Freight and Fuel Transportation Optimization Tool (FTOT)

Example Scenarios for Freight Planning

U.S. DOT Volpe Center

Background

What is the Freight and Fuel Transportation Optimization Tool (FTOT)?

- A flexible scenario-testing tool that optimizes the transportation of materials.
- Models and tracks commodity-specific information and accounts for the conversion of raw materials to products to fulfill downstream demand.
- Free and available to the public.

https://volpeusdot.github.io/FTOT-Public/

Objective

- Develop an FTOT "scenario library" that demonstrates relevant analyses for State Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) to illustrate the potential utility of FTOT to their work.

Overview of Example Scenarios

1. **Sugar Supply Chain w/ Intermodal Facility Siting**
   - Representation of a real-world sugar supply chain in Louisiana.
   - Evaluation of two potential locations for hypothetical new intermodal facilities.
2. **Sugar Supply Chain w/ Network Disruption**
   - Representation of a real-world sugar supply chain in Louisiana.
   - Impacts of hypothetical network disruption on transport patterns and road use.
   - Potential for hypothetical, strategically located intermodal facility to mitigate disruption impacts.
3. **Generalized Freight w/ Inland Ports**
   - Freight scenarios based on publicly available data.
   - Transport of freight through an inland port in Georgia to destinations in surrounding States.
   - Changes due to the addition of a proposed second inland port.
   - Resilience assessment if the original of the two inland ports goes offline.

Note: The scenarios presented herein are hypothetical examples to demonstrate FTOT functionality and do not reflect detailed regional planning or analysis.

Considerations

- Supply chain **scenario analyses** can support agencies in improved:
  - Long-term freight and resilience planning;
  - Capital planning and prioritization;
  - Analysis of future maintenance needs; and
  - Congestion management.

- FTOT can support agencies to:
  - **Evaluate transport cost and emissions changes** associated with new infrastructure investments—such as a new intermodal facility or inland port—under routine conditions as well as under disruption scenarios.
  - **Identify which transportation links** are likely to experience changes in flow due to a disruption, while helping them to prepare transportation networks for increased use and better consider maintenance needs.
  - **Assess the resilience** of optimal transportation solutions to network disruptions.

Note: The scenarios presented herein are hypothetical examples to demonstrate FTOT functionality and do not reflect detailed regional planning or analysis.

FTOT Example Scenarios

Sugar Supply Chain

+ Site Selection for Intermodal Facilities

Introduction

Objectives

- Leverage real-world supply chain data (vetted by American Sugar Cane League).
- Evaluate intermodal facility siting options and their potential effects on mode choice, emissions, etc.

Overview

- Baseline: Processing of Louisiana sugar cane into raw sugar and then refined sugar, delivered to the Port of Baton Rouge.
- New Intermodal Facility #1: Addition of a hypothetical intermodal facility in southern Louisiana with **road, rail, and waterway** connections.
- New Intermodal Facility #2: Addition of a hypothetical intermodal facility in central Louisiana with **road and rail** connections.

Questions Explored

- How will intermodal facility siting options affect use of Louisiana's road, rail, and water networks?
- How will intermodal facility siting options affect likely mode choice?
- How will intermodal facility siting options affect emissions associated with transport of goods?

Note: The Louisiana baseline sugar supply chain scenario was developed in collaboration with the American Sugar Cane League. The variant scenarios are hypothetical cases to demonstrate FTOT functionality and do not reflect real-world regional planning or analysis.

Baseline Scenario – *Supply Chain*

Louisiana sugar supply chain

Sugar Cane Producer → **sugar cane** → Sugar Mill → **raw sugar** → Sugar Refinery → **refined sugar** → Port

Raw Material Producer
- 16 facilities
- Available supply of 227,500 to 1,918,000 tons sugar cane per facility

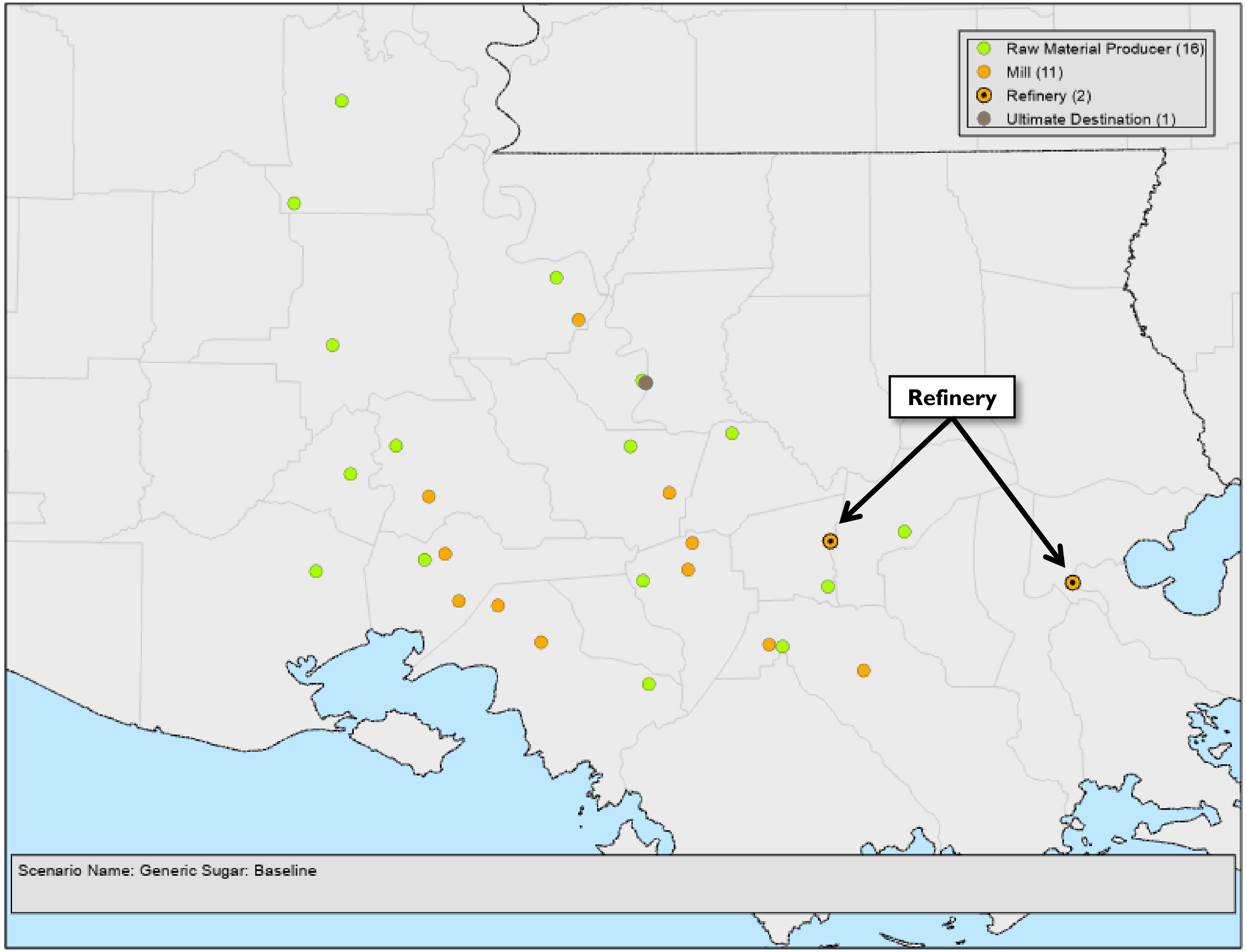
Processor
- 11 facilities
- 11.5% processing efficiency

Processor
- 2 facilities
- 100% processing efficiency

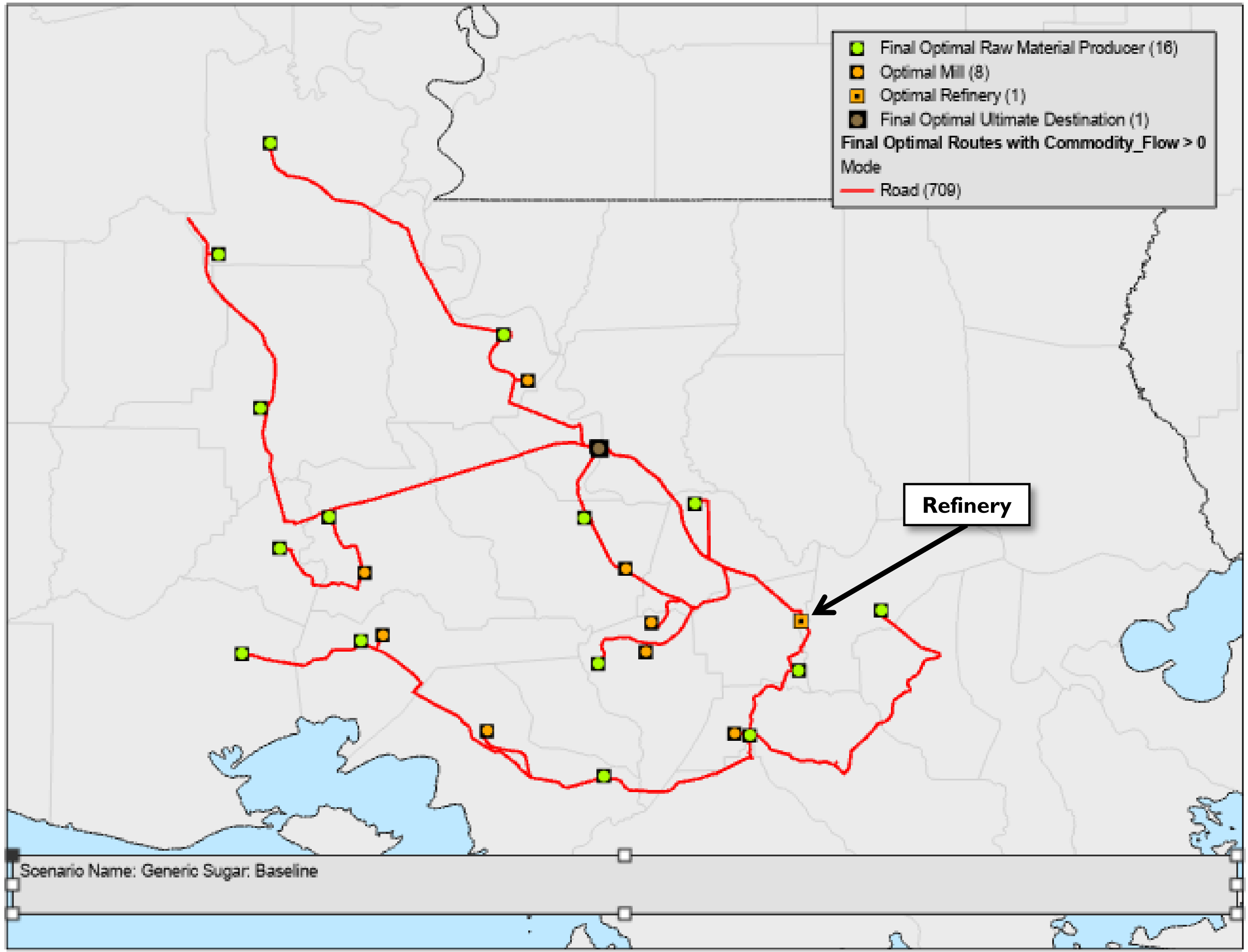
Ultimate Destination
- 1 facility
- Total demand of 10 million tons refined sugar

Note: The Louisiana baseline sugar supply chain scenario was developed in collaboration with the American Sugar Cane League. The variant scenarios are hypothetical cases to demonstrate FTOT functionality and do not reflect real-world regional planning or analysis.

