

Freight and Fuel Transportation Optimization Tool (FTOT)

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**Transportation
is a critical element
of freight and fuel
supply chains.**

- Intermodal Facility
- Crude Pipeline
- Product Pipeline
- Water

What is the best transportation solution to maximize supply chain delivery and minimize costs and/or emissions?

A photograph of a flooded street. Several cars are partially submerged in the water. In the background, there are trees, utility poles, and a building with a sign that says "CHIROPRACTOR". The image is used as a background for the text.

How does that solution change under different supply chain or network conditions?

<https://flickr.com/photos/97623182@N00/29762351987>

**FTOT can help
explore scenarios to
answer these questions.**

The Freight and Fuel Transportation Optimization Tool (FTOT)

volpeusdot.github.io/FTOT-Public

Key features:

Public/open-source scenario testing tool.

Optimizes supply chain routing and flows to maximize delivery and minimize cost.

Commodity/supply chain agnostic.

Multimodal: road, rail, waterway, pipeline.

Optional: Identify candidate processor sites based on optimal transportation patterns.

Results by commodity, mode, facility, scenario.

Users: governments, academia, private sector

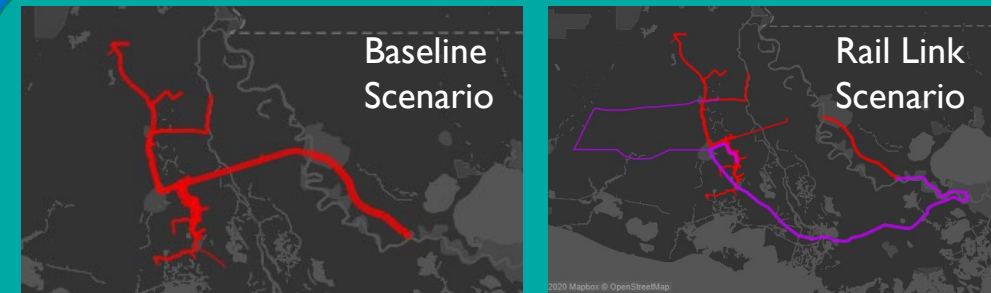
Analyze impacts of changes in:

Supply / demand

Multimodal infrastructure

Supply chain / industry patterns

Disruption and resilience



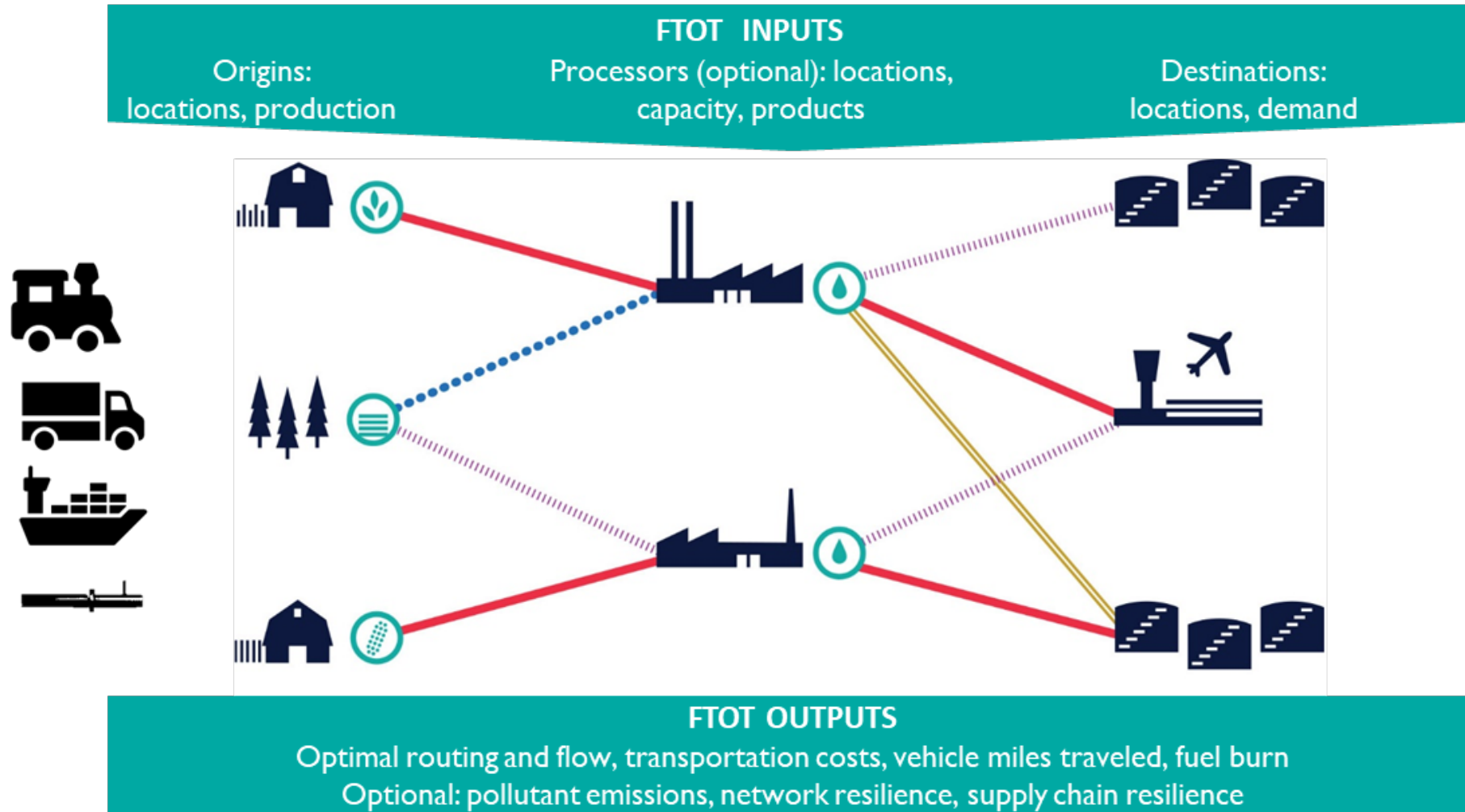
FTOT analysis: sugar supply chain in LA with rail link renewal

Enable transportation innovation:

Transportation infrastructure affects supply chain costs, resilience

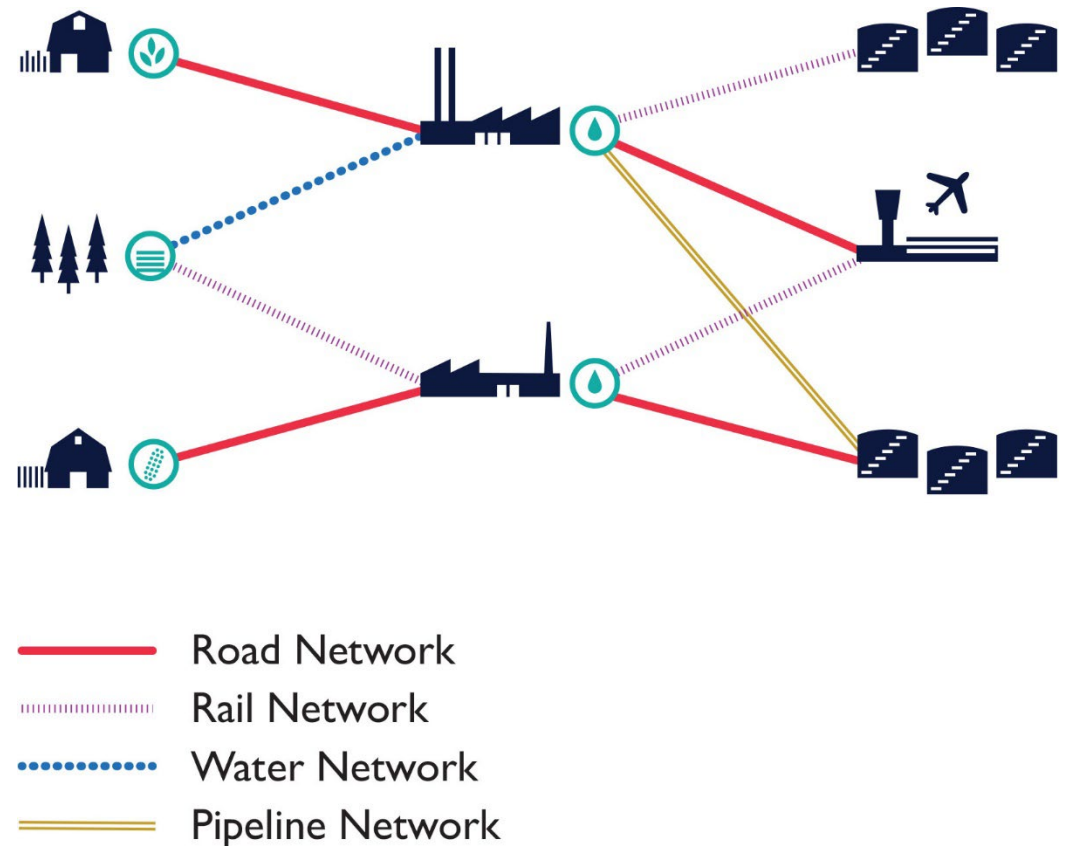
Current and future supply chains impact infrastructure needs

The Freight and Fuel Transportation Optimization Tool (FTOT)



