# Freight and Fuel Transportation Optimization Tool (FTOT)

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Volpe The National Transportation Systems Center

*Advancing transportation innovation for the public good*

U.S. Department of Transportation
**Office of the Secretary of Transportation**
John A. Volpe National Transportation Systems Center

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

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

papa1266 / 123rf

# 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

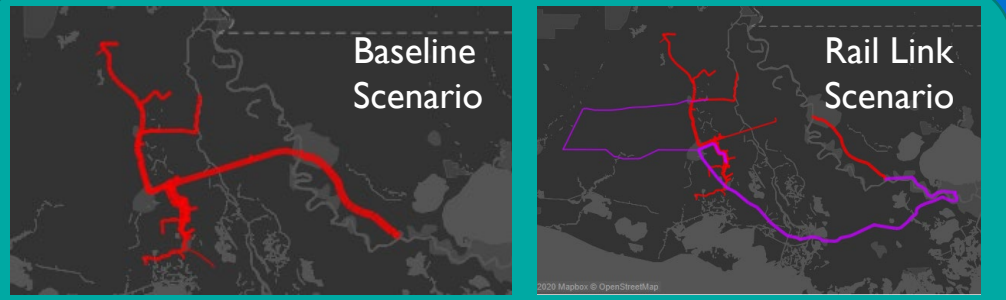
## Analyze impacts of changes in:

Supply / demand

Multimodal infrastructure

Supply chain / industry patterns

Disruption and resilience



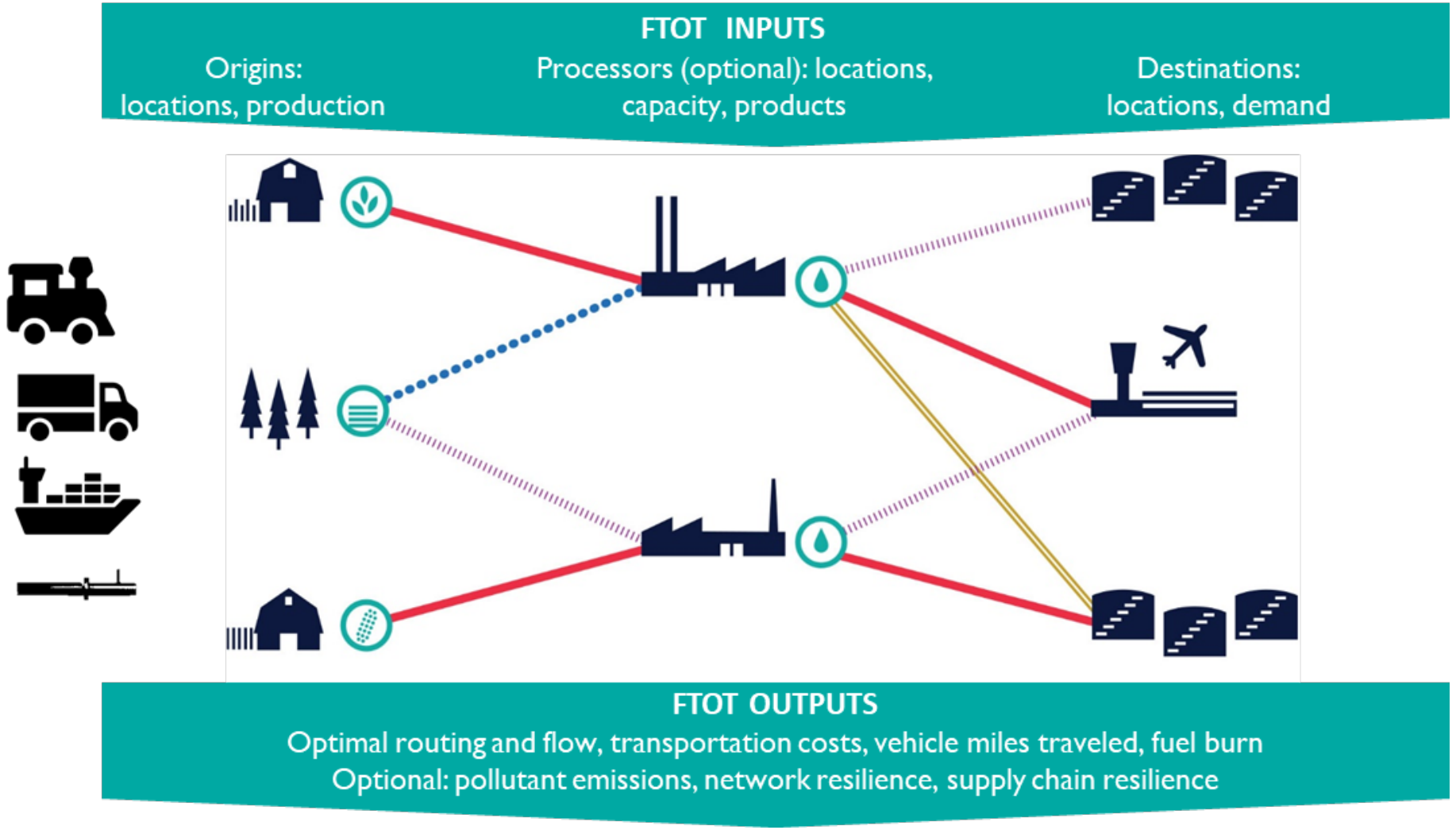

FTOT analysis: sugar supply chain in LA with rail link renewal

## Enable transportation innovation:

Transportation infrastructure affects supply chain costs, resilience

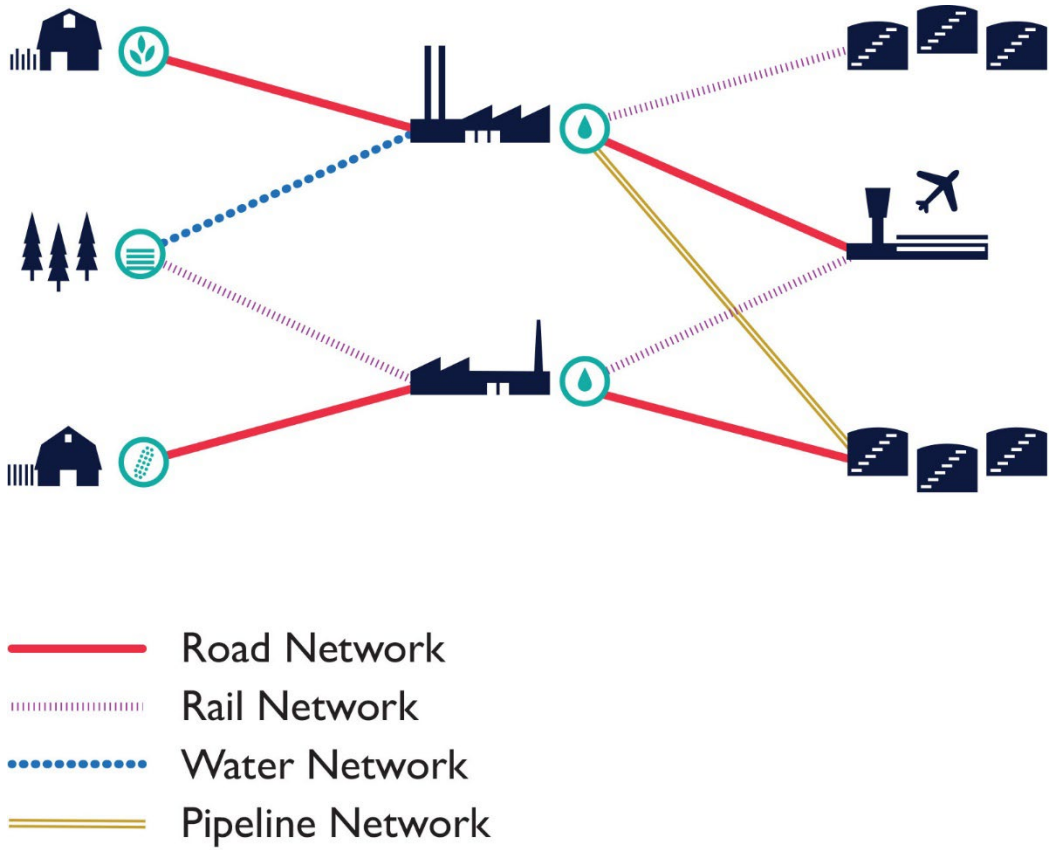
Current and future supply chains impact infrastructure needs

# The Freight and Fuel Transportation Optimization Tool (FTOT)



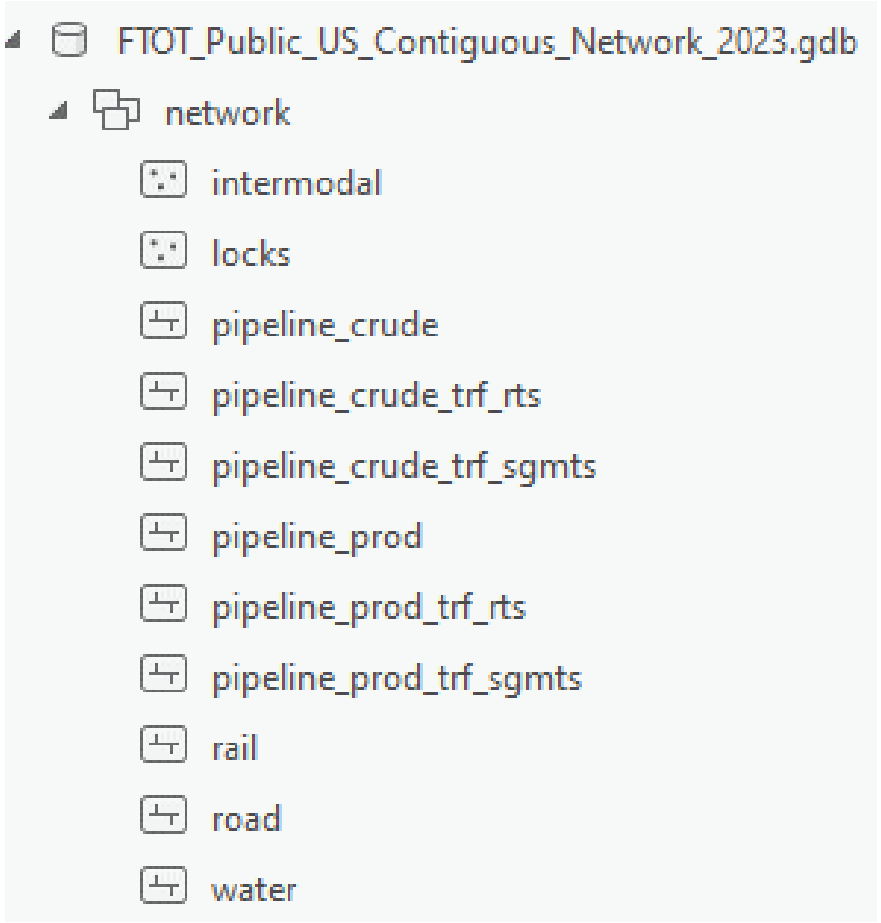
# FTOT optimizes routing of supply chain scenarios over a multimodal transportation network.