Baseline Scenario – *Facility Locations*



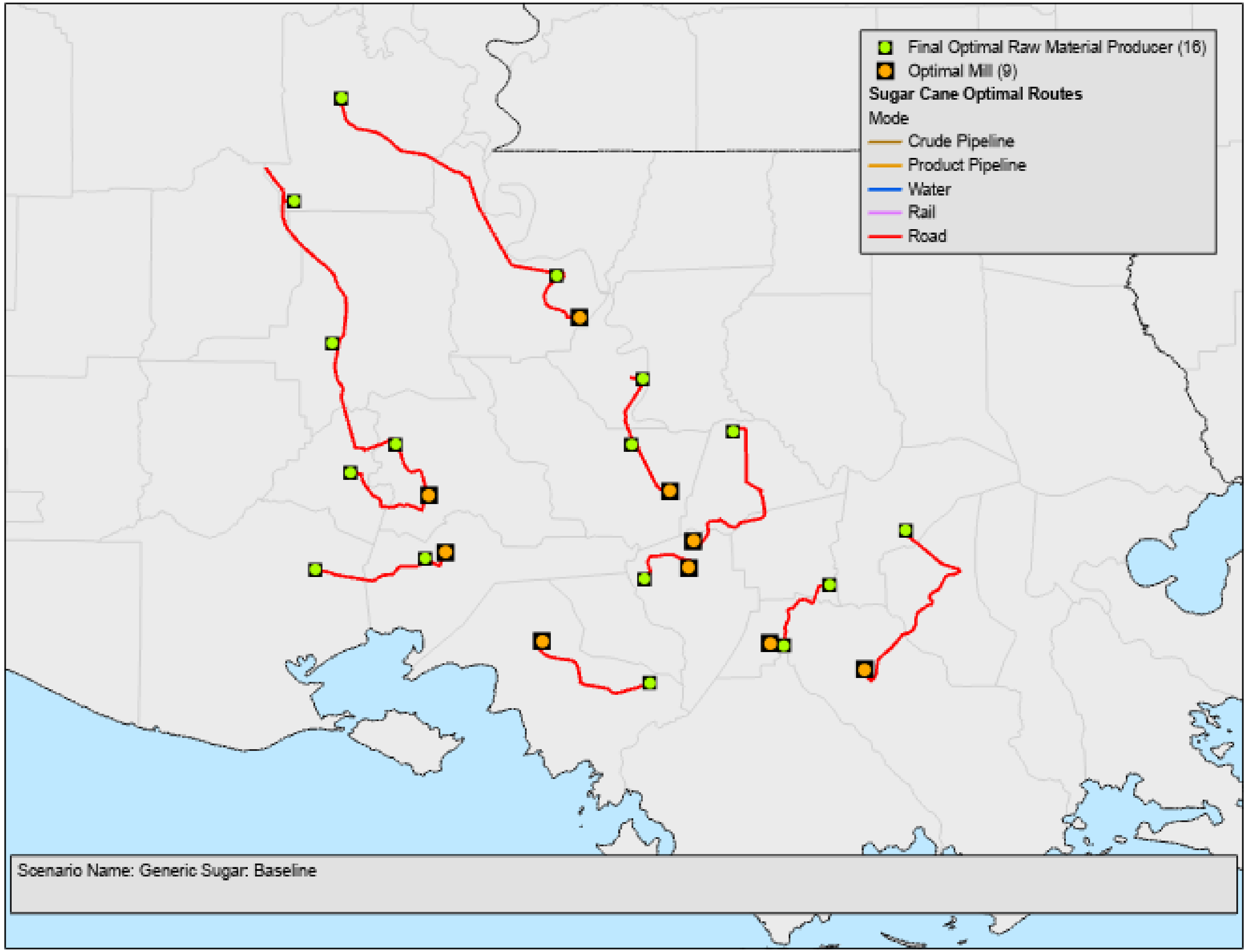
Baseline Scenario – *Optimal Solution*



Baseline Scenario – *Optimal Solution (Cont.)*

Sugar cane

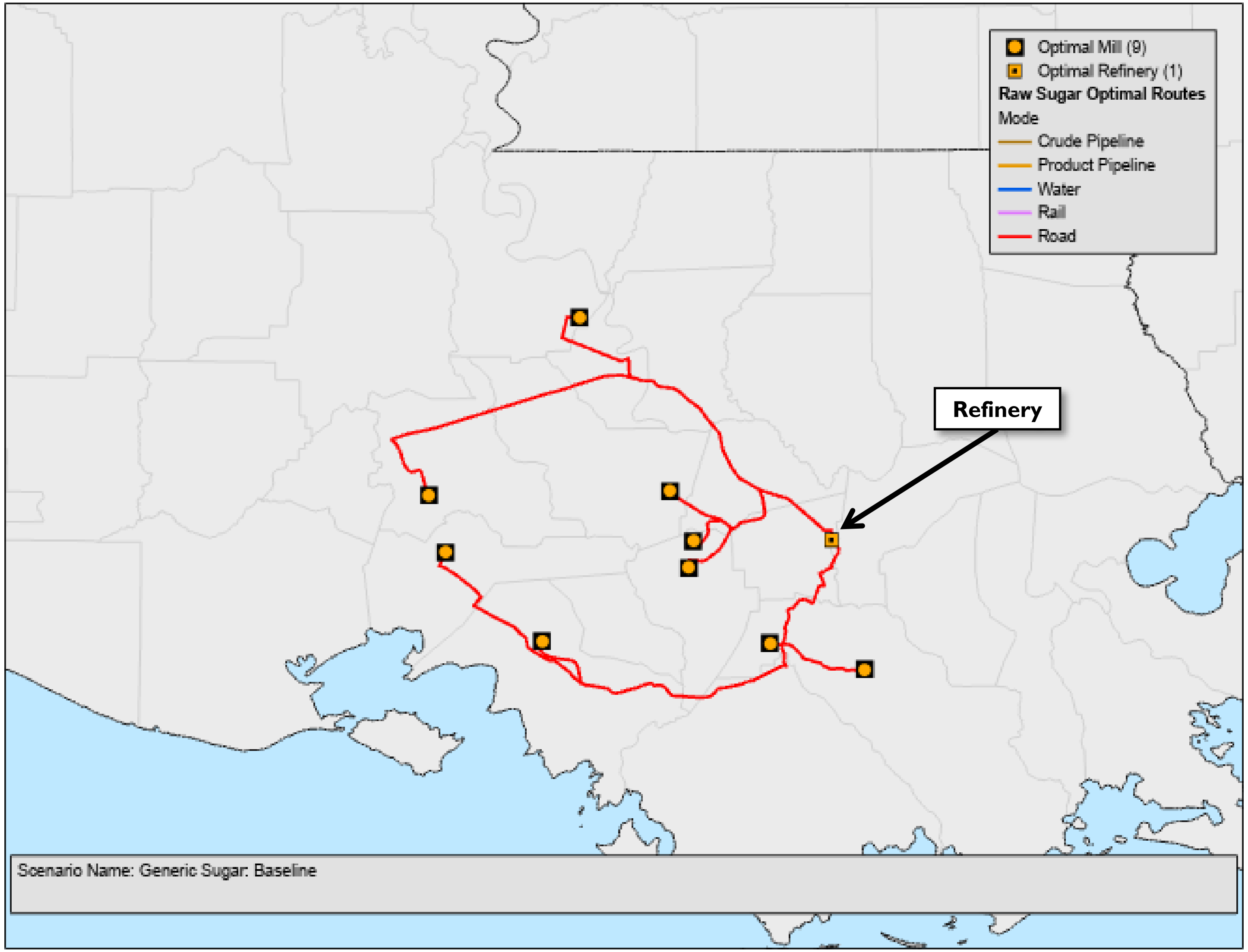
RMP → Mill



Baseline Scenario – *Optimal Solution (Cont.)*

Raw sugar

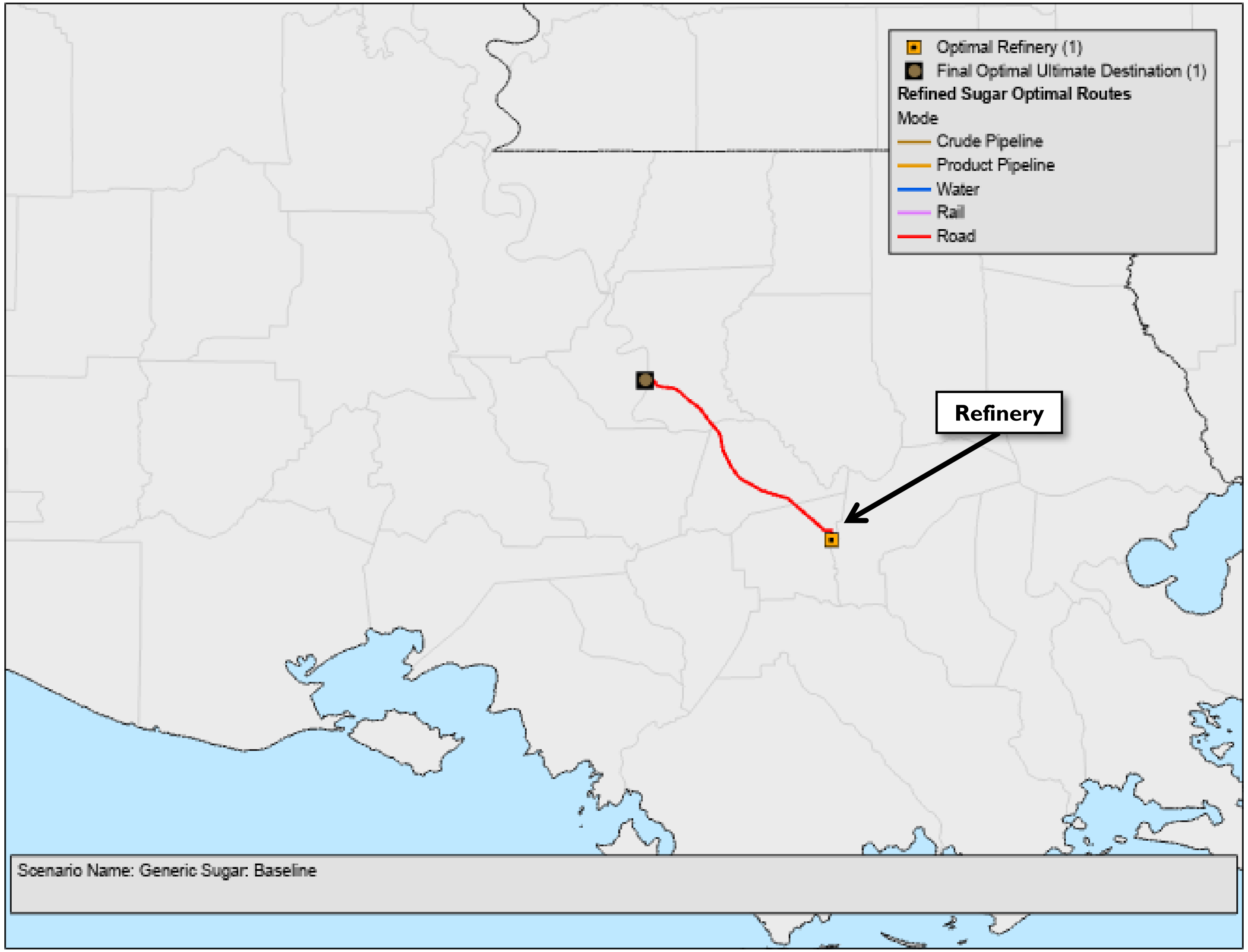
Mill → Refinery



Baseline Scenario – *Optimal Solution (Cont.)*

Refined sugar

Refinery → Port

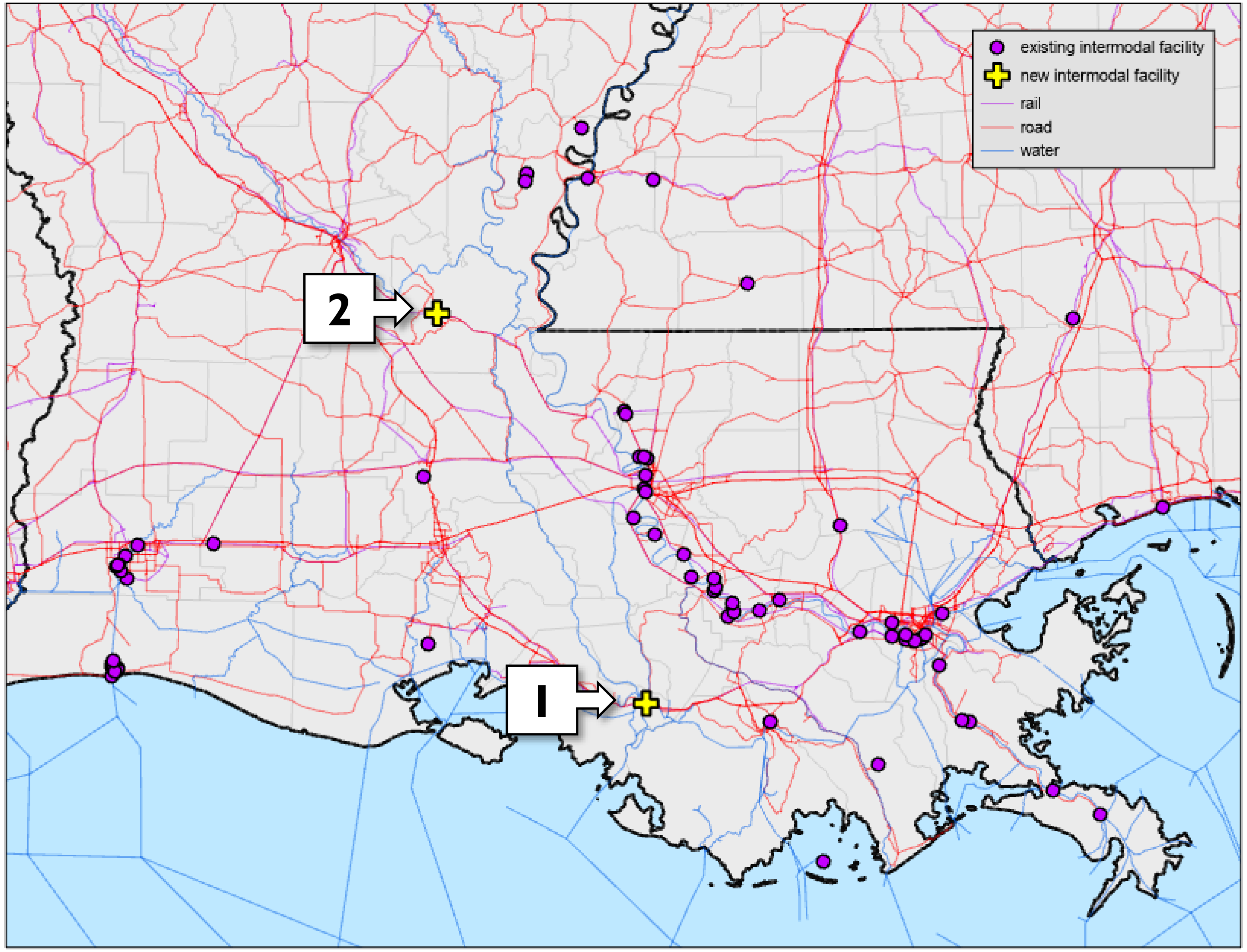


Two “New Intermodal Facility” Scenarios

Available connections:

1: road, rail, water

2: road, rail



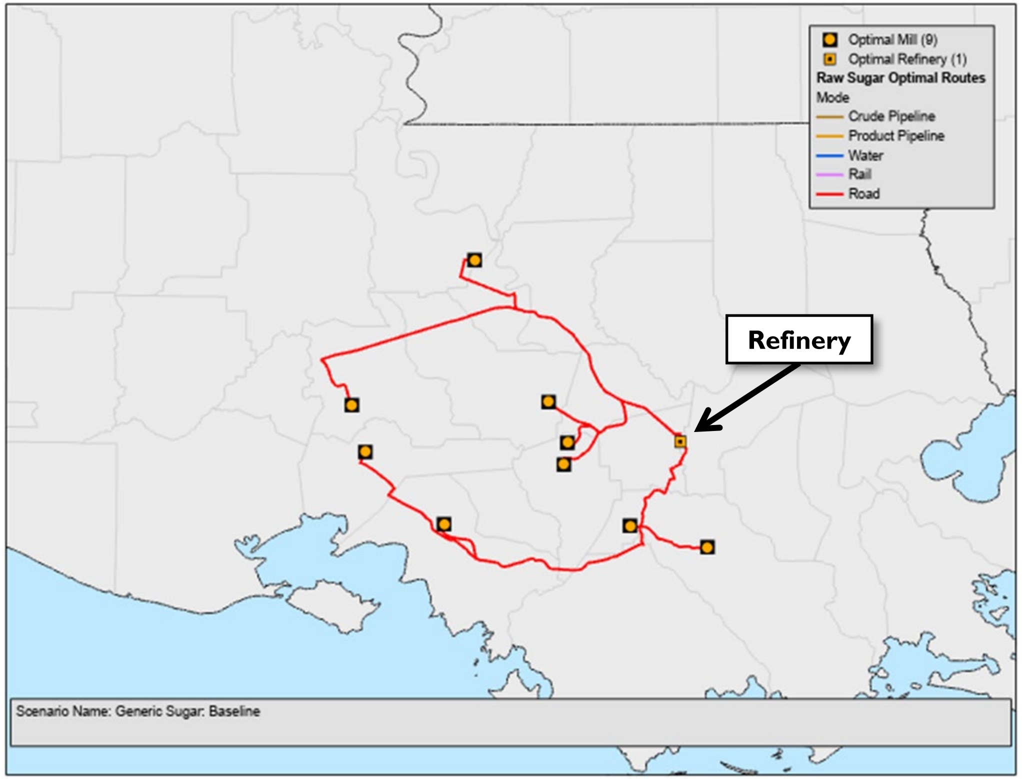
Intermodal Facility #1

Changes for transport of <u>raw sugar</u>:

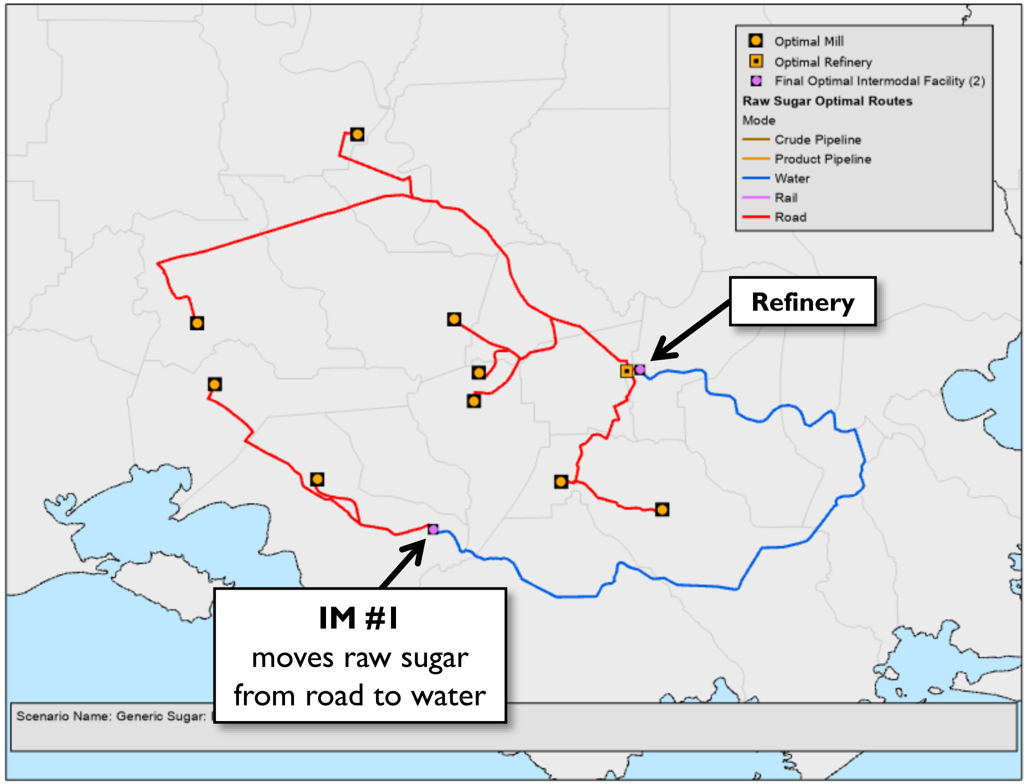
↓ 9.4%	↓ 28%	↓ 1.7%	↑ 27.4%
Road Network (Miles)	Road Vehicle-Miles Traveled	Routing Cost (USD)	CO_2 Emissions (Metric Tons)

- Reroutes raw sugar

Baseline



With Intermodal Facility #1



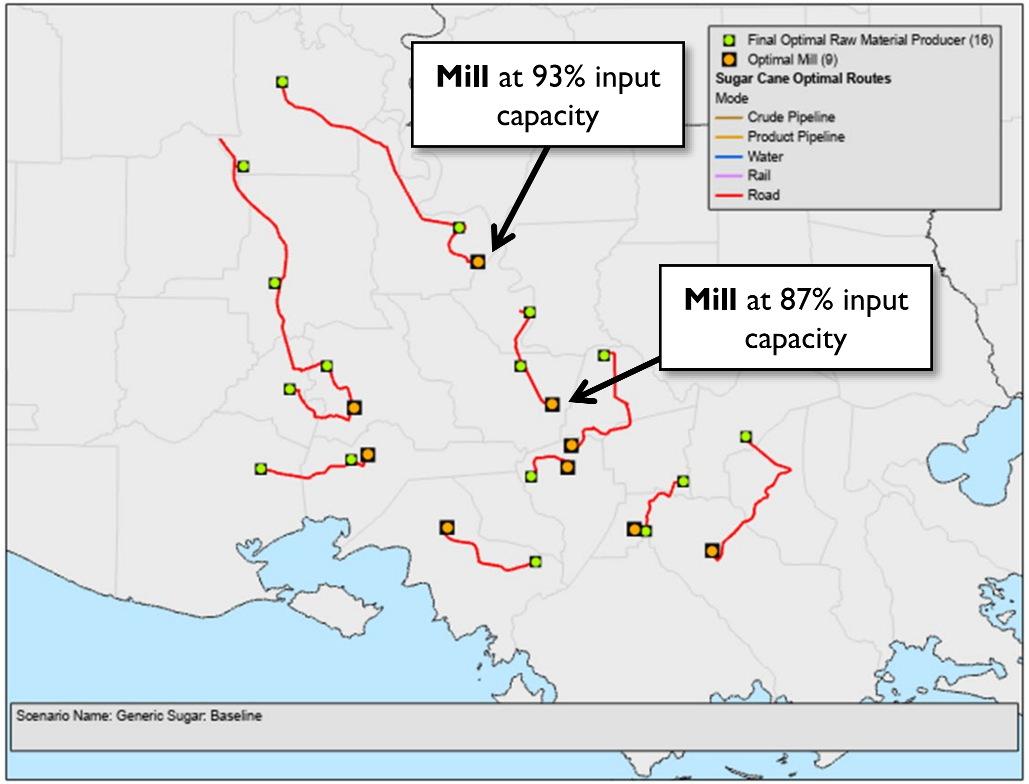
Intermodal Facility #2

- Reroutes sugar cane

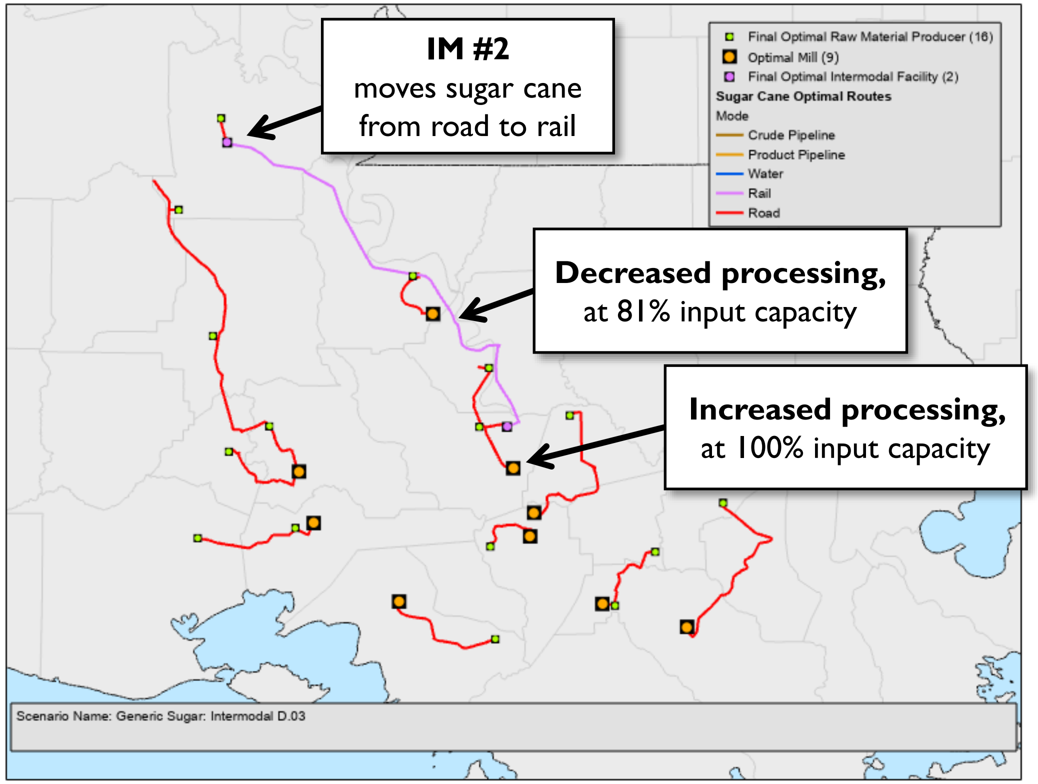
Changes for transport of sugar cane:

↓ 12%	↓ 4.5%	Little Change	↓ 0.7%
Road Network (Miles)	Road Vehicle-Miles Traveled	Routing Cost (USD)	CO_2 Emissions (Metric Tons)

Baseline



With Intermodal Facility #2



Scenario Comparison

- **Intermodal facility #1** *(road, rail, water)*
  - Moves raw sugar to water and **reduces road use** in terms of miles of network used and vehicle miles traveled.
  - **Increases overall emissions** due to use of long waterway route.

- **Intermodal facility #2** *(road, rail)*
  - Moves sugar cane to rail and **reduces road use**.
  - **Reduces overall emissions**.

Note: The Louisiana baseline sugar supply chain scenario was developed in collaboration with the American Sugar Cane League. The variant scenarios are hypothetical cases to demonstrate FTOT functionality and do not reflect real-world regional planning or analysis.

FTOT Example Scenarios

Sugar Supply Chain

+ *Network Disruption*

Introduction

Objectives

- Explore potential impacts of a hypothetical network disruption on a real-world supply chain.
- Assess the potential of a strategically placed intermodal facility to mitigate those impacts.

Overview

- Baseline: Processing of Louisiana sugar cane into raw sugar and then refined sugar delivered to the Port of Baton Rouge.
- Disruption: Removal of select road and rail bridges due to a hypothetical flooding event.
- Disruption + New Intermodal Facility: Removal of select road and rail bridges due to a hypothetical flooding event with the addition of a new, strategically placed intermodal facility.

Questions Explored

- How will disruption of key road and rail links impact freight routing?
- How will flows on individual links change as a result, and what are the planning implications?
- How could a new (hypothetical) intermodal facility affect likely mode choice? Could the new facility help mitigate the impacts of a disruption?

Note: The LA baseline sugar supply chain scenario was developed in collaboration with the American Sugar Cane League. The variant scenarios are hypothetical cases to demonstrate FTOT functionality and do not reflect real-world regional planning or analysis.

Baseline Scenario – *Supply Chain*

Louisiana sugar supply chain

Sugar Cane Producer → *sugar cane* → **Sugar Mill** → *raw sugar* → **Sugar Refinery** → *refined sugar* → **Port**

<u>Raw Material Producer</u> (Sugar Cane Producer)
- 16 facilities
- Available supply of 227,500 to 1,918,000 tons sugar cane per facility

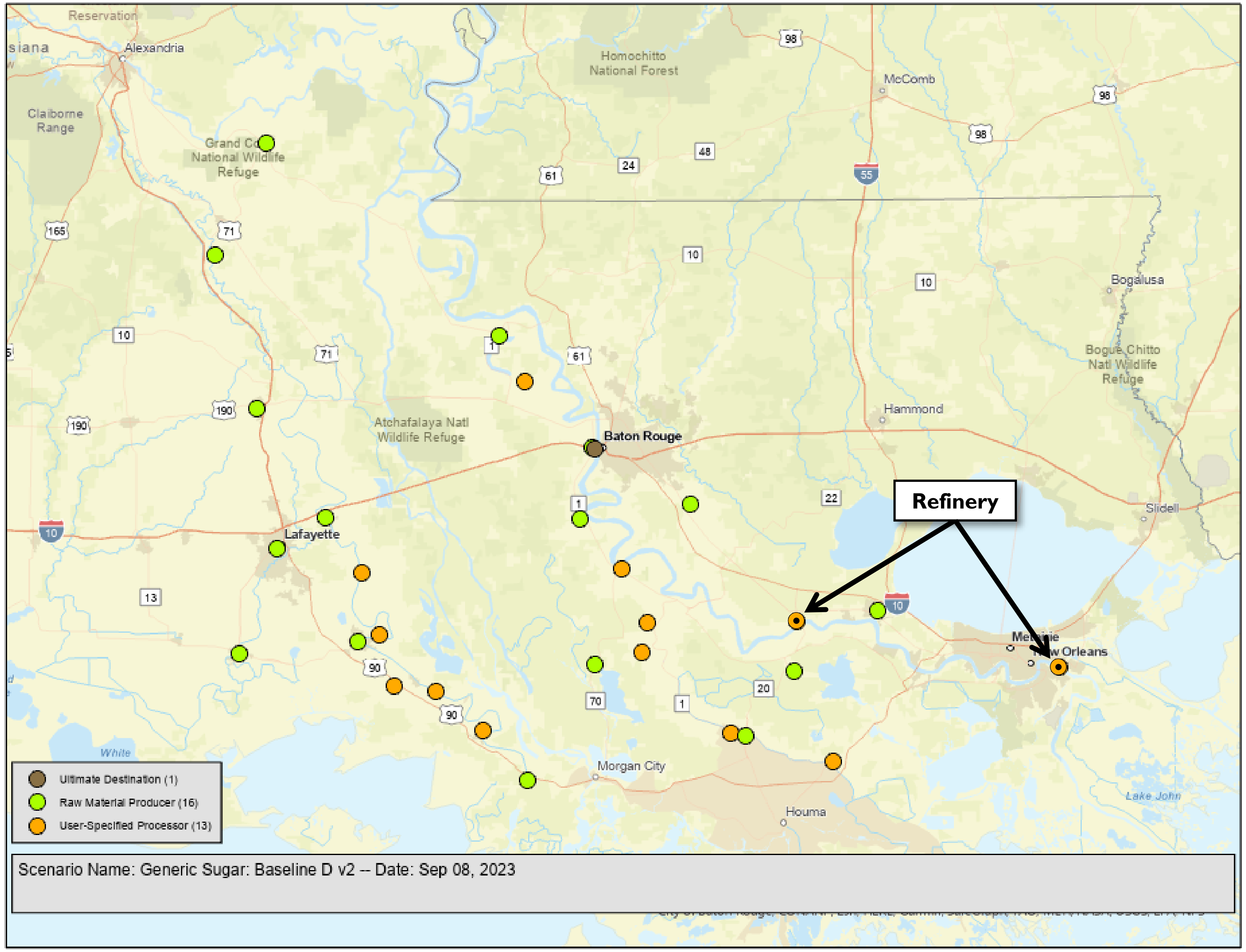
<u>Processor</u> (Sugar Mill)
- 11 facilities
- 11.5% processing efficiency

<u>Processor</u> (Sugar Refinery)
- 2 facilities
- 100% processing efficiency

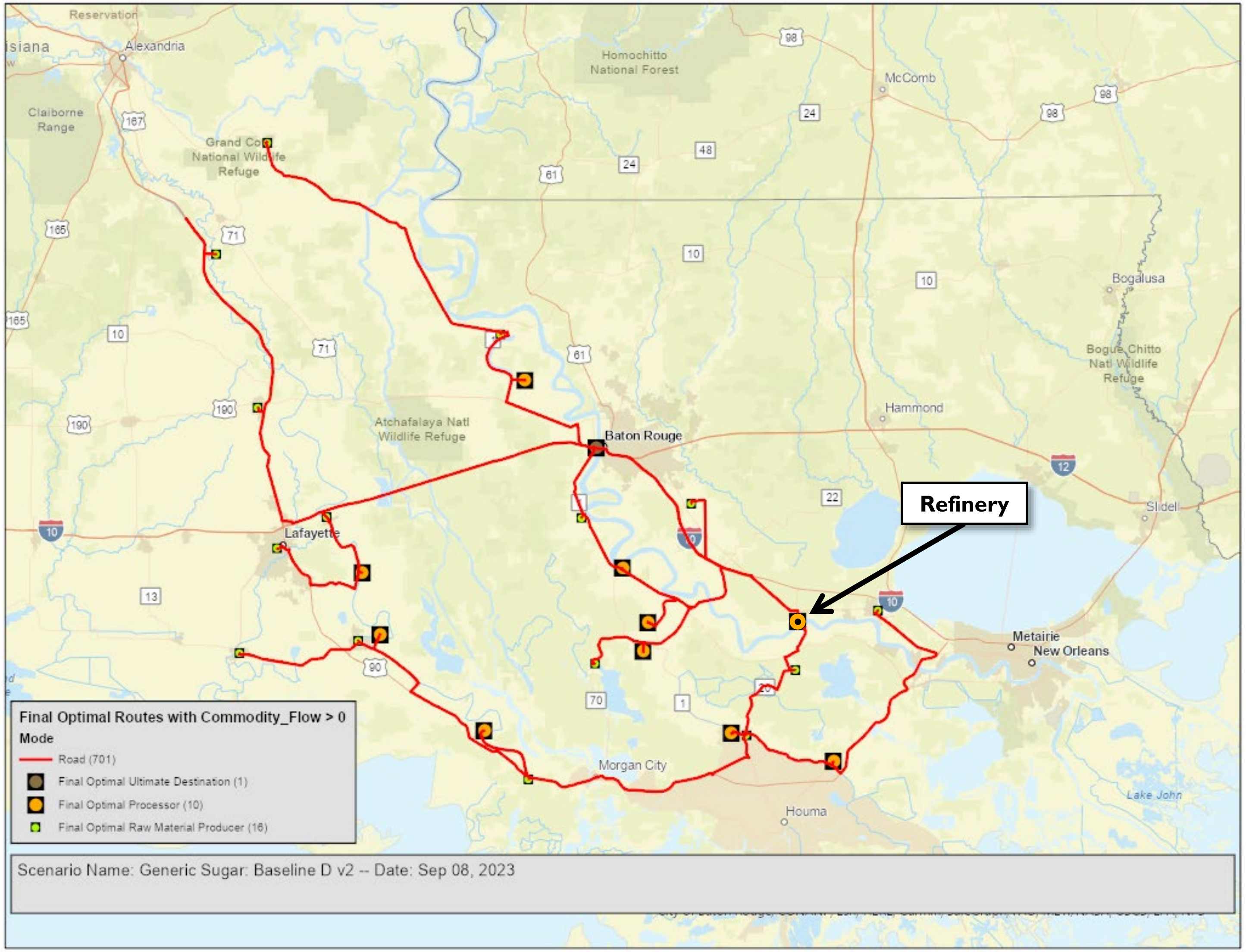
<u>Ultimate Destination</u> (Port)
- 1 facility
- Total demand of 10 million tons refined sugar

Note: The LA baseline sugar supply chain scenario was developed in collaboration with the American Sugar Cane League. The variant scenarios are hypothetical cases to demonstrate FTOT functionality and do not reflect real-world regional planning or analysis.