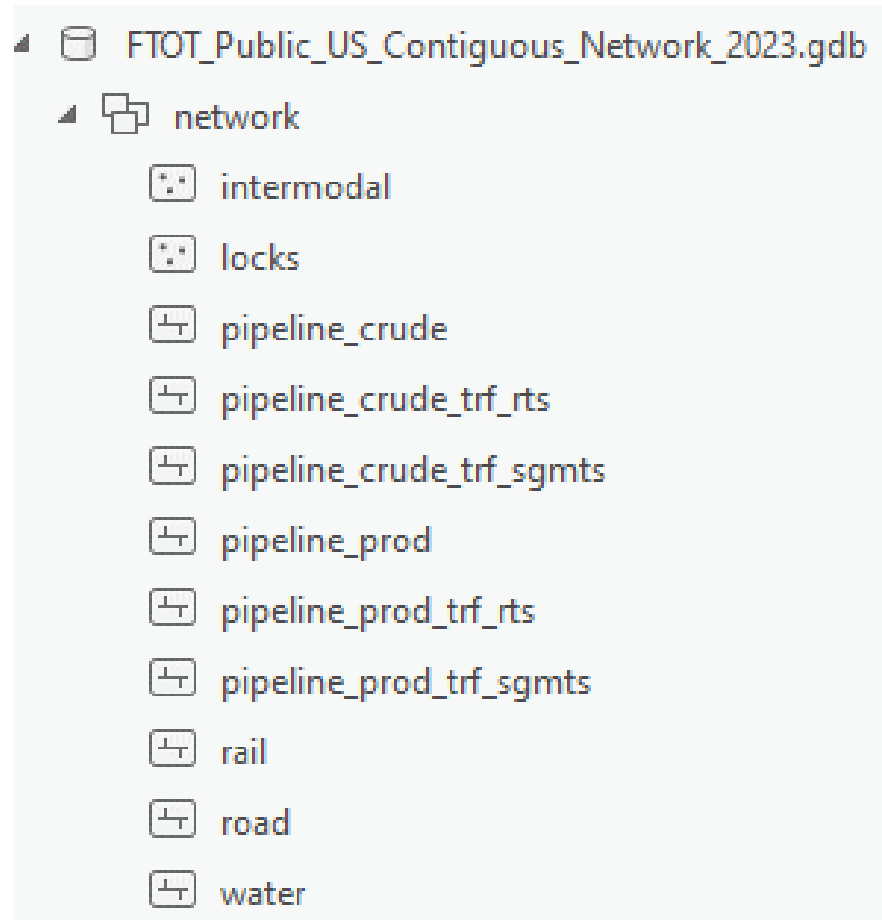
FTOT optimizes routing of supply chain scenarios over a multimodal transportation network.

- Transportation costs (per unit distance, tariff)
- Transloading costs
- Impedances/weightings
- Cost of CO₂ emissions (optional)
- Facility characteristics and output (efficiency, product slate, min/max size)
- Demand at destinations (adjusted by blend level restrictions if needed)
- Modal flow capacity



Optimizing flow and routing of raw materials (e.g., wood, agricultural feedstocks) to processing locations to produce fuel, which is sent to destination to fulfill demand.

FTOT Network Format

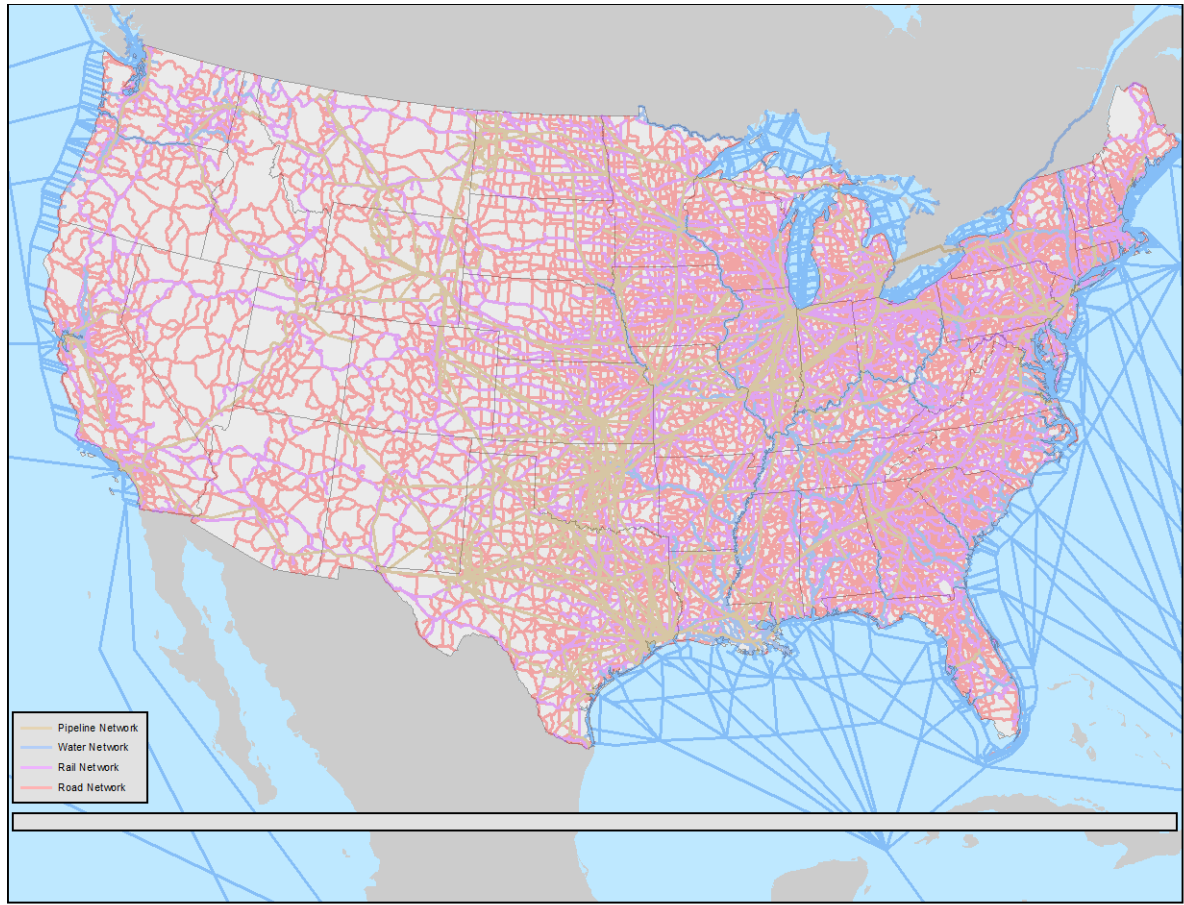


Aligned with Generalized Modeling Network Specification (GMNS)

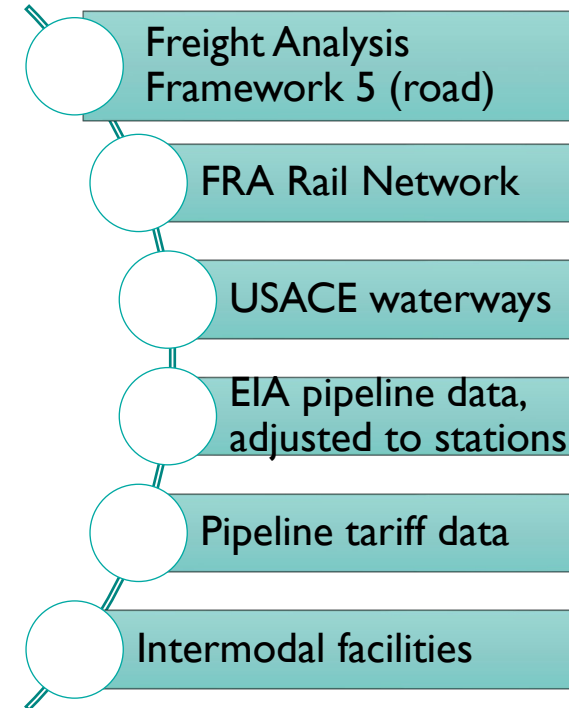
- Generalized field names
- Flexible distance units and coordinate system
- Many fields are optional to enhance flexibility for alternative networks (determines which optimization constraints are used)
- Enables local/international networks