- Transportation costs (per unit distance, tariff)
- Transloading costs
- Impedances/weightings
- Cost of $CO_2$ 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

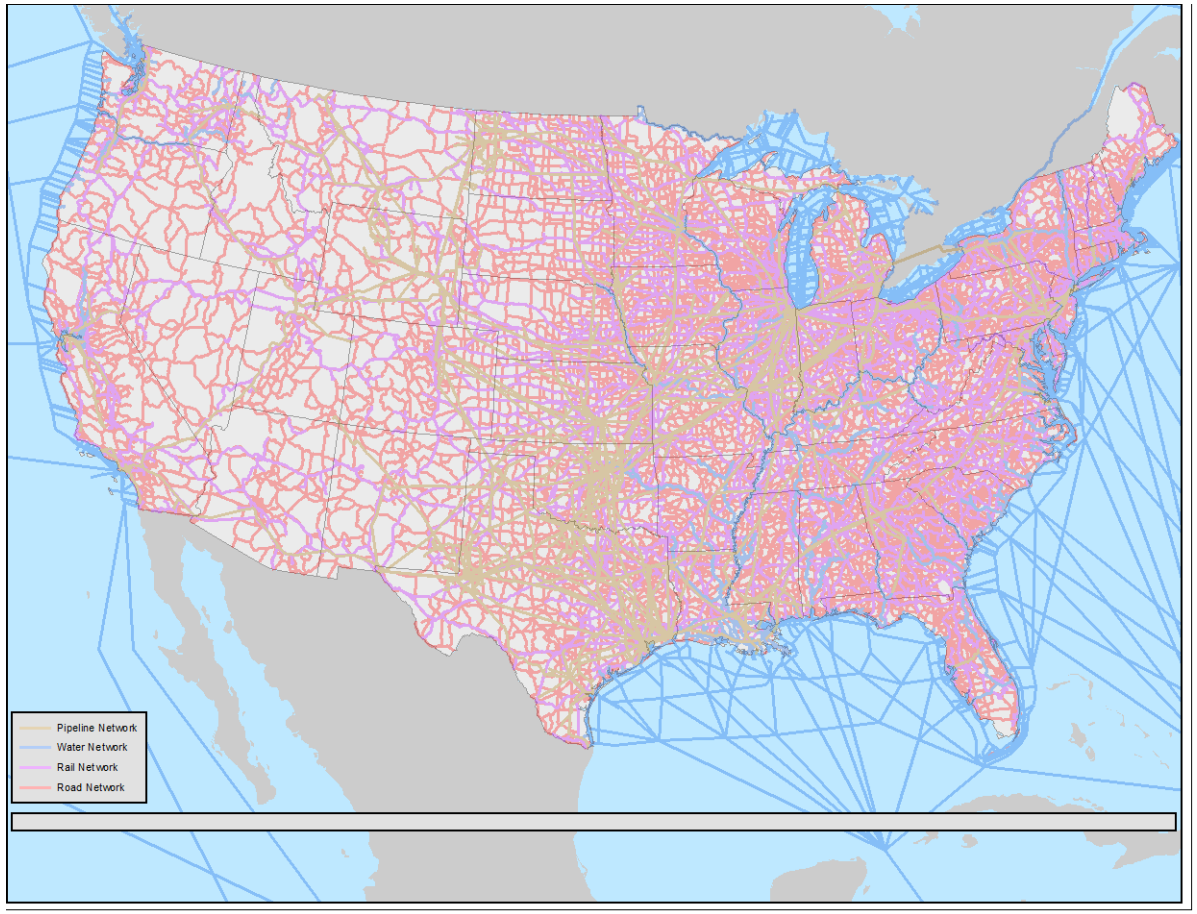



## Aligned with Generalized Modeling Network Specification (GMNS)

- 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



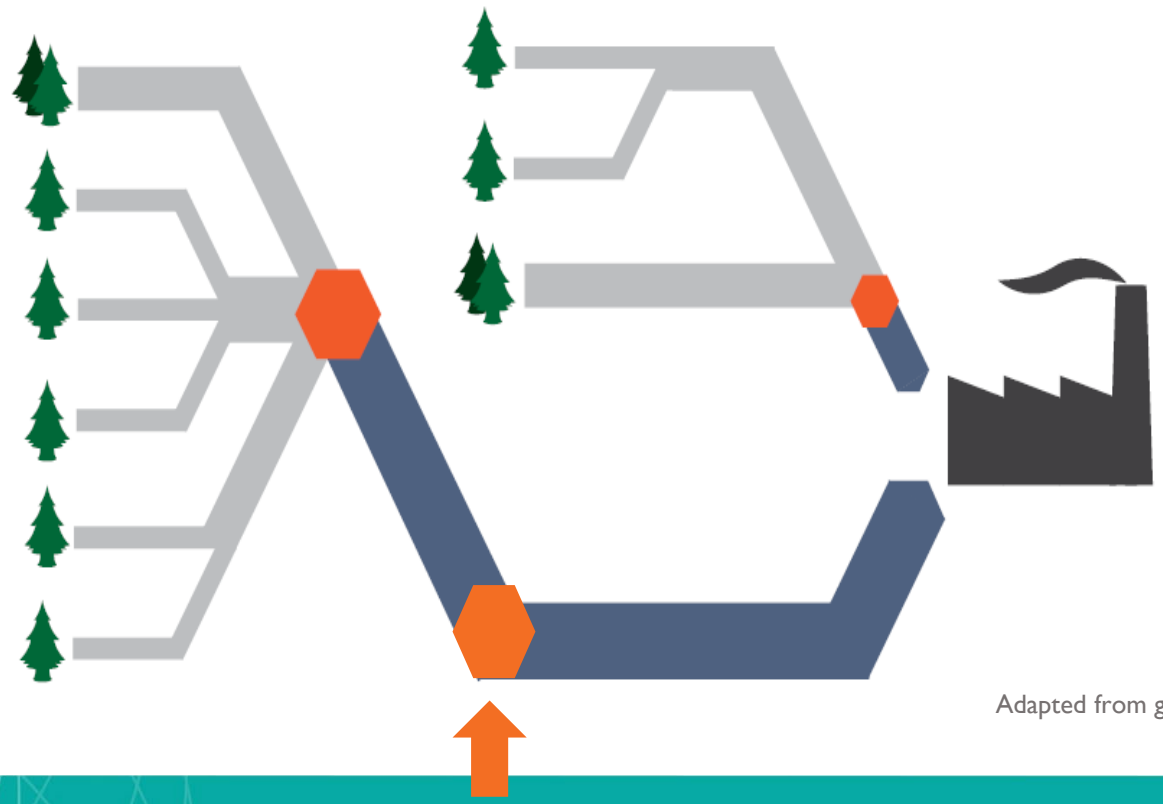

## Default Network Components

- Freight Analysis Framework 5 (road)
- FRA Rail Network
- USACE waterways
- EIA pipeline data, adjusted to stations
- Pipeline tariff data
- Intermodal facilities

Notes:

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

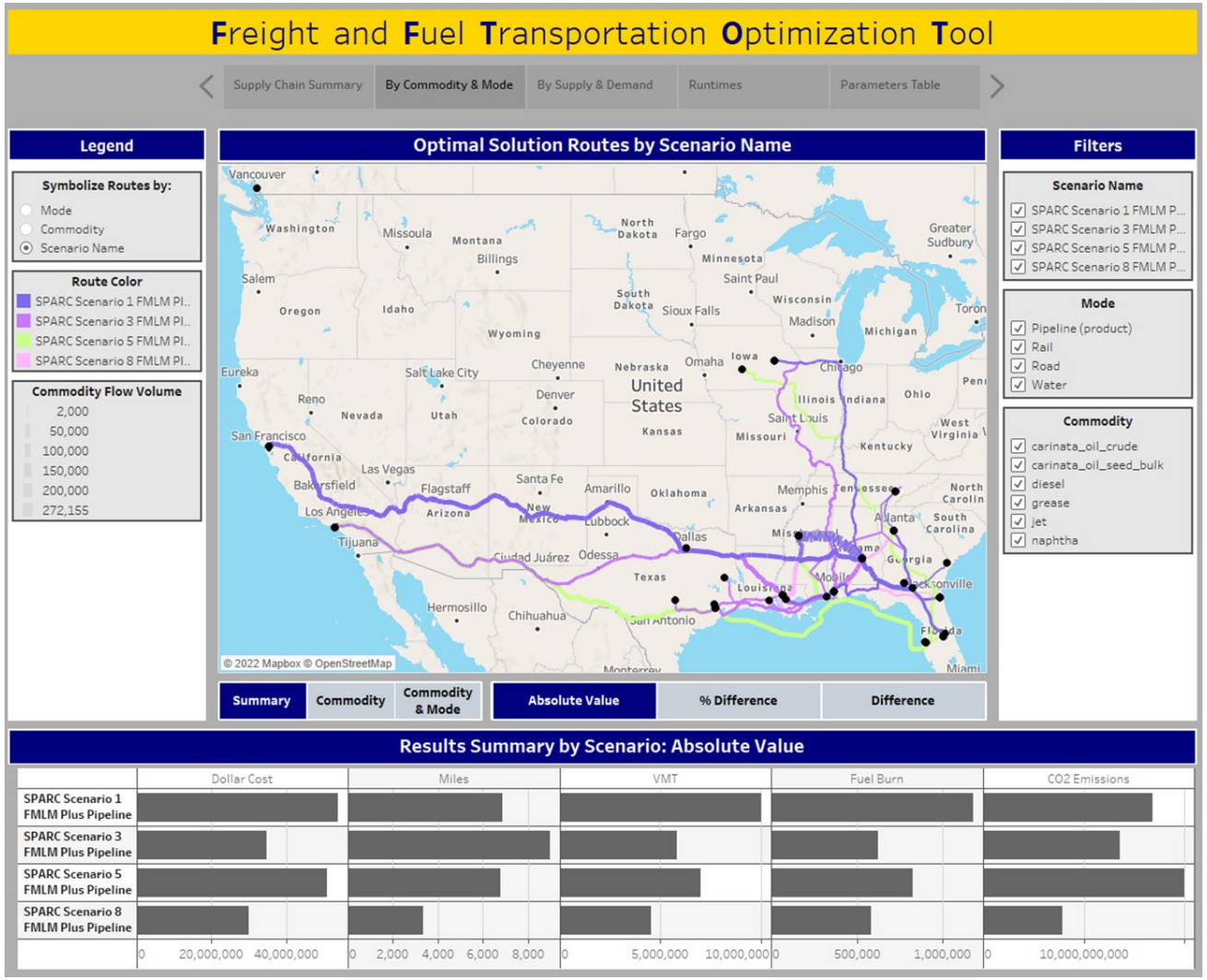
# FTOT can help identify candidate facility locations based on optimized transportation patterns.



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

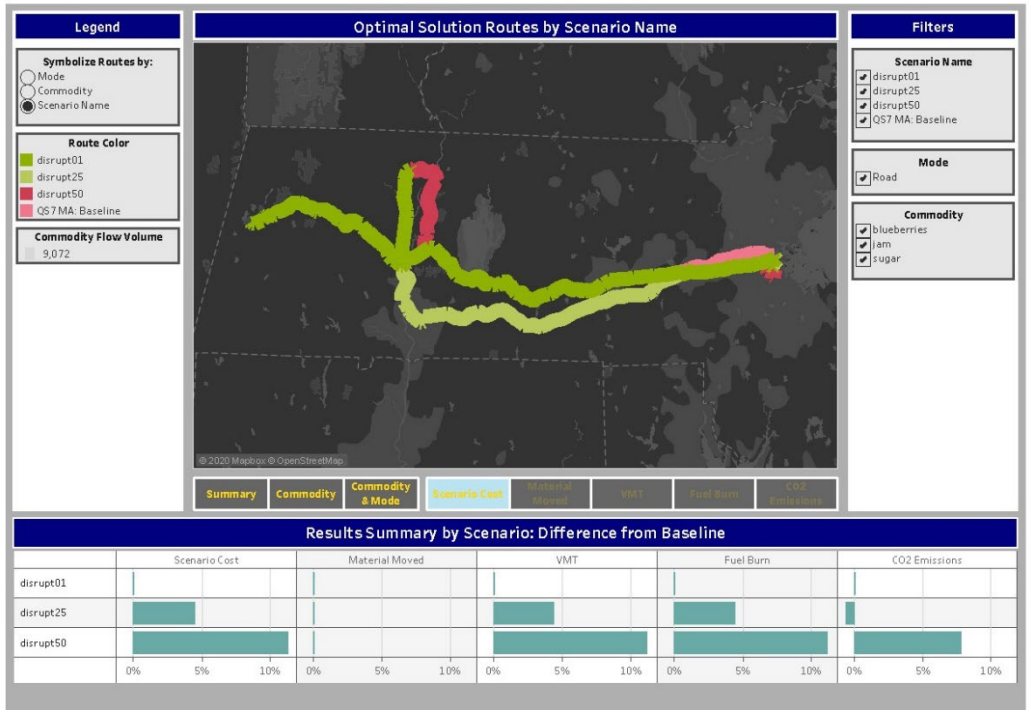
Manual network or supply chain modifications.

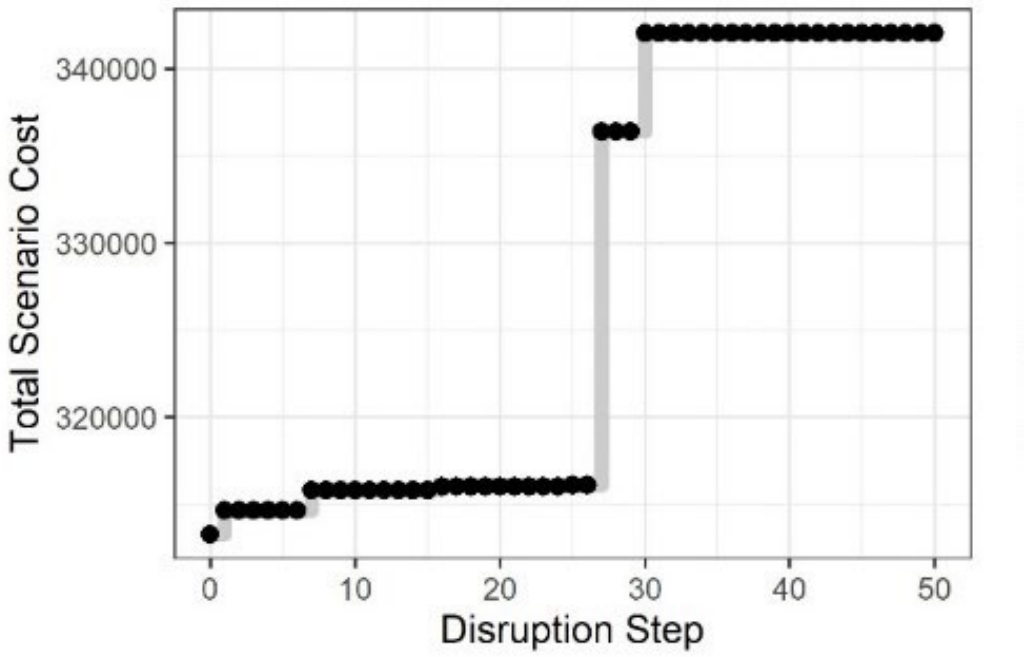
Link rank and removal process.

- 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.



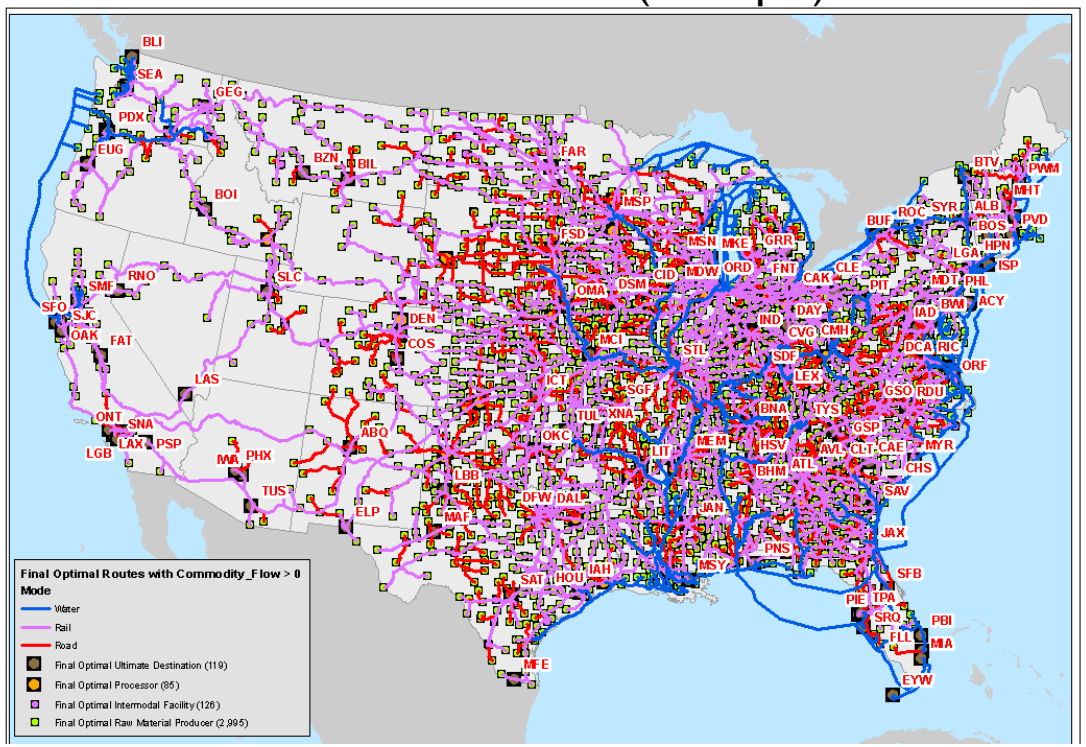




Website: volpeusdot.github.io/FTOT-Public. Email us at FTOT-Team@dot.gov.

