The Green Route: An Analysis of Mode Change as a Strategy for Carbon Emission Reduction

by

Elizabeth Marie Bruttomesso
Bachelor of Science in Ocean Engineering, Texas A&M University 2019

and

Shruti Pant
Masters of Business Administration, IIFT Delhi 2017

SUBMITTED TO THE PROGRAM IN SUPPLY CHAIN MANAGEMENT
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE IN SUPPLY CHAIN MANAGEMENT
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2023

Signature of Author: ____________________
Department of Supply Chain Management
May 12, 2023

Signature of Author: ____________________
Department of Supply Chain Management
May 12, 2023

Certified by: ____________________
Dr. Elenna Dugundji
Research Scientist and Lecturer
Capstone Advisor

Certified by: ____________________
Dr. Thomas Koch
Postdoctoral Associate
Capstone Co-Advisor

Accepted by: ____________________
Prof. Yossi Sheffi
Director, Center for Transportation and Logistics
Elisha Gray II Professor of Engineering Systems
Professor, Civil and Environmental Engineering

The Green Route: An Analysis of Mode Change as a Strategy for Carbon Emission Reduction

by

Elizabeth Marie Bruttomesso

and

Shruti Pant

Submitted to the Program in Supply Chain Management
on May 12, 2023 in Partial Fulfillment of the
Requirements for the Degree of Master of Applied Science in Supply Chain Management

ABSTRACT

Having recognized the growing need for decarbonizing the maritime transport industry, the sponsor company is assessing the economic feasibility of implementing Green Intermodal Corridors. For a route to be considered a viable option as a Green Corridor, it must have the potential for significant decarbonization while also being economically implementable. This paper covers the feasibility assessment for three corridors, exploring the different scenarios possible in each of these routes and how they compare with the base case of current operations in terms of costs of operation and carbon emission reduction. The report discusses the scenario simulations over the alternate routes that deploy an electric barge and a hybrid barge in combination with an electric truck (Route 1), an electric truck (Route 2), and an electric train in combination with an electric truck (Route 3), in place of the regular diesel trucks for the delivery of cargo from the port to the warehouse. We created a model to show the trade-off between cost and emissions and to assess the best way for the company to make decisions on its options for future infrastructure and routing. The best and easiest transition for the company, as determined by the feasibility study, is using electric trucks in place of diesel trucks for inland delivery over Route 2. The successful implementation of viable green routes can be driven by utilizing government funds and incentives that can partially offset the high initial capital expenditure. Although the cost and emission figures, as ascertained in the report, do not make a strong case for green corridors in themselves, this transition can definitely be made possible by encouraging the transportation industry, the government, and all the stakeholders involved to make the necessary contributions to establish green routes with lower carbon emissions.

Capstone Advisor: Dr. Elenna Dugundji
Title: Research Scientist and Lecturer

Capstone Co-Advisor: Dr. Thomas Koch
Title: Postdoctoral Associate

ACKNOWLEDGMENTS

We would like to extend our sincere appreciation to our advisor, Dr. Elenna Dugundji, for her unwavering guidance, expertise, and support throughout our capstone project, as well as to our capstone co-advisor, Dr. Thomas Koch, for his valuable input and advice. We would also like to thank our writing coach, Toby Gooley, for her dedication and support throughout the writing process.

To the employees of our corporate sponsor, we would like to extend our heartfelt thanks for the time, feedback, and expertise that greatly aided in our research. We have been deeply inspired by our sponsor company's focus on sustainable practices and environmental responsibility and are grateful for having been involved in a project driven by sustainability.

We are immensely grateful to our families for their constant love and support during our time at MIT.

Finally, we would like to express our gratitude to the entire MIT community, especially the Class of 2023, for the extraordinary experience and lifelong friendships that we have made during our capstone project.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

Chapter 1: Introduction

The world today is invested more than ever before in working on building green and sustainable global supply chains. International organizations and customers are requiring lower carbon emissions from companies to help combat climate change. This transition towards a greener future has touched all industries and sectors alike, and the maritime industry is no outlier in this regard. The International Maritime Organization has stated a target of reducing CO_2 emissions by at least 40% by 2030 in international shipping (IMO, n.d.).