GMNS: <https://github.com/zephyr-data-specs/GMNS>

FTOT Default Multimodal Network



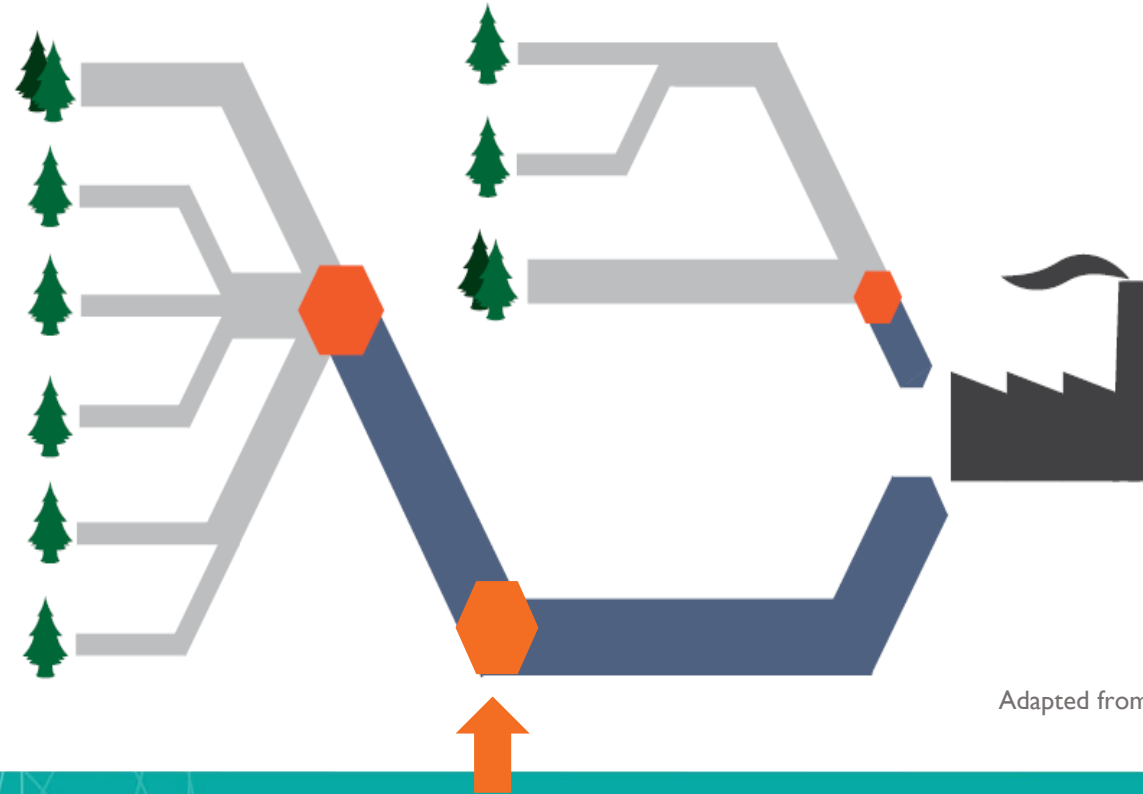
Default Network Components



Notes:

- FAF 4 is used for capacity constrained scenarios.
- North American network available with Canadian and Mexican network elements.
- User can use custom networks.

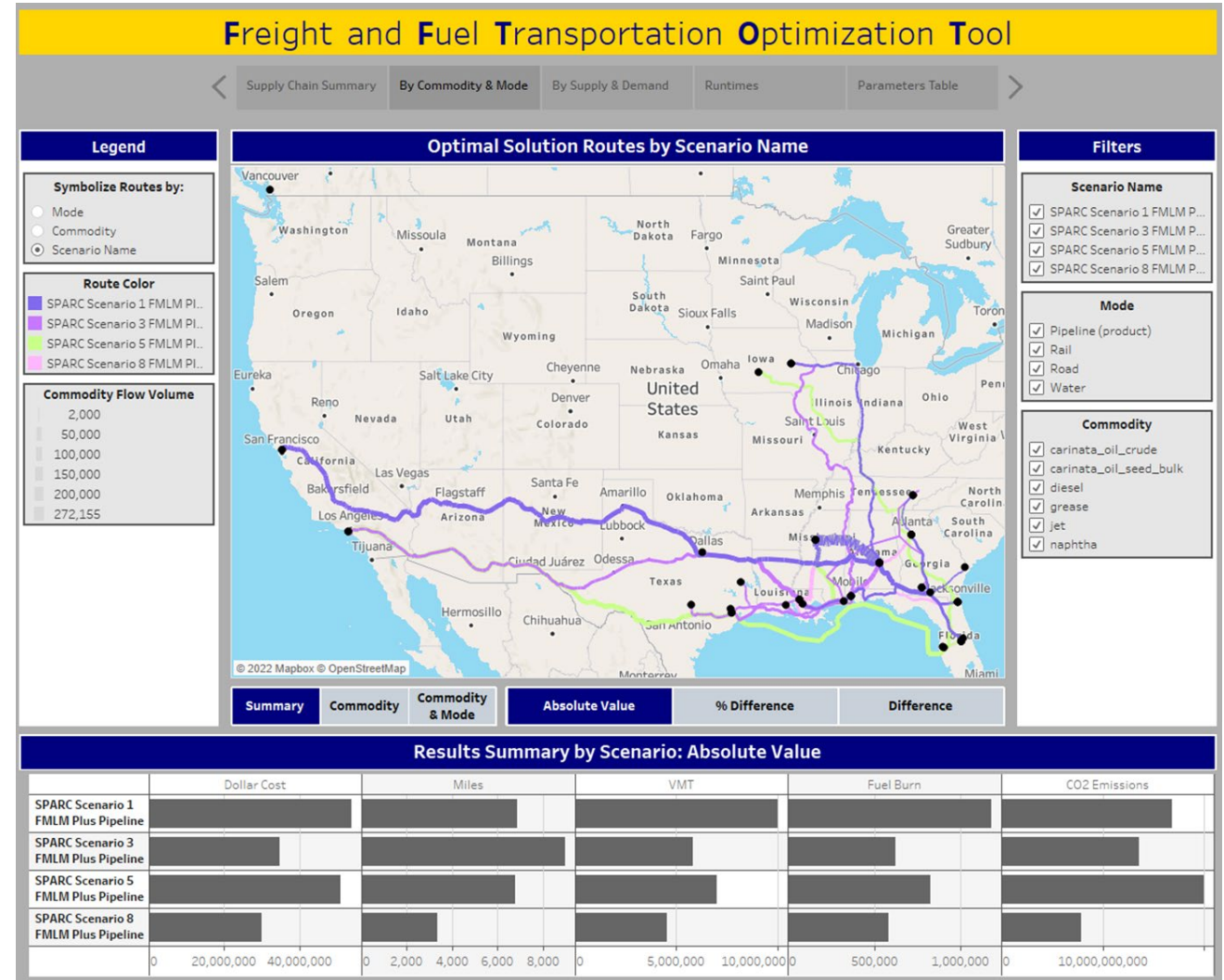
FTOT can help identify candidate facility locations based on optimized transportation patterns.



Adapted from graphic by Dane Camenzind, WSU, used with permission.

Visualizing Results

- Maps
 - Candidates and facilities used
 - Optimal routing and mode choice
- Tableau dashboards
 - Single scenario
 - Cost, VMT, fuel burn, emissions
 - Filter by mode or commodity
 - Comparison of scenario variations



FTOT also enables resilience analyses

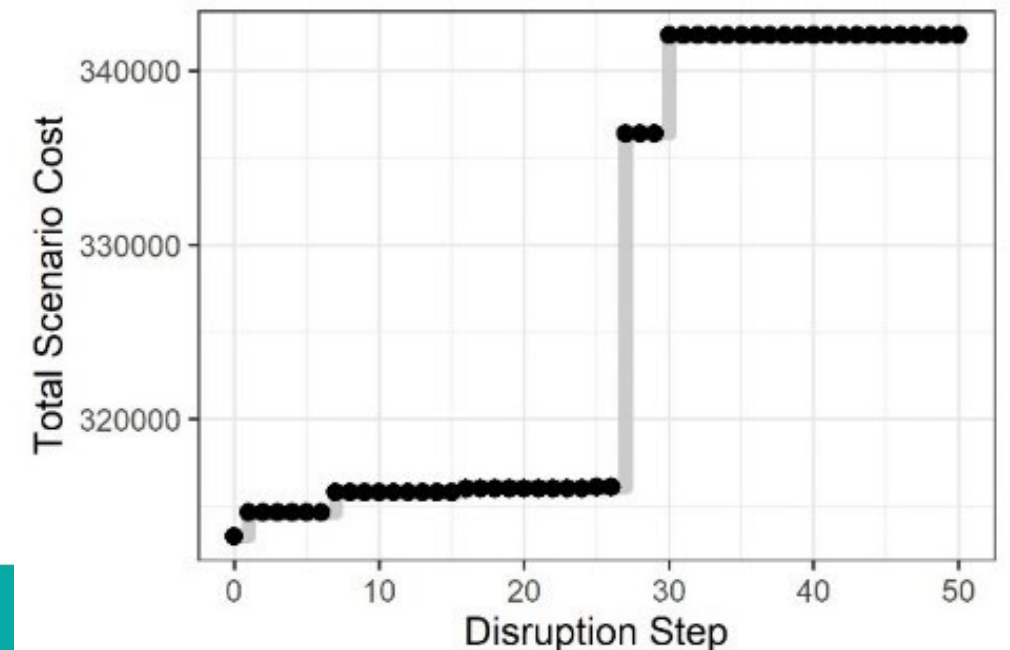
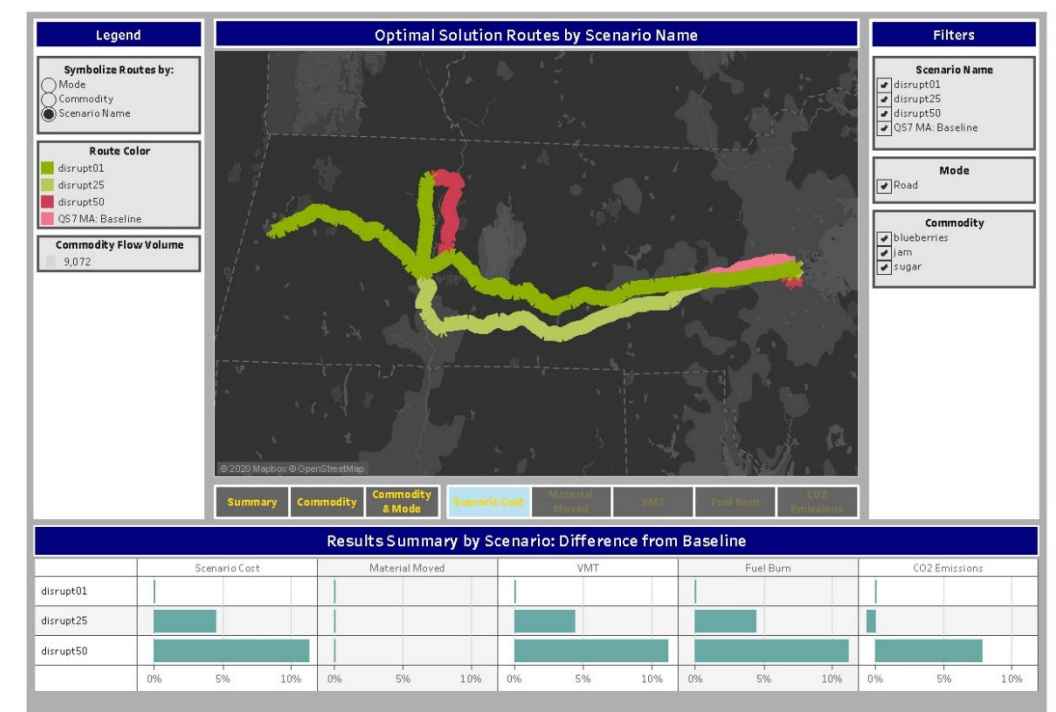
Manual network or supply chain modifications.