# 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)

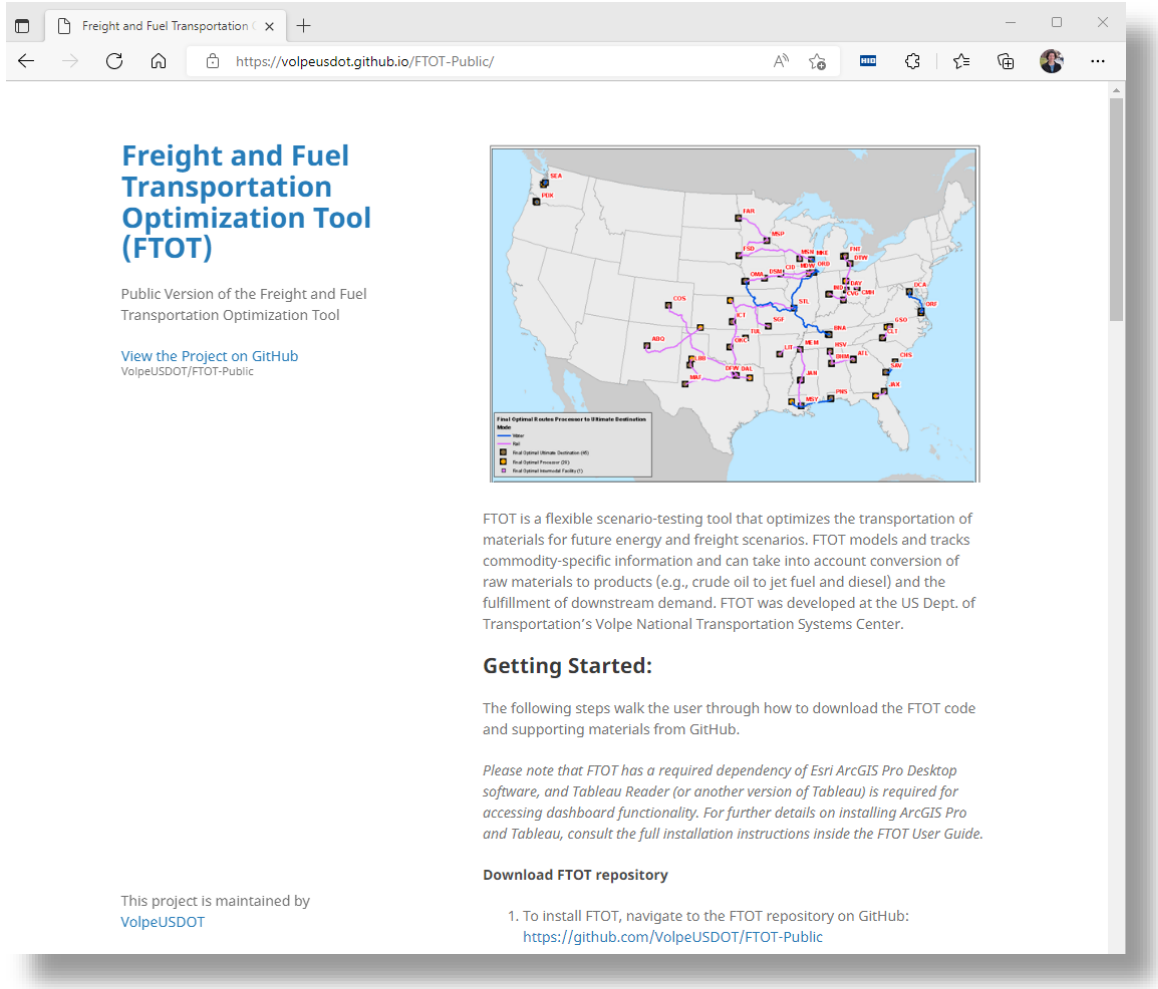



Source: USDOT Volpe Center – See also: https://doi.org/10.1002/bbb.1951

# FTOT is free and publicly available

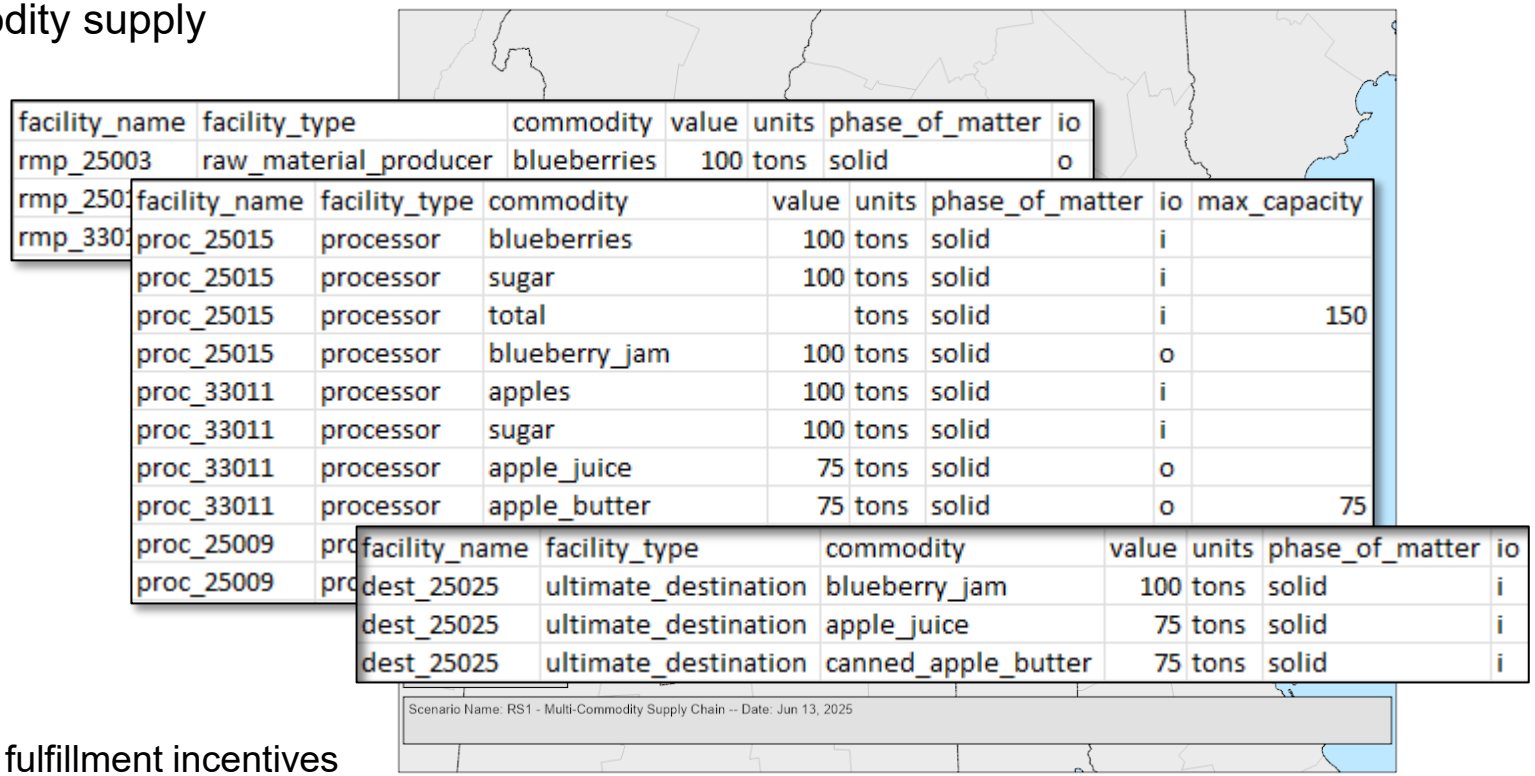
**volpeusdot.github.io/FTOT-Public**

- 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



| facility_name | facility_type | commodity | value | units | phase_of_matter | io |
|---|---|---|---|---|---|---|
| rmp_25003 | raw_material_producer | blueberries | 100 | tons | solid | o |
| rmp_250 | | | | | | |
| rmp_330 | | | | | | |

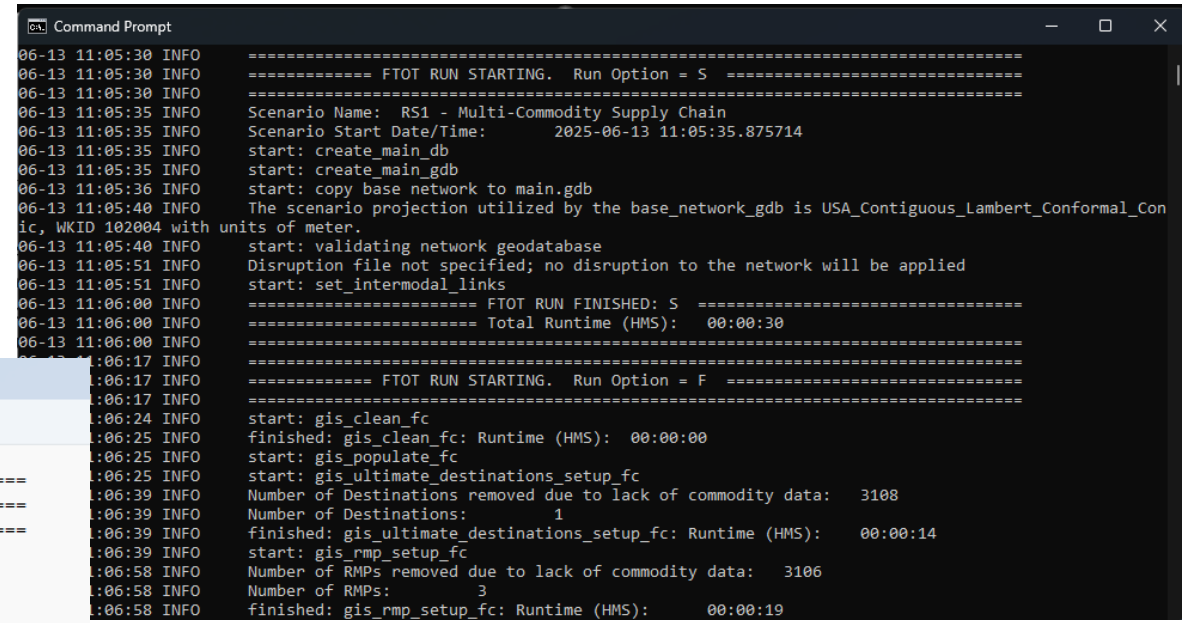
| facility_name | facility_type | commodity | value | units | phase_of_matter | io | max_capacity |
|---|---|---|---|---|---|---|---|
| proc_25015 | processor | blueberries | 100 | tons | solid | i | |
| proc_25015 | processor | sugar | 100 | tons | solid | i | |
| proc_25015 | processor | total | | 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 |
| proc_25009 | pro | | | | | | |
| proc_25009 | pro | | | | | | |

