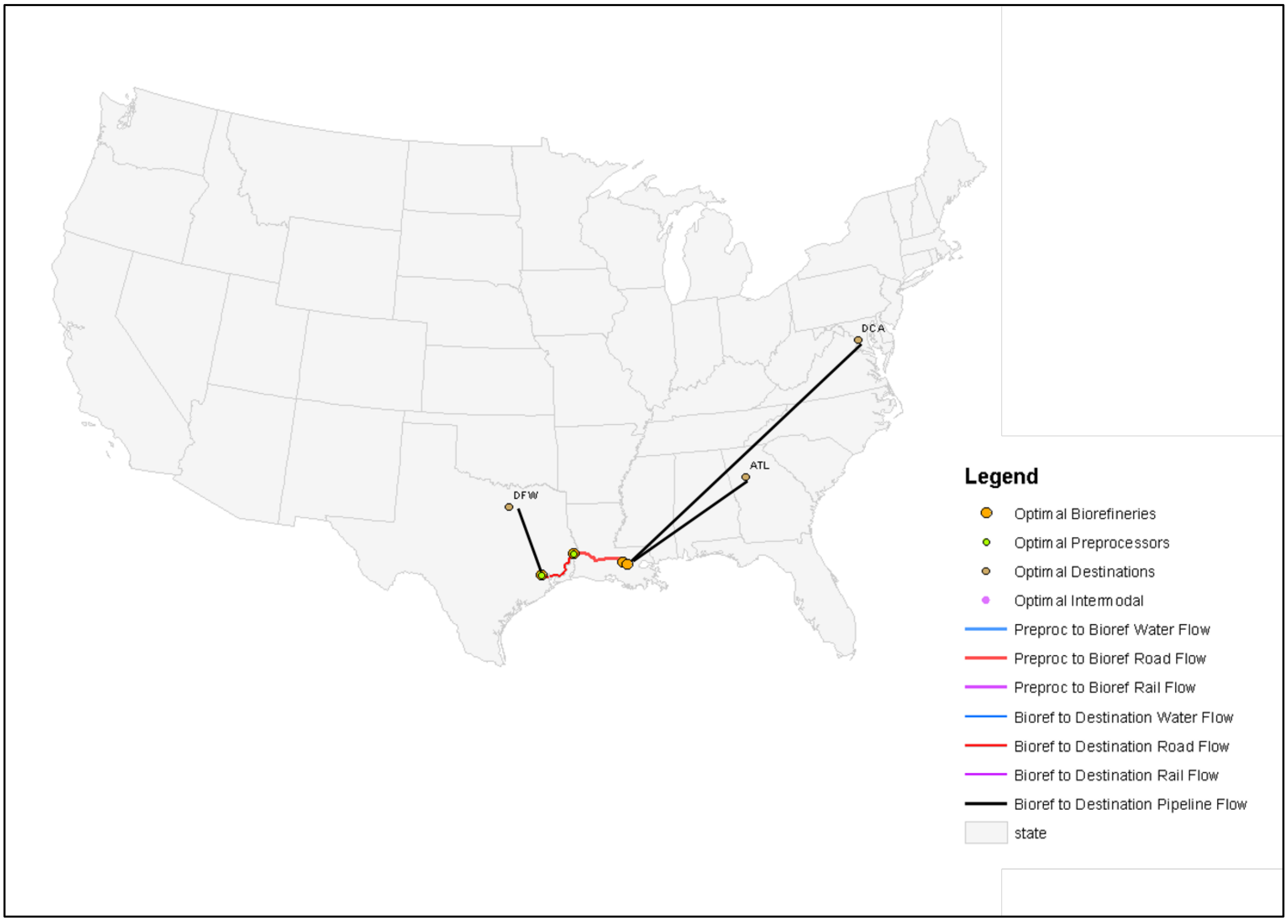
AFTOT processed Test Scenario 2 in approximately 25 minutes. Two preprocessors and eight destinations were included, leading to 16 original OD pairs. Seven candidate biorefinery locations were generated, of which two were eliminated by IDW weighting. Potential feedstock production was almost 75 million metric tons, which could support up to 97 biorefineries using AFx conversion with a minimum production floor of 30,000 kgal/year, resulting in total potential fuel production (diesel, jet, naptha, etc.) of 2.9 billion gallons of fuel. Jet fuel demand was set at 2.7 billion gallons per year, diesel at 272 million gallons.

4.2.5 Results/Conclusions

In Test Scenario 2, 19% (14.5 million metric tons) of the potential feedstock production was used to make fuel in the four candidate biorefinery locations selected by AFTOT in the optimization. This amount of feedstock produced 368 million gallons of jet fuel and 92 million gallons of diesel. This met about 14% of the jet fuel demand and about 34% of the diesel demand designated in the scenario for all potential destinations, demonstrating the tool's balancing of feedstock use/fuel production against the cost of "doing nothing" and paying the unmet demand penalty. The resulting fuel was delivered by pipeline to the Dallas-Fort Worth Airport (DFW), Atlanta Airport (ATL) and Ronald Reagan National Airport (DCA), with the initial transfer by truck from the biorefinery site not located at the pipeline. For DFW, ATL, and DCA, 31%, 71% and 0% of jet fuel demand and 78%, 100% and 15% of diesel demand were met, respectively, for a total fulfillment of 11% of jet fuel demand and 27% of diesel demand overall.

The total cost to move this material was $574 million, all of which was associated with the transport of fuel, as the biorefinery was essentially co-located with feedstock production. The per unit cost of moving the fuel was approximately $1.25 per gallon. However, this value is an underestimate, as some pipeline movements contained in this scenario did not have a base rate value in the tariff data and therefore were set to zero. Further development will include attempts to resolve zero-value movements. It would take approximately 625,000 truckloads traveling 47 million vehicle miles over 1835 miles of roadway for transport of the fuel. In addition, 3,265 miles of pipeline were used for 146 pipeline movements. The CO_2 emitted was approximately 93,000 metric tons.

Figure 10: Map of Test Scenario 2 demonstrating AFTOT ability to perform a mid-size geographic scope analysis, including utilization of pipeline. Note that pipeline routes are represented by a straight line connecting origins and destinations and do not reflect actual geospatial data on pipeline location, although actual network data are used to run the scenario and identify routing options.



4.3 Test Scenario 3 – Broad regional scenario test

4.3.1 Objective

Test Scenario 3 is similar to Test Scenario 2 in that this scenario demonstrates AFTOT's capability to run and solve scenarios integrating pipeline and testing wheat straw conversion via AFx to jet and diesel fuel. This scenario removed the destinations closets to the biorefineries in Test Scenario 2 to expand the geographic extent of the pipeline network as a larger test of the flowable pipeline network, and, provides a broader perspective on potential movements based on transport cost. The road network within approximately a 200-mile radius of Houston is included. The entire pipeline network is also included. To ensure the scenario was not constrained on the feedstock supply, the agricultural layer was updated to include one thousand times more material than Test Scenario 2, but uses the same counties.

4.3.2 Geographical Scope

Test Scenario 3 covers the eastern U.S., with feedstock production and transport focused on the Gulf Coast region, and allow demand to be met throughout the Midwestern and Eastern U.S. based on transport over pipeline.

4.3.3 Key Parameter Values

As with Test Scenario 2, Test Scenario 3 uses a small geographic subset of the USDA NASS wheat straw data, which is converted to fuels by advanced fermentation (AFx), as this is the most efficient conversion technology AFPAT identifies for this feedstock. The advanced fermentation pathway in AFPAT can be tuned to predominantly produce jet fuel. As stated earlier, the county yield is increased by a factor of 1,000 to remove feedstock supply constraints. The unmet demand penalty was set at $4,000 per thousand gallons.

4.3.4 Run Summary

AFTOT processed Test Scenario 3 in approximately 39 minutes. Two preprocessors and 17 destinations were included, leading to 34 original OD pairs. Two candidate biorefinery locations were generated, but one was eliminated by the IDW process. Potential feedstock production was 1,000 times that of Test Scenario 2 (75 billion metric tons) in order to drive the scenario production higher and thereby test the further transport along the pipeline network. This amount of feedstock could hypothetically support nearly 97,000 biorefineries using AFx conversion with a minimum production floor of 30,000 kgal/year, resulting in total potential fuel production (diesel, jet, naptha, etc.) of 2.9 trillion gallons of fuel (again, these results are 1,000 higher due to increased production at the preprocessor for this test). In this scenario, jet fuel demand was 666 million gallons per year and diesel demand was set at 10% of jet fuel demand (66 million gallons per year). This demand is 25% of the demand in Test Scenario 2 due to the elimination of large Southeastern airports (e.g. ATL, DFW) to drive pipeline use in the scenario optimization.

4.3.5 Results/Conclusions

In Test Scenario 3, only 0.01% (4.7 million metric tons) of the potential feedstock production was used to make fuel in the one candidate biorefinery location identified as the optimal solution by AFTOT. This amount of feedstock produced 120 million gallons of jet fuel and 30 million gallons of diesel. This met about 18% of the total jet fuel demand and about 45% of the diesel demand designated in the scenario for all destinations. All of this fuel was delivered to Dulles International Airport (IAD) in the Washington, DC region, at which 26.% of jet fuel demand and 65% of diesel demand were met. The total amount of fuel produced in this scenario is less than that produced in Test Scenario 2 in spite of the higher feedstock production due to the further distance travel required for the fuel to reach its final destination. The tool calculates the optimization by comparing movement cost to the "no movement" cost driven by the unmet demand penalty, cost to build biorefineries, cost of moving feedstock, and penalties and weightings.

The total cost to move this material was $46 million, all of which was associated with the transport of fuel, as the biorefinery was essentially co-located with feedstock production. The per unit cost of moving the fuel was approximately $0.31 per gallon. Moving this fuel required 216,400 truck loads and 5.7 million miles of truck travel, covering 193 miles of roadway. However most of the transport was on the pipeline, covering 1,100 miles of the pipeline network. All CO_2 was associated with truck movements and totaled 1,100 metric tons.

Figure 11: Map of Test Scenario 3 showing national scale test scenario processing wheat straw into jet fuel and diesel and transporting over a network including all modes. Note that pipeline routes are represented by a straight line connecting origins and destinations and do not reflect actual geospatial data on pipeline location, although actual network data are used to run the scenario and identify routing options.