Link rank and removal process.

- Rank optimal solution roadway links by 'importance.'
- Sequentially remove links and reanalyze.
- Change in cost indicates effect on scenario performance.
- Highlights stability of solution.
- Can help home in on key links.

Supply chain resilience testing module.

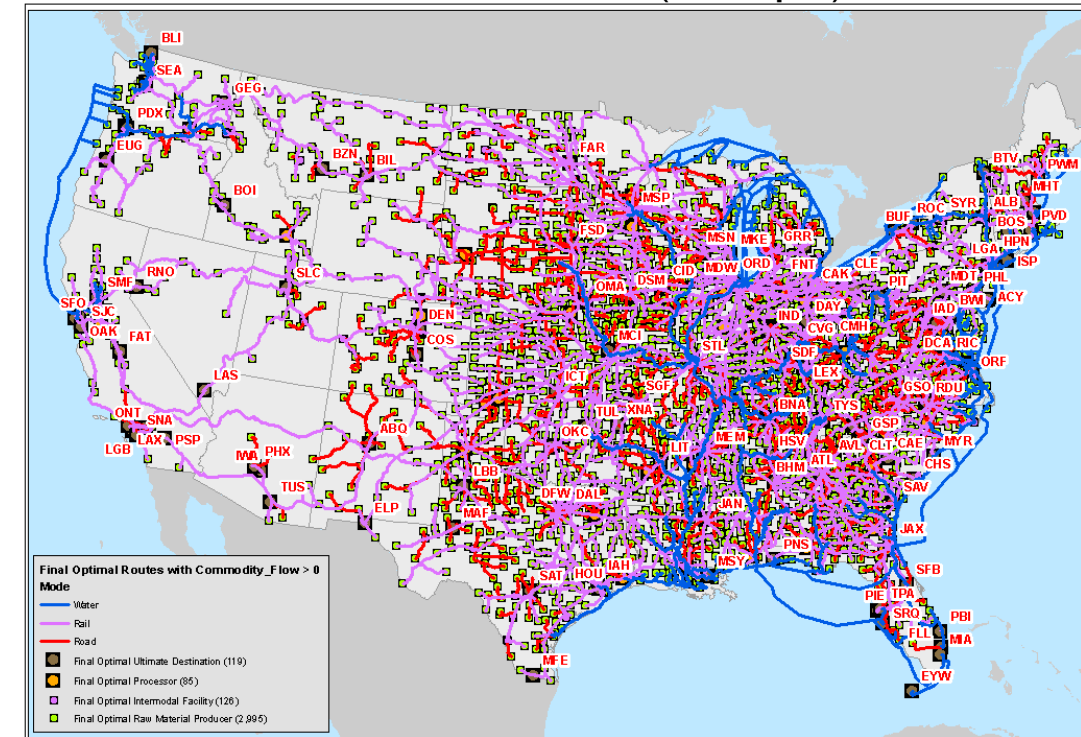
- Developed with Lee et al. at WSU.
- Leverages hazard scenarios and infrastructure fragility curves.
- Estimates supply chain resilience based on delivery.



Ongoing Work

- Future Agricultural and Energy Supply Chains – in support of FAA Office of Environment and Energy (with ASCENT (<https://ascent.aero/>))
 - Southeast – Tennessee region case study of wood-based biofuel supply with University of TN, Knoxville.
 - Hawai'i – Exploration of oilseed supply chains and interisland transport for co-processing with University of HI.
 - Colombia – Baseline lipid-to-biodiesel and future SAF supply chains with Washington State University (WSU) and Colombian partners.
 - Dominican Republic – SAF scenario development with WSU
 - Canada / U.S. cross-border SAF supply chains with WSU
- Other Fuels / Energy Supply Chain Analyses
 - Maritime fuels supply chain analysis – Ports of Seattle and Corpus Christi case studies of waste-based biofuel supply with NREL in support of DOE Bioenergy Technologies Office.
- Future Agricultural Supply Chain Analysis
 - Hemp supply chain analysis – Western regional case study in support of Oregon State University Global Hemp Innovation Center.
- Hazmat Incident Risk (Social, Environmental Impacts)
 - Developing risk-based optimization approach in support of PHMSA.

FTOT Results (Example)

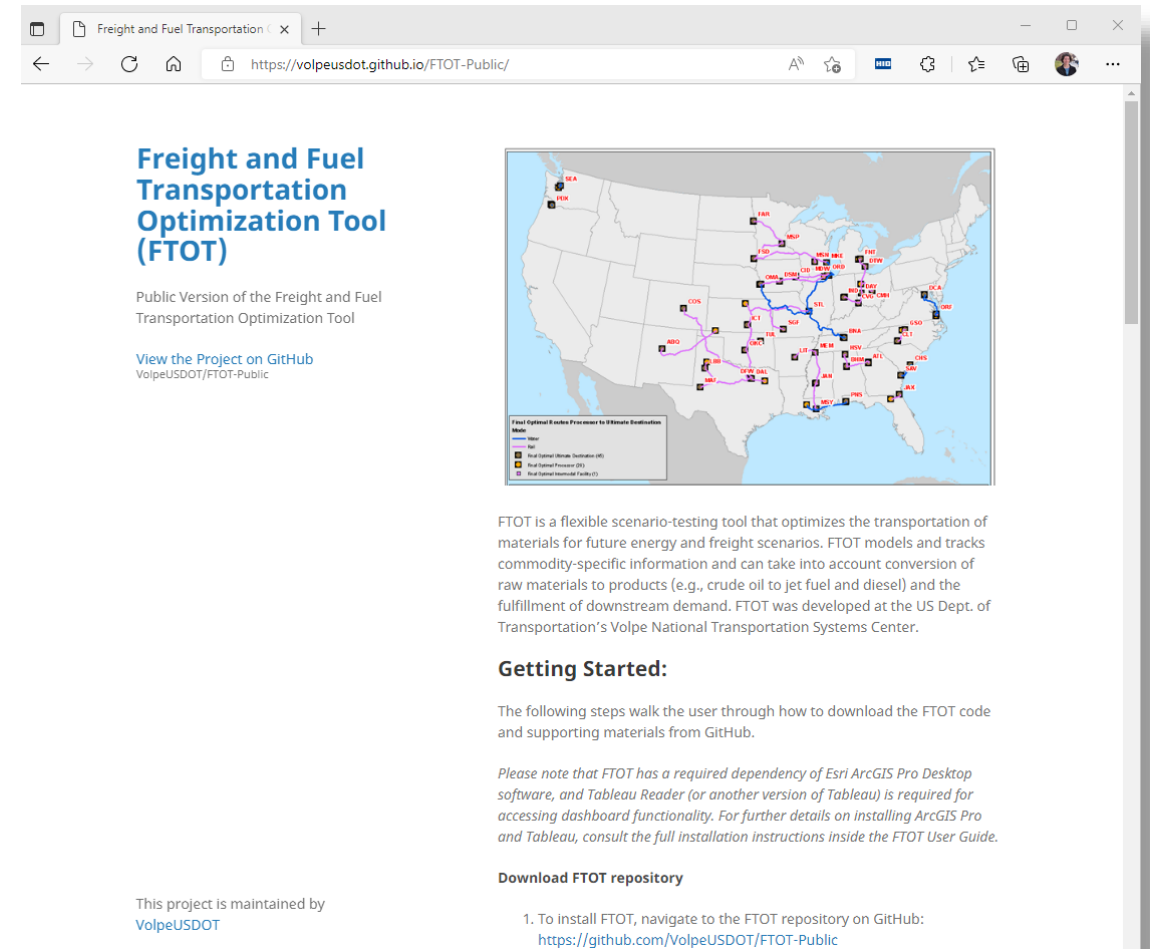


Source: USDOT Volpe Center – See also: <https://doi.org/10.1002/bbb.1951>

FTOT is free and publicly available

volpeusdot.github.io/FTOT-Public

- Includes full documentation and “Quick Start” scenarios, default datasets, default networks.
- Updated versions released quarterly.
- Current development sponsored by FAA.
- Issues / bugs / requests can be raised on GitHub site or through FTOT-Team@dot.gov.
- Training / informational video library is always expanding.
- We welcome feedback and suggestions, additional projects, collaborations.