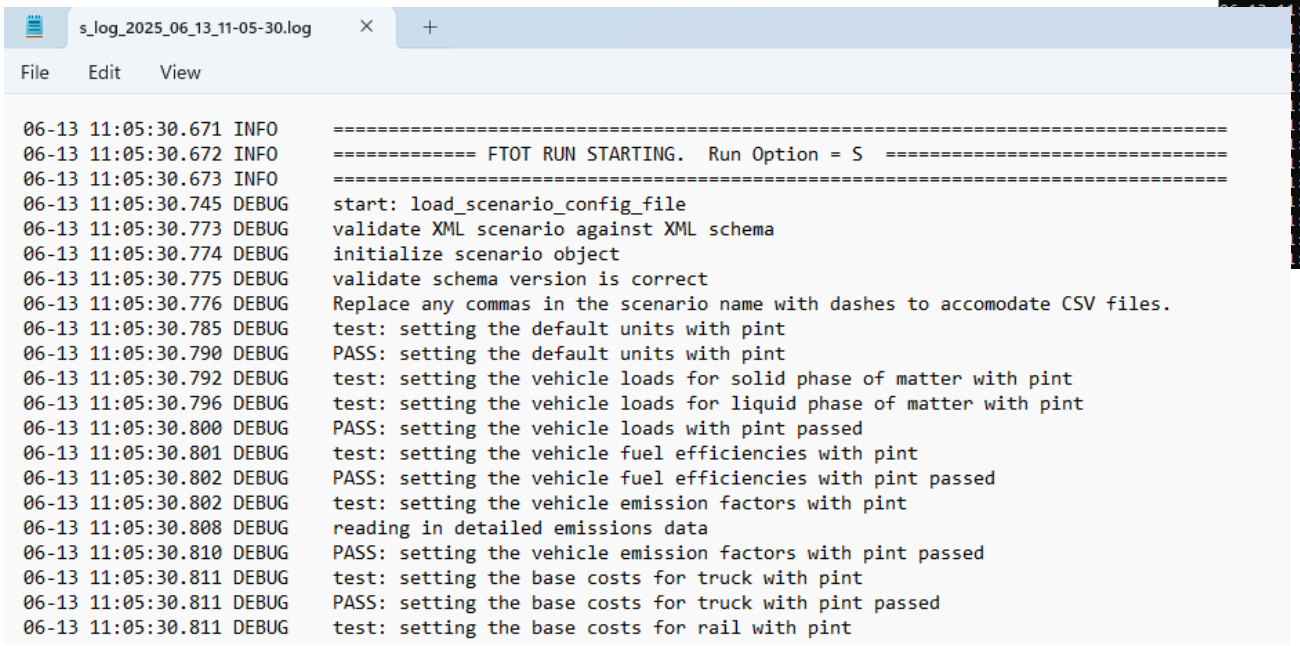
| facility_name | facility_type | commodity | value | units | phase_of_matter | io |
|---|---|---|---|---|---|---|
| dest_25025 | ultimate_destination | blueberry_jam | 100 | tons | solid | i |
| dest_25025 | ultimate_destination | apple_juice | 75 | tons | solid | i |
| dest_25025 | ultimate_destination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

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

# Reference Scenario 1: Running a Scenario

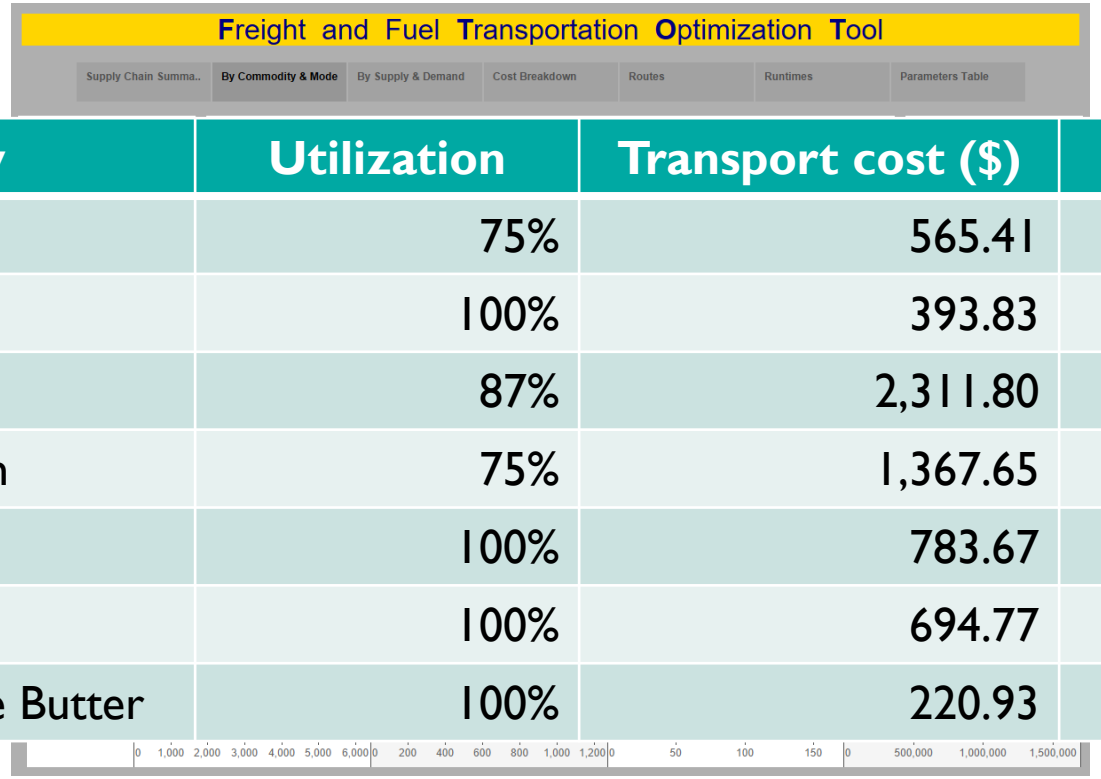
- FTOT is run through an executable batch file
- Logging messages are printed in the command prompt window in real time as the scenario runs
- Log files are written for each step of the FTOT run