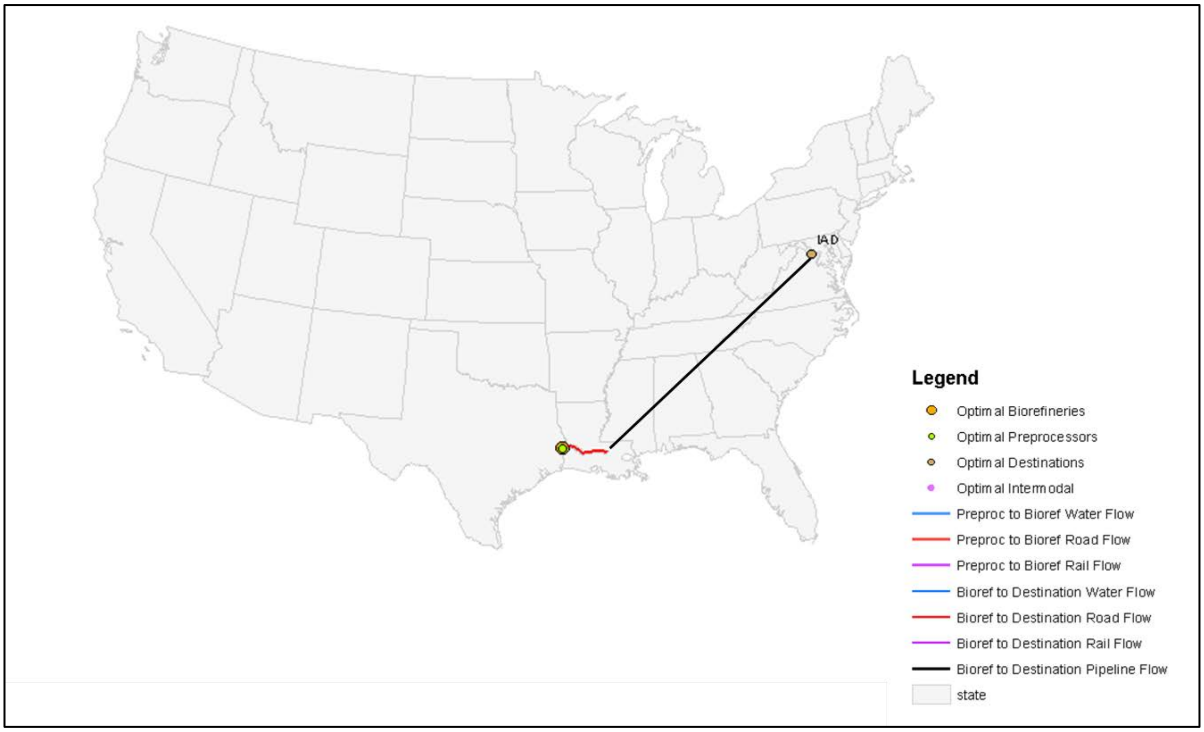


Table 9: Summary of selected inputs and results for Scenarios 4-6.

	Scenario 4	Scenario 5	Scenario 6 switchgrass	Scenario 6 sorghum	Scenario 6 woody spp.	Scenario 6 Combined
Crop and Primary Conversion Process:	Canola, HEFA	Wheat_Straw, AFx	Switchgrass, AFx	Sweet_sorghum, FTx	Harwood_Gen, PRx	Billion Ton Study Combined
Minimum Biorefinery Size	30,000	30,000	30,000	100,000	10,000	
Maximum Biorefinery Size	200,000	200,000	200,000	200,000	200,000	
			#N/A	#N/A	#N/A	
Minimum preprocessor production floor (metric tons per time period)	1,000	35,000	50,000	35,000	50,000	
Unmet demand penalty ($)	2,000	2,000	2,000	4,000	2,000	
Total preprocessors above production floor	45	379	78	211	36	325
Number of Destinations	132	132	132	132	132	132
Maximum Raw Material Transport Distance (miles)	100	250	250	150	250	
Total Potential Production from Preprocessors (metric tons per time period)	1,885,336	44,821,962	9,008,621	798,252,539	2,802,657	810,063,817
Total OD pairs	4,884	44,088	9,900	27,324	4,620	41,844
Estimated Potential Fuel Production from Feedstock Conversion (kgal/time period)	335,875	1,511,173	350,347	49,094,003	494,473	49,938,823
Maximum Number of New Biorefineres Supported	11	50	12	491	49	552
Total Demand from Destinations (kgal/time period)	9,771,231	9,771,231	9,771,231	9,771,231	9,771,231	9,771,231

	Scenario 4	Scenario 5	Scenario 6 switchgrass	Scenario 6 sorghum	Scenario 6 woody spp.	Scenario 6 Combined
Biorefineries Candidate Locations (after IDW ranking)	12	249	187	23	13	223
Total Jet Demand (kgal/year)	8,649,509	8,649,509	8,649,509	8,649,509	8,649,509	8,649,509
Total Diesel Demand (kgal/year)	1,121,722	1,121,722	1,121,722	1,121,722	1,121,722	1,121,722
Total Demand (kgal/year)	9,771,231	9,771,231	9,771,231	9,771,231	9,771,231	9,771,231
Scenario Unmet Demand Penalty ($/kgal)	2,000	2,000	2,000	4,000	2,000	
Number of Optimal Biorefineries	4	68	24	22	8	54
Cost to Build Optimal Biorefineries:	24,000,000	84,000,000	24,000,000	132,000,000	48,000,000	204,000,000
Total Unmet Demand Jet (kgal/year)	8,604,498	7,749,316	8,465,609	7,333,630	8,649,509	24,448,748
Total Unmet Demand Diesel (kgal/year)	888,277	897,345	1,075,884	-	932,174	2,008,058
Total Unmet Demand Fuel Product (kgal/year)	9,492,775	8,646,661	9,541,493	7,333,630	9,581,683	26,456,806
Total Unmet Demand Jet Cost ($/year)	17,208,996,456	15,498,632,856	16,931,217,454	29,334,520,140	17,299,018,096	63,564,755,690
Total Unmet Demand Diesel Cost ($/year)	1,776,553,836	1,794,689,801	2,151,768,891	-	1,864,347,735	4,016,116,626
Total Unmet Demand Fuel Product Cost ($/year)	18,985,550,292	17,293,322,657	19,082,986,344	29,334,520,140	19,163,365,831	67,580,872,315
Total Movements	48,771	1,121,206	164,692	1,446,620	73,150	1,684,462
Total Feedstock Flow	1,293,162	35,561,620	7,041,080	84,307,983	2,479,791	93,828,854
Total Jet Flow	45,011	900,193	183,900	1,315,879	-	1,499,779
Total Diesel Flow	233,445	224,377	45,838	1,121,722	189,548	1,357,108

	Scenario 4	Scenario 5	Scenario 6 switchgrass	Scenario 6 sorghum	Scenario 6 woody spp.	Scenario 6 Combined
Percent of Potential Feedstock Used	69%	79%	78%	11%	88%	12%
Percent of Jet Fuel Demand Met	1%	10%	2%	15%	0%	17%
Percent of Diesel Demand Met	21%	20%	4%	100%	17%	121%
Total Cost ($)	49,505,590.00	685,440,469.00	132,621,307.00	342,803,005.00	47,585,906.00	523,010,218.00
Trucking Cost ($)	17,697,099.00	474,452,716.00	70,507,702.00	160,569,707.00	26,332,243.00	257,409,652.00
Rail Cost ($)	22,330,259.00	202,917,834.00	55,372,500.00	147,309,676.00	19,567,649.00	222,249,825.00
Barge Cost ($)	8,223,886.00	6,727,424.00	6,741,106.00	32,480,677.00	1,522,688.00	40,744,471.00
Pipeline Cost ($)	1,254,345.00	1,342,495.00	-	2,442,945.00	163,326.00	2,606,271.00
Cost per Gallon of Fuel Delivered ($)	0.18	0.61	0.58	0.14	0.25	0.18
Total Vehicle Miles Traveled (VMT)	8,031,296	69,117,909.00	11,921,277	47,786,815	5,071,443	64,779,535
Truck VMT	1,740,675	40,010,968	5,737,314	16,545,750	2,350,189	24,633,253
Railcar VMT	6,212,298	29,028,574	5,995,734	30,660,985	2,706,472	39,363,191
Barge VMT	78,323	78,367	188,229	580,079	14,783	783,091
Truckloads	29,989	772,559	97,989	726,313	47,610	871,912
Railcar Loads	18,684	347,908	65,066	695,517	25,415	785,998
Barge Loads	75	660	1,627	24,737	121	26,485
Pipeline Movements	22	79	10	54	4	68
Total Miles of Network Used	47,299	98,559	14,630	83,053	11,309	
Road Network Miles Used	1,435	10,519	1,492	3,190	775	

	Scenario 4	Scenario 5	Scenario 6 switchgrass	Scenario 6 sorghum	Scenario 6 woody spp.	Scenario 6 Combined
Rail Network Miles Used	22,793	55,748	10,320	46,952	6,685	
Water Network Miles Used	21,813	22,522	2,764	30,537	3,742	
Pipeline Network Miles Used	1,259	9,770	53	2,374	107	
Total CO_2 Combustion Emissions	28,132,042,476	141,494,325,763	27,316,133,527	126,846,789,427	12,133,482,603	166,296,405,557
Total Rail CO_2 Emissions	10,853,542,050	53,464,711,208	11,418,266,708	54,602,459,761	5,002,856,410	71,023,582,879
Total Truck CO_2 Emissions	3,352,993,515	77,421,882,705	11,283,066,305	32,088,281,774	4,567,664,960	47,939,013,039
Total Barge CO_2 Emissions	13,925,506,912	10,607,731,850	4,614,800,514	40,156,047,892	2,562,961,233	47,333,809,639
Total Pipeline CO_2 Emissions	-	-	-	-	-	-

4.4 Scenario 4 – Oilseed Breakeven Scenario in North Dakota

4.4.1 Objective

Scenario 4 focuses on evaluating the downstream transportation patterns, costs, and CO2 emissions associated with a particular break-even analysis on oilseed production in wheat-growing areas, followed by HEFA processing and delivery to commercial airports and DFSPs. The USDA Agricultural Research Service developed a break-even profitability modeling approach that is used to estimate the oilseed price level at which the profitability of growing oilseeds becomes more profitable than growing other annual crops. The approach utilizes the EPIC (Environmental Policy Integrated Climate) model to simulate crop yields under varying weather conditions for each Soil Survey Geographic Database (SSURGO) soil map unit within the U.S. western wheat producing areas. Predominant crops and crop sequences are identified for each county in the region, and these are matched with management files from the USDA-NRCS management operations database. These management files are used to construct enterprise budgets and also the management inputs for the EPIC model. Each management system is modeled for each cultivated soil map unit within each county. Net returns are calculated for each cropping system on each soil map unit, and the system with highest estimated net returns is selected as the optimum on each soil. Management files and enterprise budgets are also constructed for each fuel oilseed (initially fuel rapeseed) grown in sequence with wheat. Net returns are estimated for each fuel oilseed cropping system over a range of fuel oilseed prices. Fuel oilseed system net returns at each price level are compared to the optimum system excluding fuel oilseeds to determine the overall optimum system at each fuel oilseed price level. This is used to estimate the area and quantity of fuel oilseed produced at each price level, and resulting natural resource impacts including soil erosion, soil organic carbon, nutrient runoff and leaching, fertilizer and fuel use. Enterprise budgets are based on 2104 input costs and 2010-2014 average crop prices. (Archer, USDA ARS, pers. comm.). As of August 2015, USDA has provided break-even data for three crop management zones in North Dakota as a preliminary dataset preceding release of a full canola break-even dataset focused on the entire upper Midwest wheat belt. Therefore, this scenario focuses on North Dakota break even data for canola in North Dakota (at a $600 price point) and delivers the resulting HEFA fuels to commercial airports and DFSPs across the country as determined by the optimization. The AFTOT team will provide the resulting CO_2 emissions to Michigan Institute of Technology (MichiganTech) for use in calculating life cycle GHG emissions associated with the jet fuel resulting from this scenario. Summary information for Scenarios 4-6 are presented in Table 7.