Reference Scenario 1: FTOT Inputs

- A hypothetical New England scenario with blueberries and apples

- Raw Material Producers (RMPs) – commodity supply

- Facility locations
- Commodity amounts
- [Optional] Facility access costs

- Processors – commodity conversion

- Facility locations
- Commodity conversion ratios
- [Optional] Facility capacities
- [Optional] Facility build costs

- Destinations – commodity demand

- Facility locations
- Commodity demand
- [Optional] Commodity- and facility-specific fulfillment incentives

commodity supply

facility_name	facility_type	commodity	value	units	phase_of_matter	io
rmp_25003	raw_material_producer	blueberries	100	tons	solid	o

facility_name	facility_type	commodity	value	units	phase_of_matter	io	max_capacity	
rmp_25003	proc_25015	processor	blueberries	100	tons	solid	i	
	proc_25015	processor	sugar	100	tons	solid	i	
	proc_25015	processor	total		tons	solid	i	150
	proc_25015	processor	blueberry_jam	100	tons	solid	o	
	proc_33011	processor	apples	100	tons	solid	i	
	proc_33011	processor	sugar	100	tons	solid	i	
	proc_33011	processor	apple_juice	75	tons	solid	o	
	proc_33011	processor	apple_butter	75	tons	solid	o	75

facility_name	facility_type	commodity	value	units	phase_of_matter	io	
proc_25009	proc_dest_25025	ultimate_destination	blueberry_jam	100	tons	solid	i
proc_25009	proc_dest_25025	ultimate_destination	apple_juice	75	tons	solid	i
	dest_25025	ultimate_destination	canned_apple_butter	75	tons	solid	i

Scenario Name: RS1 - Multi-Commodity Supply Chain -- Date: Jun 13, 2025

fulfillment incentives

Reference Scenario 1: Running a Scenario

- FTOT is run through an executable batch file
- Logging messages are printed in the command prompt window in real time as the scenario runs
- Log files are written for each step of the FTOT run

```
s_log_2025_06_13_11-05-30.log
File Edit View

06-13 11:05:30.671 INFO =====
06-13 11:05:30.672 INFO ===== FTOT RUN STARTING. Run Option = S =====
06-13 11:05:30.673 INFO =====
06-13 11:05:30.745 DEBUG start: load_scenario_config_file
06-13 11:05:30.773 DEBUG validate XML scenario against XML schema
06-13 11:05:30.774 DEBUG initialize scenario object
06-13 11:05:30.775 DEBUG validate schema version is correct
06-13 11:05:30.776 DEBUG Replace any commas in the scenario name with dashes to accomodate CSV files.
06-13 11:05:30.785 DEBUG test: setting the default units with pint
06-13 11:05:30.790 DEBUG PASS: setting the default units with pint
06-13 11:05:30.792 DEBUG test: setting the vehicle loads for solid phase of matter with pint
06-13 11:05:30.796 DEBUG test: setting the vehicle loads for liquid phase of matter with pint
06-13 11:05:30.800 DEBUG PASS: setting the vehicle loads with pint passed
06-13 11:05:30.801 DEBUG test: setting the vehicle fuel efficiencies with pint
06-13 11:05:30.802 DEBUG PASS: setting the vehicle fuel efficiencies with pint passed
06-13 11:05:30.802 DEBUG test: setting the vehicle emission factors with pint
06-13 11:05:30.808 DEBUG reading in detailed emissions data
06-13 11:05:30.810 DEBUG PASS: setting the vehicle emission factors with pint passed
06-13 11:05:30.811 DEBUG test: setting the base costs for truck with pint
06-13 11:05:30.811 DEBUG PASS: setting the base costs for truck with pint passed
06-13 11:05:30.811 DEBUG test: setting the base costs for rail with pint
```

```
Command Prompt

06-13 11:05:30 INFO =====
06-13 11:05:30 INFO ===== FTOT RUN STARTING. Run Option = S =====
06-13 11:05:30 INFO =====
06-13 11:05:35 INFO Scenario Name: RS1 - Multi-Commodity Supply Chain
06-13 11:05:35 INFO Scenario Start Date/Time: 2025-06-13 11:05:35.875714
06-13 11:05:35 INFO start: create_main_db
06-13 11:05:35 INFO start: create_main_gdb
06-13 11:05:36 INFO start: copy base network to main.gdb
06-13 11:05:40 INFO The scenario projection utilized by the base_network_gdb is USA_Contiguous_Lambert_Conformal_Con
ic, WKID 102004 with units of meter.
06-13 11:05:40 INFO start: validating network geodatabase
06-13 11:05:51 INFO Disruption file not specified; no disruption to the network will be applied
06-13 11:05:51 INFO start: set_intermodal_links
06-13 11:06:00 INFO ===== FTOT RUN FINISHED: S =====
06-13 11:06:00 INFO ===== Total Runtime (HMS): 00:00:30 =====
06-13 11:06:00 INFO =====
06-13 11:06:17 INFO =====
06-13 11:06:17 INFO ===== FTOT RUN STARTING. Run Option = F =====
06-13 11:06:17 INFO =====
06-13 11:06:24 INFO start: gis_clean_fc
06-13 11:06:25 INFO finished: gis_clean_fc: Runtime (HMS): 00:00:00
06-13 11:06:25 INFO start: gis_populate_fc
06-13 11:06:25 INFO start: gis_ultimate_destinations_setup_fc
06-13 11:06:39 INFO Number of Destinations removed due to lack of commodity data: 3108
06-13 11:06:39 INFO Number of Destinations: 1
06-13 11:06:39 INFO finished: gis_ultimate_destinations_setup_fc: Runtime (HMS): 00:00:14
06-13 11:06:39 INFO start: gis_rmp_setup_fc
06-13 11:06:58 INFO Number of RMPs removed due to lack of commodity data: 3106
06-13 11:06:58 INFO Number of RMPs: 3
06-13 11:06:58 INFO finished: gis_rmp_setup_fc: Runtime (HMS): 00:00:19
```


Reference Scenario 1: FTOT Outputs

- Optimal routes as static maps, geodatabase, ArcGIS Map Template file, routes report
- Facility utilizations and optimal vs. non-optimal facilities
- Output metrics include transportation costs, VMT, emissions by commodity, mode, and scenario

Freight and Fuel Transportation Optimization Tool					Size & Utilization of Facilities	
Supply Chain Summa... By Commodity & Mode By Supply & Demand Cost Breakdown Routes Runtimes Parameters Table					Map showing facility locations and utilization in the New England area.	
Commodity	Utilization	Transport cost (\$)	VMT	CO ₂ emissions (g)		
Blueberries	75%	565.41	112.18	150,137		
Apples	100%	393.83	78.14	104,577		
Sugar	87%	2,311.80	411.11	550,198		
Blueberry Jam	75%	1,367.65	271.36	363,163		
Apple Juice	100%	783.67	155.49	208,093		
Apple Butter	100%	694.77	137.85	184,487		
Canned Apple Butter	100%	220.93	43.83	58,664		

Building a custom FTOT network

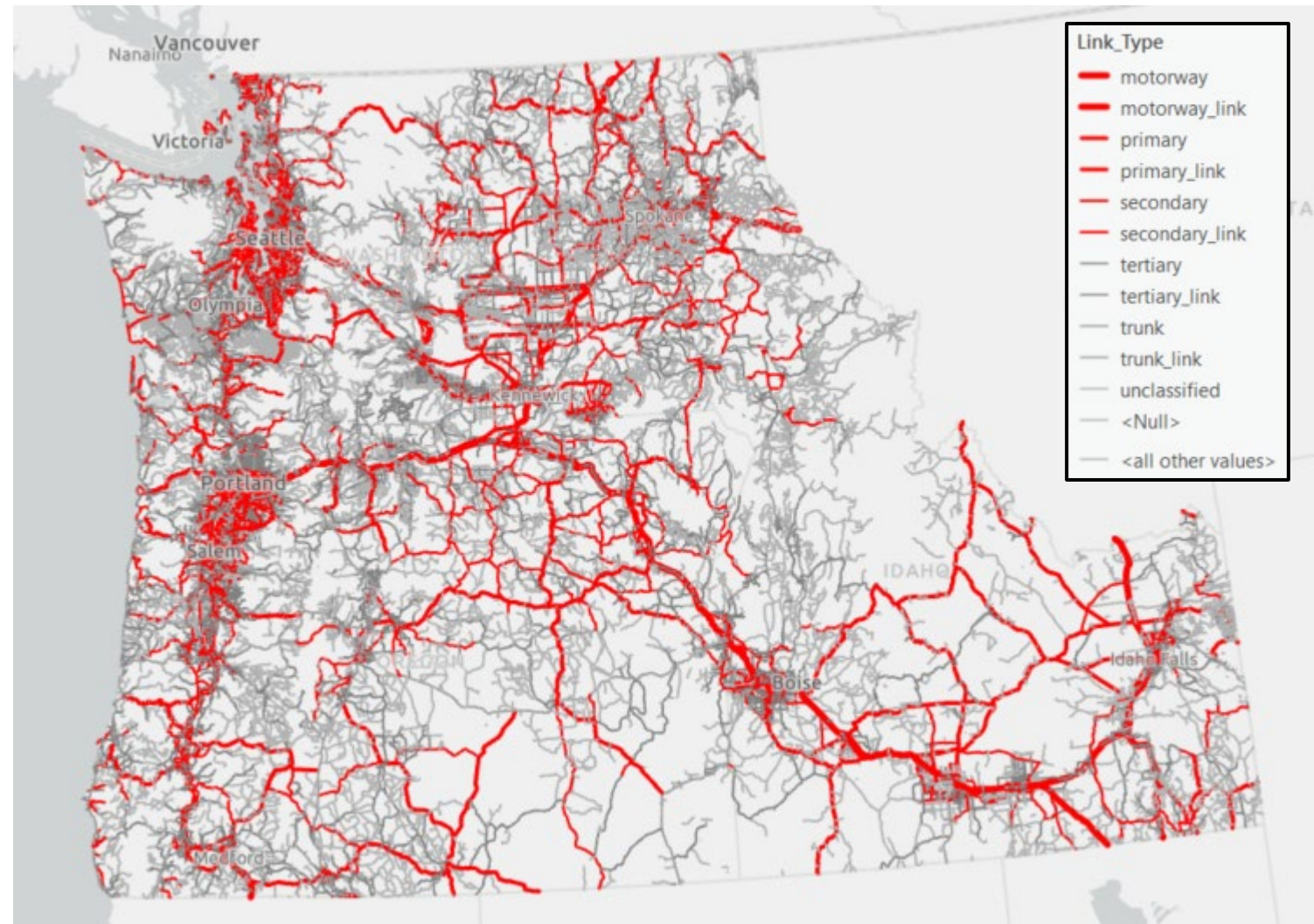
- Connected and routable geospatial network
- Network components
 - Modal networks (e.g., road, rail, water, pipeline)
 - Intermodal connections to switch among modes (if analyzing more than just road)
 - [Optional] Modal network attributes for link type, direction, urban/rural, capacity, etc.
 - [Optional] Network impedances to encourage specific routing