Baseline Scenario – *Facility Locations*



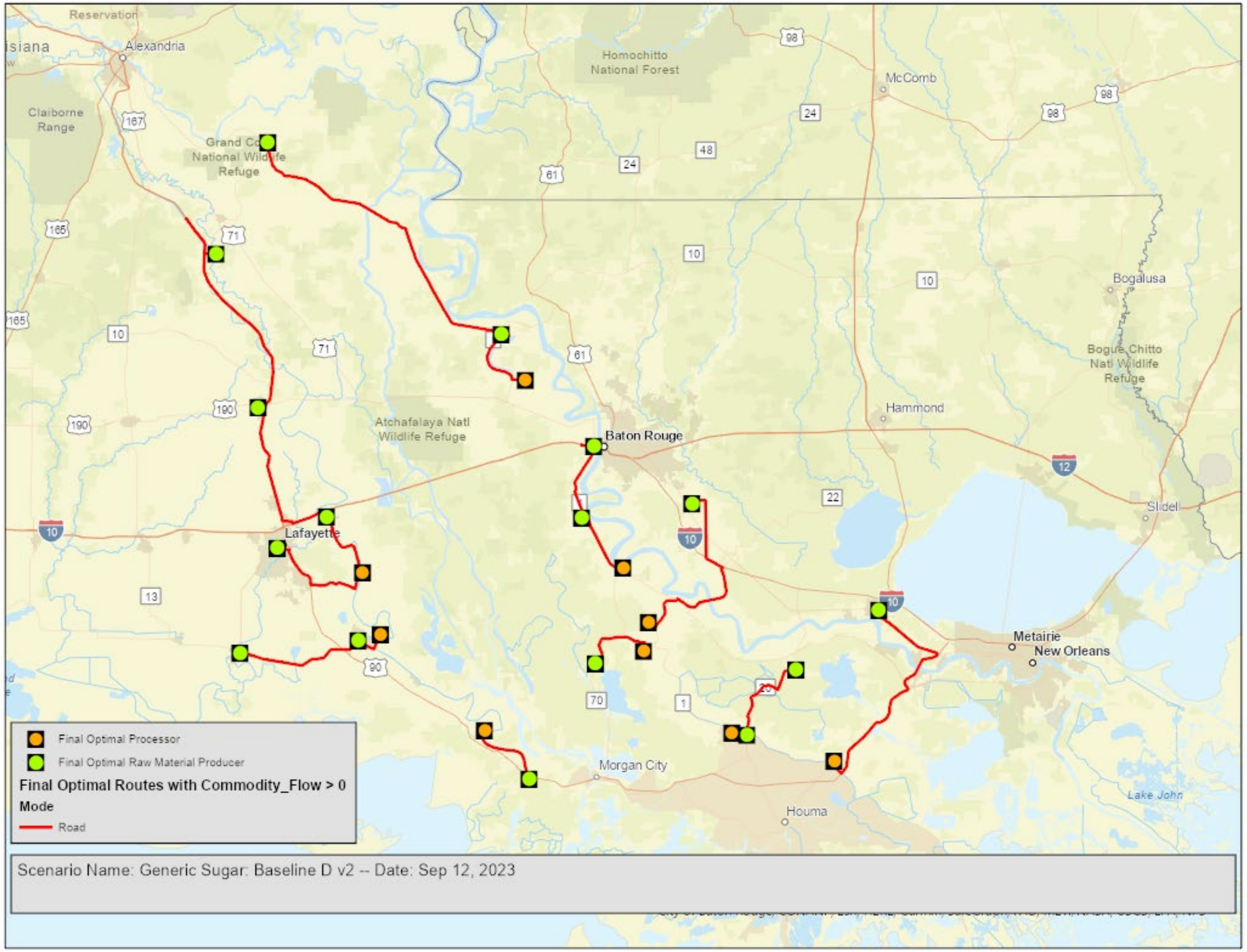
Baseline Scenario – *Optimal Solution*



Baseline Scenario – *Optimal Solution (Cont.)*

Sugar cane

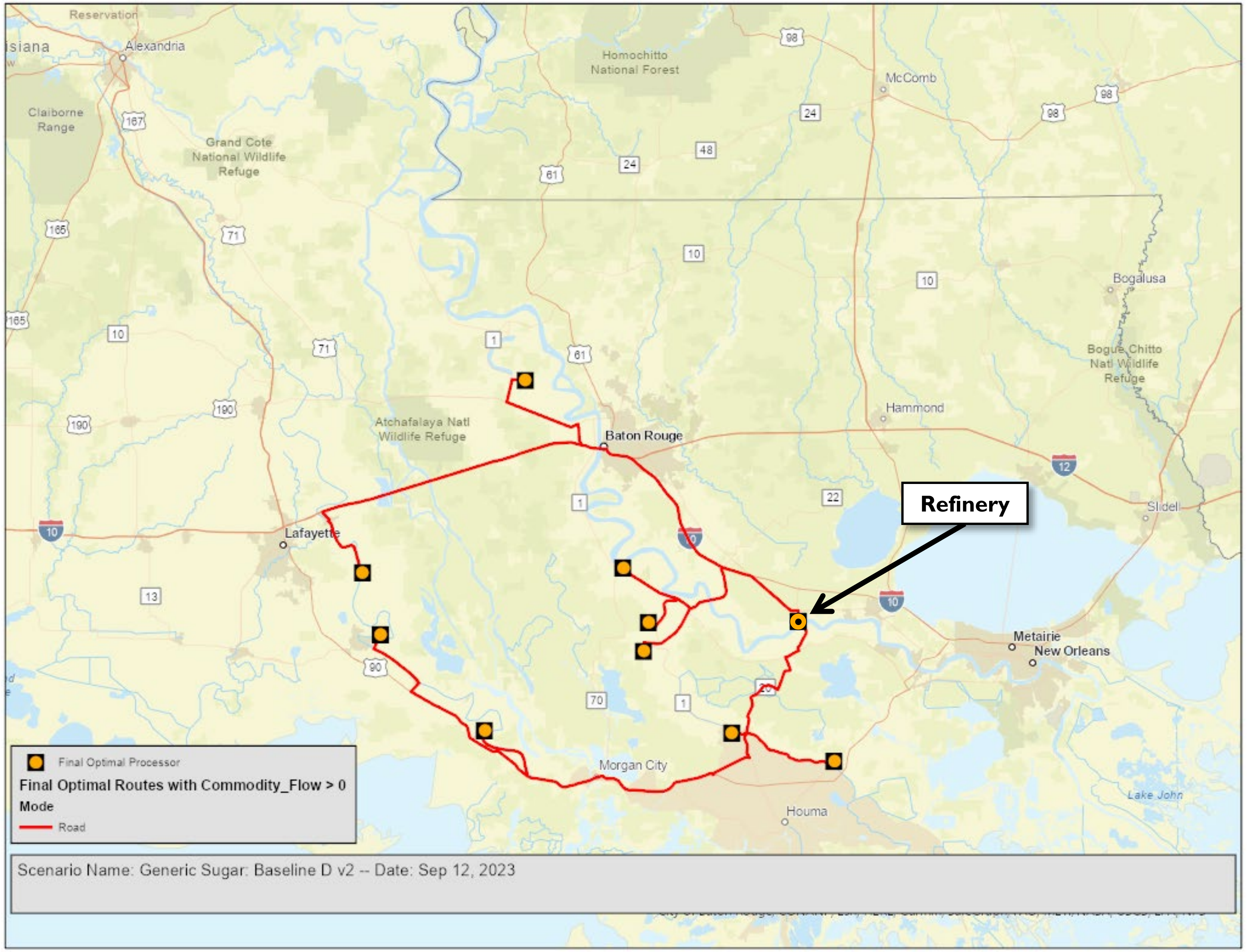
RMP → Mill



Baseline Scenario – *Optimal Solution (Cont.)*

Raw sugar

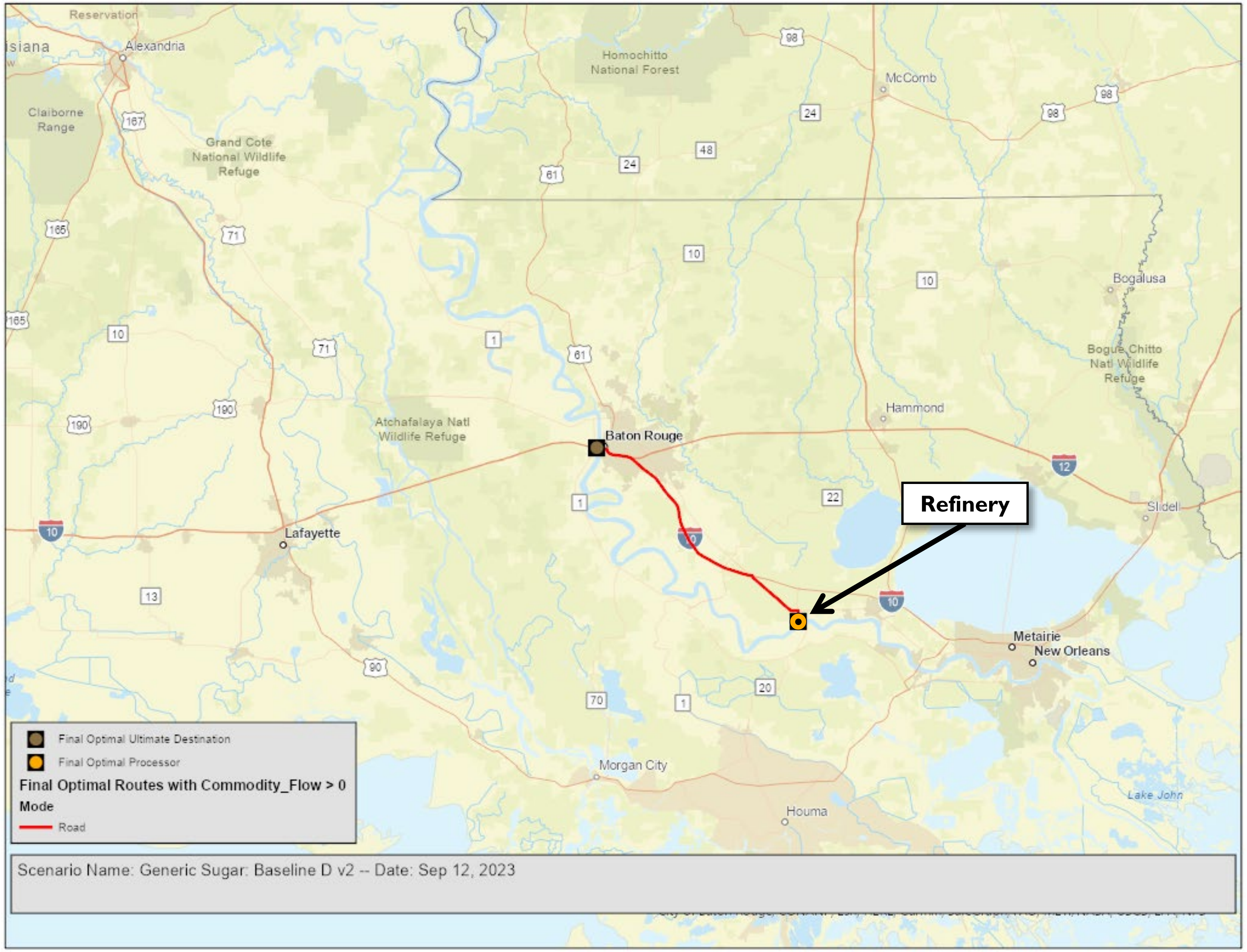
Mill → Refinery



Baseline Scenario – *Optimal Solution (Cont.)*

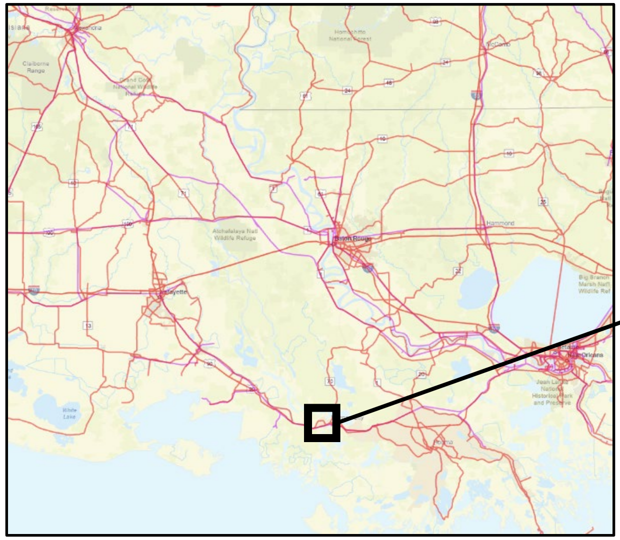
Refined sugar

Refinery → Port



Disruption Scenario – *Atchafalaya River*

- Hypothetical hazard scenario: flooding leads to long-term closure of network links over the Atchafalaya River connecting Berwick, LA with Morgan City, LA following storm surge from hurricane.
- Impacts of hazard:
  - Closes two road bridges (US 90 and LA 182).
  - Closes one rail bridge (BNSF).
  - Waterway resumes normal operations.



Note: This is a hypothetical disruption scenario to demonstrate FTOT functionality and is not based on an historical event.

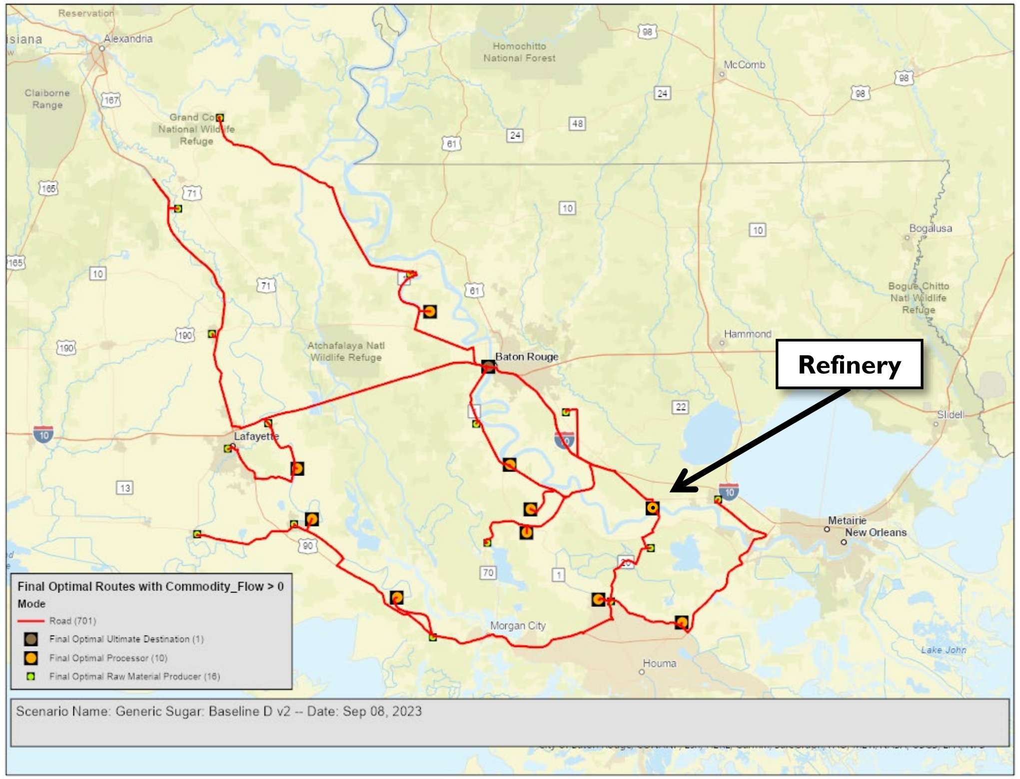
Disruption Scenario

Changes for transport of raw sugar:

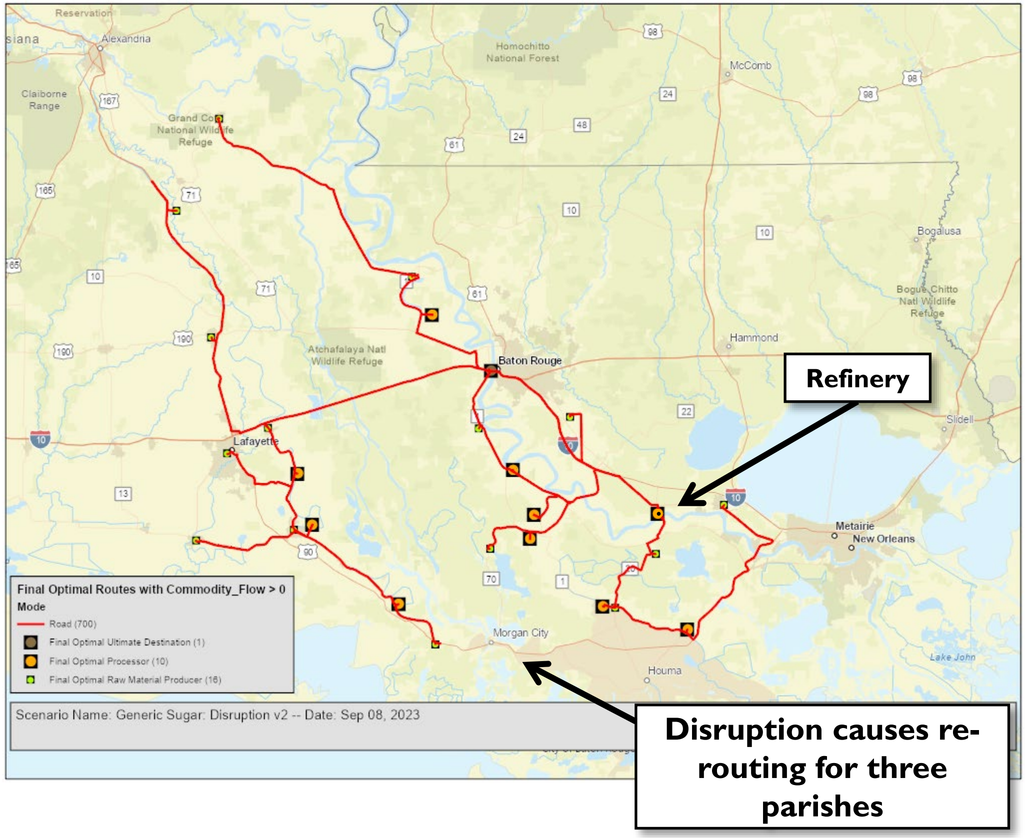
↑ 15% Road Vehicle-Miles Traveled	↑ 15% Transport Cost (USD)	↑ 15% CO_2 Emissions (Metric Tons)

- Reroutes raw sugar processed from three parishes at two mills to take a more northward route.

Baseline



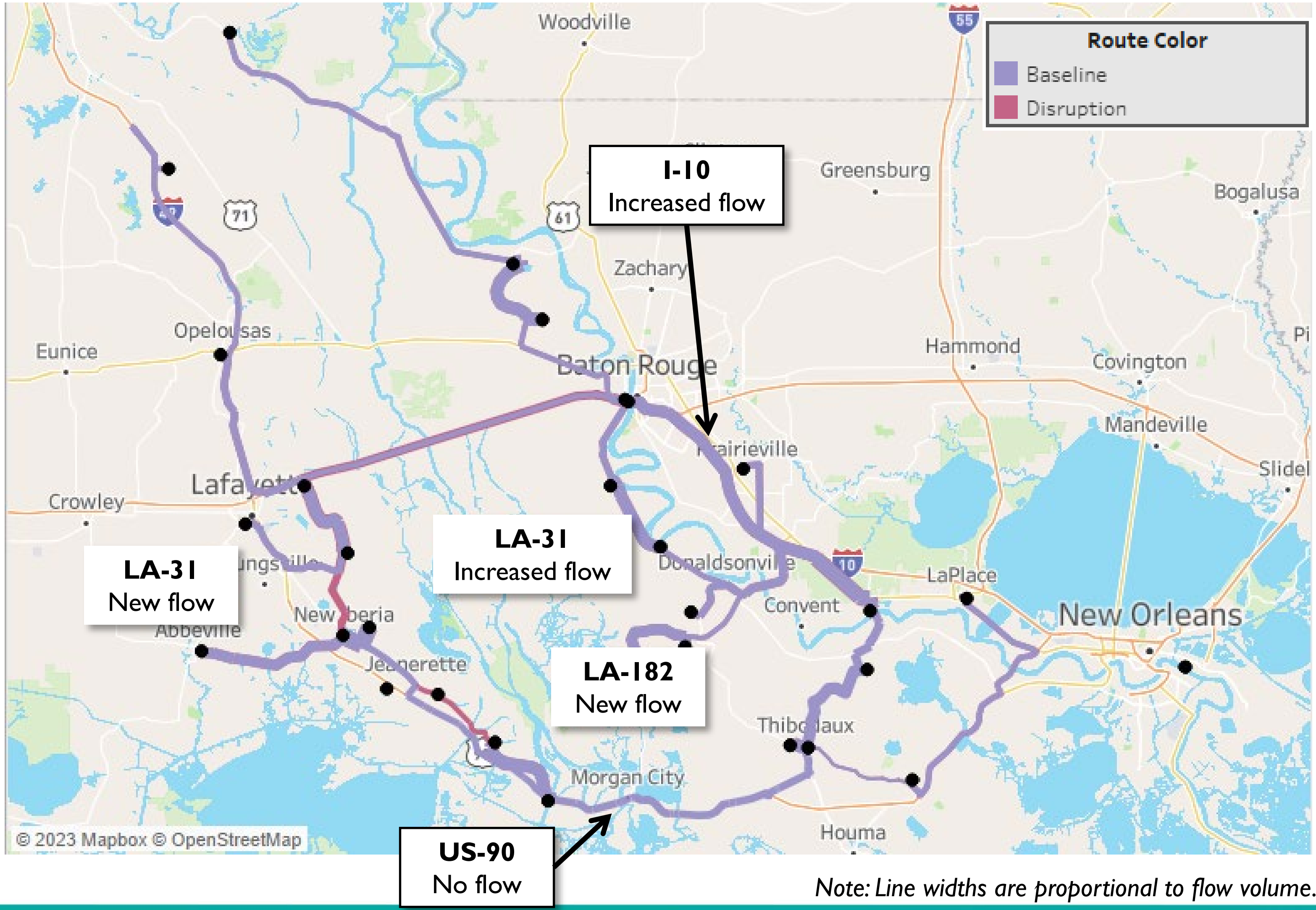
Disruption



Note: This is a hypothetical disruption scenario to demonstrate FTOT functionality and is not based on an historical event.

