A Comparative Analysis of Ships v. Trucks to Transport Cargo along the Great Lakes

Sustainable Intermodal Freight Transport Research Program

James J. Corbett, PhD., University of Delaware
James J. Winebrake, PhD, Rochester Institute of Technology
Heather Thomson, University of Delaware
Arindam Ghosh, Rochester Institute of Technology

Goods Transport

- Great Lakes shipping occurs across three modes
  - Railroad
  - Ship
  - Truck
- Each has pros and cons, and intermodal combinations offer flexibility and efficiency
- One intermodal ship is SS Badger carferry.


BADGER

SS Badger

- Started as a railcar ferry in 1953
- Now ferries cars, passengers, and cargo
- Engines declared a mechanical engineering landmark by the American Society for Mechanical Engineers
- Ship itself placed on the National Register of Historic Places
- Only coal-fired steamship in US

Outline

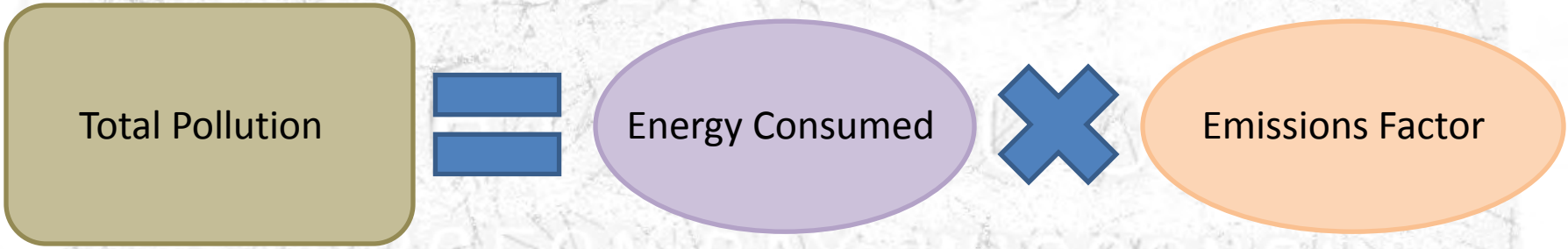
- What did we study?
- How did we analyze it?
- What were our results?
- How robust are they?
- What are our conclusions?

What we studied

- Emissions of 6 criteria pollutants
  - Carbon dioxide (CO_2), Sulfur oxides (SOx), Nitrogen oxides (NOx), particulate matter (PM_{10}), methane (CH_4), and carbon monoxide (CO)
- Looked at current emissions from both truck and Badger
- Compared to a fuel switch from coal
  - Intermediate Fuel Oil (IFO), Marine Distillate Oil (MDO), Compressed Natural Gas (CNG), Liquified Natural Gas (LNG) and a biodiesel blend (BD20)


Truck Route (Intermodal Scenario)
Total Distance ~ 45 miles
Travel Time ~ 0.8 hrs
Ferry Route (Intermodal Scenario)
Total Distance ~ 62 miles
Travel Time ~ 4 hrs
Truck Route (Intermodal Scenario)
Total Distance ~ 260 miles
Travel Time ~ 4.5 hrs
All-Truck Route (Scenario B)
Total Distance ~ 500 miles
Travel Time ~ 8 hrs
All-Truck Route (Scenario A)
Total Distance ~ 620 miles
Travel Time ~ 10.5 hrs
Green Bay, WI
Manitowoc, WI
Ludington, MI
Detroit, MI
Lake Huron
Lake Michigan
Milwaukee
Chicago
INDIANA
ILLINOIS
Legend
Truck Route
Ferry Route
0 10 20 40 60 80
Miles