Shipping companies around the globe are striving to develop sustainable approaches for meeting these targets, and the sponsor company is one of the forerunners in these developments. A global player in sea, land, air, and logistics solutions, the sponsor company has implemented various pioneering solutions to make international trade more sustainable. The sponsor company owns and operates some terminals, but we are only focusing on its shipping business. With regard to carbon emissions, the sponsor company has begun implementing liquefied natural gas (LNG) and other alternative fuels for their ships. With the international ocean shipping segment of the business making progress to lower carbon emissions, the company also wants to continue reducing emissions in the movement of cargo once it has reached the port. The sponsor company wishes to explore the potential of “Green Corridors” for the movement of cargo between ports, as Green Corridors are poised to create a healthy ecosystem of intermodal logistics. A Green Corridor in the industry is a maintained route that has been demonstrated to produce zero emissions (Getting to Zero Coalition, 2021). This project used a slightly different definition of Green Corridors: corridors of trade that have lower carbon emissions compared to the traditional system of using diesel trucks for delivery.

Guided by similar ideas of maritime decarbonization, many ports in the US are working to reduce greenhouse gas emissions. The Port of Virginia aims to reduce greenhouse gas emissions by 65% and operate with 100% renewable energy by 2032 in a journey to carbon neutrality (*Environmental Sustainability | Port of Virginia*., n.d.). The Port Authority of New York and New Jersey has committed to having net zero carbon emissions by 2050 across its entire port operations (*Port Authority of New York and New Jersey).* The Port of Houston has a similar goal of being carbon neutral by 2050 (*Port of Houston)*. The Massachusetts Port Authority has a goal of net zero by 2031 (*Massport)*. Many ports are taking on different initiatives to achieve similar goals. The Port of Los Angeles has an initiative called Zero- and Near Zero-Emission Freight Facilities shore-to-store project to help reduce greenhouse gas emissions by using hydrogen fuel cell electric trucks (*Port of Los Angeles).* The Port of Virginia, along with the Port of Los Angeles, has multiple initiatives to reduce emissions by making major investments in electrifying cargo handling equipment to help reduce carbon emissions.

The sponsor company is working in tandem with some of the ports on the East Coast and is actively exploring greener routes to move its intermodal cargo to give customers the opportunity to have a greener cargo move end to end.

In the current scenario, there are multiple ways to move cargo once it reaches the coastal port. Cargo can be moved by diesel truck directly to a warehouse, by a barge to an inland marine terminal, or by train to an inland port. If the sponsor company is able to optimize routes based on balancing costs and emissions, then adopting these low-emission routes will help it on its journey to zero emissions.

This study analyzed three transportation routes to value the potential of adopting electric vehicle technology for the company. Route 1 shows that using a hybrid tugboat in combination with electric trucks can significantly reduce their CO_2 emissions and provide savings in operating cost. However, the payback period is currently longer than the expected lifespan. Route 2 demonstrated that electric trucks offer emission reductions and operating cost savings but the payback period in this case too is longer than the estimated 15-year lifespan of the truck. Seeking grants to cover the charging infrastructure could make the payback period more attractive. Route 3 reveals the electric train and truck scenario produces more emissions than diesel due to the efficiency of the electric train and the emission from the grid. To achieve environmental and financial benefits, the sponsor company should explore grant funding opportunities and stay informed about technological advancements in the electric vehicle space.

1.1 Problem Statement

Having recognized the growing need for decarbonizing shipping, the sponsor company is now assessing the economic feasibility of implementing Green Corridors, a popular solution for tackling this issue. The focus is on determining the investment required to make these "green solutions" possible for all stakeholders involved. Implementing these solutions will necessitate additional investment, which will increase the cost of services compared to current methods. Therefore, it is critical to evaluate the investment gap and how long it takes for the investment to be paid back if no government funding is used.

To determine whether a Green Corridor can be created in the designated area that will be economically competitive for customers, the following questions need to be answered:

1. What are the costs and emissions associated with the current diesel trucks being used by the sponsor company in the designated trade corridor and what would the costs be for an electric truck?

2. What are the costs and emissions associated with the current diesel barges being used by the sponsor company in the designated trade corridor and what would the costs be for a hybrid tug and an electric tug?

3. What are the costs and emissions associated with the current diesel trains being used by the sponsor company in the designated trade corridor and what would the costs be for an electric train?