Disruption Scenario – *Changes in Road Use*

- Changes in road use from rerouted raw sugar.
- New roads used:
  - **LA-182** from Franklin to Jeanerette (14 miles)
  - **LA-31** from New Iberia to St. Martinville (10 miles)
  - *Additional 160K metric tons on LA-182 and 482K metric tons on LA-31*
- Increased road use:
  - **LA-31** from St. Martinville to Breaux Bridge (16 miles)
  - **I-10** from Breaux Bridge to Gramercy (72 miles)
  - *Additional 482K metric tons on LA-31 and I-10*
- Roads no longer used:
  - **US-90** from Jeanerette to Thibodaux (66 miles)



Note: Line widths are proportional to flow volume.

Note: This is a hypothetical disruption scenario to demonstrate FTOT functionality and is not based on an historical event.

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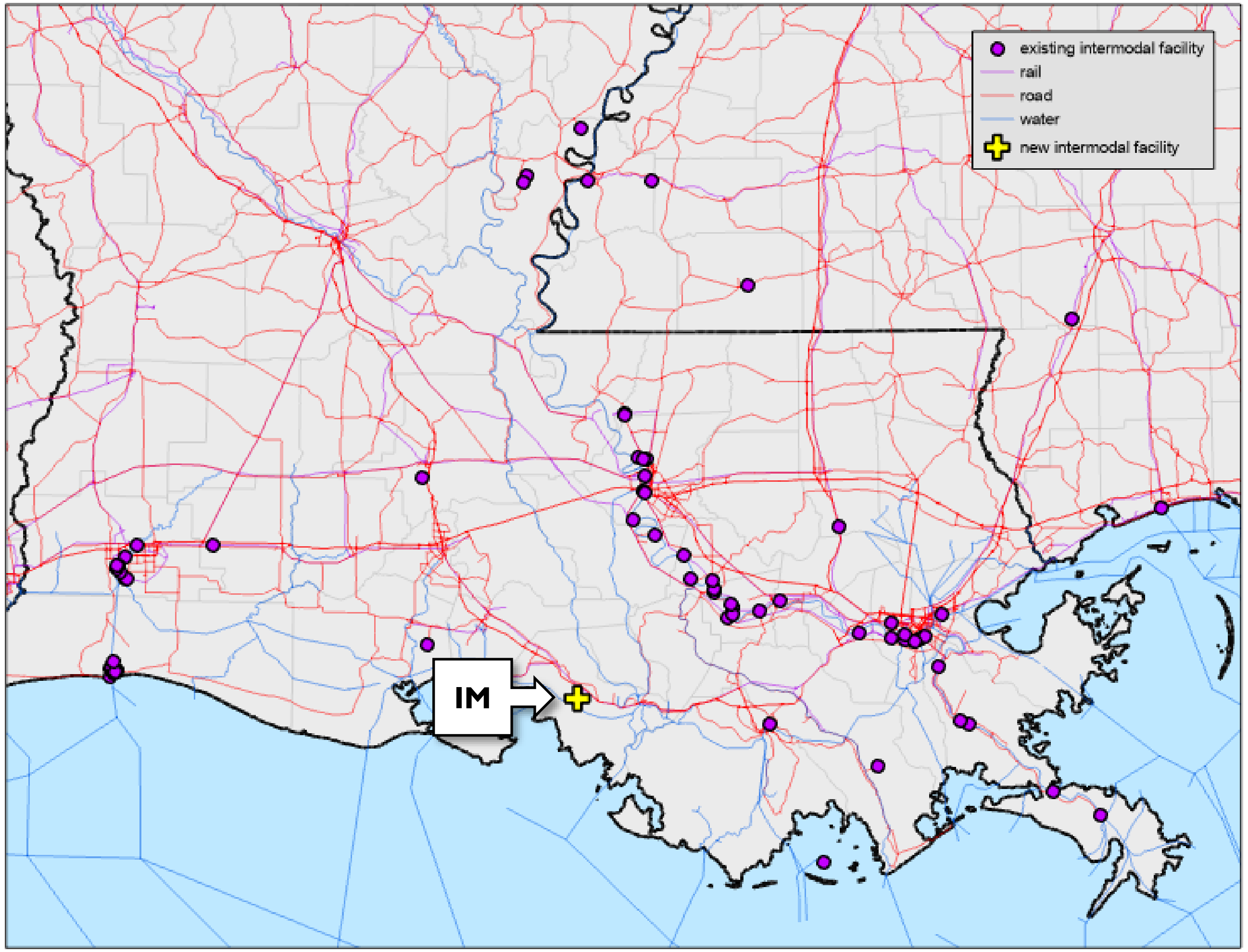
“Disruption + New Intermodal Facility” Scenario

Evaluated whether hypothetical new IM facility would mitigate impacts of the network disruption.

Hypothetical new intermodal (IM) facility:

- Located in St. Mary Parish
- Has road, rail, and water connections



Note: This is a hypothetical facility scenario to demonstrate FTOT functionality and is not based on real-world planning or analysis.

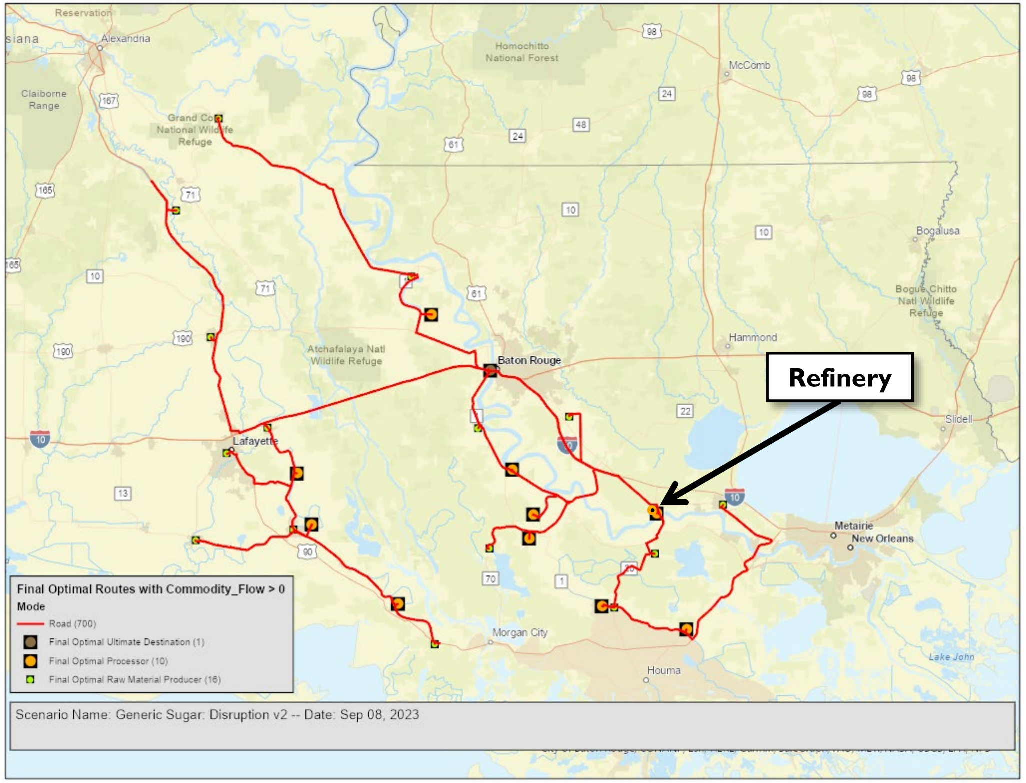
Disruption + IM Facility

Changes for transport of <u>raw sugar</u>:

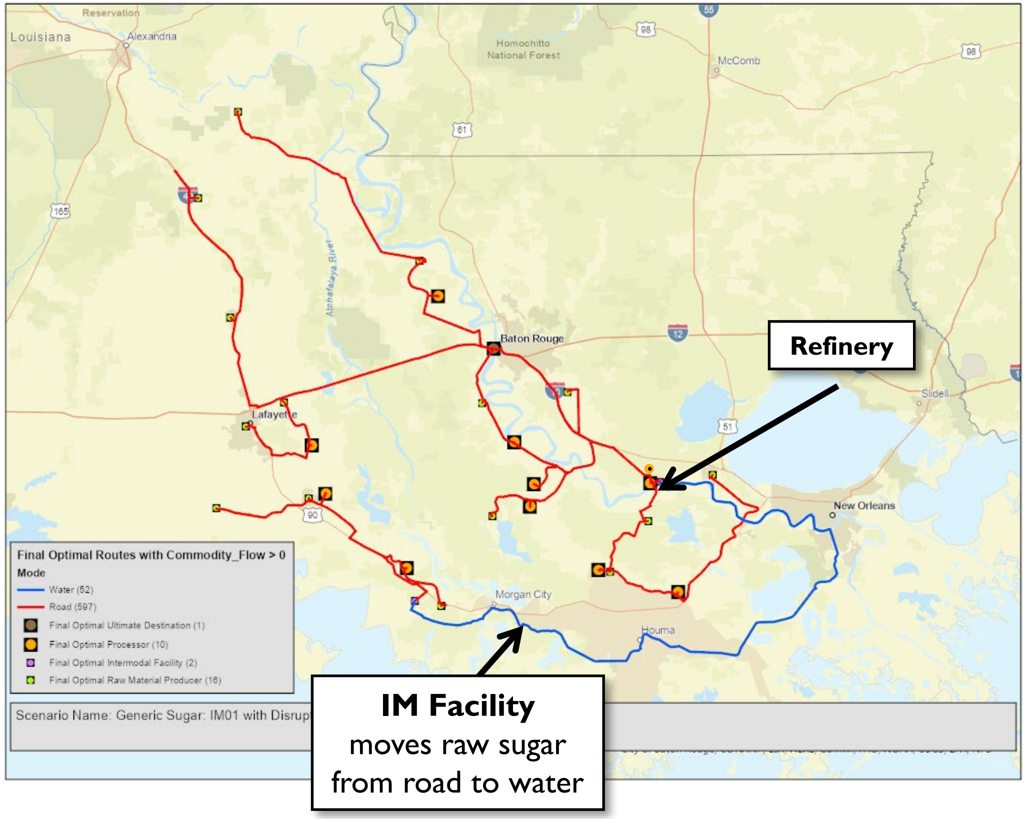
↓ 42%	↓ 16%	↑ 12%
Road Vehicle-Miles Traveled	**Transport Cost (USD)**	**CO_2 Emissions (Metric Tons)**

- Reroutes raw sugar.

Disruption

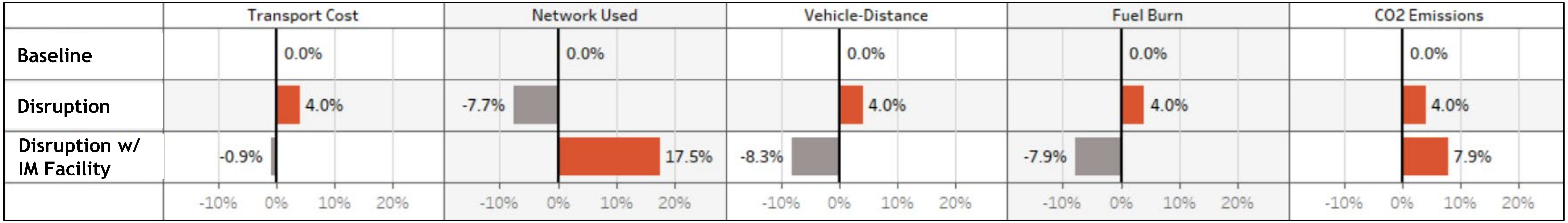


Disruption with IM Facility



Scenario Comparison

- Network disruption **increases costs, vehicle miles traveled, and fuel burn**, but **new IM facility mitigates those impacts**.
- Mode shift with new intermodal facility from road to water **increases CO2 emissions** due to longer distance traveled.



Note: The “network used” metric currently sums up miles of network considering each commodity independently. As a result, network links used for multiple commodities will be counted more than once.

FTOT Example Scenarios

Generalized Freight

+ *Existing and Planned Inland Ports*

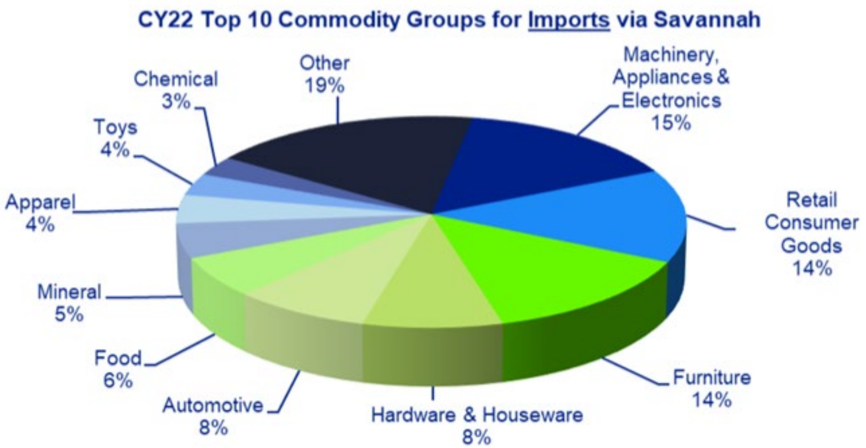
Introduction

- **Objectives**
  - Demonstrate a generalized freight scenario showing regional freight patterns based on public data.
  - Assess potential effects of an additional intermodal facility on freight flows in the region.
  - Assess potential disruption to original intermodal facility and effects on freight flows in the region.
- **Overview**
  - Baseline: Freight moves by rail from Port of Savannah to the Appalachian Regional Port (ARP) and then by truck to 14 metropolitan areas.
  - New Port: Addition of a second inland port proposed by Georgia Ports Authority.
  - Disruption: Knocks out the ARP and assesses effect on freight flows that results from only using the proposed second inland port.
- **Questions Explored**
  - How might the proposed second inland port affect the routing of freight?
  - If a disruption takes the existing ARP offline, how will transport patterns change?

Note: The GA scenarios are hypothetical based on public data/generalized assumptions to demonstrate FTOT functionality and do not reflect detailed regional planning or analysis.

About the Port of Savannah

- **Third busiest port in the U.S.**
  - Handled <u>4.7 million TEUs</u> (Twenty Foot Equivalent Container Units) of exports and imports in 2020.
  - Equivalent to about 9.3 percent of total containerized cargo volume in the U.S.
- **Top import commodity groups (2022):**
  - Machinery, Appliances, and Electronics → 433,627 TEUs
  - Retail Consumer Goods → 404,457 TEUs
  - Furniture → 384,182 TEUs
- **Extensive rail connections**
  - Has two Class I railroads at the port terminal.
  - Plans for a $128 million project to increase rail capacity.



Source: Georgia Ports Authority (2023)

Data Sources:
- https://seda.org/do-business-here/infrastructure/
- https://gaports.com/sales/by-the-numbers/
- http://savannah.uberflip.com/i/1489710-2023-economic-trends-brochure/53

Baseline Scenario – *Supply Chain*

Generalized freight supply chain in Georgia

bulk freight | **parcel freight**

Port of Savannah → by rail → Inland Port → by road → County Destinations

Raw Material Producer

- 1 facility
- Supply of 924,360 metric tons (see next slide)

Processor

- 100% processing efficiency

Ultimate Destinations

- 14 counties with large cities/towns
- Total demand matches supply and is apportioned by real-world commodity flows and population (see next slide)

Note: The GA scenarios are hypothetical based on public data/generalized assumptions to demonstrate FTOT functionality and do not reflect detailed regional planning or analysis.

Baseline Scenario – *Using Public Data*

1. Estimate the volume of freight flowing inland from Port of Savannah:

a) Port of Savannah handled 1.13 million TEUs in loaded imports in FY2023. **[1]**
b) Around 21.6% of these TEUs travel intermodally. **[2]**
c) Assume 24 metric tons per TEU (weight when full). **[3]**
d) Calculated Total Intermodal Supply from Savannah → 5,857,920 metric tons of intermodal cargo from Port of Savannah.
e) Of total flow from Savannah in the Commodity Flow Survey (CFS, for 2017), 16% went to the 13 CFS regions containing the 14 destinations. **[4]**
f) **Calculated Supply for Scenario** → 924,360 metric tons of "bulk freight" flowing from Port of Savannah through intermodal ports to 14 scenario destinations.

2. Determine locations of the existing and planned intermodal ports:

a) Existing ARP → Murray County, GA [5]
b) Planned Northeast Georgia Inland Port → Hall County, GA [6] → Note: for use in variation scenario w/ two ports

3. Estimate a quantity demanded by select destinations:

a) Select counties containing larger cities or towns in Southeast and Central U.S.
b) Determine county populations using U.S. Census 2020 data. **[7]**
c) Assume 100% of scenario supply is demanded. Take the calculated flow to each CFS region and apportion it among destinations in that region according to population.
d) Calculated Demand for Scenario → **Ranging from 5,785 metric tons** of parcel freight in Hamilton County, OH (Cincinnati area) **to 406,255 metric tons** in Richland County, SC (Columbia area), according to county population.

When constructing scenarios, you can use specific quantities and locations if known. For this example, facilities are assumed to be counties' population centroids.