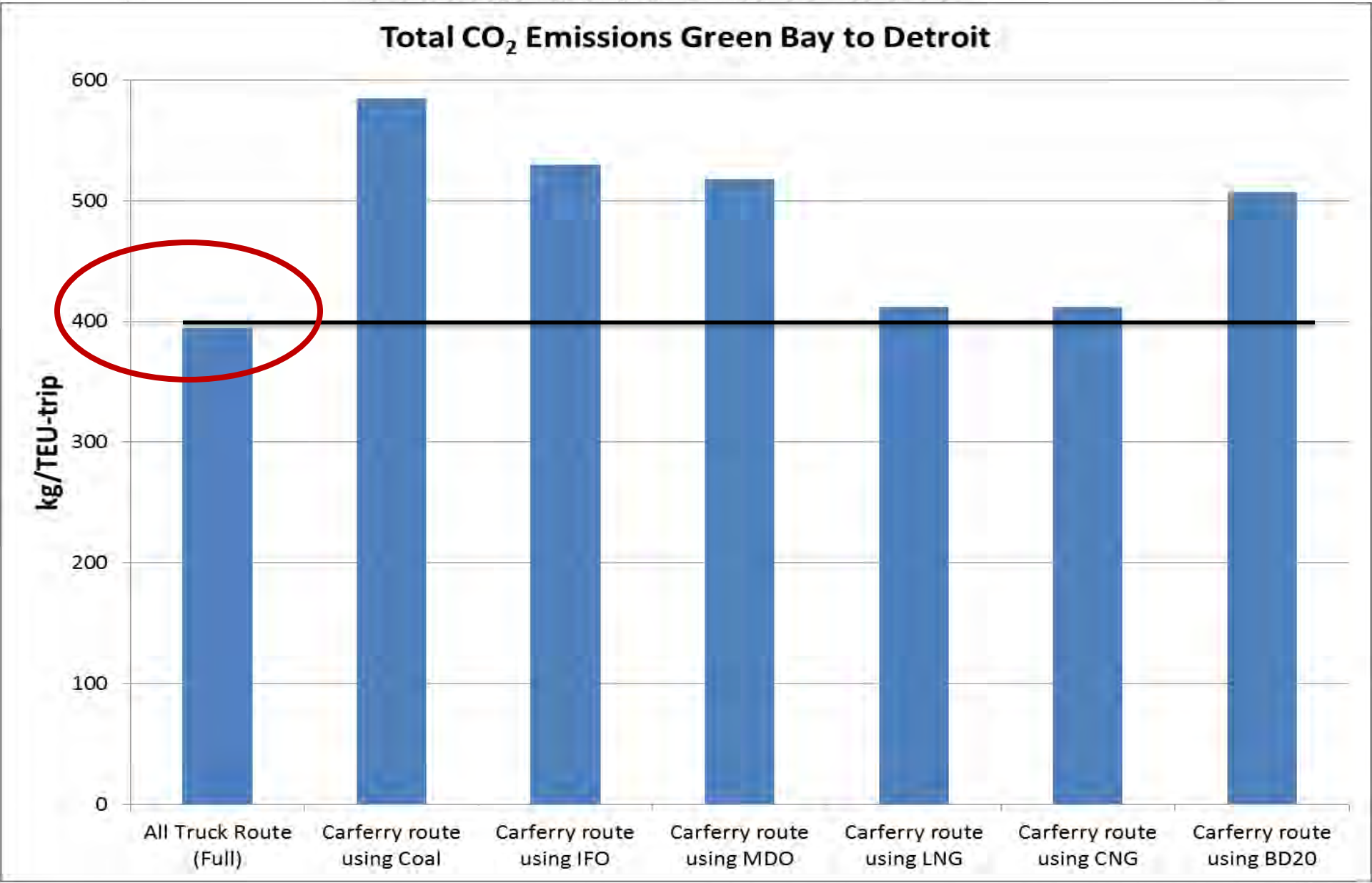
Emissions Estimation Basics



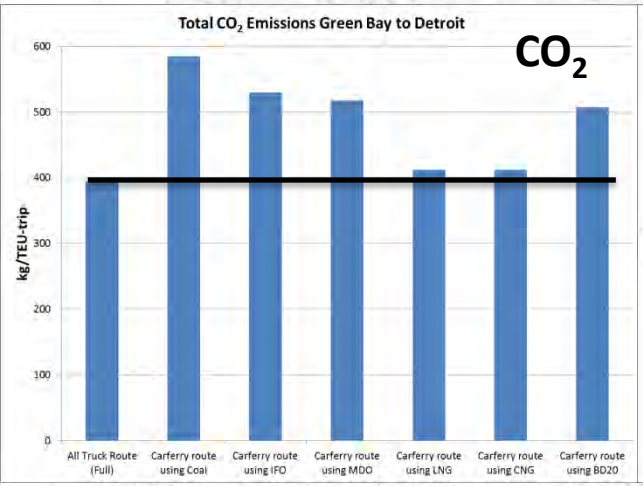
General equation used:

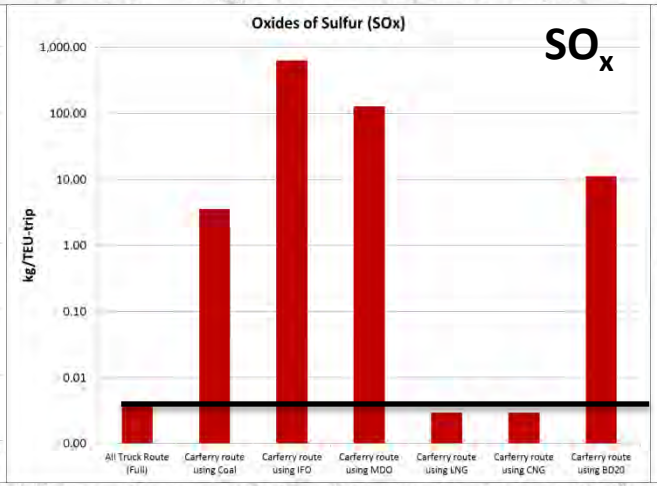
$$P_{ij} = E_j \cdot EF_{ij}$$

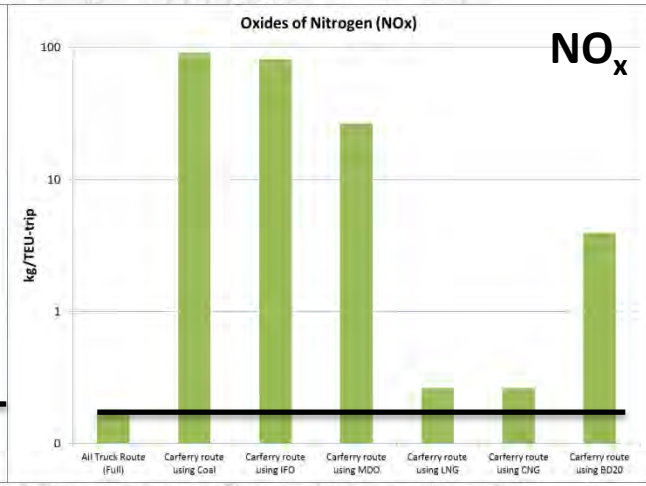
where P_{ij} represents pollutant of type *i* for mode *j* in kg/segment; E_j represents energy consumption for mode *j* in BTU/segment; and EF_{ij} represents an emissions factor for pollutant *i* for mode *j* in mass/energy unit (e.g., g/BTU or g/hp-hr).