Resources

- [FTOT Minimum Data Requirements checklist](#) for scenario development
- [“Preparing and Using Your Custom FTOT Network”](#) tutorial video
- Network Validation Helper Tool can verify a custom network is constructed according to the FTOT network schema

Example: Pacific Northwest Road Network

- Default U.S. FTOT network did not have enough granularity for rural areas in PNW.
- Leveraged [OpenStreetMap](#) (OSM) and created scripts to use OSM API (via [OSMNx](#) Python module) to pull data into FTOT format.
- OSM network contains approximately 189,000 network segments representing motorways, trunks, primary, secondary, tertiary, and unclassified roads.
- Used FTOT tools/scripts to ensure connectivity and add other modes.



Creating SAF Scenarios

FTOT Scenario Setup Template

Freight and Fuel Transportation Optimization Tool (FTOT) Scenario Input Template [BETA Version]

The Freight and Fuel Transportation Optimization Tool (FTOT) is a flexible scenario-testing tool that optimizes the transportation of materials for future energy and freight scenarios. FTOT was developed at the U.S. Department of Transportation's Volpe National Transportation Systems Center.

The **FTOT Scenario Input Template** is a user-friendly helper tool to assist FTOT users in setting up new scenarios. Each copy of this template should be updated to reflect input data for a single scenario. When complete, the XLSX template can be used as input to the "XLSX Conversion" tool in the FTOT Tools suite, which in turn will output a new scenario directory with (1) the facility-commodity CSV files representing the scenario's supply chain, (2) the scenario XML file with all scenario settings, and (3) the batch file needed to execute the FTOT program.

Note: The template is currently designed for simple supply chains and does not create optional input files needed for more advanced scenarios, such as scenarios using pipelines, disruption scenarios, or scenarios with facility production schedules. The supplementary CSV files for those advanced scenarios should be created outside of this template. The template also does not create the facilities GIS data required as input by FTOT. Refer to the FTOT documentation and quick start/reference scenarios for more guidance.

Instructions for the Scenario Input Template

1. Create a copy of this template file. Give it a descriptive filename.

Instructions

Configuration

Commodities and Processes

Facilities and Amounts

Reference Tables

County locations or other user-

of the table to add or remove

of output commodity, add the

Resulting output quantity to the **Output Amount** column and the appropriate units to the **Output Units** column. Considered together, the input and output amounts and units define the overall process

Commodities

Name	Phase	Required for use w/ non-existing facility	Max Transport Distance
blueberries	solid		
sugar	solid		
apples	solid		
blueberry_jam	solid		
apple_juice	solid		
apple_butter	solid		
canned_apple_butter	solid		

Processes

Existing facilities:

Process name: **make_jam**

Inputs	Input Amount	Input Units	Outputs	Output Amount	Output Units
blueberries	100	tons	blueberry_jam	100	tons
sugar	100	tons			

Process name: **use_apples**

Existing facilities:

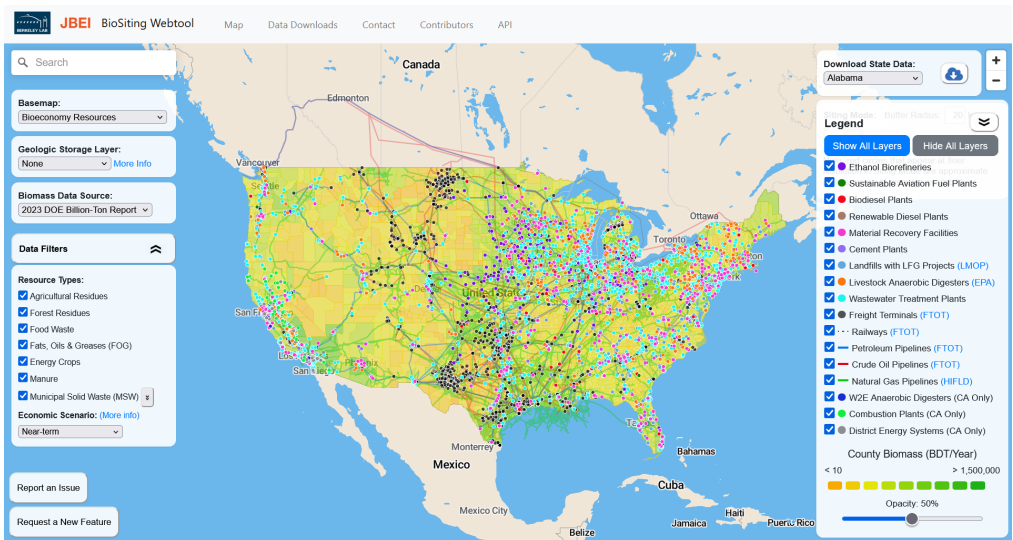
Inputs	Input Amount	Input Units	Outputs	Output Amount	Output Units
apples	100	tons	apple_juice	75	tons
sugar	100	tons	apple_butter	75	tons

Process name: **can_apples**

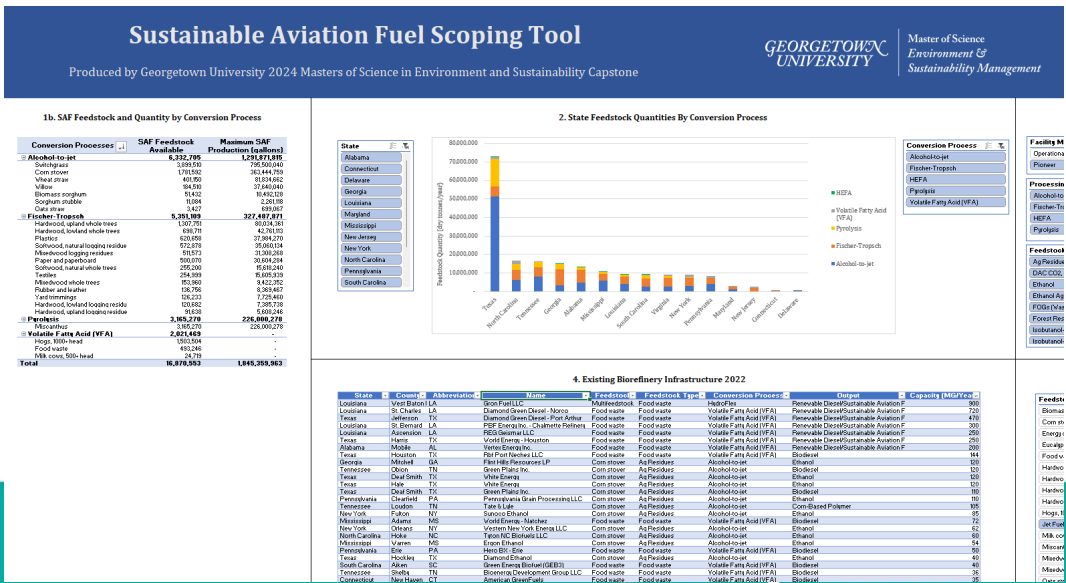
Existing facilities:

Inputs	Input Amount	Input Units	Outputs	Output Amount	Output Units
apple_butter	100	tons	canned_apple_bs	100	tons