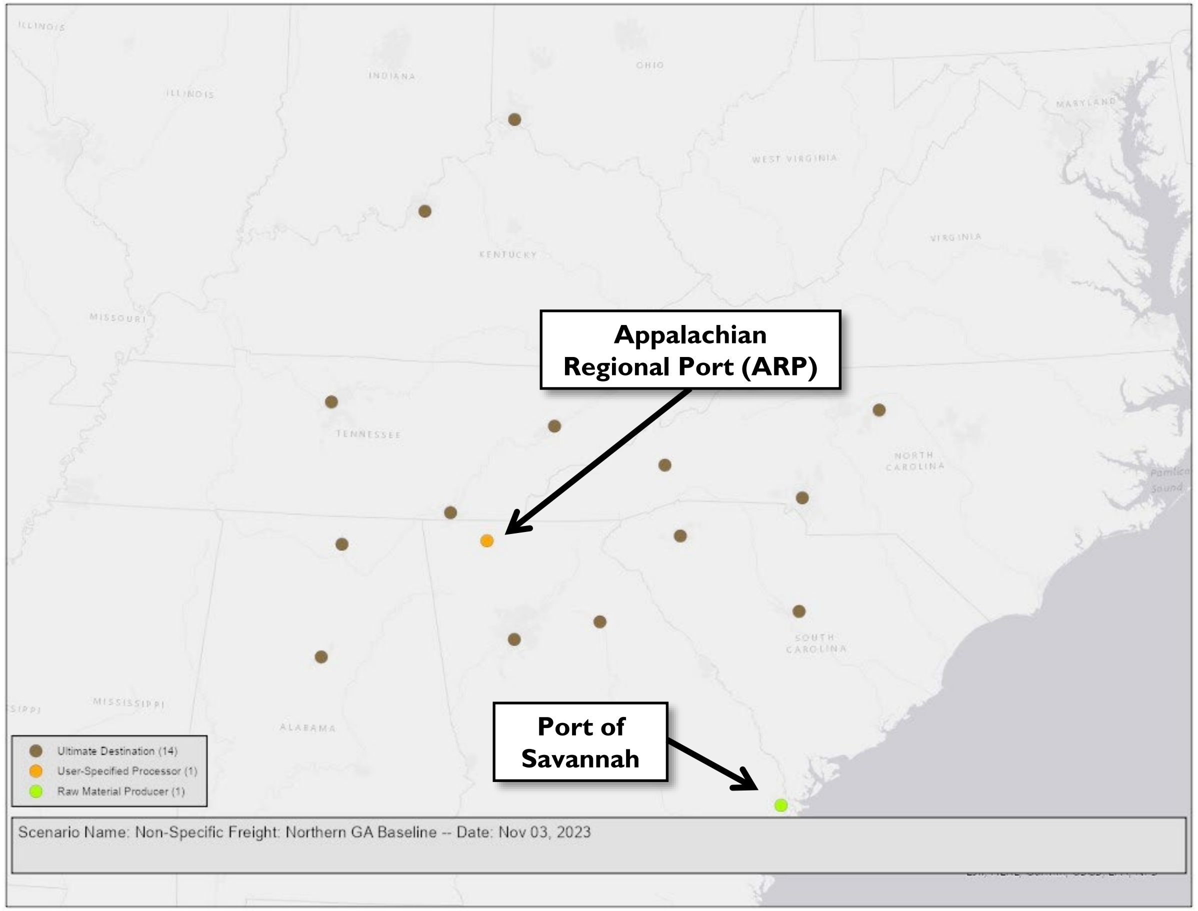
Data Sources:

1. https://www.freightwaves.com/news/georgia-ports-fiscal-year-volumes-slide-nearly-7
2. https://gaports.com/press-releases/gpa-prepares-for-the-future-adds-inland-rail-connectivity/
3. https://www.marineinsight.com/maritime-law/teu-in-shipping-everything-you-wanted-to-know/#:~:text=Logistics%20and%20shipping%20companies%20normally,kilograms%20(2.24%20metric%20tons
4. https://data.census.gov/table?q=cf1700a21&hidePreview=true&tid=CFSAREA2017.CF1700A21
5. https://gaports.com/facilities/inland-ports/appalachian-regional-port/
6. https://gaports.com/facilities/inland-ports/northeast-georgia-inland-port/
7. https://www.census.gov/data/tables/time-series/demo/popest/2020s-counties-total.html

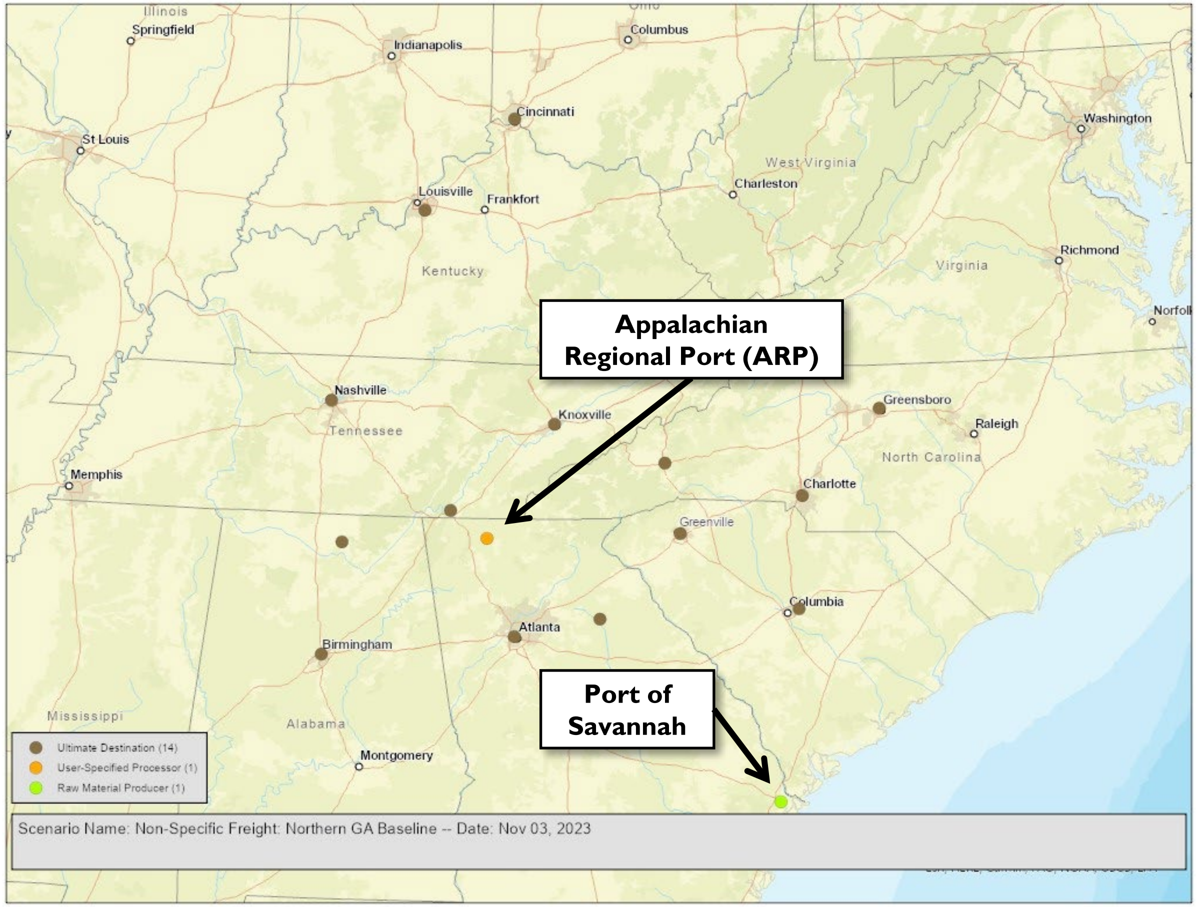
Note: The GA scenarios are hypothetical based on public data/generalized assumptions to demonstrate FTOT functionality and do not reflect detailed regional planning or analysis.

Baseline Scenario – *Facility Locations*

Gray Base Map

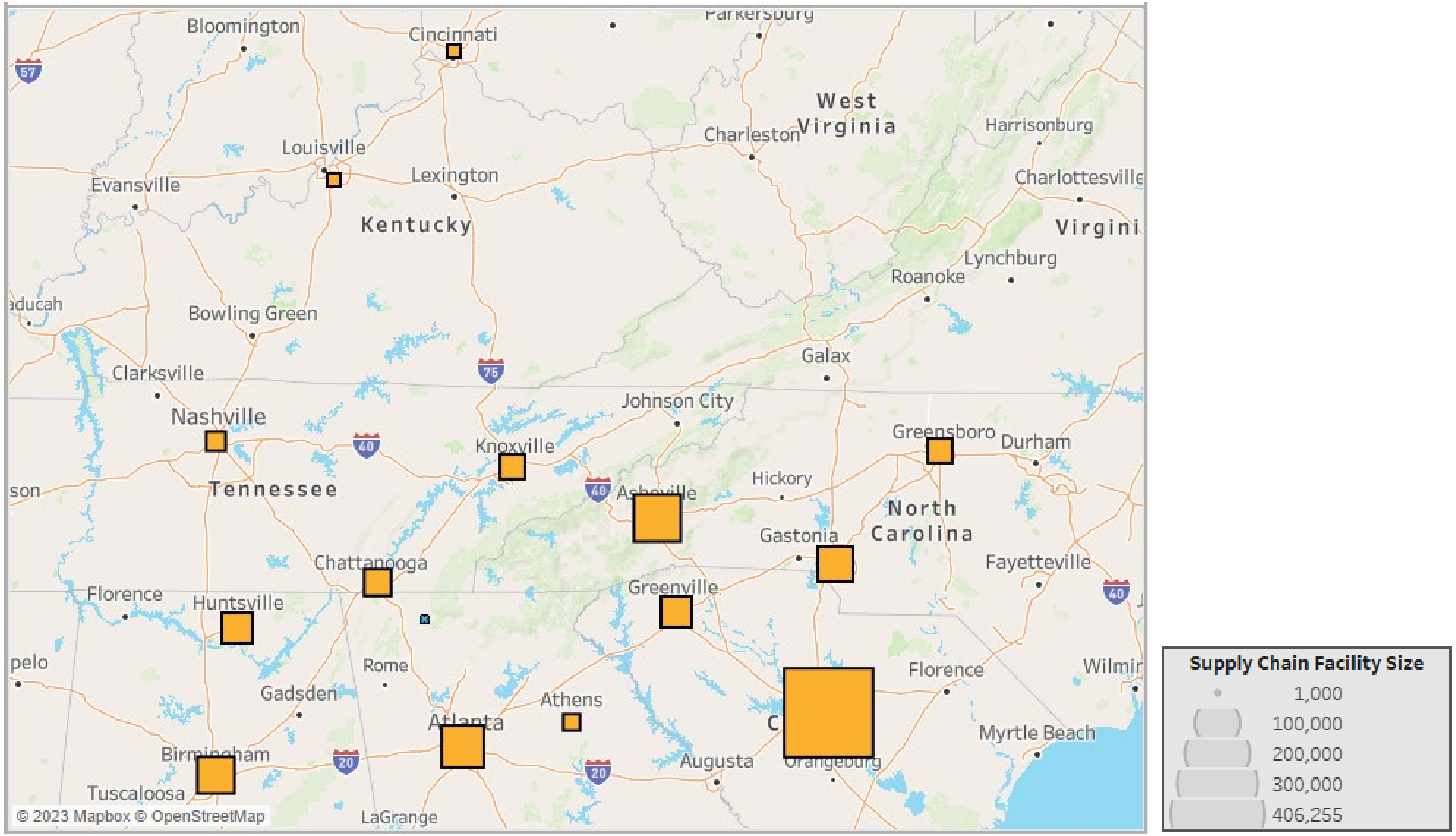


Street Base Map



Note: The GA scenarios are hypothetical based on public data/generalized assumptions to demonstrate FTOT functionality and do not reflect detailed regional planning or analysis.

Baseline Scenario – *Quantity Demanded*



Note: The GA scenarios are hypothetical based on public data/generalized assumptions to demonstrate FTOT functionality and do not reflect detailed regional planning or analysis.

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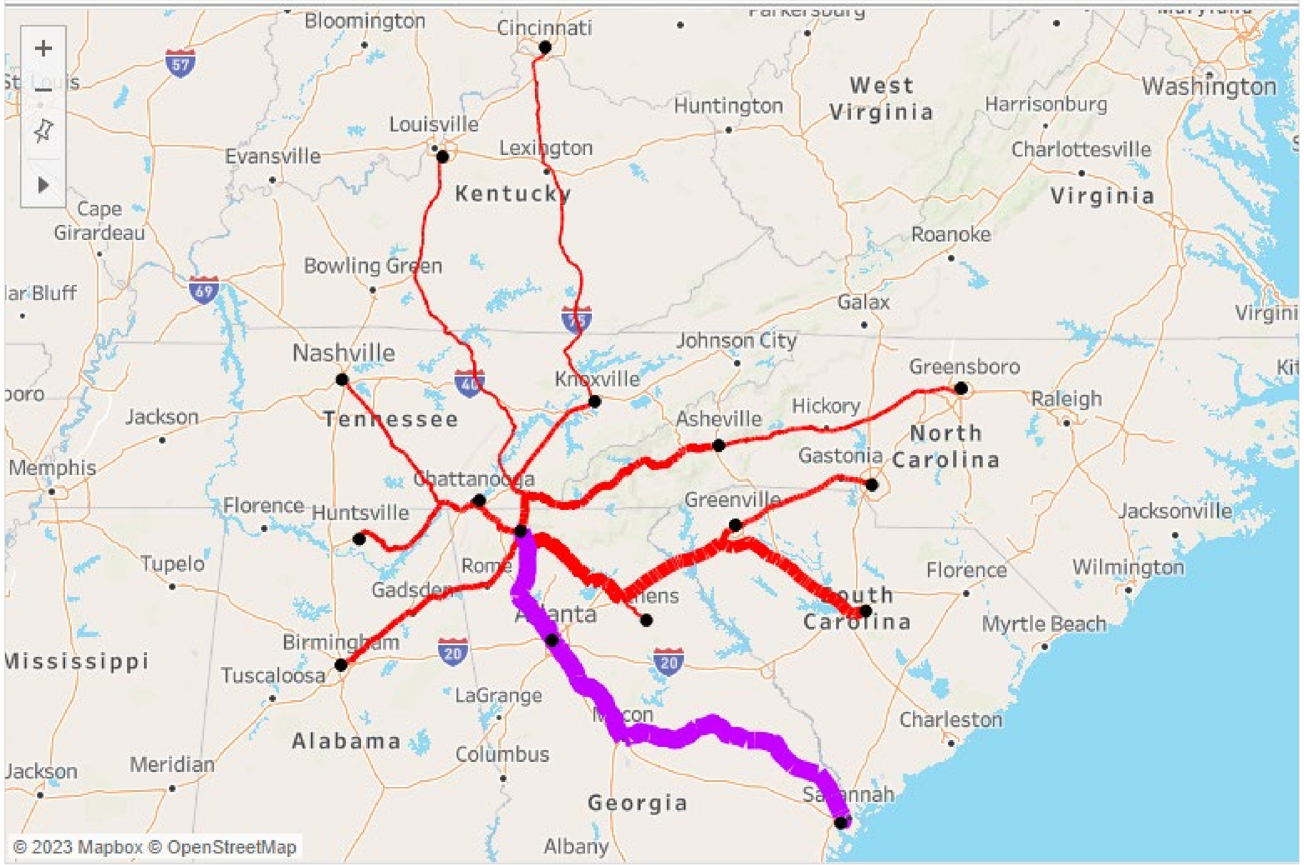
Baseline Scenario – *Optimal Solution*



Route Color
- Road
- Rail

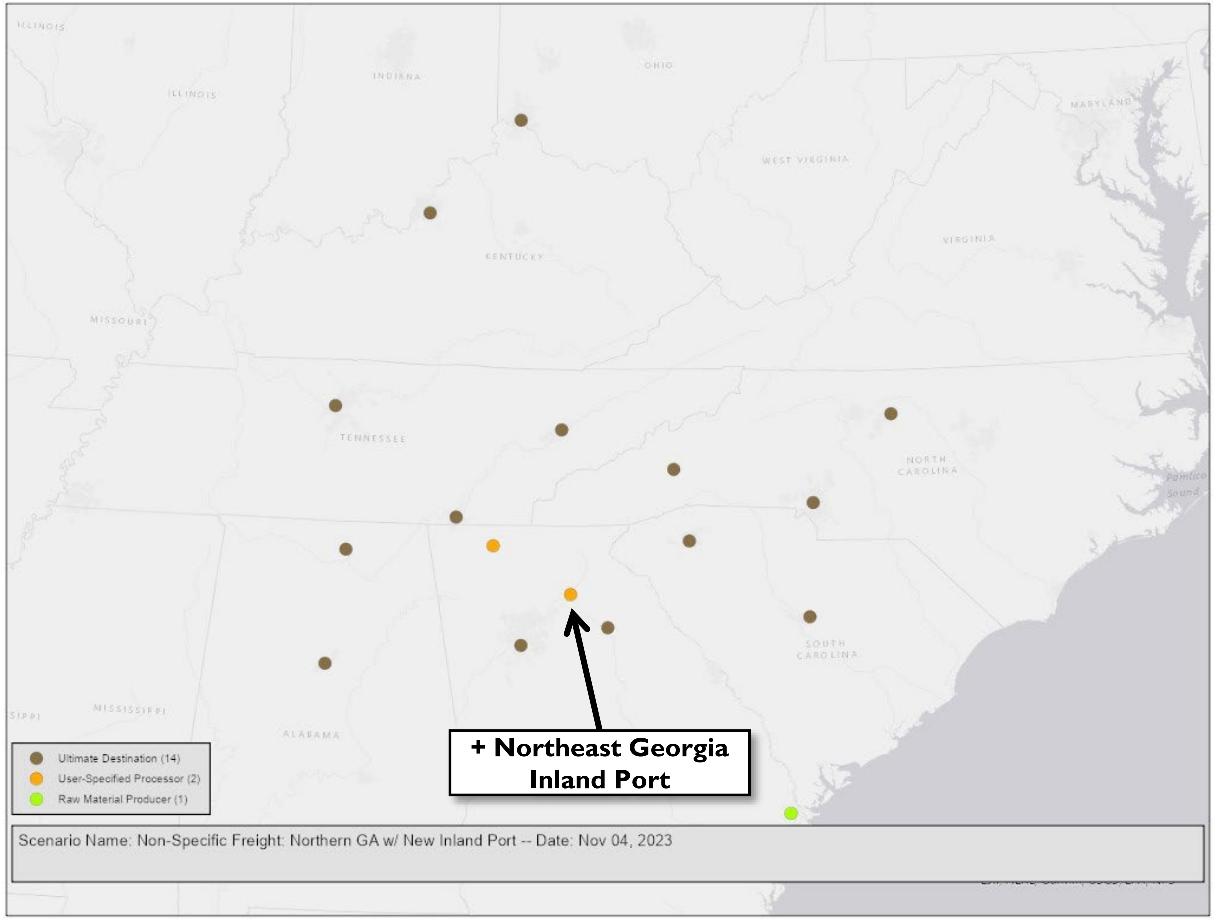
Commodity Flow Volume
- 5,785
- 200,000
- 400,000
- 600,000
- 800,000
- 924,359