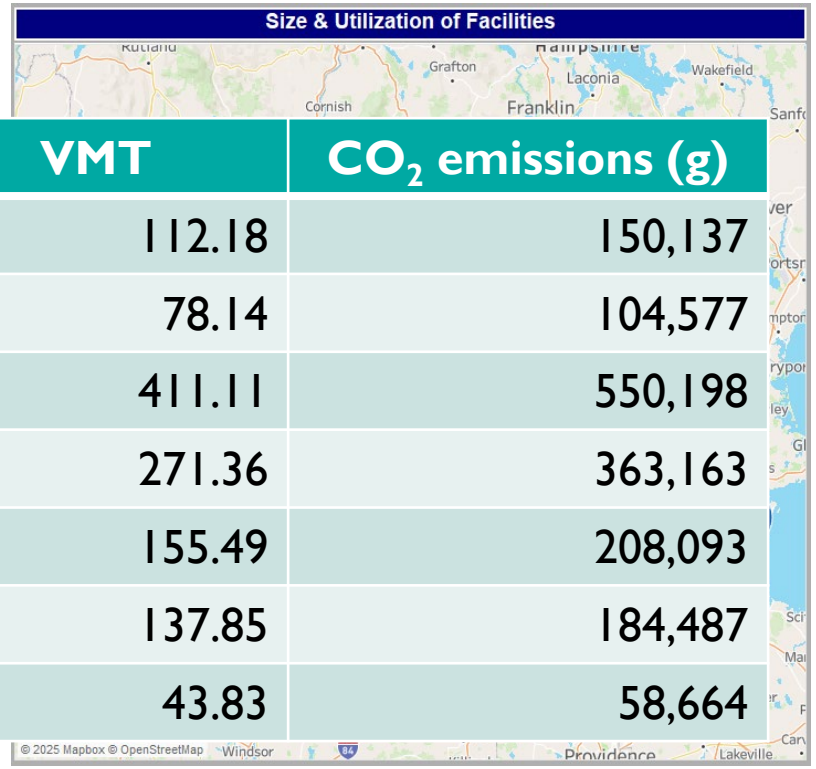


# Reference Scenario 1: FTOT Outputs

- 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




| 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

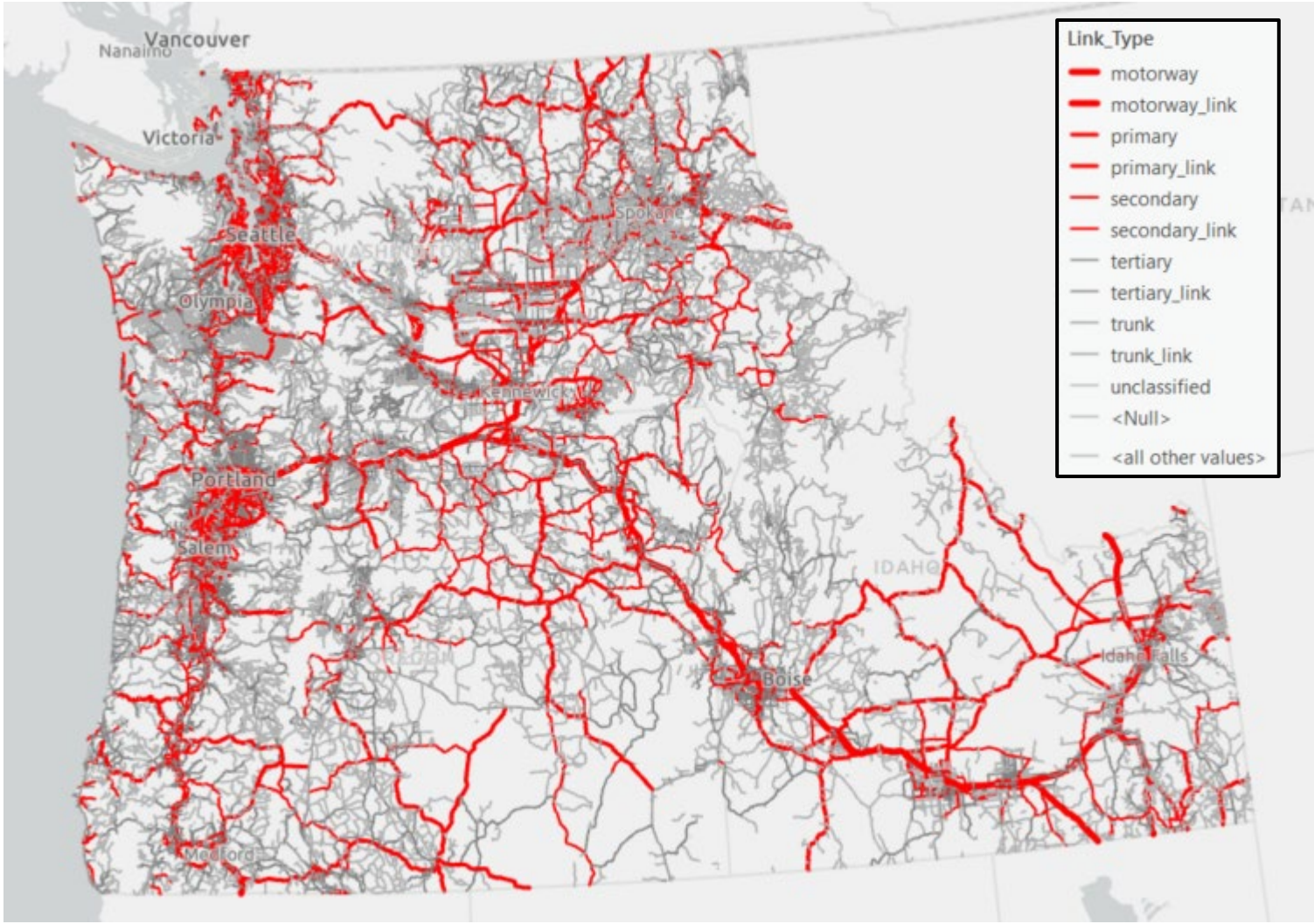
- Connected and routable geospatial network
- Network components
  - Modal networks (e.g., road, rail, water, pipeline)
  - Intermodal connections to switch among modes (if analyzing more than just road)
  - [Optional] Modal network attributes for link type, direction, urban/rural, capacity, etc.
  -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

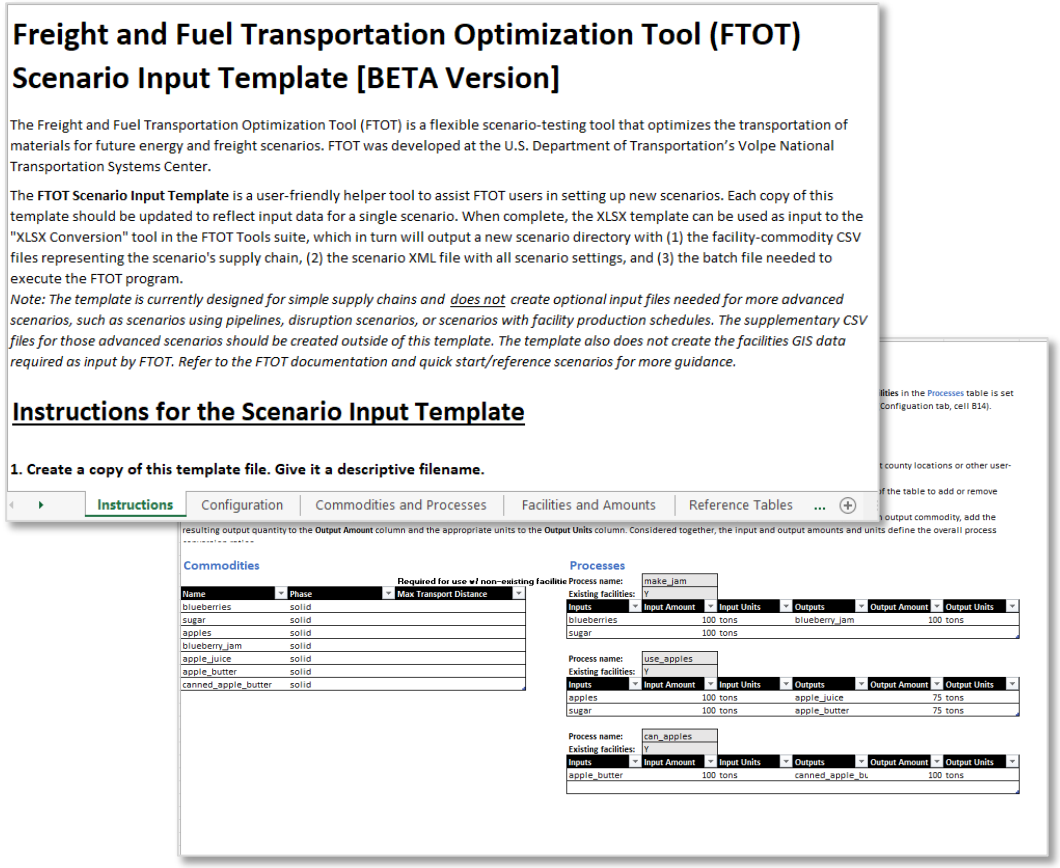
# Example: Pacific Northwest Road Network

- 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

Commodities

| Name | Phase | Max Transport Distance |
|---|---|---|
| blueberries | solid | |
| sugar | solid | |
| apples | solid | |
| blueberry_jam | solid | |
| apple_juice | solid | |
| apple_butter | solid | |
| canned_apple_butter | solid | |

Processes

Process name: make_jam — Existing facilities: Y

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

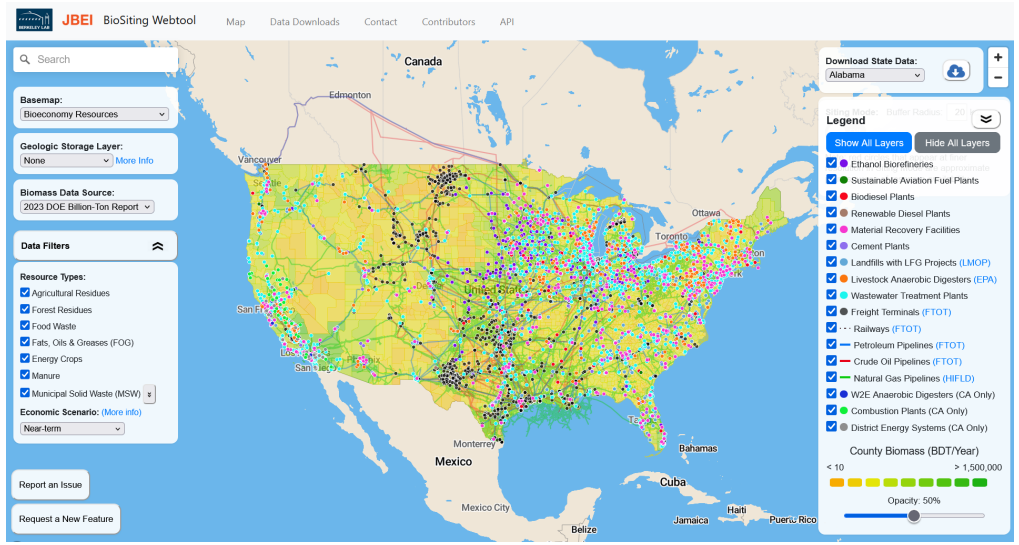
Process name: use_apples — Existing facilities: Y