This scenario is performed in collaboration with USDA's Agricultural Research Service.

4.4.2 Geographical Scope

This scenario focuses on canola production in the North Dakota as a test dataset for future analysis of the entire upper Midwest (the wheat belt), as defined in the ONR- and NIFA-funded study at USDA's Agricultural Research Service (and collaborators). The data were provided at 9x9 kilometer grid scale, which was then aggregated to county level production. In cases where a grid cell was split between two or more counties, production was allocated proportionally by area to the appropriate counties.

4.4.3 Key Parameter Values

This scenario includes a minimum biorefinery capacity of 30 million gallons per year and a maximum of 200 million gallons per year. The unmet demand penalty was $2,000, the maximum feedstock transport distance was 100 miles, and the minimum county-level feedstock production amount was 1,000 metric tons.

4.4.4 Run Summary

AFTOT processed Scenario 4 in approximately two hours. There were 45 counties with sufficient production to meet the minimum threshold, and 132 potential destinations were included, resulting in nearly 4,900 OD pairs. Thirty candidate biorefinery locations were generated, of which 18 were deleted because of IDW ranking, leaving 12 candidate sites for the optimization. Of these, 4 were used in the optimal solution. Potential feedstock production was nearly 1.9 million metric tons. This amount of feedstock could hypothetically support 11 biorefineries using HEFA conversion with a minimum production floor of 30,000 kgal/year. In this scenario, jet fuel demand was 8.6 billion gallons per year and diesel was 1.1 billion gallons per year. The HEFA facilities were assumed to be producing based on a "maximum distillate" product slate approach that produces predominantly diesel.

4.4.5 Results/Conclusions

In Scenario 4, 1.3 million metric tons, or about 69% of the total available feedstock was used in the optimal solution. Conversion of this feedstock produced 45 million gallons of jet fuel and 233 million gallons of diesel in the four biorefineries selected for the optimal solution. This met only about 1% of the jet fuel demand and about 21% of the diesel demand designated in the scenario. Given that the destination layer used for this case study was national in scope in preparation for a larger analysis of the full wheat belt, it is not surprising that such a low demand was satisfied, particularly for jet fuel given the maximum distillate product slate assumption used.

This solution included use of all the surface modes of transportation, including 30,000 truckloads traveling 1.7 million vehicle miles, as well as 18,700 rail cars traveling over 6.2 million rail car miles. 75 bargeloads traveled 78,000 vehicle miles. And over 1,200 miles of pipeline were used. Figure 13 presents graphical descriptions of contributions of the different modes toward total scenario cost, CO_2 emissions, movements, and vehicle miles traveled. From the map in Figure 14, one can see that many airports and DFSPs received alternative fuels in this scenario. Any airport or DFSP that is shown on the map received some amount of fuel. This suggests that even geographically constrained oilseed production may result in cost-effectively delivered fuel at many airports and DFSPs that are outside the region of feedstock production. However, Table 8 shows a list of airports receiving fuel in this scenario and shows that only Minneapolis-St. Paul airport received both jet and diesel fuel.

Table 10: Destinations receiving jet and/or diesel fuel and percent demand fulfilled at airports and DFSPs for Scenario 4. Note that airport codes and names are listed in Appendix A – Airports Abbreviations.

Destination (DFSP name or airport code)	% Jet Demand	% Diesel Demand
ATL	0	100
BNA	0	100
CLE	0	100
CLT	0	100
CMH	0	100
COS	0	100
CVG	0	100
DSM	0	100
DTW	0	100
GRR	0	100
ICT	0	100
IND	0	100
ITH	0	100
LCK	0	100
LIT	0	100
MCI	0	100
MDW	0	100
MEM	0	100
MKE	0	100
MSP	30	100
MSY	0	100
ORD	0	100
PIT	0	100
PNS	0	100
RDU	0	38.6
ROC	0	100
SDF	0	100

Destination (DFSP name or airport code)	% Jet Demand	% Diesel Demand
STL	0	100
All Destinations	1	21

The total cost to move this material was $49.5 million of which approximately $17.7 million was trucking cost, $22.3 million was rail cost, nearly $8.2 million was barging cost, and $1.3 million was pipeline cost. This resulted in a per gallon fuel transport cost of approximately $0.18 per gallon (see Figure 14 for a comparison of per gallon fuel transport costs for the scenarios presented herein). The CO_2 combustion emissions associated with transportation in this scenario totaled 24,800 metric tons.

Figure 12: Modal contribution to Scenario Costs, CO_2 Combustion Emissions, Movements (e.g., truckloads, etc.), and vehicle miles traveled (VMT) for Scenarios 4-6. Note that pipeline contribution to total cost is underestimated due to missing base rate values for some routes.

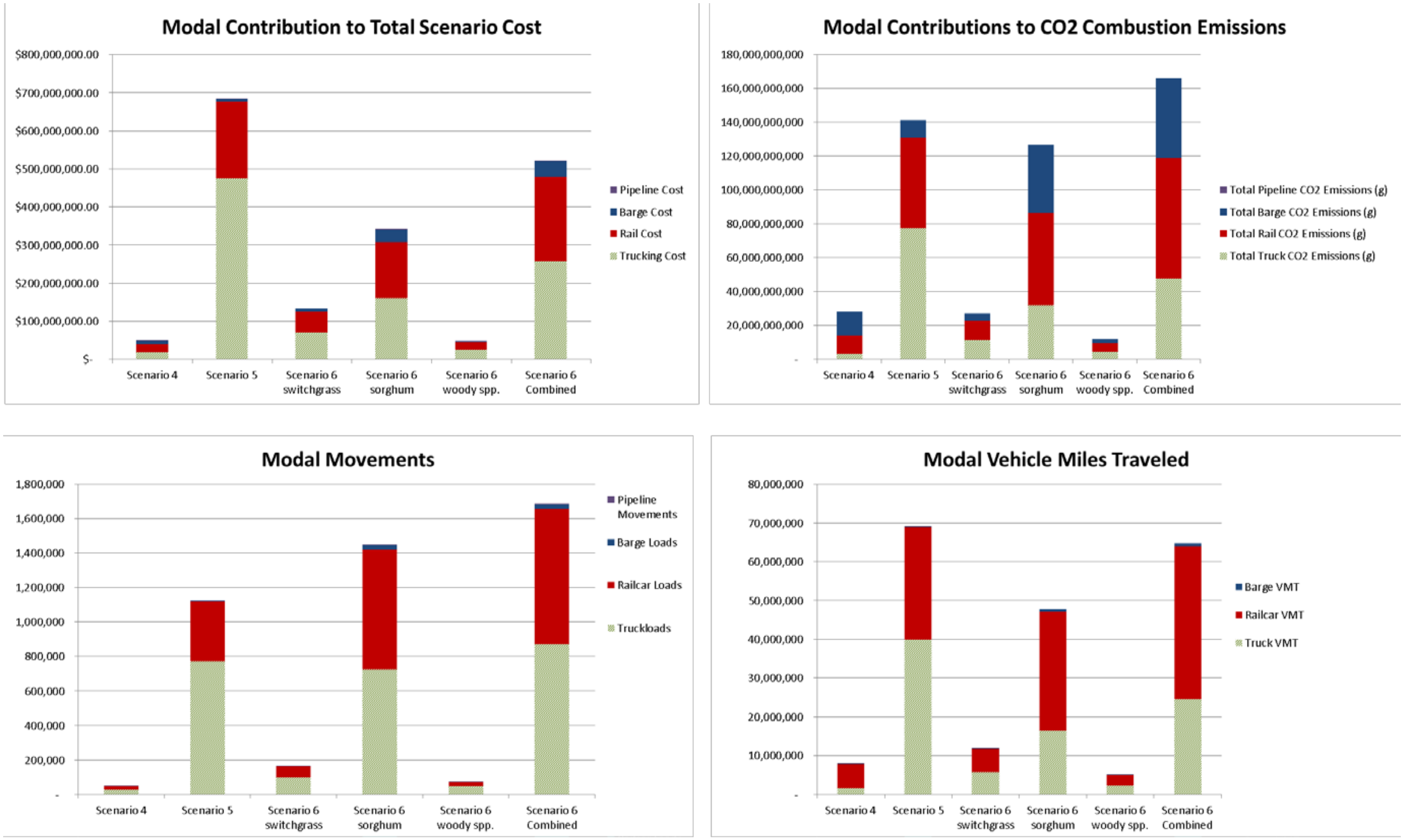


Figure 13: Per gallon cost of transport for fuel delivered in Scenarios 4-6. Note that pipeline contribution to per unit transport cost is underestimated due to missing base rate values for some routes.

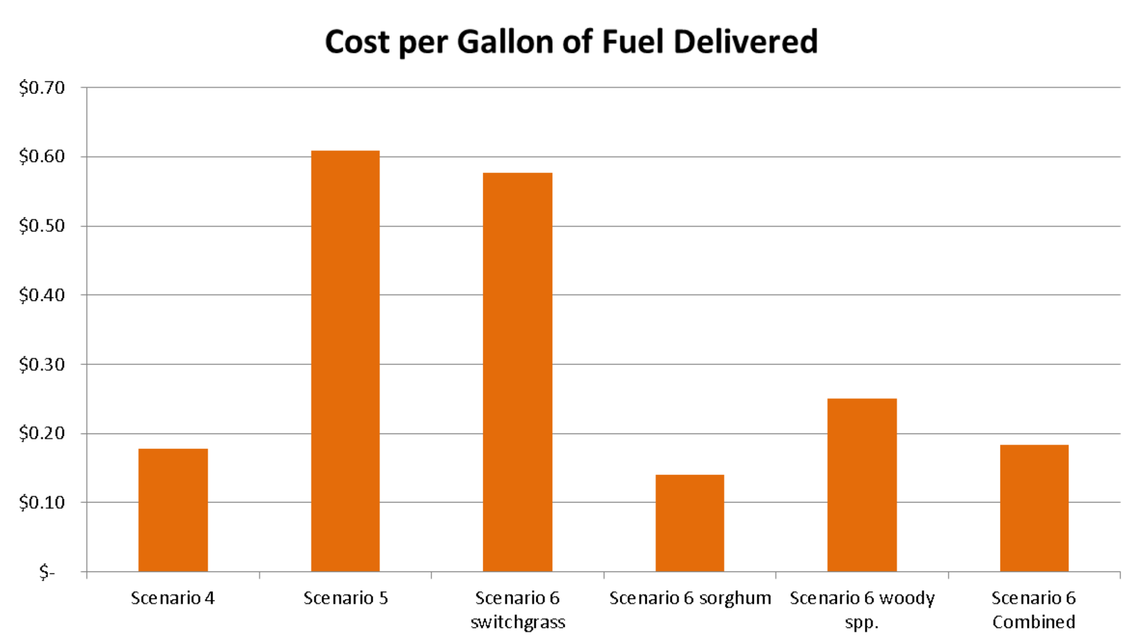


Figure 14: Average CO_2 emissions per gallon of fuel delivered in Scenarios 4-6.