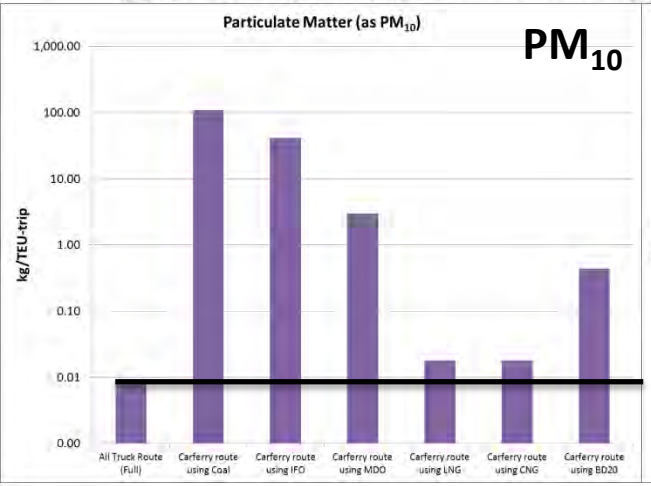

Total CO_2 Emissions Green Bay to Detroit
kg/TEU-trip
600
500
400
300
200
100
0
All Truck Route (Full)
Carferry route using Coal
Carferry route using IFO
Carferry route using MDO
Carferry route using LNG
Carferry route using CNG
Carferry route using BD20

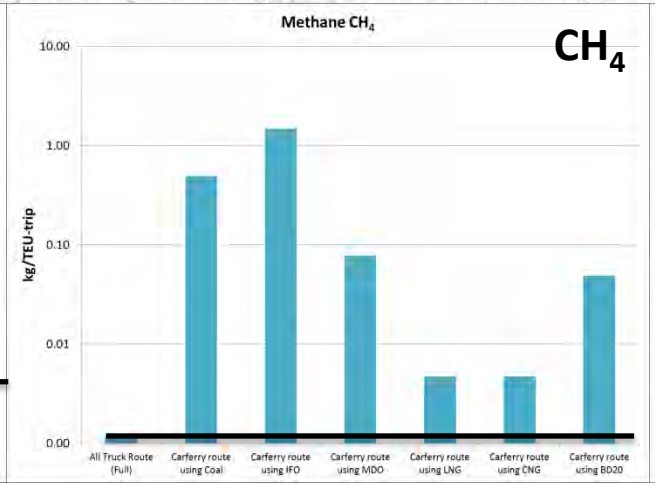
Results for Different Pollutants

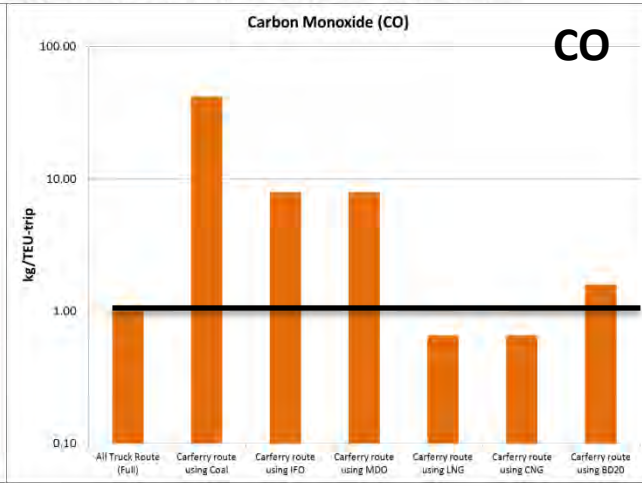












Example of sensitive assumptions

- Current configuration is for 12 tractor trailers
- Capacity is 180 “Vehicle Units”
  - One tractor trailer = 4 Vehicle Units
- Assuming only 12 trailers would assign all pollution to those trailers
- Therefore assumed 45 trailers on board

- Is this a good assumption?
  - More freight than normal max (Calculated emissions too low)
  - We allocate ALL emissions to payload (Calculated emissions too high)