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

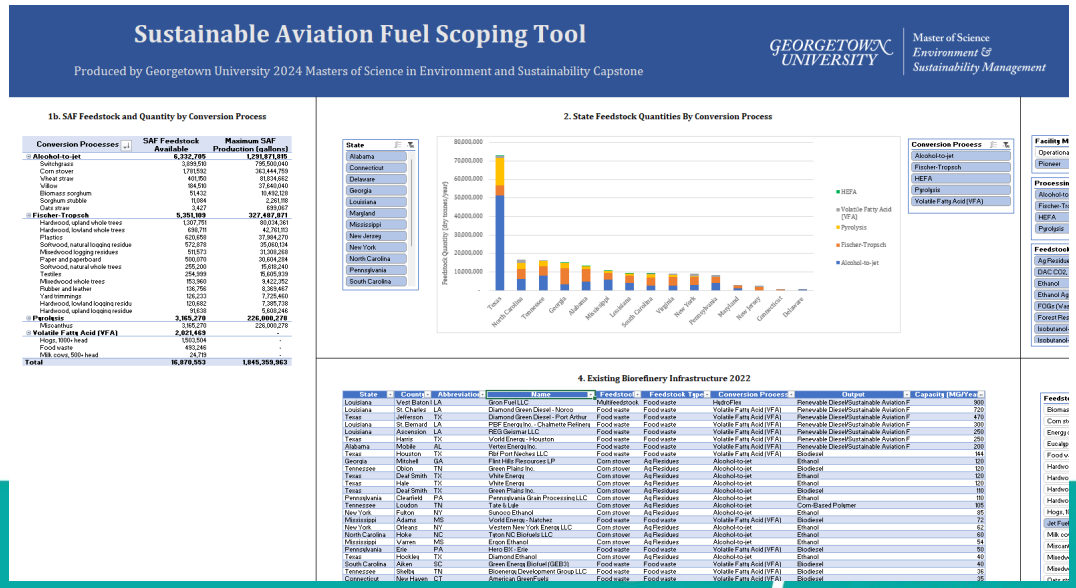
Process name: can_apples — Existing facilities: Y

| Inputs | Input Amount | Input Units | Outputs | Output Amount | Output Units |
|---|---|---|---|---|---|
| apple_butter | 100 | tons | canned_apple_bu | 100 | tons |

## JBEI BioSiting Webtool: biositing.jbei.org/national




## Georgetown SAF Scoping Tool

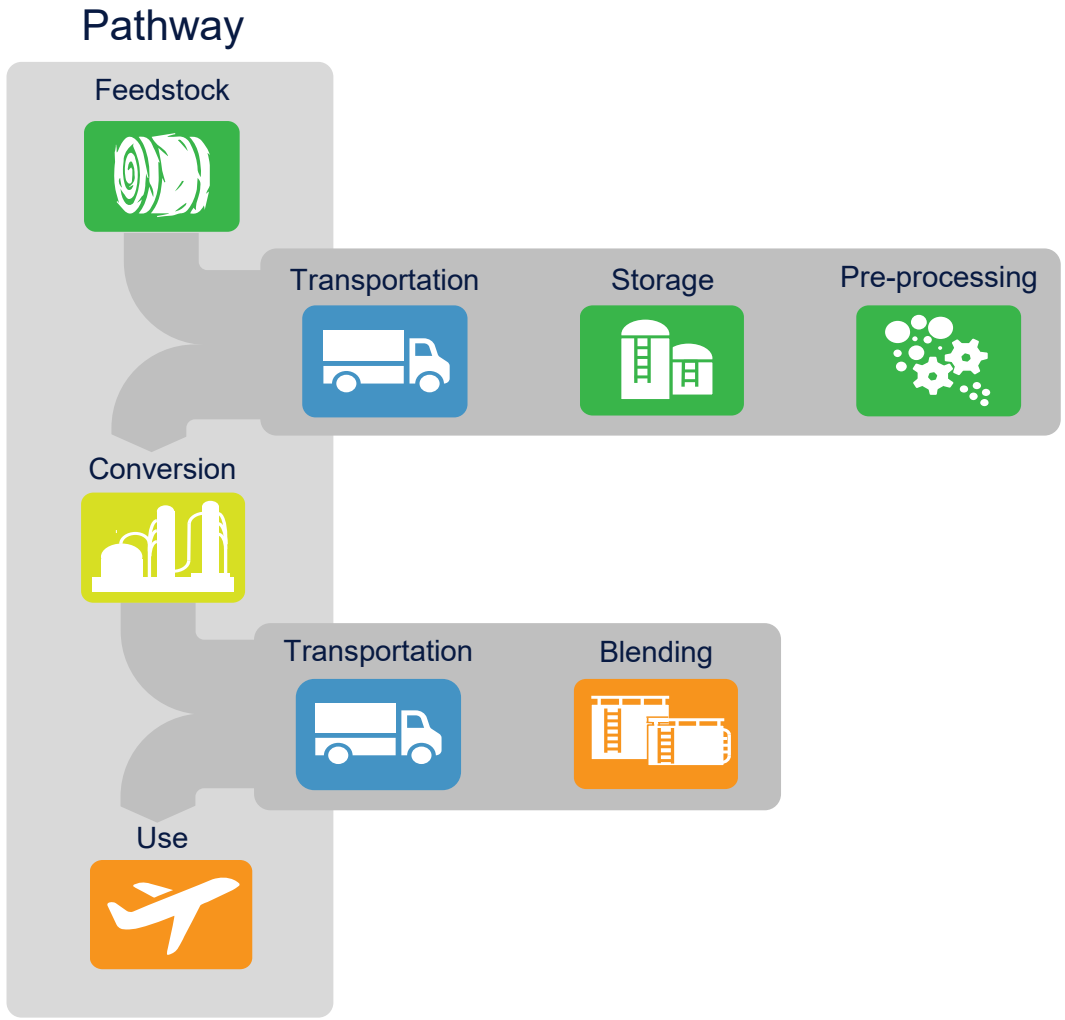



Website: volpeusdot.github.io/FTOT-Public. Email us at FTOT-Team@dot.gov.

# New in FTOT 2025.1: SAF Scenario Setup Template

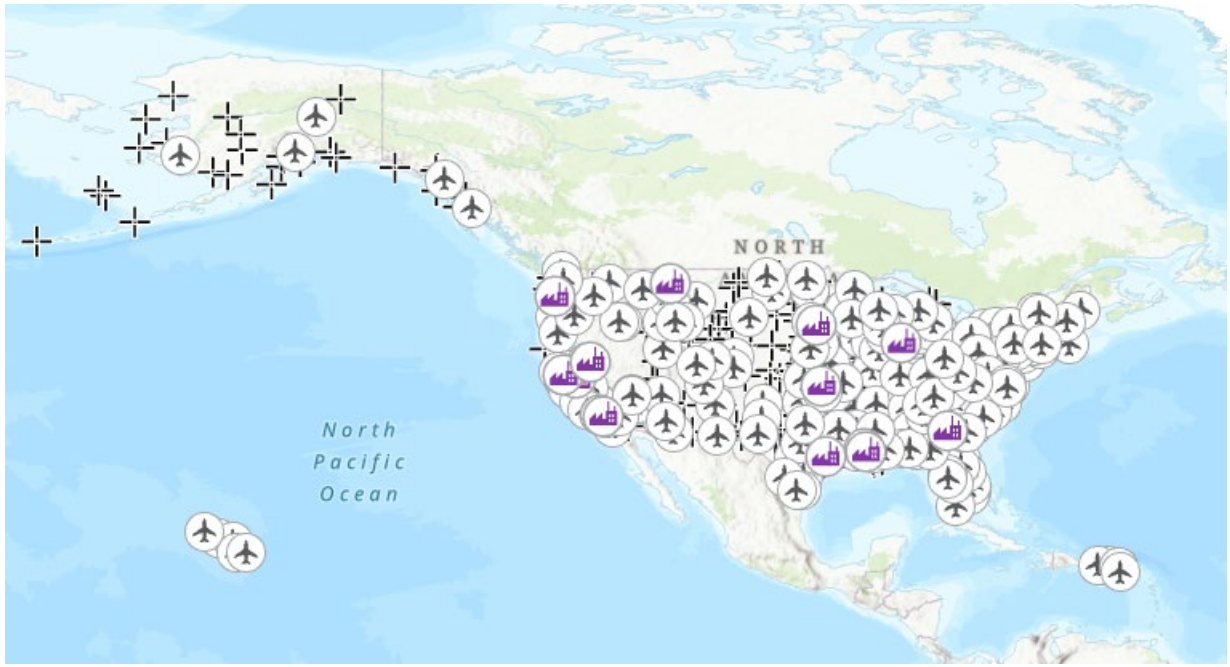
## What is it?

- 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/biodieselmap-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

Raw Material Producer → Feedstock → Refinery → SAF → Blending Facility → Fuel Blend → Airport