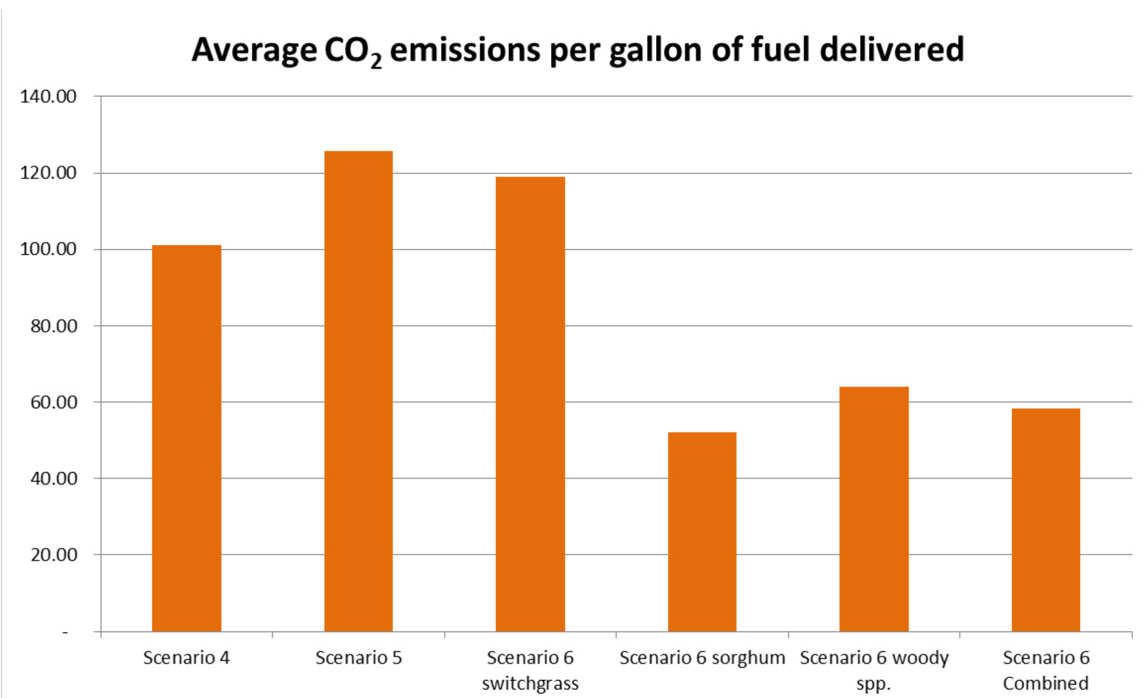
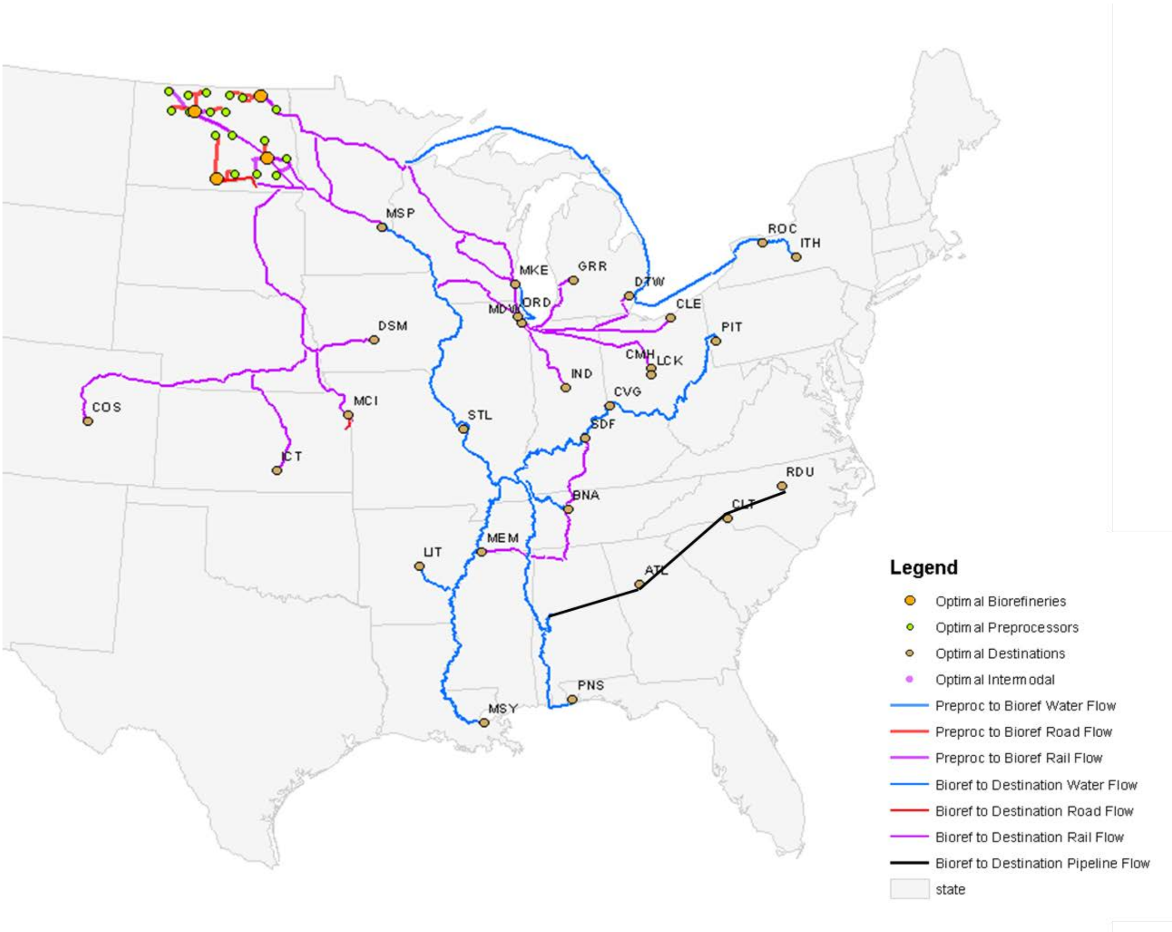


Figure 15: Map of Scenario 4 showing optimal routing of North Dakota canola production to candidate biorefineries and destinations (arports and DFSPs). Note that pipeline routes are represented by a straight line connecting origins and destinations and do not reflect geospatial data on pipeline location, although actual network data are used to run the scenario and identify routing options.



4.5 Scenario 5 – Historic Production of Wheat Straw

4.5.1 Objective

This scenario focuses on evaluating the potential for producing advanced alternative jet fuel from wheat straw based on existing wheat production by county in the U.S. as recorded in the USDA NASS and utilizing the existing ethanol production infrastructure. The processing pathway is advanced fermentation (AFx): conventional ethanol fermentation and oligomerization preceded by dilute acid pretreatment, which was selected as the most efficient processing option included in AFPAT. The 176 ethanol biorefineries listed on the BioKDF were also included as prefunded biorefinery sites in this scenario. Resulting fuel will be delivered to commercial airports and DFSPs and can travel over all modes.

4.5.2 Geographical Scope

This scenario is national in scope, constrained only by selection of counties where wheat straw production meets a minimum threshold level of 35,000 metric tons of feedstock production. For this scenario it is assumed that 100% of the available wheat straw is available for conversion. The 176 existing ethanol facilities in the US (as reported by the BioKDF database) were also included in the analysis.

4.5.3 Key Parameter Values

The wheat straw data are derived from wheat production in the U.S. in 2012 as recorded in the USDA NASS. This scenario includes a minimum biorefinery capacity of 30 million gallons per year and a maximum of 200 million gallons per year. The unmet demand penalty was $2,000 per kgal, the maximum feedstock transport distance was set at 250 miles, and the minimum county-level feedstock production amount was 35,000 metric tons.

4.5.4 Run Summary

AFTOT processed Scenario 5 in approximately eighteen hours. There were 379 preprocessors with sufficient production to meet the minimum threshold, and 132 potential destinations were included resulting in 44,000 OD pairs. Three hundred twenty five candidate biorefinery locations were generated, of which 76 were deleted because of IDW ranking, leaving 249 candidate sites for the optimization. Of these, 68 were used in the optimal solution. Potential feedstock production was nearly 45 million metric tons. This amount of feedstock could hypothetically result in total potential fuel production (diesel, jet, naptha, etc.) of 1.5 billion gallons of fuel. In this scenario, jet fuel demand was 8.6 billion gallons per year and diesel was 1.1 billion gallons per year.

4.5.5 Results/Conclusions

In Scenario 5, 36 million metric tons, or about 79% of the total available feedstock was used in the optimal solution. Conversion of this feedstock produced 900 million gallons of jet fuel and 224 million gallons of diesel in the 68 biorefineries selected for the optimal solution. The fuel was delivered to 41 different airports (see Table 9). In aggregate, the fuel delivered met about 10% of the jet fuel demand and about 20% of the diesel demand designated in the scenario.

Table 11: Destinations receiving jet and/or diesel fuel and percent demand fulfilled at airports and DFSPs in Scenario 5. Note that airport codes and names are listed in Appendix A – Airports Abbreviations.