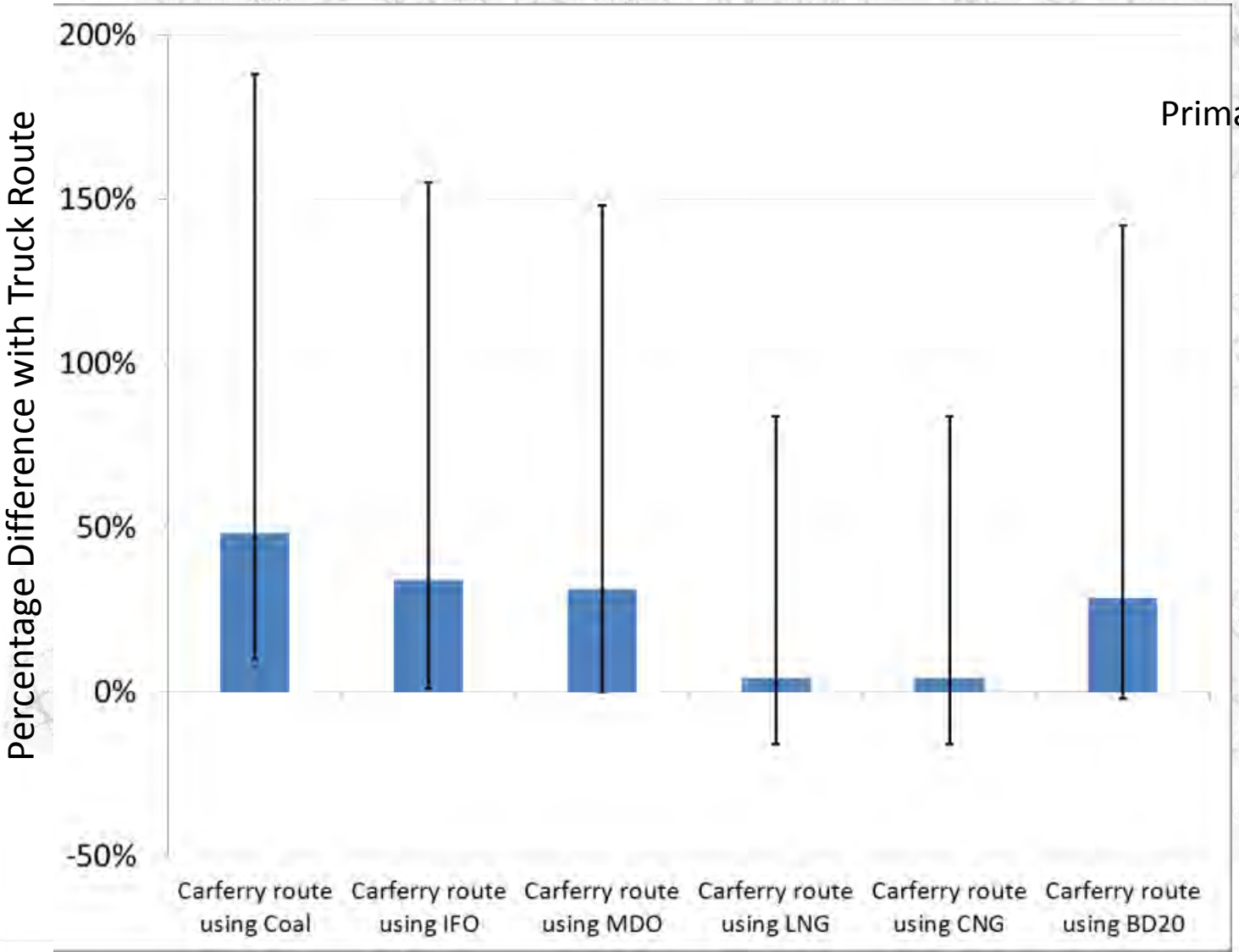
- Our “best estimate” for study was 117 TEUs,
  - May be conservatively high (optimized for freight)

Sensitivity Analysis

Ranges for vessel and vehicle characteristics

Parameter	Low	Best	High
Annual Vessel Trips	445	445	460
Vessel Engine Load Factor (%)	50	73	80
Vessel Boiler-Engine Efficiency (%)	17	22	45
Vessel Payload Capacity (TEU)	31.2	117	117
Ship Speed (knots)	15.9	18.0	18.6
Truck efficiency (mpg)	5.5	6	7.2
Truck Payload Capacity (TEU)	1	2.6	2.6
All-truck route distance (miles)*	500	620	650