JBEI BioSiting Webtool: biositing.jbei.org/national



Georgetown SAF Scoping Tool

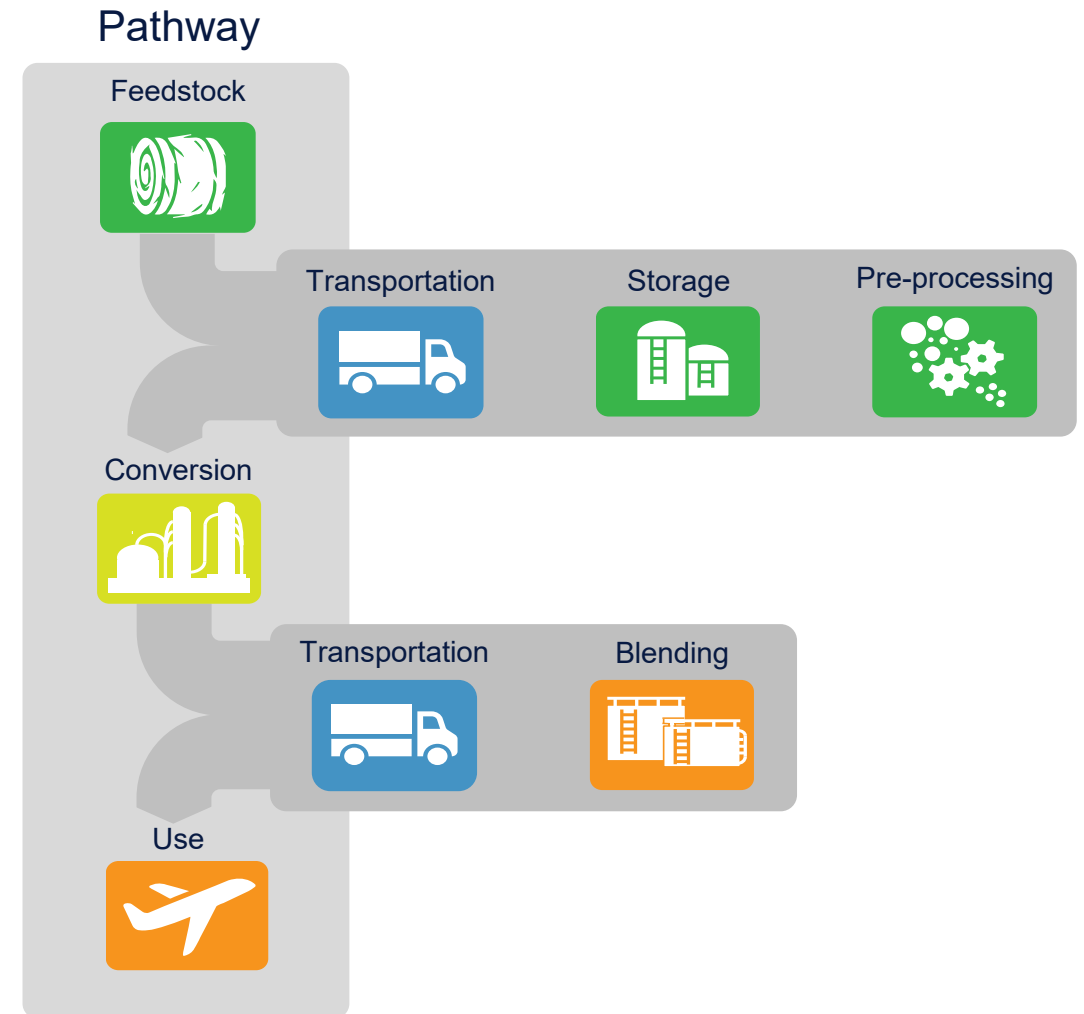


Website: volpeusdot.github.io/FTOT-Public. Email us at FTOT-Team@dot.gov.

New in FTOT 2025.1: SAF Scenario Setup Template

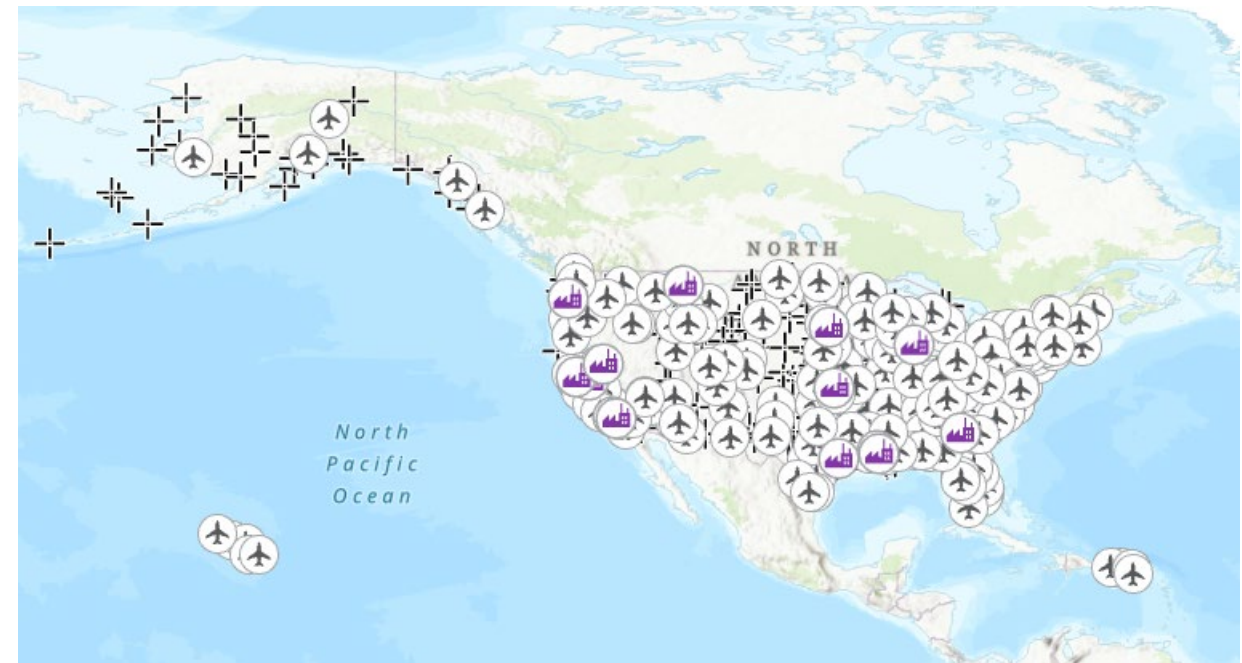
What is it?

- User-friendly Excel-based template for creating regional sustainable aviation fuel (SAF) supply chain scenarios
- Follows a generalized supply chain structure for creating SAF
- Queries publicly available or for public use data sources
- **Goal:** Enable users to quickly build a high-level analysis of feedstock availability, conversion needs, and fuel demand for specific SAF pathways



SAF Template Data Sources

- **Feedstock Data:** [JBEI BioSiting Tool](#) / [DOE Billion-Ton Report](#) – quantities and locations
 - County-level quantities by feedstock classes
 - Queries JBEI API on the back end
- **SAF TEAs:** [SAF Rules of Thumb](#)
- **Existing SAF Facilities:** [JBEI BioSiting Tool](#) / [BBI International](#) – RD / SAF plant locations
- **Blending Facilities:** [EIA](#) – petroleum product terminal locations
- **Airport Fuel Demand:** Airlines for America (A4A)



SAF facilities geodatabase

References

JBEI BioSiting Tool: biositing.jbei.org/national

DOE Billion-Ton Report: https://www.energy.gov/sites/default/files/2024-03/beto-2023-billion-ton-report_2.pdf

SAF Rules of Thumb: https://www.icao.int/environmental-protection/Pages/SAF_RULESOFTHUMB.aspx

BBI International: <https://issuu.com/bbiinternational/docs/biodieselmmap-2023>

EIA: <https://atlas.eia.gov/datasets/eia::petroleum-product-terminals-1/about>

Currently Available Options in SAF Template

Filter	Values
Market Scenario	Near-term, Mature-market medium, Mature-market low, Mature-market high, Emerging
Feedstock Categories	Ag processing waste, Agricultural residues, Fire reduction thinnings, FOG, Forest processing waste, Intermediate oilseeds, Logging residues, Other forest waste, Other solid waste, Paper, Plastic, Small-diameter trees
SAF Pathways	Fischer-Tropsch, HEFA, Pyrolysis
Plant Type	Nth, Pioneer
Blending	1,384 facilities filtered by state and city
Airports	112 airports filtered by state, city, FAA hub size

User Workflow



Instructions for the FTOT SAF Scenario Setup Template

STEP 1. Use filters

Note: Filters (c) and (d) are in

a) Select

Single select

Billion Ton

Emerging

Mature-n

Mature-r

Mature-n

Near-term

Report for sc

DOF BETO 20

Error: Select

4.

STEP 2.

Note: Filters

11

1

site: vo

~~It the Excel based SAE Scenario Setup~~

facility_name	facility_type	commodity	value	units	phase_of_matter	id
rmf_16055	raw_material_producer	FOG	2768.99999	tonnes	solid	1
rmf_16049	raw_material_producer	FOG	150.0000004	tonnes	solid	2
rmf_16069	raw_material_producer	FOG	532.9999984	tonnes	solid	3
rmf_16085	raw_material_producer	FOG	140	tonnes	solid	4
rmf_16023	raw_material_producer	FOG	10	tonnes	solid	5
rmf_16027	raw_material_producer	FOG	4132.999969	tonnes	solid	6
rmf_16001	raw_material_producer	FOG	10589.00002	tonnes	solid	7
rmf_16019	raw_material_producer	FOG	1642.999995	tonnes	solid	8