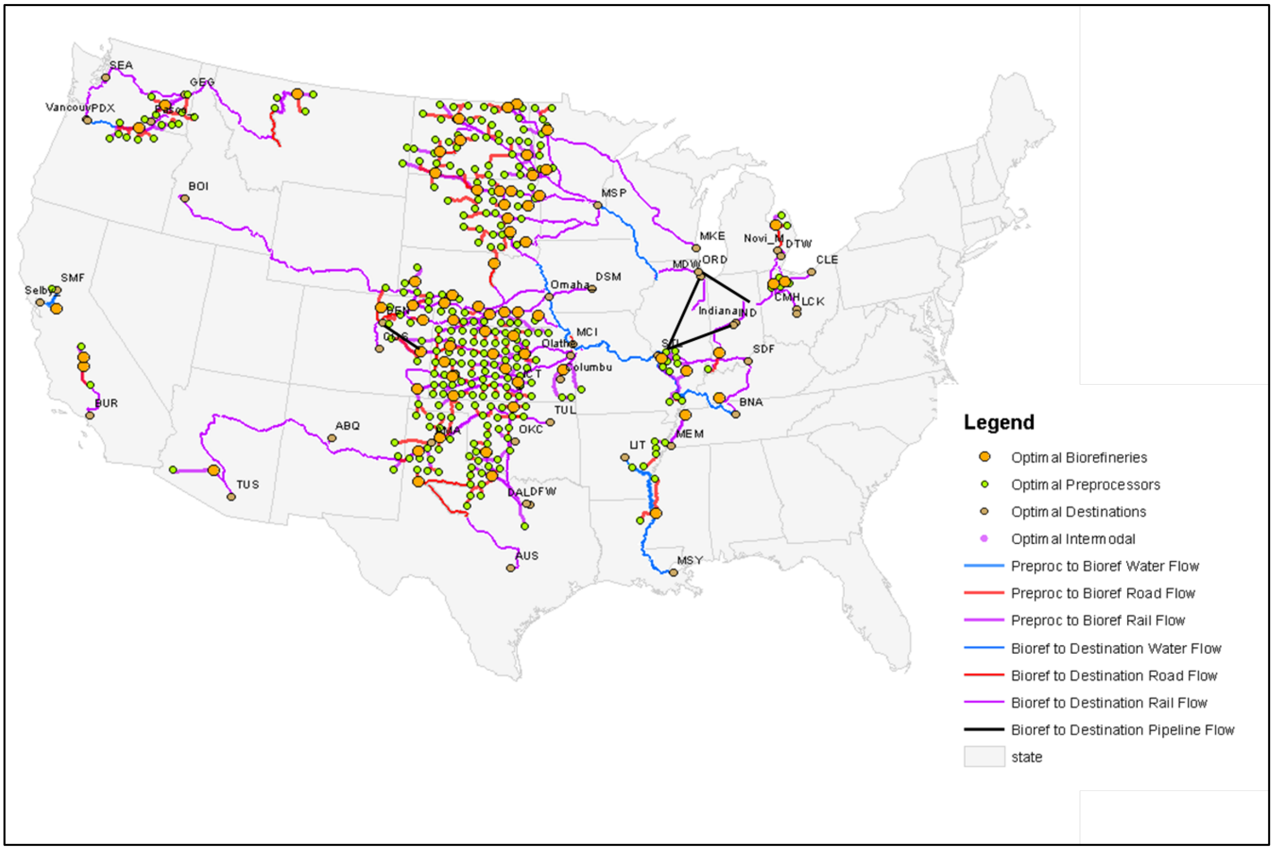
Destination (DFSP name or airport code)	% Jet Demand	% Diesel Demand
ABQ	100	100
AMA	100	100
AUS	0	6
BNA	3	100
BOI	0	100
BUR	15	34
CLE	0	100
CMH	0	100
Columbus, GA DFSP	100	0
COS	100	100
DAL	0	100
DEN	100	100
DFW	34	100
DSM	100	100
DTW	3	100
GEG	100	100
ICT	100	100
IND	2	100
Indianapolis, IN DFSP	100	0
LCK	0	100
LIT	72	100
MCI	100	100
MDW	28	100
MEM	4	10
MKE	0	100
MSP	100	100
MSY	0	10
Novi_MI DFSP	99	0
OKC	100	100
Olathe KS DFSP	100	0
Omaha, NE DFSP	100	0
ORD	28	100
Pasco, WA DFSP	100	0
PDX	100	100
SDF	6	55
SEA	10	78
Selby, CA DFSP	2	0
SMF	0	8
STL	100	100
TUL	100	100

Destination (DFSP name or airport code)	% Jet Demand	% Diesel Demand
TUS	9	100
Vancouver, WA DFSP	100	0
All Destinations	10	20

This solution included use of all the surface modes of transportation, including 773,000 truckloads traveling 40 million vehicle miles, as well as 350,000 rail cars traveling 29 million rail car miles. 660 bargeloads covered 78,000 vehicle miles. And nearly 10,000 miles of pipeline were used for 79 movements. However, trucking and rail dominated the transport cost in this scenario. Figure 13 presents graphical descriptions of contributions of the different modes toward total scenario cost, CO_2 emissions, movements, and vehicle miles traveled. Figure 15 shows the results of this scenario. One can see the concentration of feedstock production in the central and upper Midwest, represented by the clusters of green feedstock production points. The feedstock from these facilities is delivered to biorefineries by truck and rail, then moved by all modes from biorefineries to airports and DFSPs across a large portion of the country, although the central West and Northeast did not receive alternative fuel delivery from this scenario.

The total cost to move this material was $685 million of which approximately $474.5 million was trucking cost, $202 million was rail cost, $6.7 million was barging cost, and $1.3 million was pipeline cost. This resulted in a per gallon fuel transport cost of approximately $0.61 per gallon, which is higher than in the other scenarios.

Figure 16: Map of Scenario 5 showing a national wheat straw scenario based on historical wheat production patterns, advanced fermentation processing, delivery to airports and DFSPs,, and transporting via all modes. Note that pipeline routes are represented by a straight line connecting origins and destinations and do not reflect actual geospatial data on pipeline location, although actual network data are used to run the scenario and identify routing options.



4.6 Scenario 6 – Billion Ton Feedstock Production Scenario

4.6.1 Objective

This scenario is actually a combination of three distinct scenarios run for different feedstocks and processes based on the Billion Ton Study data. This scenario focuses on evaluating the downstream transportation, processing, and distribution patterns of alternative jet fuel generated from feedstocks identified in the U.S. Department of Energy (DOE) Billion Ton Study Update (Perlack and Stokes 2011). The study was intended to estimate potential biomass available within the contiguous United States and includes assumptions about production capacity and technology availability, and provides supply curves (i.e., price vs. feedstock availability). It attempts to use conservative assumptions so as not to over-estimate availability. It includes county-by-county estimates of potential availability of specific feedstocks that can be used in

AFTOT as origin points. For the AFTOT scenario, the baseline Billion Ton Study data were used for the 2018 year and $80/dry ton price point. Feedstocks are processed based on the most efficient processing option for each feedstock type as identified in AFPAT. Fuels are delivered to U.S. commercial airports and DFSPs.

4.6.2 Geographical Scope

This scenario is national in scope and counties are selected based on meeting a minimum production threshold of 10,000 metric tons of feedstock.

4.6.3 Key Parameter Values

For switchgrass, the processing pathway was via advanced fermentation (AFx), with a minimum biorefinery capacity of 30 million gallons per year and a maximum of 200 million gallons per year. For sweet sorghum, the most efficient process identified in AFPAT was Fischer-Tropsch (FTx) processing, with a minimum biorefinery capacity of 100 million gallons per year and maxium of 200 million gallons per year, as FT facilities tend to be larger. For hardwood species, the most efficient processing type was pyrolysis (PRx), with a minimum biorefinery capacity of 10 million gallons per year and a maximum of 200 million gallons per year. The unmet demand penalties for the three feedstocks (switchgrass, sorghum, hardwoods) were $2,000, $4,000, and $2,000, respectively, to better match the varying capital costs associated with the different processes. The maximum feedstock transport distances were 250, 150 and 250 respectively, and the minimum preprocessor production amounts were 50,000, 35,000, and 50,000 metric tons, respectively – the sorghum scenario had lower material availability and therefore needed a lower threshold origin size to identify an optimal scenario.

4.6.4 Run Summary

Total combined run time for these three feedstocks was approximately 13 hours. There were 325 preprocessors above the minimum production floor (78, 211, and 36 for switchgrass, sorghum, and hardwoods, respectively) and 132 final destinations with a total jet fuel demand of 8.65 billion gallons per year and total diesel demand of 1.1 billion gallons. Nearly 42,000 OD pairs were processed during the analysis. The total potential feedstock production was 810 million metric tons, which had the potential to be converted into 50 billion gallons of fuels, with a total potential for 552 supported biorefineries (12 AFx, 491 FT and 49 PRx facilities). AFTOT generated 325 total biorefinery candidate locations and deleted 102 because of IDW (1, 66, and 35 , respectively). Two hundred and twenty-three biorefinery locations were used in the optimal solution (187, 23, and 13, respectively).

4.6.5 Results/Conclusions

Based on the optimized scenarios for each feedstock/process combination, the total amount of feedstock used was 94 million metric tons, or about 12% of total available feedstock (78, 11, and 88% of switchgrass, sorghum, and woody feedstock used, respectively). This resulted in production of 1.5 billion gallons of jet fuel and 1.4 billion gallons of diesel, fulfilling 17% and 121% of demand, respectively. Due to the high diesel production from these scenarios, low diesel demand at the airports, and the single pathway run constraint, this combination of scenarios delivers excess diesel to some destinations. This highlights the need for the user to adjust scenario demand values when running multiple feedstock/pathway scenarios to the same destinations. Future development will include an approach to address the issue either by enabling aggregated demand limitations or by integrating multiple conversion processes into a single optimization scenario. Table 8 shows the airports and DFSPs that received fuel in this scenario and the amounts provided from each sub-scenario, as well as the total demand fulfillment.

Table 12: Destinations receiving jet and/or diesel fuel and percent demand fulfilled at airports and DFSPs for Scenario 6. Note that airport codes and names are listed in Appendix A – Airports Abbreviations.

	Scenario 6 Switchgrass		Scenario 6 Sorghum		Scenario 6 Woody Spp.		Scenario 6 Combined	
Destination	**% Jet Demand Filled**	**% Diesel Demand Filled**	**% Jet Demand Filled**	**% Diesel Demand Filled**	**% Jet Demand Filled**	**% Diesel Demand Filled**	**Total % Jet Fulfilled**	**Total % Diesel Fulfilled**
ABQ			100	100			100	100
Alamogordo, NM DFSP			100	100			100	100
ALB			100	100	0	100	100	200
AMA	0	97	100	100			100	197
Annacostia DFSP			100	100			100	100
ATL	0	1	0	100			0	101
AUS			100	100			100	100
Baltimore, MD DFSP			100	100			100	100
BDL			100	100			100	100
BNA			0	100	0	64	0	164
BOI			0	100			0	100
BOS			0	100			0	100
Bremen, GA DFSP	31	0					31	0
BUF	0	72	0	100	0	100	0	272
BUR			0	100			0	100
BWI			4	100	0	100	4	200
Charleston, SC DFSP	100	0					100	0
CHS	66	100	0	100			66	200
CLE	91	100	0	100	0	100	91	300
CLT	14	31	63	100			77	131

	Scenario 6 Switchgrass		Scenario 6 Sorghum		Scenario 6 Woody Spp.		Scenario 6 Combined	
Destination	**% Jet Demand Filled**	**% Diesel Demand Filled**	**% Jet Demand Filled**	**% Diesel Demand Filled**	**% Jet Demand Filled**	**% Diesel Demand Filled**	**Total % Jet Fulfilled**	**Total % Diesel Fulfilled**
CMH	100	100	0	100	0	100	100	300
COS			0	100			0	100
Craney Island, VA DFSP	0	1	100	100			100	101
CRP			100	100			100	100
CVG			85	100	0	60	85	160
DAB			0	100			0	100
DAL			100	100			100	100
DCA			100	100	0	100	100	200
DEN			0	100			0	100
DFW			71	100			71	100
DSM	0	85	0	100			0	185
DTW	12	69	0	100	0	100	12	269
Ells Jet, SD DFSP			100	100			100	100
ELM			0	100	0	100	0	200
ELP			0	100			0	100
EWR			0	100	0	41	0	141
FLL			0	100			0	100
GEG			0	100			0	100
GRR			0	100	0	100	0	200
GSP			100	100			100	100
Holy Corp , ID DFSP			100	100			100	100
HOU			0	100			0	100
Houston, TX DFSP			65	100			65	100
HPN			0	100			0	100
HRL			100	100			100	100