4. How can the combination of these modes reduce the emissions on the corridors?

5. What infrastructure would the sponsor company and the port need to install to make the green corridor viable?

1.2 Scope

The project's overall goal is to provide the sponsor company with a model that simulates green intermodal corridors in the East Coast port so the sponsor company can analyze the feasibility of implementing these alternate routes. This method will allow the company to see how small changes in their policies will affect the emission rates and transportation costs.

We hypothesize that a model that can show the trade-off between cost and emissions would be the best way for the company to make decisions on what its future infrastructure and routing should look like. This would include deciding on the most efficient modes of transport (train vs. barge vs. EV) congruous with all the stakeholders involved and investing in the infrastructure and technologies to enable this transition. Publicly available data and information were collected for parameters such as emission factors for different modes. The cost of future infrastructure is also being estimated through publicly-available information. The model thus created would let the user investigate different scenarios and compare the cost and emissions.

The deliverables to the company will include the following:

1. A model of three routes determined by the company to demonstrate green intermodal corridors in the East Coast Port that considers cost, infrastructure capacity, emissions, and the required investment to change the technology.
2. A report outlining the business case for setting up green intermodal corridors in the East Coast port that can help the company analyze the feasibility of implementing this project.

A business case will be formulated that helps the sponsor company evaluate the value proposition of investing in the “Low Carbon Intermodal Corridors.” Once this business case has been tested on these routes and has gained stakeholder acceptance, the sponsor company can expand on the concept of Green Corridors to other regions of the United States, allowing them to reach their emission targets.

Chapter 2: State of the Art

To address the problem of how an intermodal carbon corridor can become low-carbon, we reviewed the following areas of literature: (1) how barge transportation in corridors can reduce carbon emissions, and what is the future technology in barges in the next few years that can make them more efficient; (2) what is the current state of emissions from trucks and what technology can help reduce carbon emissions from trucks; (3) what is the current state of emissions from trains and is there technology that can help reduce emissions; (4) what federal and state policies might affect the adoption of a Green Corridor in the designated area; and (5) what methods exist for calculating greenhouse gas emissions for transportation modes and what method would work for our case.

2.1: Barge: Fuel Efficiency and the Path Forward

Transporting freight by barges has lower emissions when compared to transporting freight by road because, on average, barge transport generates only 50g of CO_2 per ton-km versus 115g of CO_2 per ton-km for road transport (*Neutraceutical Business Review* 2021.). The three major challenges with using barge transportation are the volume of goods needed to make the mode cost-efficient, limitations to where the barge can deliver freight, and the limited schedule in many areas. Currently, this East Coast Port has twice-a-week service to the inland marine terminal, so the freight must arrive at the correct time of the week to minimize dwell time before being delivered to the warehouses near the marine terminal. One of the major concerns about moving volume from trucks to barges is the lack of flexibility in terms of schedule, so some supply chain managers see the move to barges as a negative factor for their supply chain (Dong et al., 2018, p. 43).

2.2: Truck: Fuel Efficiency and the Path Forward

Trucking forms an essential component of the intermodal transportation model. The advantage of trucking over other common intermodal choices like train or barge is the freedom from following fixed running schedules. However, trucks must be routed and scheduled to enhance overall efficiency and minimize operating time and carbon emissions. Heavy-duty, long-haul tractor-trailers form the backbone of freight movement and contribute two-thirds of trucking's energy use and GHG emissions (Greene and Plotkin, 2011)

The East Coast Port is heavily reliant on motor carriers for hauling containers, and one of the major challenges facing the trucking industry remains the massive consumption of fossil fuels which contributes to carbon emissions. Electric vehicles and vehicles running on alternative fuels are poised to provide a solution to this problem. However, the lack of adequate EV charging infrastructure remains a limitation to the widespread adoption of electric vehicles. Another important challenge in the deployment of electric vehicles in the case of intermodal transportation is the available payload, which refers to the weight a vehicle can carry. Currently, vehicles with higher payload capacity are not being widely offered in the market. This remains a key area for improvement to make widespread usage of electric vehicles a reality (MacHaris et al., 2007, p. 313).

2.3: Train: Fuel Efficiency and the Path Forward

Railways form a preferred choice of transportation when it comes to the reduction of greenhouse gas emissions. The East Coast Ports have good access to railways with two Class I railroads, namely CSX and Norfolk Southern, serving the ports via on-dock intermodal container transfer facilities. The ports have scheduled daily services to customers along a good radius from the docks.