Metric	Rail	Road	Total
Transport Cost (USD)	$16 million	$45 million	$61 million
CO_2 Emissions (Metric Tons)	7.98 thousand	11.4 thousand	19.4 thousand
Vehicle-Miles Traveled	4.15 million	8.54 million	12.7 million

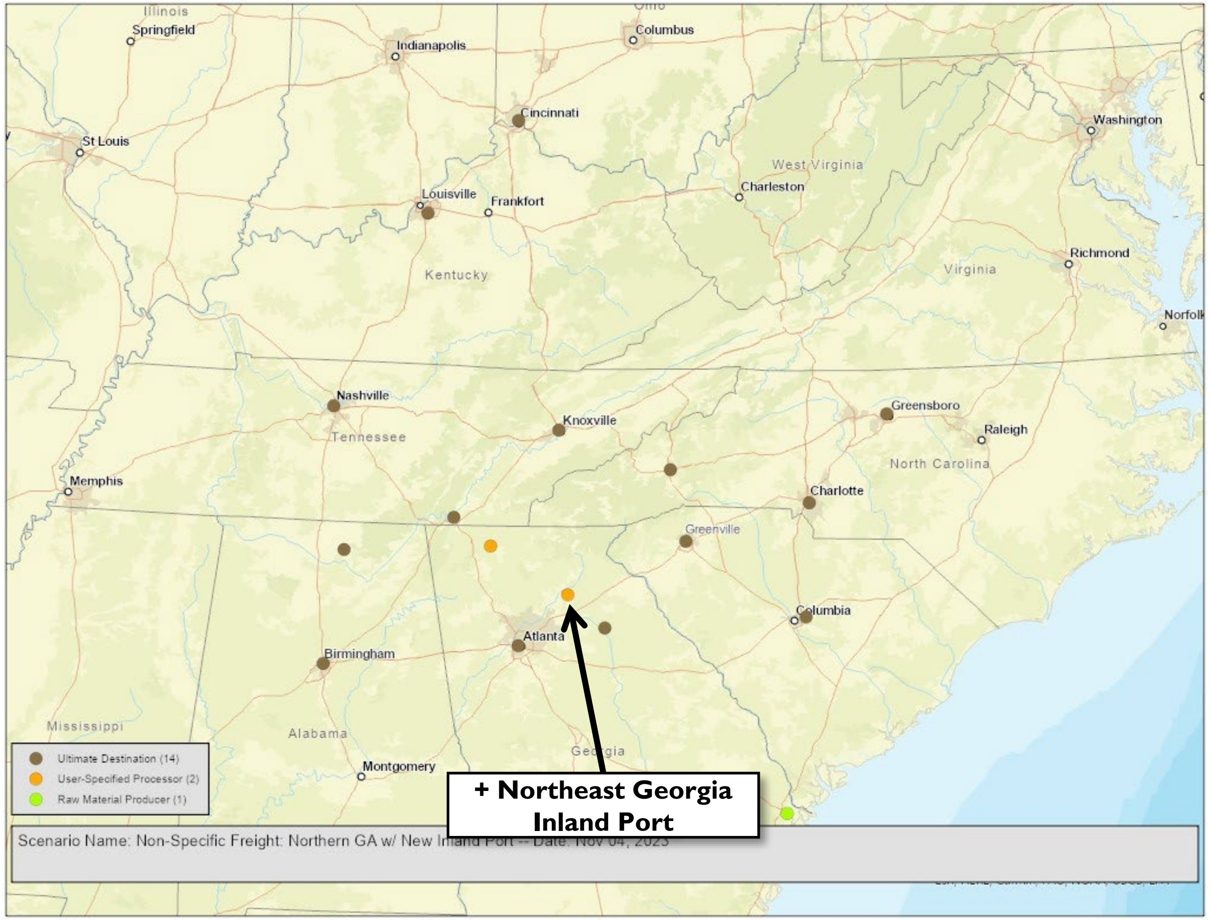
Notes: Total VMT represents a simple sum across modes. Mode columns may not add to total due to rounding.

New Port Scenario – *Facility Locations*

Gray Base Map



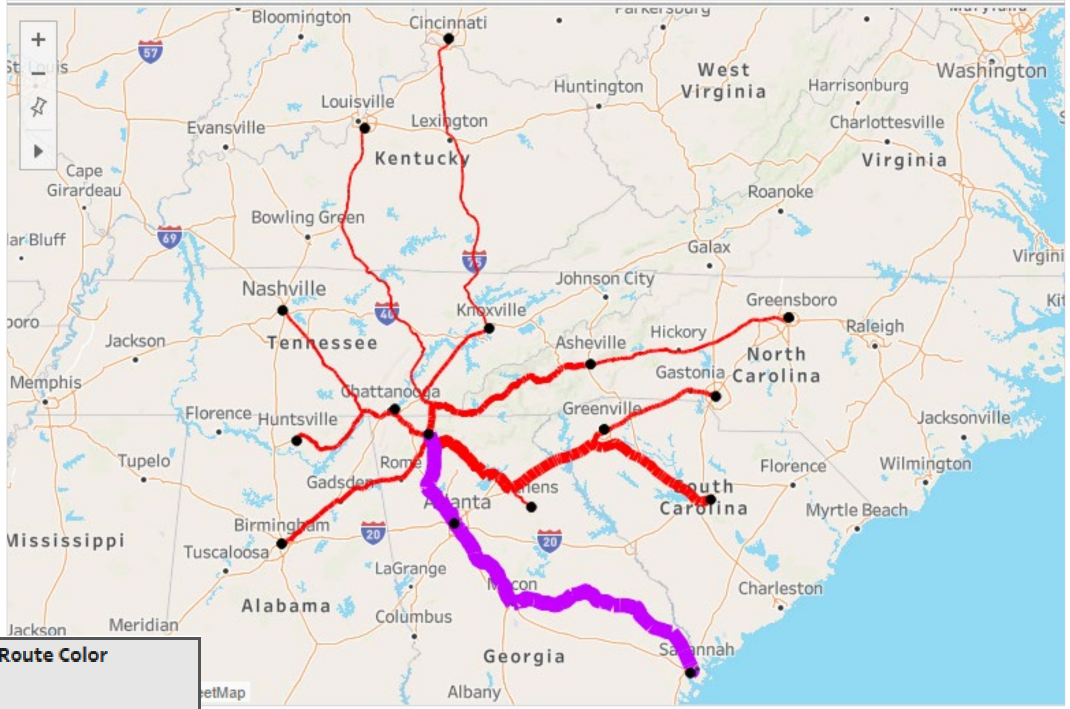
Street Base Map



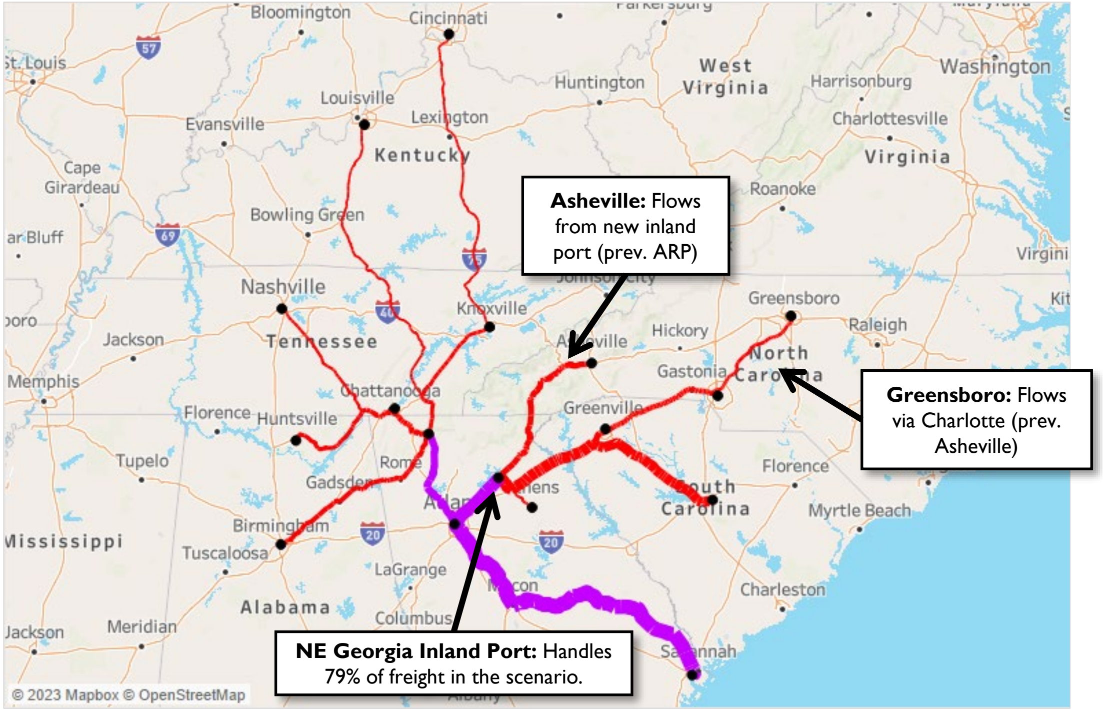
Note: The GA scenarios are hypothetical based on public data/generalized assumptions to demonstrate FTOT functionality and do not reflect detailed regional planning or analysis.

New Port Scenario – *Optimal Solution*

Baseline (For Comparison)



Existing + New Inland Port



Route Color
- Road
- Rail

Commodity Flow Volume
- 5,785
- 200,000
- 400,000
- 600,000
- 800,000
- 924,359

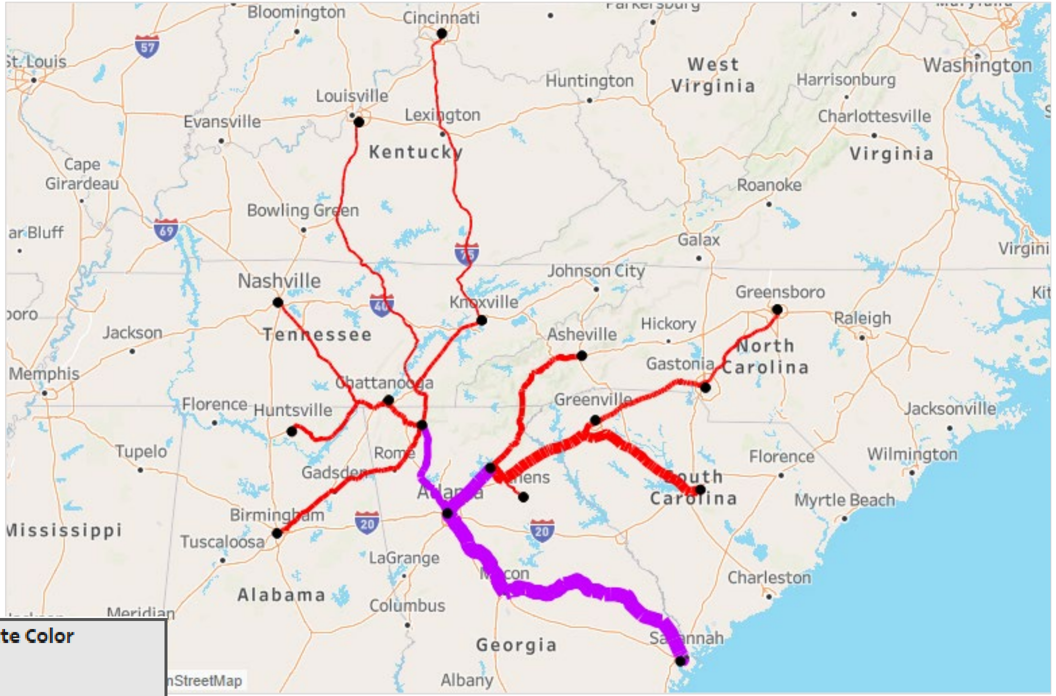
Change from Baseline

Metric	Rail	Road	Total	Total as % Change
Transport Cost (USD)	-$1.3 million	-$11.0 million	-$12.4 million	-20%
CO_2 Emissions (Metric Tons)	-0.66 thousand	-2.8 thousand	-3.5 thousand	-18%
Vehicle-Miles Traveled	-0.34 million	-2.0 million	-2.4 million	-19%

Notes: Total VMT represents a simple sum across modes. Mode columns may not add to total due to rounding.

Disruption Scenario – *Optimal Solution*

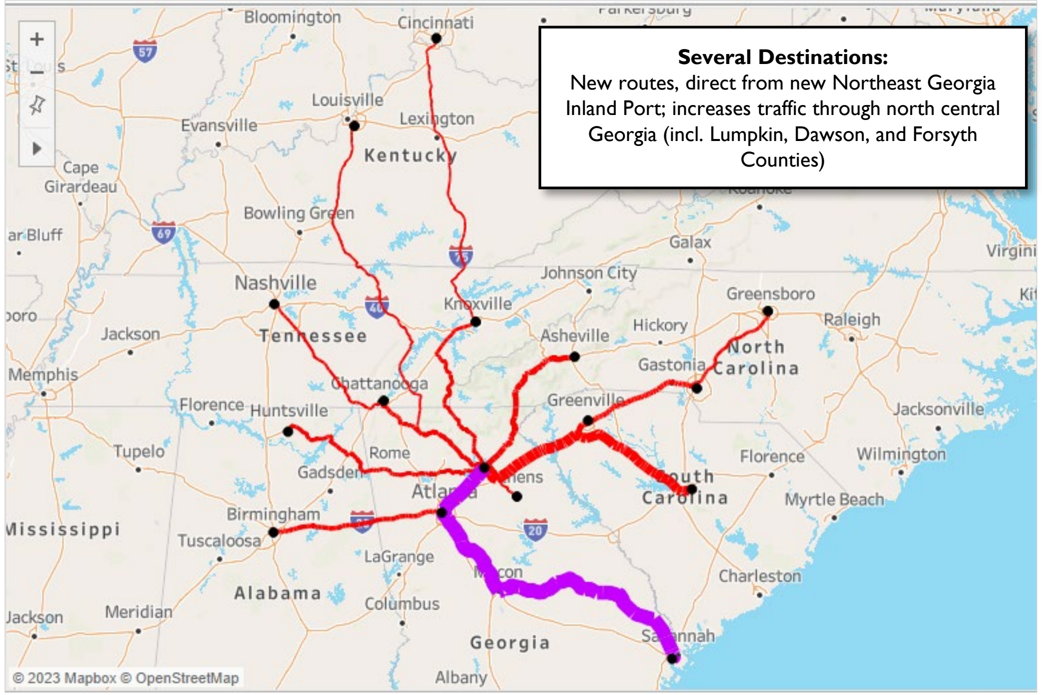
Existing + New Inland Port (For Comparison)



Route Color
- Road
- Rail

Commodity Flow Volume
- 5,785
- 200,000
- 400,000
- 600,000
- 800,000
- 924,359

Disruption (New Inland Port Only / Existing Port Offline)



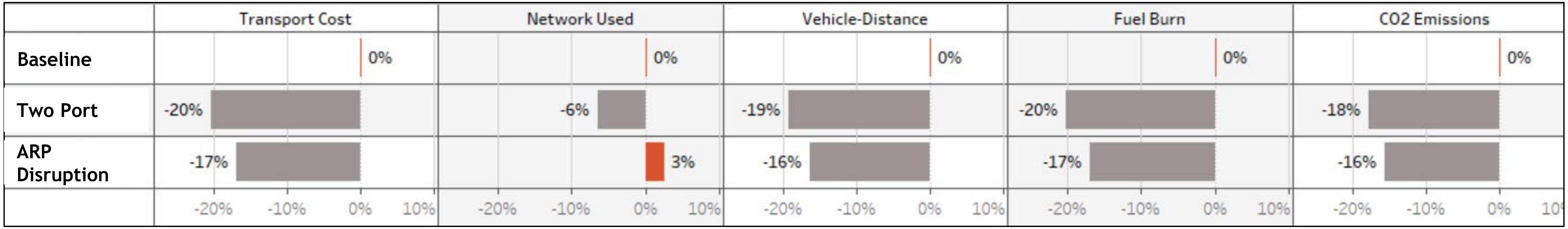
Change from "Two Port" Scenario

Metric	Rail	Road	Total	Total as % Change
Transport Cost (USD)	-\$0.34 million	+\$2.34 million	+\$2.05 million	+4%
CO_2 Emissions (Metric Tons)	-0.17 thousand	+0.61 thousand	+0.44 thousand	+3%
Vehicle-Miles Traveled	-88.7 thousand	+453 thousand	+364 thousand	+4%

Notes: Total VMT represents a simple sum across modes. Mode columns may not add to total due to rounding.