	Scenario 6 Switchgrass		Scenario 6 Sorghum		Scenario 6 Woody Spp.		Scenario 6 Combined	
Destination	**% Jet Demand Filled**	**% Diesel Demand Filled**	**% Jet Demand Filled**	**% Diesel Demand Filled**	**% Jet Demand Filled**	**% Diesel Demand Filled**	**Total % Jet Fulfilled**	**Total % Diesel Fulfilled**
IAD			0	100			0	100
IAH			0	100			0	100
ICT	63	100	100	100			163	200
IND			0	100	0	100	0	200
ISP			0	100			0	100
ITH	100	100	0	100	0	100	100	300
Jacksonville, FL DFSP			0	100			0	100
JFK			0	100	0	28	0	128
LAS			11	100			11	100
LAX			0	100			0	100
LCK	100	100	0	100	0	100	100	300
LGA			24	100	0	100	24	200
LGB			0	100			0	100
LIT			100	100			100	100
Ludlow, MA DFSP			100	100			100	100
Mayport, FL DFSP	0	56	0	100			0	156
MCI	0	39	100	100			100	139
MCO			0	100			0	100
MDW			0	100	0	100	0	200
MEM	2	5	0	100			2	105
MHT			0	100			0	100
MIA			0	100			0	100
MKE			100	100	0	100	100	200
MSP	7	25	40	100	0	100	46	225
MSY			0	100			0	100

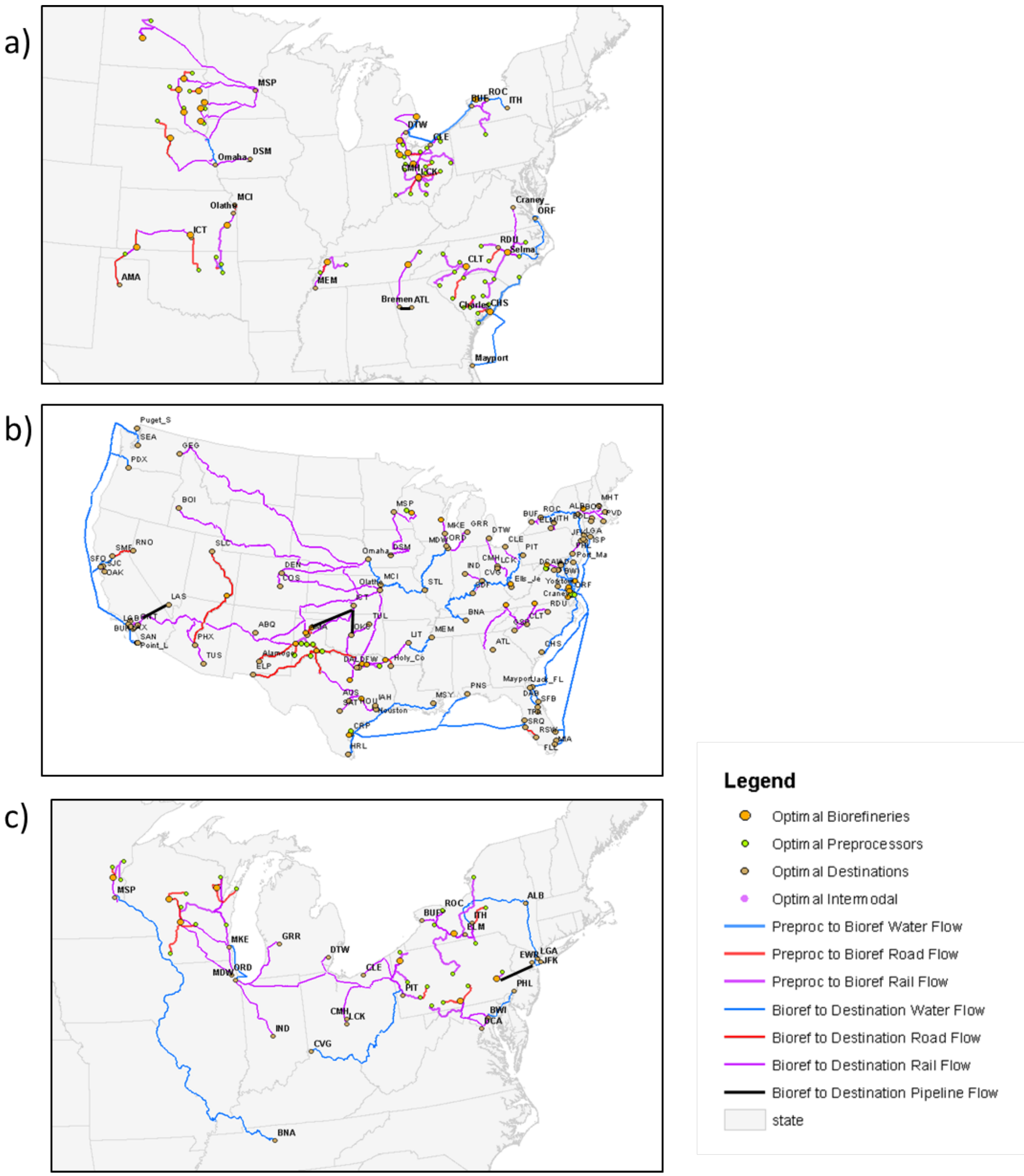
	Scenario 6 Switchgrass		Scenario 6 Sorghum		Scenario 6 Woody Spp.		Scenario 6 Combined	
Destination	**% Jet Demand Filled**	**% Diesel Demand Filled**	**% Jet Demand Filled**	**% Diesel Demand Filled**	**% Jet Demand Filled**	**% Diesel Demand Filled**	**Total % Jet Fulfilled**	**Total % Diesel Fulfilled**
OAK			0	100			0	100
OKC			100	100			100	100
Olathe, KS DFSP	65	0	100	100			165	100
Omaha, NE DFSP	100	0	100	100			200	100
ONT			0	100			0	100
ORD			8	100	0	100	8	200
ORF	0	100	100	100			100	200
PBI			0	100			0	100
PDX			0	100			0	100
PHL			23	100	0	23	23	123
PHX			0	100			0	100
PIT			0	100	0	100	0	200
PNS			0	100			0	100
Point Loma, CA DFSP			0	100			0	100
Port Mahon, DE DFSP			100	100			100	100
Puget Sound, WA DFSP			0	100			0	100
PVD			0	100			0	100
RDU	0	100	0	100			0	200
RNO			0	100			0	100
ROC	100	100	0	100	0	100	100	300
RSW			0	100			0	100
SAN			0	100			0	100
SAT			0	100			0	100
SDF			0	100			0	100
SEA			0	100			0	100

	Scenario 6 Switchgrass		Scenario 6 Sorghum		Scenario 6 Woody Spp.		Scenario 6 Combined	
Destination	**% Jet Demand Filled**	**% Diesel Demand Filled**	**% Jet Demand Filled**	**% Diesel Demand Filled**	**% Jet Demand Filled**	**% Diesel Demand Filled**	**Total % Jet Fulfilled**	**Total % Diesel Fulfilled**
Selma_	68	0	0	0			68	0
SFB			0	100			0	100
SFO			0	100			0	100
SJC			0	100			0	100
SLC			85	100			85	100
SMF			0	100			0	100
SNA			0	100			0	100
SRQ			0	100			0	100
STL			0	100			0	100
TPA			0	100			0	100
TUL			100	100			100	100
TUS			100	100			100	100
Watson, CA DFSP			0	100			0	100
Yorktown, VA DFSP			100	100			100	100
All Destinations	2	4	15	100	0	17	17	121

Figure 16 shows the outcomes of each of the feedstock/pathway scenarios that were combined for Scenario 6 total results. Many different airports and DFSPs were supplied with alternative jet fuel by these three scenarios. The sorghum/FT pathway analysis covered the broadest geographical area. The total transport cost of the scenario was $523 million, of which $257 million was for trucking (25 million VMT 5y about 870,000 truckloads), $222 million for rail transport (40 million VMT by about 786,000 rail cars), $40.7 million was for barge transport (approximately 783,000 VMT by 26,000 bargeloads), and $2.6 million was for pipeline movement (68 movements), with the caveat that the pipeline movement costs are underestimated due to missing base rates for some routes. Figure 13 presents graphical descriptions of contributions of the different modes toward total scenario cost, CO_2 emissions, movements, and vehicle miles traveled. Average per gallon fuel transport cost also varied widely, ranging from $0.58/gal) for switchgrass-derived AFx fuels to 0.14/gal for sorghum-derived FT Fuels to $0.25/gal for hardwood-based PRx fuels. The average per unit cost of fuel transport was $0.18/gal..

Total CO_2 emissions associated with all of these movements was 166,300 metric tons, of which about 70,000 metric tons caome from rail, 48,000 from trucking, and 47,000 from barge transport.

Figure 17: Map of Scenario 6 showing a national analysis of multiple feedstocks as identified in the Billion Ton Study Update by the U.S. DOE, delivery to airports and DFSPs,, and transporting via all modes. Feedstocks included a) switchgrass processed by advanced fermentation, b) sweet sorghum processed by Fischer-Tropsch, and c) hardwood species processed by pyrolysis. Note that pipeline routes are represented by a straight line connecting origins and destinations and do not reflect actual geospatial data on pipeline location, although actual network data are used to run the scenario and identify routing options.



5 Conclusion

This report summarizes the development and current capabilities of the AFTOT model, which is an expansion of the former "BTAT" model. AFTOT includes the capability to effectively optimize transport for multiple feedstocks and fuels at regional and national scales based on transportation-specific costs and weightings, feedstock processing information, conversion process efficiency, product slate, and capital cost, and other user-defined parameters. The tool now includes waterway transport by barge as well as a partial pipeline network, and these have been successfully integrated into the AFTOT optimization process. This version of AFTOT also includes the capability to address seasonality of harvest and movements by incorporating explicit time-steps into the model. The ability to take in yield and process information from the AFPAT tool has also been expanded.

The test scenarios included herein demonstrate these capabilities at multiple scales and provide insight into particular future scenarios of alternative fuel production. The more realistic scenarios (Scenarios 4-6) are based on existing feedstock production data and demand centers, for which AFTOT provides screening level analysis to understand potential for cost-effective delivery of feedstocks and fuels throughout the continental U.S.

Scenario 4 using USDA breakeven data for canola shows that even from a narrow production zone (North Dakota), airports and DFSPs around the country may be supplied with alternative jet fuel when using optimal transportation patterns to move feedstock and fuel along the transportation network. The wheat straw results (Scenario 5) corroborate this result, showing delivery from the central US to many places in the east, southeast, and southwest. The Billion Ton Study scenarios together cover most of the US and suggested that transport to over 100 airports and DFSPs could be achieved from these feedstock scenarios based on optimized transport patterns and costs. Management of demand over multiple scenarios will need to be addressed in a future phase of development to better enable fulfillment of demand without over-delivery of materials when multiple conversion process are being modeled.

The scenarios presented herein demonstrate the capabilities of the current AFTOT version. AFTOT provides a foundation for testing a variety of assumptions about how future scenarios will affect transportation patterns and what the associated cost and emissions implications of those patterns will be. Future expansions will build on this fundamental basis for expanded fuels scenario testing.