Norfolk Southern appears to be a promising partner in this regard with its commitment to driving sustainability solutions for freight transport. It has improved fuel efficiency by more than 25% since it first began tracking in 1987. Around 1.4 million metric tons of greenhouse gas emissions were avoided in 2019 alone. (*Norfolk Southern | Sustainability*, n.d.). Currently, Norfolk Southern has services to 24 seaports, 10 river ports, and nine Great Lake ports in the United States.

One major challenge to increasing the overall efficiency of intermodal railway shipment over truckload is having an adequate length of the linehaul. An intermodal shipment can comprise the movement of cargo from the origin to the railway terminal, the rail line haul, and then from the end terminal to the final destination. For the overall route to be more cost-effective, the length of the linehaul should be larger than the other two components. (Craig et al., 2013, p. 50)

Currently, nearly all US locomotives are propelled by diesel-electric drives, but improved battery technology can open doors to the possibility of having battery electric rail. There is an opportunity to tap into the near-term climate action by employing battery-powered locomotives. Increasing battery energy densities and improving battery technologies coupled with access to affordable renewable electricity can support this transition to battery electric rail.

2.4: Policies: Currently in Effect or Coming in the Future

Implementation of suitable public policies can accelerate the transition to greener and more sustainable intermodal freight transport. The Inflation Reduction Act of 2022 outlines a slew of incentives for environmental protection, relevant among which is the Grants to Reduce Air Pollution at Ports. Under this incentive, the Inflation Reduction Act will provide $3 billion to establish a program to award grants and rebates for the purchase and installation of zero-emission equipment and technology at ports, as well as the development of climate action plans at ports (epa.gov | *Inflation Reduction Act presentation*, n.d.).

Investments in alternative fuel and advanced technology vehicles are also gaining significant traction from the Biden administration. "The CHIPS and Science Act will make critical investments in building domestic capacity for the semiconductors necessary for electric vehicles," whereas the Bipartisan Infrastructure Law is set to invest $7.5 billion towards building a reliable and more predictable EV charging infrastructure (Whitehouse.gov | briefing-room, September 14, 2022). On November 15, 2021, President Biden signed the Bipartisan Infrastructure Law, also referred to as the Infrastructure Investment and Jobs Act, which contains significant new funding for EV charging stations. The National Electric Vehicle Infrastructure Formula Program, which has a budget of $5 billion, allocates funds to states for the purpose of strategically deploying charging infrastructure and building an interconnected network to improve data collection, access, and reliability. Meanwhile, the Discretionary Grant Program for Charging and Fueling Infrastructure, which has a budget of $2.5 billion, is a competitive grant program that aims to install publicly accessible electric vehicle charging infrastructure and other alternative fueling infrastructure along designated alternative fuel corridors (Transportation.gov |Federal Funding Programs).

The effective utilization of government policies and subsidies to spur a reduction in greenhouse gas emissions will offset some of the additional costs of adequate infrastructure development for building Green Corridors.

2.5: Carbon Emission Calculations

There are multiple ways to calculate carbon emission for operations: direct measurement, fuel consumption, and activity-based approaches. Direct measurements of emissions require specialized equipment and are costly and time-consuming but provide very accurate results. Fuel consumption estimates the amount of emissions based on how much fuel the vehicles consume and requires actual consumption information. Activity-based emission calculations come from an emission factor multiplied by the weight and distance of the transportation. The emission factor takes into account the equipment type but can vary dramatically depending on what organization publishes the emission factor.

Chapter 3: Data and Methodology

Chapter 3 focuses on the data and methodology used to build the scenario simulations to evaluate the different modes of transportation available for the three specified routes. These scenarios are designed to compare the cost, emissions, and infrastructure requirements of different transportation options for each route. This chapter presents the details of the capital and operating expense model used for each scenario, as well as the methodology used for calculating emissions.