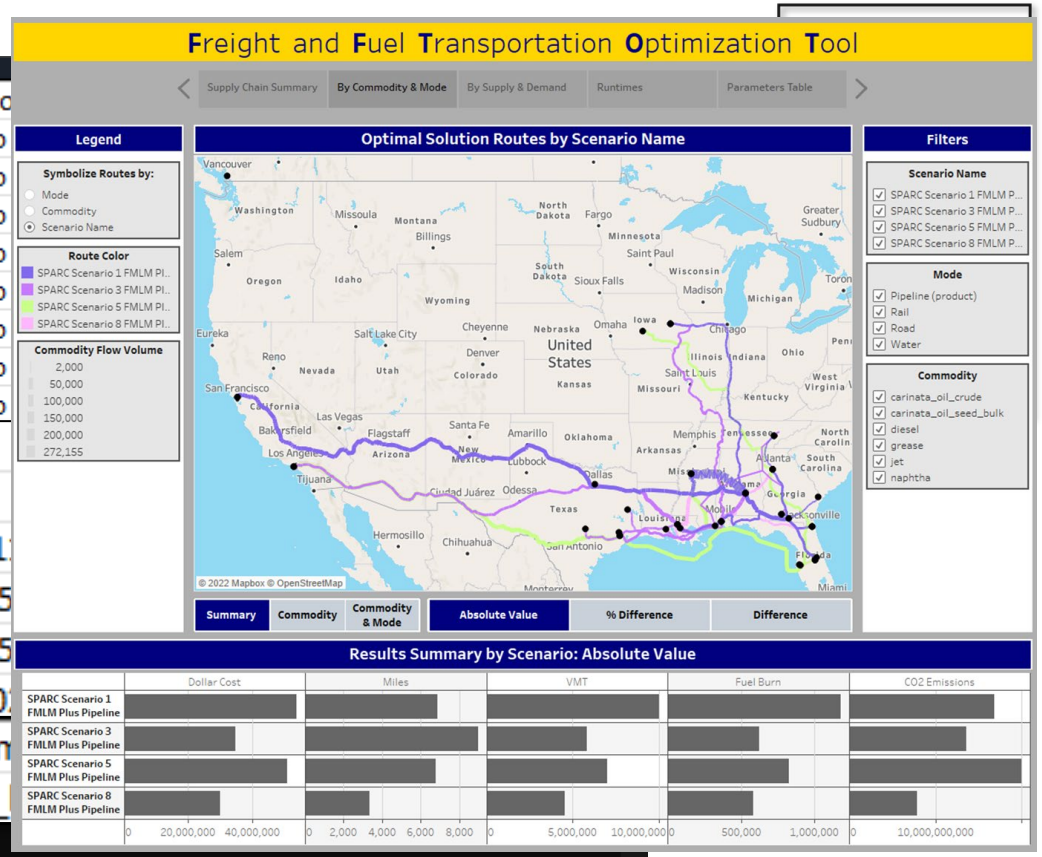
1. Fill out the Excel-based SAF Scenario Setup
2.
3.
4. [Optional] standard F scenario co

## Instructions for the FTOT SAF Scenario Setup Template

| facility_name | facility_type | commodity | value | units | phase_of_matter | io |
|---|---|---|---|---|---|---|
| rmp_16055 | raw_material_producer | FOG | 2768.99999 | tonnes | solid | o |
| rmp_16049 | raw_material_producer | FOG | 150.0000004 | tonnes | solid | o |
| rmp_16069 | raw_material_producer | FOG | 532.9999984 | tonnes | solid | o |
| rmp_16085 | raw_material_producer | FOG | 140 | tonnes | solid | o |
| rmp_16023 | raw_material_producer | FOG | 10 | tonnes | solid | o |
| rmp_16027 | raw_material_producer | FOG | 4132.999969 | tonnes | solid | o |
| rmp_16001 | raw_material_producer | FOG | 10589.00002 | tonnes | solid | o |
| rmp_16019 | raw_material_producer | FOG | 1642.999995 | tonnes | solid | o |
| rmp_16059 | raw | | | | | |
| rmp_16011 | raw | | | | | |
| rmp_16057 | raw | | | | | |
| rmp_16017 | raw | | | | | |
| rmp_16025 | raw | | | | | |
| rmp_16005 | raw | | | | | |
| rmp_16077 | raw | | | | | |

| facility_name | facility_type | commodity | value |
|---|---|---|---|
| cand_HEFA_FOG | processor | FOG | |
| cand_HEFA_FOG | processor | SAF | 127.21 |
| cand_HEFA_FOG | processor | minsize | 571075 |
| cand_HEFA_FOG | processor | maxsize | 114215 |
| cand_HEFA_FOG | processor | cost_formula | 28.220 |
| cand_HEFA_FO | | | |

| facility_name | facility_type | comm |
|---|---|---|
| airport_sea | ultimate_destination | fuel_ |




STEP 1. Use filters
Note: Filters (c and d) are
a) Select
Single select
Billion Ton
Emerging
Mature-n
Mature-n
Mature-n
Near-term
*See Table E
Report for sc
DOE BETO 20
Error: Selec

STEP 2. Use filters
Note: Filters (c
a) Select processing te
Single select

Review
DO NOT E
after running

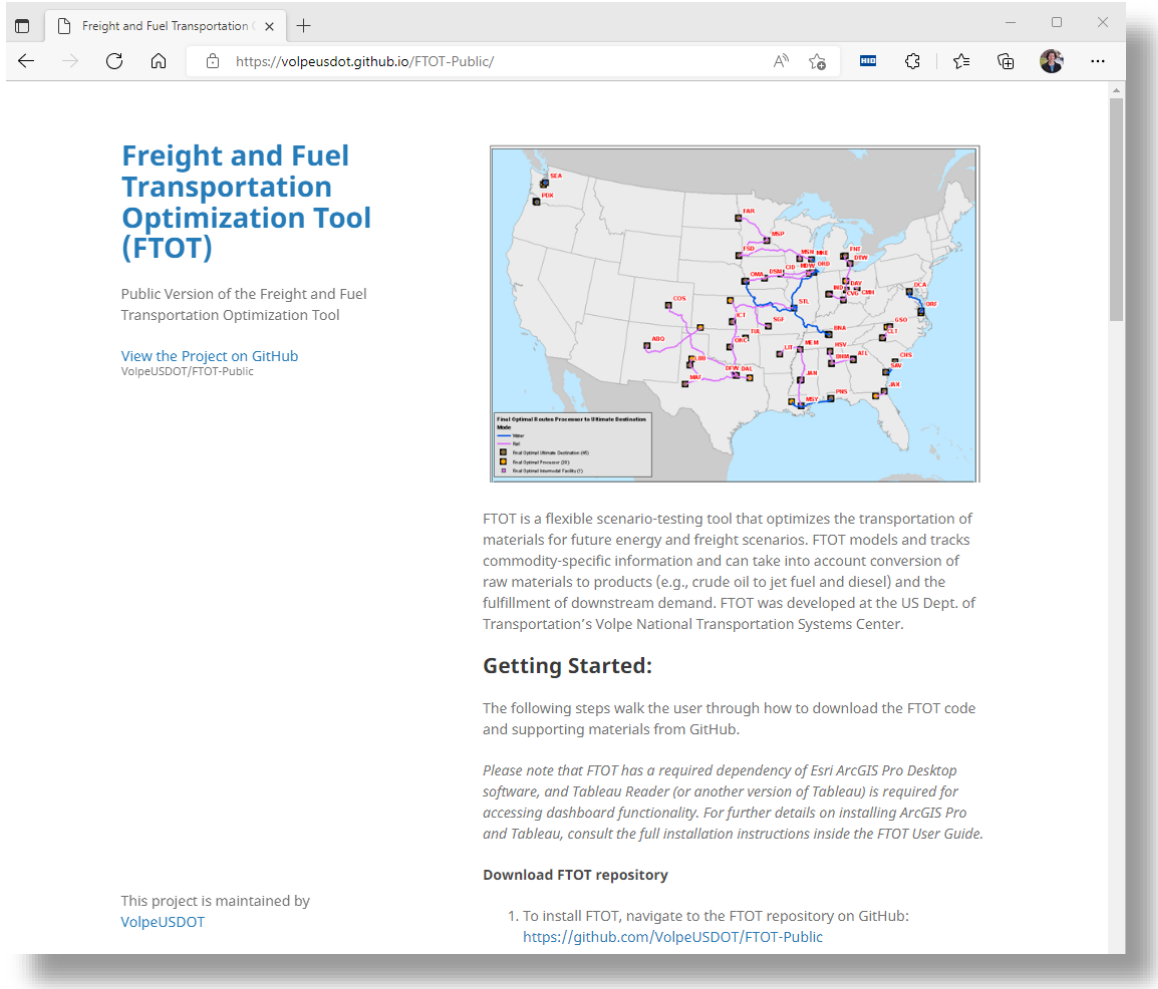
4. Save the
a) When prompted, drag the template file from your File Explorer into the Command Prompt.
b) Specify a folder file path to put the FTOT input files that will be generated by the tool.

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

Instructions | SAF Filters | Configuration | Commodities and Processes | Facilities and Amounts | +

# 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.



# 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.

Zhao et al.. 2023. Multi-Component Resilience Assessment Framework for a Supply Chain System. Sustainability 15(7): 6197. Special issue: Towards Resilient Infrastructure. https://doi.org/10.3390/su15076197.

Ma et al., 2022. Probabilistic Wildfire risk assessment methodology and evaluation of a supply chain network. International Journal of Disaster Risk Reduction. https://doi.org/10.1016/j.ijdrr.2022.103340.

Zhao et al., 2022. Effect of Connected and Autonomous Vehicles on Supply Chain Performance. Transportation Research Record. https://doi.org/10.1177/0361198122111542

Shi et al.. 2019. Analysis of Renewable Jet from Oilseed Feedstocks Replacing Fallow in the U.S. Northern Great Plains Sustainable Chemistry and Engineering: 7(23): 18753-18764. doi/10.1021/acssuschemeng.9b02150.

Lewis et al. 2018 U.S. Alternative Jet Fuel Deployment Scenario Analyses Identifying Key Drivers and Geospatial Patterns for the First Billion Gallons. BioFPR: doi.org/10.1002/bbb.1951.

Shi et al. 2017. Life cycle water footprint analysis for rapeseed derived jet fuel in North Dakota. Sustainable Chemistry and Engineering: Web, April 6, 2017: http://pubs.acs.org/doi/abs/10.1021/acssuschemeng.6b02956.

Ukaew et al. 2016. Full chain life cycle assessment of greenhouse gases and energy demand for canola-derived jet fuel in North Dakota, United States. ACS Sustainable Chemistry and Engineering. DOI: 10.1021/ACSSUSCHEMENG.6B00276.


## Downloadable technical documents available on GitHub

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

# Thank you!

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**FAA Office of Environment and Energy (PM Prem Lobo)**
Primary public tool development and SAF scenarios

**Pipeline Hazardous Materials Safety Administration**
**U.S. Dept. of Energy Bioenergy Technologies Office**
**U.S. Dept. of Agriculture**
**Oregon State University**

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