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

6.1 Next Steps

An additional phase of development has already been funded by FAA. Phase 3 of AFTOT development will include:

1) Completion of pipeline integration

The current version of AFTOT includes 10 complete and 20 partial pipeline systems. In Phase 3, the remaining pipeline systems will be added and the origin-destination pairs will be completed for all systems.

2) Additional scenarios

The current version of the tool, plus the remaining pipeline network elements, will be used to run additional scenarios, potentially including ASCENT Project 1, CAAFI State Initiatives, Farm 2 Fly 2.0 analyses, parallel runs with ORNL to compare their models to AFTOT, etc.

3) Petroleum processing infrastructure

To better understand the available infrastructure for alternative fuel production (e.g., for co-processing and/or blending), GIS layers for petroleum blenders and refineries will be added to the network

4) Existing roadway flows

To begin to develop capabilities to investigate capacity issues, existing flows on the network must be taken into account. To start with, Phase 3 will include incorporation of roadway flows from FAF into a network layer that can be overlain onto the AFTOT intermodal network.

6.2 Future Needs - Additional Future Tasks Necessary to Create a Turnkey Model

The longer term opportunity to turn AFTOT 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 AFTOT 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
- Excision of restricted datasets with option to incorporate user datesets in their place
- Code modifications to enable deployment
- Greater automation of features to enable user modification
- Create self-contained installation package

Other potential expansions could include

- Addition of Hawaii, Canada, or other non-CONUS locations.
- Incorporation of existing flows on railway, waterway and barge
- Incorporation of commodity-specific existing flow data (e.g., existing agricultural commodities, petroleum products)
- Incorporation of gas and oil fields as sources of fossil-based fuels for combined modeling
- Development of FAF-level and regional-level capacity analysis for roadways
- Development of capacity analysis capability for rail
- Add option to calculate life cycle CO_2 equivalent emissions
- Allocate feedstock transport costs and GHG emissions in accordance with accepted life cycle methodologies.
- 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 destination supplies that are vulnerable to disruption from single route disruptions.
- Add option of requiring movement of a minimum volume of fuels (for example, for a volumetric regulatory requirement such as the Renewable Fuel Standard) to drive the scenario.

The development of a capacity analysis capability for the different modes would enable evaluation of whether scenarios would exceed the capacity of available infrastructure. The following section outlines some considerations for developing such an approach.

6.3 AFTOT and Transportation Capacity

The capacity of a transportation link is limited by both the availability of vehicles and of line capacity. For example, a railroad origin-destination movement for a commodity may be limited by both the availability of cars of the correct type, as well as the capacity of the rail line to handle trains between two points. Similar constraints apply for other modes.

Congestion occurs when the demand for transportation reaches or exceeds the vehicle or line capacity. Two types of congestion issues are relevant to the scenarios run in AFTOT:

First is where the added feedstock and fuel flows become a significant portion of the total flow on a transportation network element (e.g, a rail line), and create a congestion problem. This is most likely to occur in the vicinity of large preprocessors and biorefineries. It may also occur near destinations if the AFTOT flow arrives by a different mode of transportation than what was previously used for fossil fuel flow.

Second is where AFTOT flows are added to links that are already congested. The AFTOT flow may add marginally to the congestion, and it may be worthwhile to choose AFTOT routings that avoid these areas.

6.3.1 Symptoms of a Capacity Issue

A capacity issue will manifest itself in several ways:

First is via pricing. If prices can be set freely, the transportation provider can increase the price charged so that demand is reduced to available supply. So, an unusually high price for a particular movement may indicate a capacity issue.

Second is via availability of transportation. For example, there may be a long wait for rail cars of a certain type.

Third is via increased travel time and reduced travel time reliability. As a link on the transportation network (highway, rail or water) becomes more congested, travel times increase, and may become less reliable, because small changes in demand or capacity (e.g., a closed lane) can have larger effects on travel time as demand approaches capacity.

6.3.2 Challenges in Addressing Capacity

There are several significant challenges in addressing capacity. First is understanding exactly what the capacity is. If the issue is availability of vehicles (rail cars or trucks), this information is generally privately held. Furthermore, the capacity in terms of vehicle availability will often depend on the direction of flow. In the primary flow direction (head haul), capacity may be tightly constrained, as all of the vehicles are full. However, in the other direction (back haul), there may be significant available capacity, as most of the vehicles are moving empty. With vehicles that are more specialized (e.g., a tanker truck versus a box trailer), these head haul / back haul differences are likely to be more pronounced.

If the capacity issue is one of link capacity (e.g., vehicles per hour on a highway), some resources are available.

An older report that provides some quick rules-of-thumb on highway link capacity is NCRHP Report 365: Travel Estimation Techniques for Urban Planning (Martin and McGuckin 1998)Chapter 10 provides some useful approximations. More detailed capacity estimation for highways and road intersections can be found in the Highway Capacity Manual (Transportation Research Board 2010). Typically, highway capacity is a function of the type of road (is it a freeway or local road?), the number and type of intersections (are there signals or stop signs?) and the number of lanes.

For rail capacity, some information is available in the National Rail Freight Infrastructure Capacity and Investment Study(Cambridge Systematics 2007), which as commissioned by the Association of American Railroads. This report noted that "capacity of rail corridors is determined by a large number of factors, including the number of tracks, the frequency and length of sidings, the capacity of the yards and terminals along a corridor to receive the traffic, the type of control systems, the terrain, the mix of train types, the power of the locomotives, track speed, and individual railroad operating practices. " Factors used in their analysis included tracks, type of control (signal) systems, and mix of train types.

The second major challenge in addressing capacity is that in order to understand congestion, and where capacity issues might exist, it is necessary to know about the background traffic volumes on a link and how they compare to the capacity of a link, in addition to the AFTOT generated volumes. This information may not be readily available.

Furthermore, capacity is highly time dependent. Most highways are not congested 24 hours / day, and capacity issues on other modes may be highly seasonal. Finally, since AFTOT is a planning model of flows that may be several years in the future, today's capacity issues may not be the same as tomorrow's. Background traffic might grow, or, conversely, a highway might be expanded.

6.3.3 How to Address Capacity

There are three approaches to addressing capacity, presented below in increasing order of difficulty in modeling.

1. First is to run an uncapacitated model, and simply report the volumes on transportation links and well as the numbers of vehicles used. This is what is done now, and provides useful information as to where alternative fuel movements are likely to significantly contribute to capacity issues. It does not require knowledge of background traffic volumes or link capacities.
2. To reducing the AFTOT-recommended volume on a link because of known capacity issues, one could block flow over the link entirely, or add an artificial cost to the link that would be high enough to reduce optimal flow volume over that link.
3. The final step would be an explicit modeling of capacity. This requires a complete picture of the background volume on the link, as well as its capacity. This level of modeling may be most appropriate when performing detailed modeling of the area near a biorefinery or destination, where the AFTOT-flows on the transportation links are a significant proportion of the total flows.

7 References

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Appendix A – AFTOT Airports List and Abbreviations

Airports included in AFTOT Destinations Layer		
Abbreviation	**Full Name**	**State**
ANC	Ted Stevens Anchorage International Airport	AK
JNU	Juneau International Airport	AK
PHX	Phoenix Sky Harbor International Airport	AZ
TUS	Tucson International Airport	AZ
BUR	Bob Hope Airport	CA
LAX	Los Angeles International Airport	CA
OAK	Oakland International Airport	CA
ONT	Ontario International Airport	CA
SAN	San Diego International Airport	CA
SFO	San Francisco International Airport	CA
SJC	Norman Y. Mineta San José International Airport	CA
SMF	Sacramento International Airport	CA
SNA	John Wayne Airport – Orange County	CA
COS	City of Colorado Springs Municipal Airport	CO
DEN	Denver International Airport	CO
BDL	Bradley International Airport	CT
ECP	Northwest Florida Beaches International Airport	FL
FLL	Fort Lauderdale–Hollywood International Airport	FL
MCO	Orlando International Airport	FL
MIA	Miami International Airport	FL
PBI	Palm Beach International Airport	FL
RSW	Southwest Florida International Airport	FL
SFB	Orlando Sanford International Airport	FL
SRQ	Sarasota–Bradenton International Airport	FL
TPA	Tampa International Airport	FL
ATL	Hartsfield-Jackson Atlanta International Airport	GA
HNL	Honolulu International Airport	HI
ITO	Hilo International Airport	HI
KOA	Kona International Airport at Keahole	HI
LIH	Lihue Airport	HI
OGG	Kahului Airport	HI
MDW	Chicago Midway International Airport	IL
ORD	Chicago O'Hare International Airport	IL
IND	Indianapolis International Airport	IN

Airports included in AFTOT Destinations Layer		
Abbreviation	**Full Name**	**State**
DSM	Des Moines International Airport	IO
CVG	Cincinnati/Northern Kentucky International Airport	KY
MSY	Louis Armstrong New Orleans International Airport	LA
BOS	General Edward Lawrence Logan International Airport	MA
BWI	Baltimore/Washington International Thurgood Marshall Airport	MD
DTW	Detroit Metropolitan Wayne County Airport	MI
MSP	Minneapolis–St. Paul International Airport	MN
MCI	Kansas City International Airport	MO
STL	Lambert-St. Louis International Airport	MO
CLT	Charlotte/Douglas International Airport	NC
RDU	Raleigh-Durham International Airport	NC
EWR	Newark Liberty International Airport	NJ
ABQ	Albuquerque International Sunport	NM
LAS	McCarran International Airport	NV
RNO	Reno/Tahoe International Airport	NV
BUF	Buffalo Niagara International Airport	NY
JFK	John F. Kennedy Intenational Airport	NY
LGA	LaGuardia Airport	NY
ROC	Greater Rochester International Airport	NY
CLE	Cleveland-Hopkins International Airport	OH
CMH	Port Columbus International Airport	OH
LCK	Rickenbacker International Airport	OH
OKC	Will Rogers World Airport	OK
TUL	Tulsa International Airport	OK
PDX	Portland International Airport	OR
PHL	Philadelphia International Airport	PA
PIT	Pittsburgh International Airport	PA
PVD	Theodore Francis Green State Airport	RI
CHS	Charleston International Airport	SC
BNA	Nashville International Airport	TN
MEM	Memphis International Airport	TN
AFW	Fort Worth Alliance Airport	TX
AUS	Austin-Bergstrom International Airport	TX
DAL	Dallas Love Field	TX
DFW	Dallas/Fort Worth International Airport	TX
ELP	El Paso International Airport	TX
HOU	William P. Hobby Airport	TX
IAH	George Bush Intercontinental Airport	TX
SAT	San Antonio International Airport	TX
SLC	Salt Lake City International Airport	UT
DCA	Ronald Reagan Washington National Airport	VA

Airports included in AFTOT Destinations Layer		
Abbreviation	**Full Name**	**State**
IAD	Washington Dulles International Airport	VA
ORF	Norfolk International Airport	VA
SEA	Seattle–Tacoma International Airport	WA
MKE	General Mitchell International Airport	WI