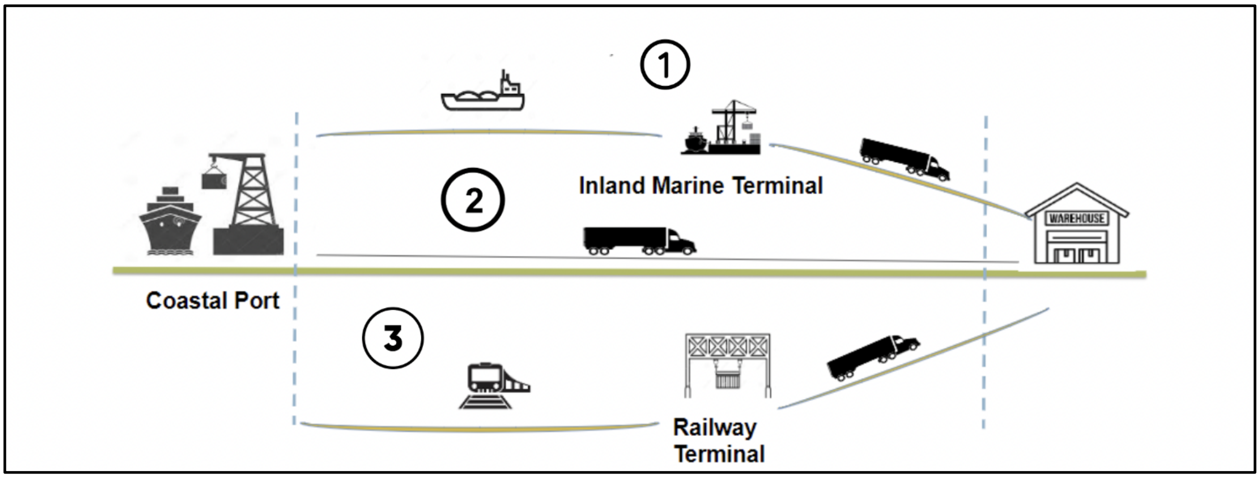
In this chapter, we build scenario simulations for the following cases:

1. Comparison between the existing model of using diesel trucks for delivery and a future scenario involving alternate technology/fuels taking both capital and operational expenses into consideration.
2. Comparison between using diesel trucks and railway and their electric counterparts over the designated corridor.
3. Comparison between using diesel trucks and barge services and their electric/hybrid counterparts over the designated corridor.
4. Present an overall comparative analysis by evaluating the use of different modes of transportation available, such as rail, barge, and truck transportation over the three corridors

The company requested that we investigate the following three routes:

Figure 1

Three routes being examined



- Route 1: Transport by barge from a coastal port to an inland marine port, then trucking up to 25 miles to a customer warehouse.

- Route 2: Trucking from a coastal port 100 miles inland to warehouses.

- Route 3: Loading TEUs on a train from the coastal port to an inland rail port and trucking up to 25 miles to a warehouse.

For calculations, we focus on the cost of the leg, the cost of any infrastructure improvements that are needed, and the carbon emissions. When calculating carbon emissions, we will include the emissions from the modes and calculate the emissions for generating electricity used by electric vehicles. We will consider any current subsidies that are being offered by the federal and state government that relate to infrastructure in the scenarios listed above and how they will affect the payback period for the investment.

Emission factors for each mode of transport have been gathered from *The Green Freight Handbook* and converted to metric tons per TEU mile. For the price of fuel, we have used the national average price for diesel reported by the U.S. Department of Energy for October 1-15, 2022. The model was built for Route 2 first and presented to the sponsoring company to make sure all the information they wanted had been included in a useful manner. After that, the model was expanded to include the other two routes. The model presents the capital expense and operating expense for the scenarios considering different technologies and the emissions that would be associated with the route.

3.1 Data

To build the base case of modes and calculate the cost of carbon and emission values, publicly-available data was used to help shape the scenarios. To obtain information for parameters like emission factors for different modes, publicly-available data has been used. The cost of future infrastructure is also being estimated through publicly-available information. Information was then validated by the sponsor company. If a piece of information could not be validated, then a sensitivity analysis was completed to see what would happen if the value was off.

3.2 Capital Expense Model and Calculations

The capital expense model is similar for each of the three routes and takes into consideration the following components:

- cost of truck (diesel and electric)
- cost of barge (diesel, electric, and hybrid)
- cost of locomotive (diesel and electric)
- cost of charging facility for electric vehicles

The model does not take into account the training of staff because that would be similar across the scenarios for the routes.