SS Badger CO_2 performance using current steam propulsion

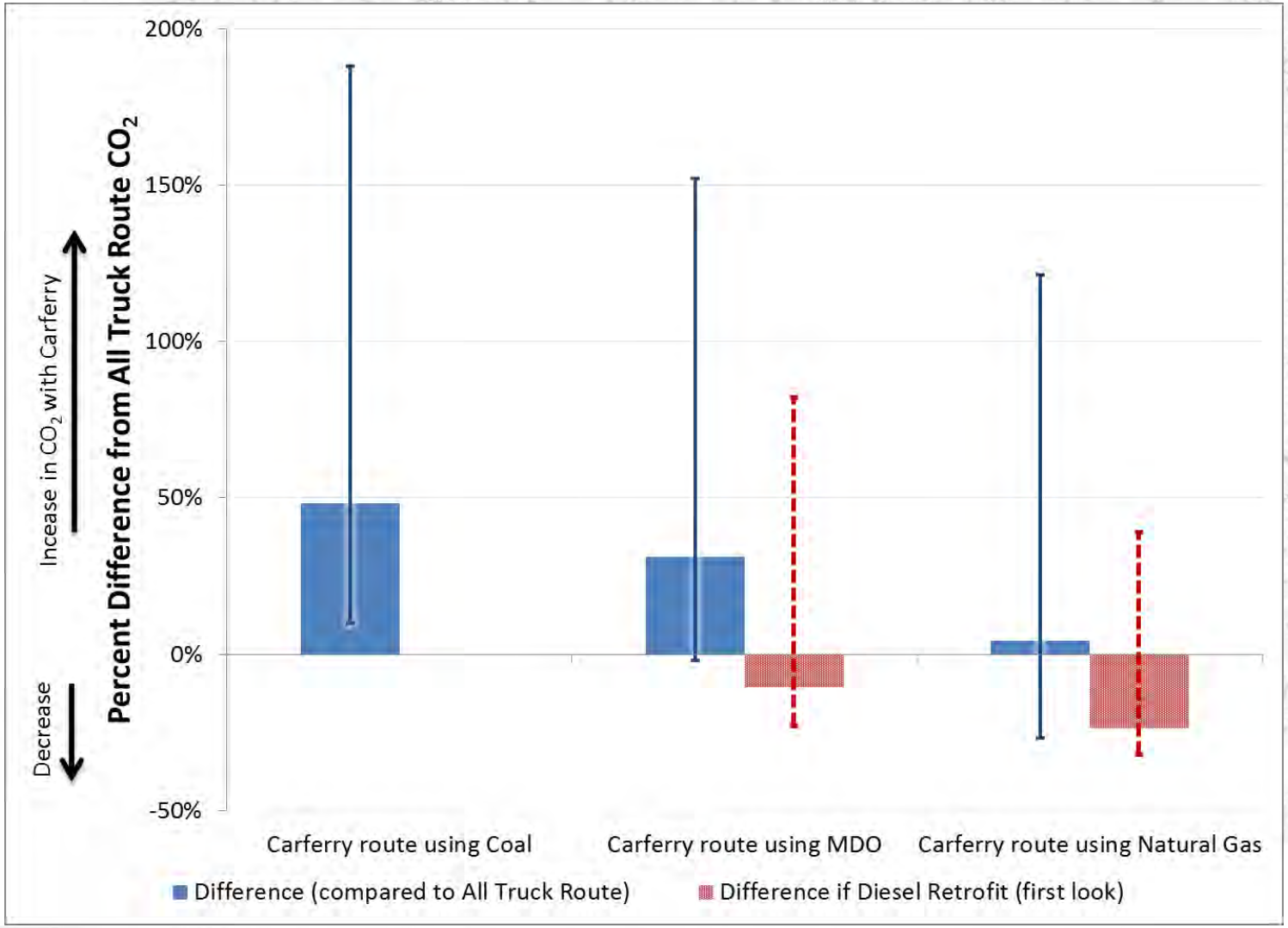


Primary inputs of influence

1. Vessel utilization
   (payload capacity)
2. Truck utilization
   (payload capacity)
3. Route distance
   (truck options)
4. Truck fuel efficiency