Scenario Comparison

- Disruption of the ARP increases costs, network used, vehicle miles traveled, fuel burn, and CO_2 emissions as compared with the “Two Port” scenario, but **still outperforms the baseline scenario in several areas.**
- Suggests there is **strategic value** in the proposed port’s siting for freight traveling from Port of Savannah to destinations in the southeastern U.S.



Note: The “network used” metric currently sums up miles of network considering each commodity independently. As a result, network links used for multiple commodities will be counted more than once.

Spotlight: “Link Rank and Removal” Tool

- Resilience-focused variation of FTOT that **iteratively removes** network links in order of importance (e.g., network centrality) and re-runs FTOT to generate new optimal routes.
- Generates a shareable HTML report on a routing solution’s **resilience to potential link-level impacts**.
- Publicly available at: https://github.com/VolpeUSDOT/FTOT-Resilience-Link_Removal

Sequential removal of links and resiliency testing

- Disruption of a network by removal of links, based on:
  - Sum of betweeness centrality of from and to nodes
  - Link length
  - Volume of commodity flow
- Calculation of performance in terms of cost and unmet demand by re-running disrupted network
- Plot link removal along x-axis and performance on y-axis, comparing networks of differing evenness. Dynamic report generated in an RMarkdown automatically from this Notebook.

Assumptions

- Working in a Python 3.x environment for this notebook
  - Refer to the README in this repository for instructions on setup of all dependencies with `conda`
- Access to ArcGIS license server if necessary

Reference

- [NetworkX Documentation]()

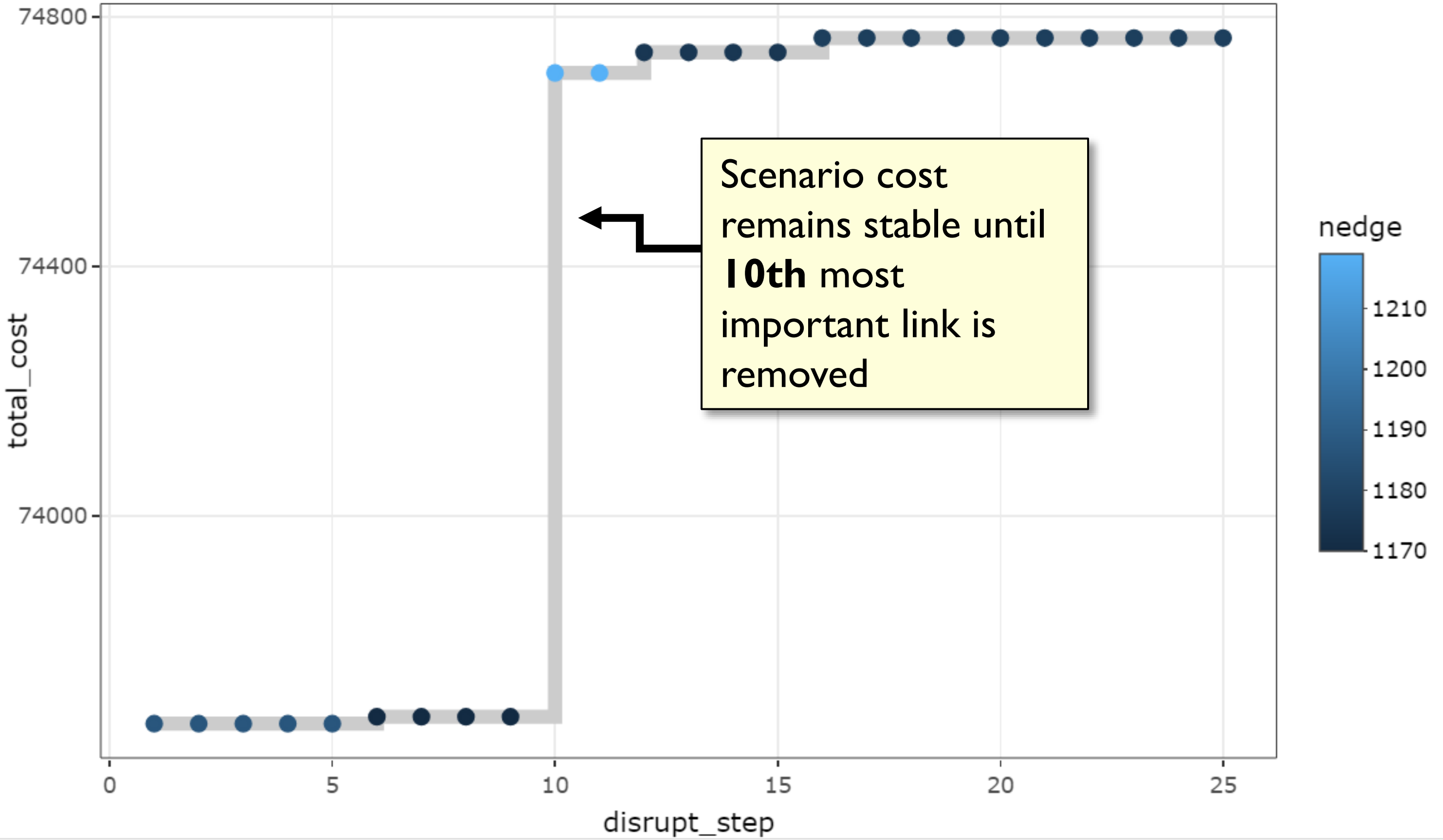
In [1]:

```
import pandas as pd
import geopandas as gpd
import sqlalchemy
import networkx as nx
import os
```

Spotlight: “Link Rank and Removal” Tool

How does the **scenario cost** increase as network links are **incrementally removed**?

Two Port Scenario

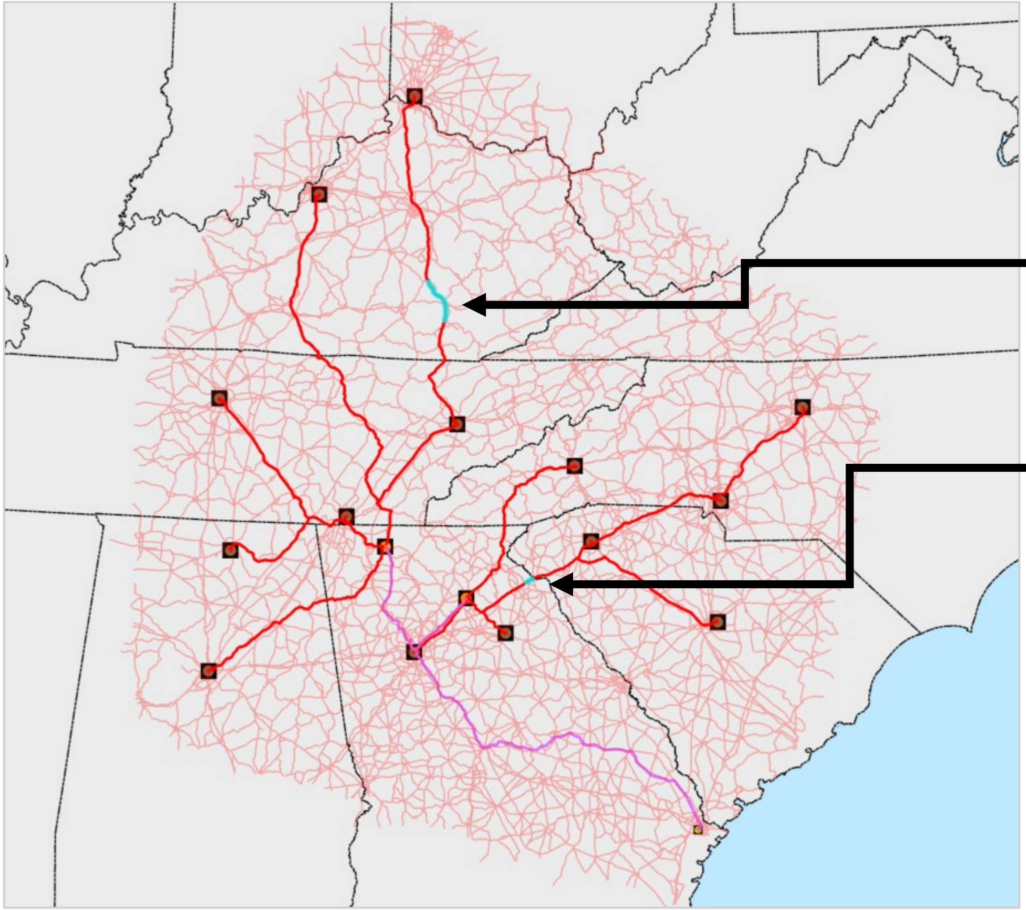


Scenario cost remains stable until **10th** most important link is removed

Color legend:
Total number of network edges used in the scenario solution

Spotlight: "Link Rank and Removal" Tool

Top 10 links (blue highlighting) ranked by betweenness centrality as a measure of importance and connectedness.



Top 9 ranked important links

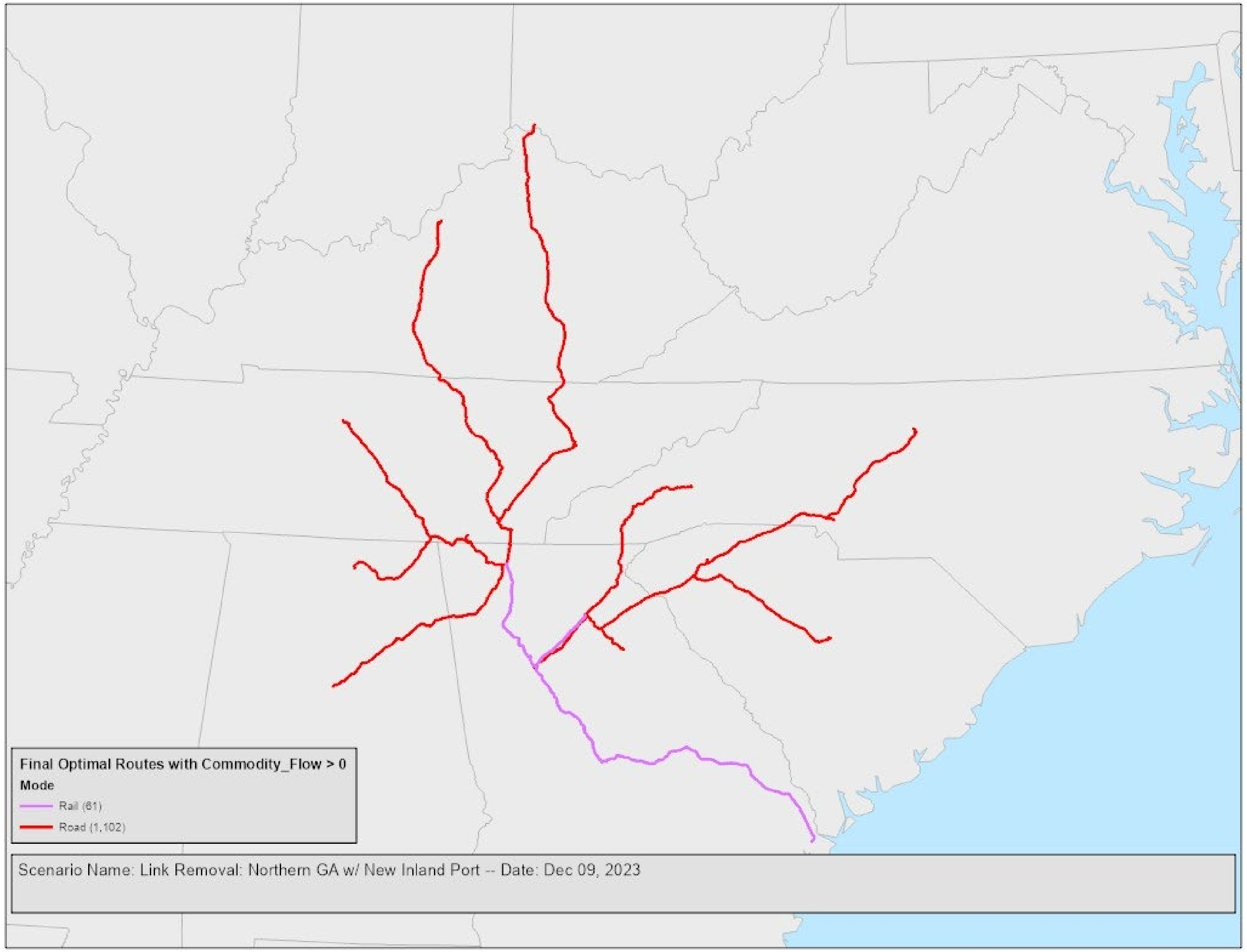
10th ranked most important link. Causes a **large cost increase** when disrupted.

Note: The "Link Rank and Removal" tool is only compatible with road networks.

Spotlight: “Link Rank and Removal” Tool

Original Optimal Solution

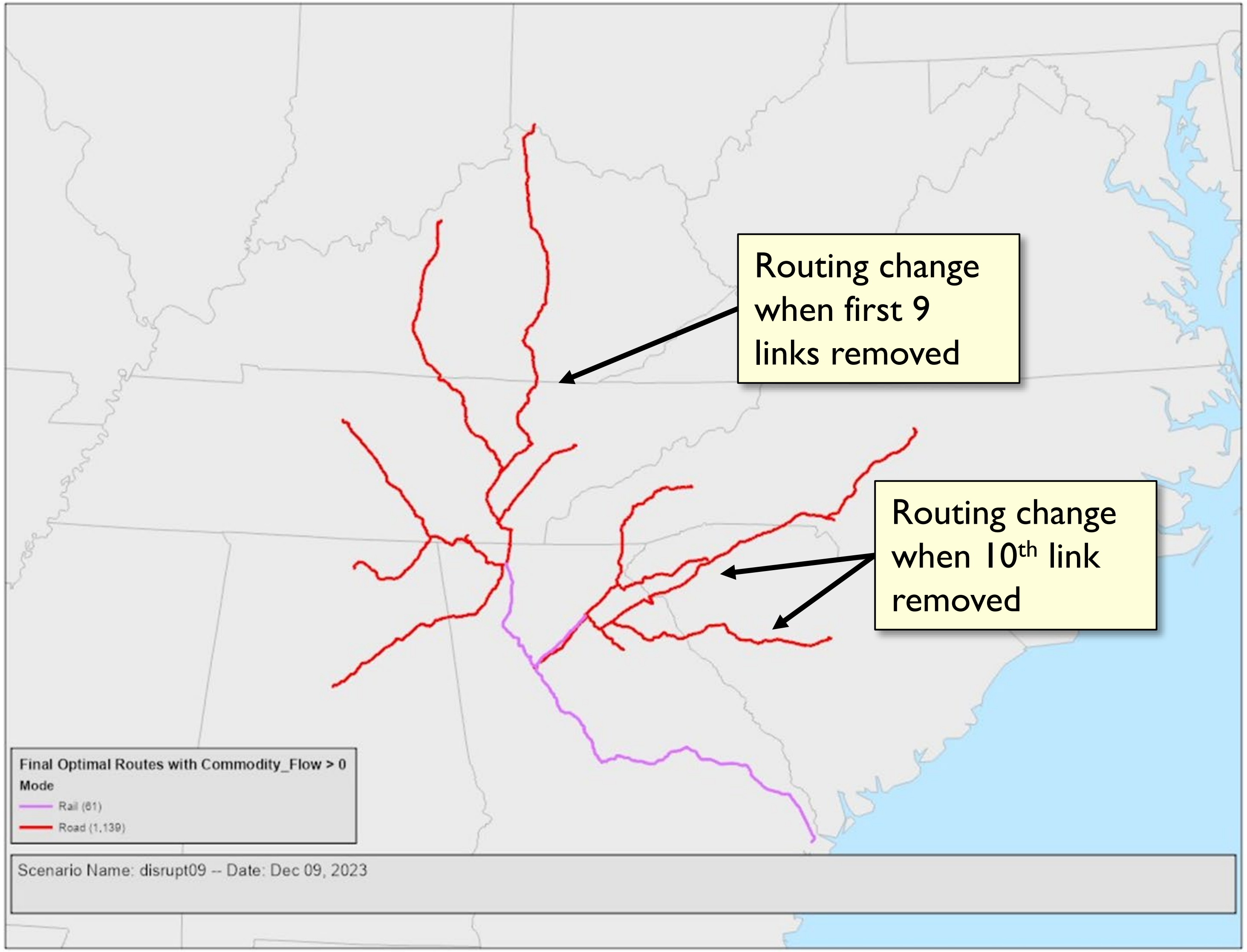
- Two Port Scenario



Spotlight: "Link Rank and Removal" Tool

Disruption Step #10

- Removes the 10 most connected links
- Results in 1.4% increase in scenario cost



Questions?

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U.S. Department of Transportation
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- **Professional Excellence**
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