The capital expense for a scenario is the sum of all of the items that make up the capital expenses for that scenario. Equation 1 shows how capital expense was calculated for route 1 scenario 1.

$$Capital\ Expense = Cost\ of\ Diesel\ Tugboat + Cost\ of\ Diesel\ Truck \quad (1)$$

For each scenario and route the formula was changed to the relevant equipment. Equations 2 through 4 show the equation for route 3 scenario 2, electric train and electric truck. This requires

$$Capital\ Expense = Electric\ Train\ Costs + Electric\ Truck\ costs \quad (2)$$

$$Electric\ Train\ Cost = Cost\ of\ Electric\ Train + Cost\ of\ Train\ Charging\ Equipment \quad (3)$$

$$Electric\ Truck\ Cost = Cost\ of\ Electric\ Truck + Cost\ of\ Truck\ Charging\ Equipment \quad (4)$$

Due to being electric equipment, charging infrastructure needs to be included in the capital expense.

3.3 Operating Expense Model and Calculations

The operating expense model is similar for each of the three routes. The model changes depending on the scenario and accounts for the following components:

- cost of diesel (for diesel trucks, train, and barge)
- cost of electricity (for electric trucks, tugboat, and locomotive)
- maintenance charges

Calculating the operating expense involves more than simple addition, as it requires determining the amount of fuel needed based on the vehicle's efficiency. Equations 5 through 9 calculate the operating expense for each scenario using route 1 scenario 1 as the example.

$$Operating\ Expense = \ Barge\ Operating\ Cost\ +\ Truck\ Operating\ Cost \quad (5)$$

$$Barge\ Operating\ Cost = \ Maintenance\ Cost\ +\ Total\ Rate\ expenditure \quad (6)$$

$$Barge\ Total\ Rate\ Expenditure = Rate\ per\ TEU * TEU\ moved\ per\ year \quad (7)$$

$$Truck\ Operating\ Cost = Maintenance\ Cost + \ Fuel\ Cost \quad (8)$$

$$Truck\ Fuel\ Cost = (miles\ per\ year/miles\ per\ gallon) * price\ per\ gallon \quad (9)$$

These equations are used for all scenarios, but there are some slight differences when calculating how much money is spent on electricity a year. Equation 10 shows the calculation for annual electricity costs.

$$Cost\ of\ Electricity = \ (miles\ per\ year * \ KWH\ per\ mile) * cost\ per\ KWH \quad (10)$$

3.4 Emissions Calculations

For emission calculations, we are utilizing an activity-based methodology. Direct measurement cannot be conducted since the operations have not yet started. The same challenge holds true for fuel consumption, and the efficiency cannot be properly determined as the model of the vehicle is not yet set. To be consistent in our calculations across modes, we are using weight emission factors for each methodology from the Green Freight Handbook and then assuming a weight of 30 short tons per TEU. Table 1 shows the emission factors from the *Green Freight Handbook* before we converted them to metric tons per TEU mile.

Table 1

Emission Factors from Green Freight Handbook

Mode	Emission Factor
Barge	17.5 grams CO_2 per short-ton mile
Rail	22.9 grams CO_2 per short-ton mile
Truck	161.8 grams CO_2 per short-ton mile
Electricity	0.315 kg CO_2 per Kilowatt hour

These emission factors were used in equation 11 to generate the emission factors that were fed into the model. The model is calculating everything in terms of Metric Tons CO_2 per TEU, so the emission factors from the *Green Freight Handbook* needed to be converted to match Metric Tons CO_2 per TEU_2.

$$Emission\ Factor(\frac{MTCO_2}{TEU\ mile}) = Emission\ factor\,\frac{gCO_2}{short\ ton\ mile} * \frac{ton}{TEU} * (\frac{1\ MT}{1000000\ g}) \quad (11)$$

Table 2

Emission Factors Taking Into Account the Weight of a TEU

Mode	Emission Factor
Barge	0.000525 Metric Tons CO_2 per TEU mile
Hybrid Barge	0.00038325 Metric Tons CO_2 per TEU mile
Rail	0.000687 Metric Tons CO_2 per TEU mile
Truck	0.004854 Metric Tons CO_2 per TEU mile
Electricity	0.000315 Metric tons CO_2 per Kilowatt hour

The emission factors in Table 2 are then used in equation 12 to calculate the emissions generated by each mode of transportation.

$$Emission(\frac{MT\ CO_2}{year}) = Emission\ factor(\frac{MT\ CO_2}{TEU\ mile}) * \frac{TEU\ miles}{year} \qquad (12)$$

These emission values are used to compare the different scenarios on the routes to see which modes reduce CO_2 emissions.