Sensitivity results

Considering potential for improved thermal efficiency



Improving fuel economy on the SS Badger (e.g., plant thermal efficiency) would substantially transform the analysis

Dieselization or other prime mover modernization can be coupled with alternative fuels to outperform all-truck route

Discussion Summary

- Study scope
  - Compare environmental performance of alternative routes (all-truck v. intermodal) under various fuel scenarios
- Methods
  - Apply GIFT model and SS Badger data to explore routes and environmental performance
  - Apply sensitivity analysis to identify high-leverage variables

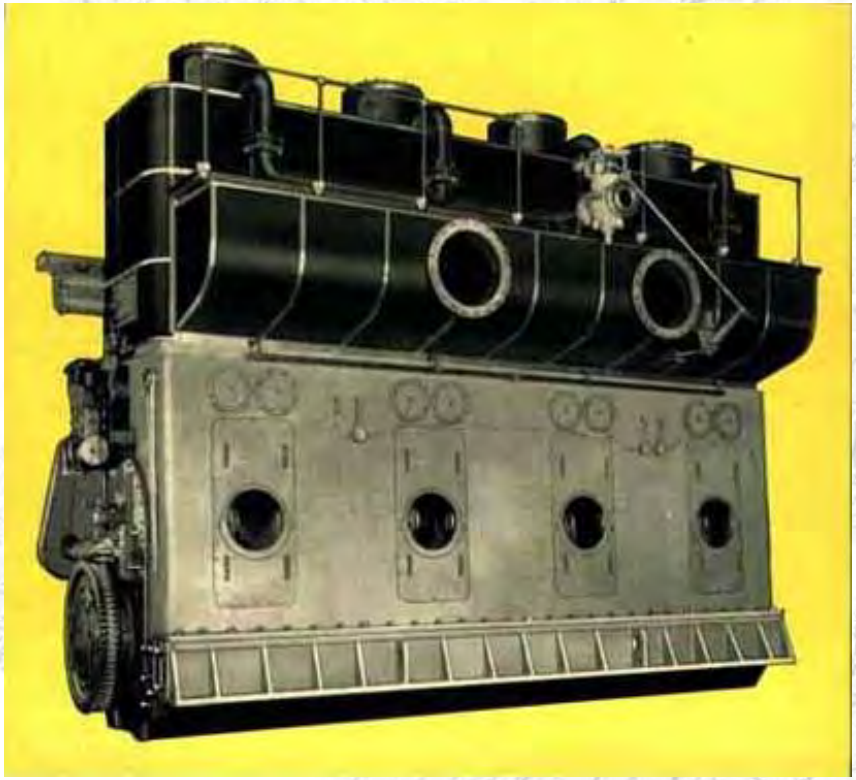
Results Summary

- Current all-truck route outperforms intermodal scenarios in most cases
- Results are case-specific to 1950s steam-propulsion technology and route served by SS Badger and do not include total fuel cycle emissions
- Sensitivity analysis reveals opportunities for natural gas or MDO with or without new engine designs, payload configuration, etc.
- Natural-gas-fueled engine propulsion can perform at lower CO_2 emissions than all-truck route

Conclusions

- Natural gas shows promise as a marine fuel for Great Lakes vessels
- Technology modernization can accompany a fuel-transition for Great Lakes (such as scrubbers, dieselization, payload configuration)
- A Great Lakes shipping transition to natural gas fuels will need to be strategic, and analyses like this study can serve as important decision support role for GLMRI and industry partners
- Adding a total fuel cycle analysis to this work will provide additional insights into the role of alternative fuels

Thank you



http://tlc_ferry.tripod.com/images/fleet/Badger-5.jpg