Appendix B – AFTOT Default DFSP List

LOCATION	Abbreviation in AFTOT
DFSP Alamogordo, NM	Alamogo
DFSP Annacostia, DC	Annacos
DFSP Baltimore, MD	Baltimo
DFSP Boston, MA	Boston
DFSP Bremen, GA	Bremen
DFSP Carson, CA	Carson
DFSP Charleston, SC	Charles
DFSP Columbus PL, GA	Columbu
DFSP Craney Island, VA	Craney_
DFSP Ells Jet, SD	Ells_Je
DFSP Holy Corp, ID	Holy_Co
DFSP Houston, TX	Houston
DFSP Indianapolis, IN	Indiana
DFSP Jacksonville, FL	Jack_FL
DFSP Jacksonville, NJ	Jack_NJ
DFSP Key West Pipeline, FL	Key_Wes
DFSP Lebanon, OH	Lebanon
DFSP Lockhart Pipeline, MS	Lockhar
DFSP Ludlow, MA	Ludlow
DFSP Macon, GA	Macon_
DFSP Mayport, FL	Mayport
DFSP Montgomery, AL	Montgom
DFSP Moundville, AL	Moundvi
DFSP New Haven, CT	New_Hav
DFSP Novi, MI	Novi_M
DFSP Olathe, KS	Olathe
DFSP Omaha, NE	Omaha_
DFSP Pasco, WA	Pasco_
DFSP Pittsburg, PA	Pittsbu
DFSP Point Loma, CA	Point_L
DFSP Port Everglades, FL	Port_Ev
DFSP Port Mahon, DE	Port_Ma
DFSP Portland, ME	Portlan
DFSP Puget Sound, WA	Puget_S

LOCATION	Abbreviation in AFTOT
DFSP Selby, CA	Selby_
DFSP Selma, NC	Selma_
DFSP Standard Transpipe, VA	Standar
DFSP Tampa, FL	Tampa_
DFSP Vancouver, WA	Vancouv
DFSP Watson, CA	Watson
DFSP Yorktown, VA	Yorktow

Appendix C – XML-based Scenario Input File Example

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

```
<?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_Schema_Version>1.3.0</Scenario_Schema_Version>
      <Scenario_Name>scenario_002</Scenario_Name>
      <Scenario_Description>scenario_002 is a full AFTOT scenario that
simulates the transportation and conversion of wheat straw across the
entire transportation network and to all DFSP and airport
destinations.  All modes are available. </Scenario_Description>

      <Scenario_Inputs>

      <Base_Network_Gdb>C:\AFTOT_Repository_2\trunk\Scenarios\common_da
ta\networks\network_2015_06_05.gdb</Base_Network_Gdb>

      <Base_Destination_Layer>C:\AFTOT_Repository_2\trunk\Scenarios\com
mon_data\destinations.gdb\all_dfsp_and_airport_2014</Base_Destination_
Layer>

      </Scenario_Inputs>

      <Assumptions>

      <Jet_Fuel_Density_kg_per_liter>0.757</Jet_Fuel_Density_kg_per_lit
er>
            <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>
            <!--Atmospheric CO2 emissions for truck are in g/mi-->
      <Atmos_CO2_Urban_Unrestricted>2393.08</Atmos_CO2_Urban_Unrestrict
ed>
      <Atmos_CO2_Urban_Restricted>1993.25</Atmos_CO2_Urban_Restricted>
      <Atmos_CO2_Rural_Unrestricted>1922.52</Atmos_CO2_Rural_Unrestrict
ed>
      <Atmos_CO2_Rural_Restricted>1930.87</Atmos_CO2_Rural_Restricted>
      <Railroad_CO2_Emissions_g_ton_mile>21.3</Railroad_CO2_Emissions_g
_ton_mile>
      <Barge_CO2_Emissions_g_ton_mile>29.5</Barge_CO2_Emissions_g_ton_m
ile>
      <Pipeline_CO2_Emissions_g_ton_mile>0.0</Pipeline_CO2_Emissions_g_
ton_mile>
```

```
	</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_Cost is in 
dollars per thousand gallon-mile-->
	<Railroad_Class_I_Cost>0.12</Railroad_Class_I_Cost>
					</Railroad>
					<Truck>
						<!--Truck_Base_Cost is in dollars per 
thousand gallon-mile-->
	<Truck_Base_Cost>0.45</Truck_Base_Cost>
						<!--Truck_Interstate includes FAF 
Function Classes 1,11,12-->
	<Truck_Interstate_Weight>1.00</Truck_Interstate_Weight>
						<!--Truck_Principal_Arterial includes 
FAF Function Classes 2,14-->
	<Truck_Principal_Arterial_Weight>1.10</Truck_Principal_Arterial_W
eight>
						<!--Truck_Minor_Arterial includes FAF 
Function Classes 6,16-->
	<Truck_Minor_Arterial_Weight>1.20</Truck_Minor_Arterial_Weight>
						<!--Truck_Local includes all other FAF 
Functions Classes (excluding those above)-->
	<Truck_Local_Weight>1.30</Truck_Local_Weight>
					</Truck>
					<Barge>
						<!--Barge_Cost is in dollars per 
thousand gallon-mile-->
						<Barge_cost>0.05</Barge_cost>
					</Barge>
					<Pipeline>
						<!--Pipeline_cost is found from a 
table of Tarrifs based on origin-destination pair-->
						<Pipeline_cost>0.01</Pipeline_cost>
					</Pipeline>
				</Intermodal_Costs_Per_Gallon_Mile>
				<Intermodal_Transloading_Costs>
	<transloading_dollars_per_ton>40.00</transloading_dollars_per_ton
>  <!-- NOT CURRENTLY USED -->
```

```
	<transloading_dollars_per_thousand_gallons>40.00</transloading_do
llars_per_thousand_gallons>
				</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>
			<Feedstocks_to_Use>
				<Feedstock>
	<Base_Feedstock_Gdb>C:\AFTOT_Repository_2\trunk\Scenarios\common_
data\preprocessors.gdb</Base_Feedstock_Gdb>

					<!--Available Feedstocks: Corn Stover,
Wheat Straw, Canola, Harwood - General, Softwood - General,
Switchgrass, Sweet sorghum, Sugarcane Bagasse, Corn, Camelina,
Jatropha, Salicornia, Edible Tallow, Inedible Tallow, Lard, Poultry
Fat, Yellow Grease, Other Greases, Harwood - American Sycamore,
Harwood - Black Locust, Harwood - Eastern Cottonwood, Harwood -
Eucalyptus, Harwood - Hybrid Poplar, Harwood - Yellow Poplar, Softwood
- Monterey Pine, Softwood - General, Big Bluestem, Sericea Lespedeza,
Switchgrass, Tall Fescue, Agave, Sweet sorghum, Forage sorghum-->
					<Feedstock_type>Wheat
Straw</Feedstock_type>
					<!--Available Feedstock Sources: NASS,
FBEP, USDA-->
	<Feedstock_Data_source>NASS</Feedstock_Data_source>

					<!--Available Feedstock Units: Tonne,
Metric Ton, Short Ton, Long Ton, Weight Ton, Pound, Gross Ton, Cubic
Meter, US Gallon, US Quart, US Pint-->
					<Feedstock_unit>AFPAT</Feedstock_unit>
					<!--N/A, kg/m3, kg/L-->
	<Feedstock_density_unit>N/A</Feedstock_density_unit>
					<Feedstock_density>0</Feedstock_density>

	<Replacement_Percentage>100</Replacement_Percentage>
					<!--Time periods are weekly, 52 weeks in a
year, minimum Time_Period_Start = 1, maximum Time_Period_End = 52-->
					<Time_Period_Start>1</Time_Period_Start>
					<!--Time periods are weekly, 52 weeks in a
year, minimum Time_Period_Start = 1, maximum Time_Period_End = 52-->
					<Time_Period_End>1</Time_Period_End>
					<!--Available Primary Processing Types:
AFx, SRx (n-paraffins), SRx (n-/iso-paraffins), CRx, PRx, FTx, HEFA-->
	<Primary_Processing_Type>AFx</Primary_Processing_Type>
```

```
                            <!--Dilute acid pretreatment, Dilute alkali
pretreatment, Aq. Ammonia pretreatment, Conventional milling
technology, Advanced milling technology (low GHG), Advanced milling
technology (high GHG), N/A-->
                            <Secondary_Processing_Type>Dilute acid
pretreatment</Secondary_Processing_Type>
                            <!--Available Tertiary_Processing_Types:
Advanced fermentation to alkanes (low GHG), Advanced fermentation to
alkanes (mid GHG), Advanced fermentation to alkanes (high GHG),
Advanced fermentation to fatty acids (low GHG), Advanced fermentation
to fatty acids (mid GHG), Advanced fermentation to fatty acids (high
GHG), Advanced fermentation to TAGs (low GHG), Advanced fermentation
to TAGs (mid GHG), Advanced fermentation to TAGs (high GHG),
Conventional fermentation to ethanol (low GHG), Conventional
fermentation to ethanol (mid GHG), Conventional fermentation to
ethanol (high GHG), Conventional fermentation to butanol (low GHG),
Conventional fermentation to butanol (mid GHG), Conventional
fermentation to butanol (high GHG)-->
                            <Tertiary_Processing_Type>Conventional
fermentation to ethanol (mid GHG)</Tertiary_Processing_Type>
                      </Feedstock>
                </Feedstocks_to_Use>
                <!--Minimum production floor is metric tons per time
period per country/preprocessor. -->
     <Minimum_Production_Floor>35000</Minimum_Production_Floor>
           </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_Mate
rial_Travel_Distance_Miles>
                <!--Enter 'AFPAT' if these values should be derived
from AFPAT-->
     <Min_Biorefinery_Capacity_Kgal>30000</Min_Biorefinery_Capacity_Kg
al>
```

```
      <Max_Biorefinery_Capacity_Kgal>200000</Max_Biorefinery_Capacity_K
gal>
      <Biorefinery_Building_Fixed_Cost_Dollars>6000000</Biorefinery_Bui
lding_Fixed_Cost_Dollars>
                  <Currently_Funded_Biorefineries>
                        <Biorefinery>
                              <Name>Null</Name>
                              <Latitude>Null</Latitude>
                              <Longitude>Null</Longitude>
                              <Capacity_Gallons>Null</Capacity_Gallons>
                        </Biorefinery>
                  </Currently_Funded_Biorefineries>
                  <!-- and/or specify a layer -->
      <Currently_Funded_Biorefineries_Layer>C:\AFTOT_Repository_2\trunk
\Scenarios\common_data\biorefineries.gdb\BioenergyKDF_EthanolRefinerie
s</Currently_Funded_Biorefineries_Layer>
            </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>5</Max_Artificial_Link_Distan
ce_Miles>
      <Penalty_For_Not_Fulfilling_Depot_Demand>2000</Penalty_For_Not_Fu
lfilling_Depot_Demand>
            </Route_Optimization_Script>
            <!--Data reporting
            DATA REPORTING SCRIPT -->
            <Data_Reports_Script>
            </Data_Reports_Script>
      </scriptParameters>

</Scenario>
```