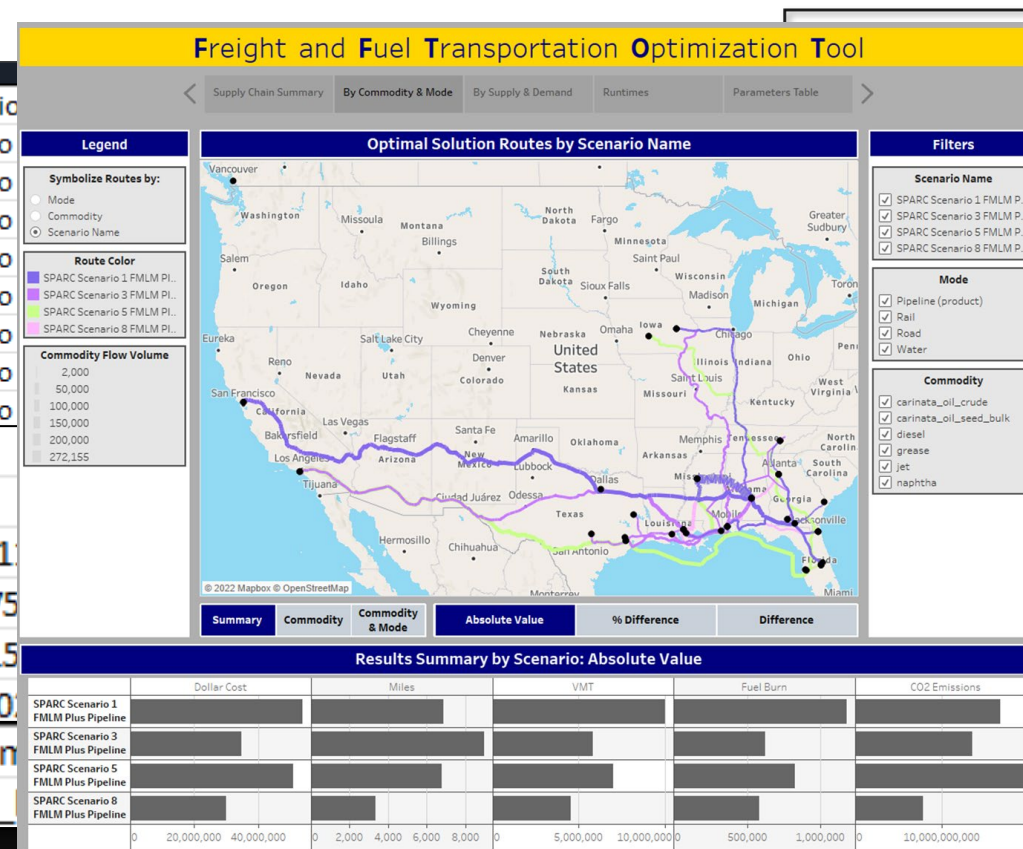
facility_name	facility_type	commodity	value
cand_HEFA_FOG	processor	FOG	
cand_HEFA_FOG	processor	SAF	127.21
cand_HEFA_FOG	processor	minsize	57107
cand_HEFA_FOG	processor	maxsize	11421
cand_HEFA_FOG	processor	cost formula	28.220

and HEFA F	facility_name	facility_type	com
ing	airport sea	ultimate destination	fuel

a) When prompted, drag the template file from your File Explorer into the Command Prompt.

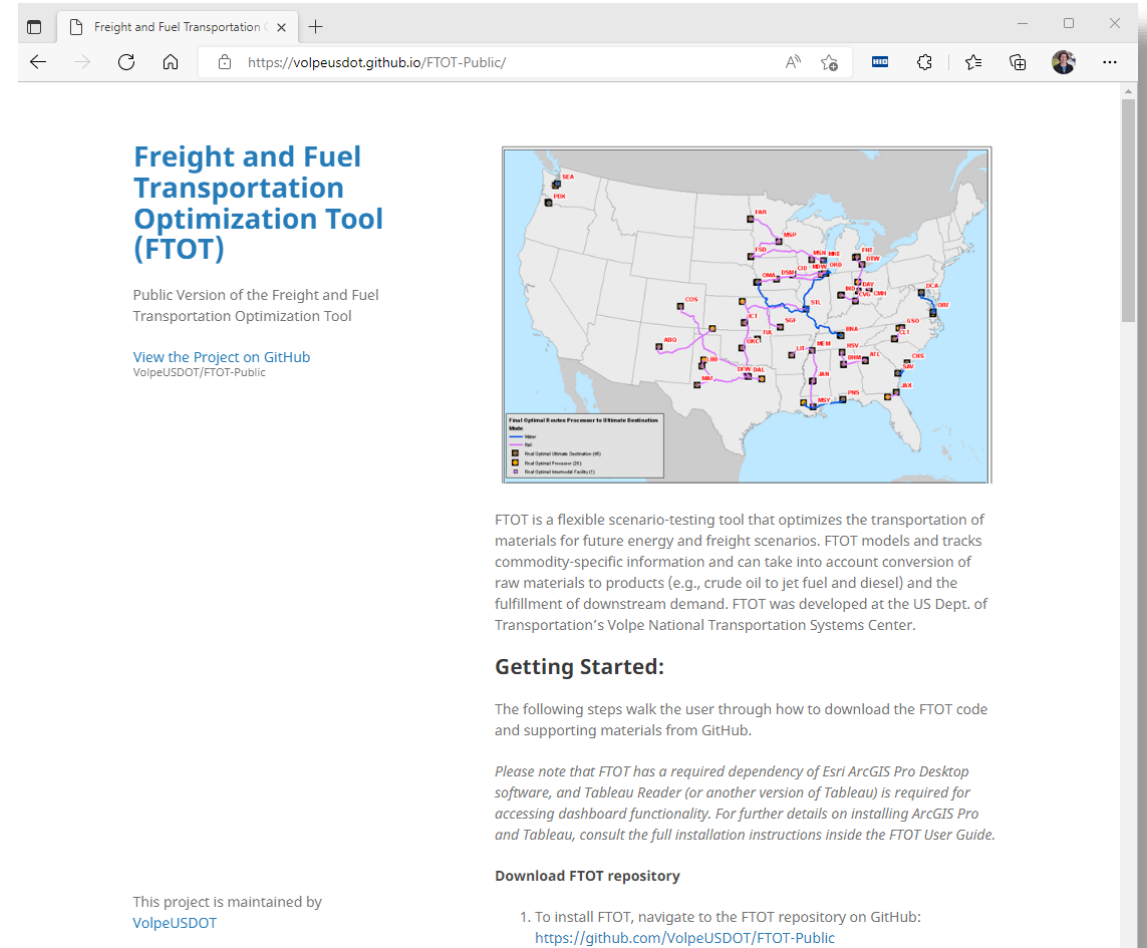
b) Specify a folder file path to put the FTOT input files that will be generated by the tool.

5. Run the FTOT scenario using the batch file created.



Upcoming FTOT Training

- **FREE 2 hour virtual training: July 29, 2025, 1-3 pm EDT/10 am-12 pm PDT**
- CAAFI will send out an invitation to register.
- We will provide optional prework to enable following on your own computer.
- Additional opportunities:
 - Likely virtual training in the fall
 - In-person training with rescheduled CAAFI Biennial General Meeting (date/location still TBD)
- Please contact us with questions via FTOT-Team@dot.gov.



The screenshot shows the GitHub repository page for the Freight and Fuel Transportation Optimization Tool (FTOT). The page title is "Freight and Fuel Transportation Optimization Tool (FTOT)". Below the title, it says "Public Version of the Freight and Fuel Transportation Optimization Tool" and "View the Project on GitHub VolpeUSDOT/FTOT-Public". There is a map of the United States showing various transportation routes and nodes. Below the map, there is a legend titled "Freight Optimization Scenario Parameters to Ultimate Destination". The legend includes: "Route", "Water", "Air", "Rail", "Road", "Sea", "Port of Origin (Source Distribution (M))", "Port of Destination (Destination (M))", "Port of Origin (Source Distribution (M))", and "Port of Destination (Destination (M))". Below the legend, there is a paragraph describing FTOT as a flexible scenario-testing tool that optimizes the transportation of materials for future energy and freight scenarios. It mentions that FTOT models and tracks commodity-specific information and can take into account conversion of raw materials to products (e.g., crude oil to jet fuel and diesel) and the fulfillment of downstream demand. It also states that FTOT was developed at the US Dept. of Transportation's Volpe National Transportation Systems Center. Below this paragraph, there is a section titled "Getting Started:" which provides instructions on how to download the FTOT code and supporting materials from GitHub. It includes a note that FTOT has a required dependency of Esri ArcGIS Pro Desktop software, and Tableau Reader (or another version of Tableau) is required for accessing dashboard functionality. It also mentions that for further details on installing ArcGIS Pro and Tableau, users should consult the full installation instructions inside the FTOT User Guide. Below the "Getting Started:" section, there is a section titled "Download FTOT repository" which provides a list of steps to install FTOT, including navigating to the FTOT repository on GitHub and cloning the repository.

Freight and Fuel Transportation Optimization Tool (FTOT)

Public Version of the Freight and Fuel Transportation Optimization Tool

[View the Project on GitHub](#)
VolpeUSDOT/FTOT-Public

FTOT is a flexible scenario-testing tool that optimizes the transportation of materials for future energy and freight scenarios. FTOT models and tracks commodity-specific information and can take into account conversion of raw materials to products (e.g., crude oil to jet fuel and diesel) and the fulfillment of downstream demand. FTOT was developed at the US Dept. of Transportation's Volpe National Transportation Systems Center.

Getting Started:

The following steps walk the user through how to download the FTOT code and supporting materials from GitHub.

Please note that FTOT has a required dependency of Esri ArcGIS Pro Desktop software, and Tableau Reader (or another version of Tableau) is required for accessing dashboard functionality. For further details on installing ArcGIS Pro and Tableau, consult the full installation instructions inside the FTOT User Guide.

Download FTOT repository

1. To install FTOT, navigate to the FTOT repository on GitHub:
<https://github.com/VolpeUSDOT/FTOT-Public>

Published FTOT studies and documentation

Peer reviewed papers

Atnoorkar et al., 2025. Future marine biofuels in the Port of Seattle region. Frontiers in Energy Research. <https://www.frontiersin.org/articles/10.3389/fenrg.2025.1550093>.

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Downloadable technical documents available on GitHub

- FTOT Technical Documentation
- FTOT User Guide
- FTOT Quick Start
- FTOT Reference Scenarios

Thank you!

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