Chapter 4: Results and Analysis

Chapter 4 presents the results and analysis of a comprehensive capital and operating expense model developed for the sponsor company. This model allows the sponsor company to understand how large an investment is needed to switch from diesel equipment to other technology. Each route will be discussed separately. By providing a detailed analysis of cost and emissions, this chapter provides valuable insights for the sponsor company to make informed decisions about the future of their transportation routes.

4.1: Route 1

Route 1 can be served by barge and truck. Three scenarios were created to compare the technology:

- Scenario 1 uses a diesel barge to an inland port and then a diesel truck to the distribution center
- Scenario 2 uses an electric tugboat to the inland port and then an electric truck to the distribution center
- Scenario 3 uses a hybrid tugboat to an inland port and then an electric truck to the distribution center.

Route 1 has 92 miles covered by the tug from the coastal port to the inland barge port. Then the truck covers 25 miles out to a warehouse and 25 miles back to be ready to pick up the next TEU.

4.1.1: Route 1 Scenario 1: Base Case Diesel Barge and Diesel Truck

This scenario is also known as the base case scenario because it is the technology that is currently in place. Table 3 shows the values for capital and operating expenses for scenario 1.

Table 3

Values for Route 1 Scenario 1

Item		Unit
# of TEUs moved a year	1,000	TEUs per year
Cost of diesel tugboat	$8,000,000	$ per vessel
Yearly maintenance for a diesel tugboat	$30,000	$ per year
Rate per TEU for tugboat	$323	$ per TEU
Cost of diesel truck	$150,000	$ per truck
Yearly maintenance for a diesel truck	$15,000	$ per year
Miles covered a year	50,000	Miles
Truck efficiency	6.5	Miles per Gallon
Diesel price	$5.17	$ per gallon of diesel

The values are used to calculate the capital expense for having one diesel tugboat and one diesel truck to move 1,000 TEUs. The capital expense is $8.15 million, with most of the cost coming from purchasing a tugboat to move the barge. Operating expense is calculated as it was shown in section 3.3 and is $407,779. Most of the cost comes from the rate per TEU for the tugboat, which is being used to represent how much it would take to fuel the barge, but likely also includes a markup to help the barge company make a profit.

The other important piece of the model is the calculation of emissions for the scenario to determine if the other scenarios produce a reduction in carbon dioxide emitted. Table 4 shows the values that feed into the emission part of the model for Route 1 Scenario 1.

Table 4

Emission Values for Route 1 Scenario 1

Barge	
Miles covered	92,000
Emission factor	0.000525 MT CO_2 per TEU Mile
Barge emissions	48.3 MT CO_2
Truck	
Miles covered	50,000
Emission factor	0.004854 MT CO_2 per TEU Mile
Truck Emissions	242.7 MT CO_2
Total Emissions: 291.0 MT CO_2	

This scenario serves as the baseline that needs to be improved upon in the other scenarios to make implementation worthwhile. Most of the emissions, in this case, come from the diesel truck because barges are more efficient per TEU mile.

4.1.2: Route 1 Scenario 2: Electric Barge and Electric Truck

In this scenario, the barge and truck are transitioned to electric alternatives. This modification entails an increase in the cost of the tugboat for the barge by $23 million, as well as the incorporation of electric charging infrastructure. The primary consideration in this scenario is shifting towards environmentally-sustainable transportation options and seeing if using fully-electric alternatives meets that goal.

Table 5

Values for Route 1 Scenario 2

Item		Unit
# of TEUs moved a year	1,000	TEUs per year
Cost of Electric Tugboat	$31,000,000	$
Cost of Electric Tugboat charging	$205,984	$
Yearly maintenance for an Electric Tugboat	$20,000	$ per year
Miles covered a year by electric tugboat	92,000	miles
Efficiency of the Electric Tugboat	26.6	KWH per mile
Cost of Electric Truck	$450,000	$
Cost of Electric Truck Charging Infrastructure	$103,185	$
Yearly maintenance for an electric truck	$7,500	$ per year
Miles covered a year	50,000	Miles
Truck efficiency	1.7	KWH per mile
Cost of Electricity	$0.166	$ per KWH

The capital expense required to successfully implement the technology in this scenario amounts to $31,759,169. The operating expense is $447,845.20 per year, which is more than the base scenario, so the sponsor company would not ever make a return on the investment. The major part of the operational expenses comes from the cost of electricity for the barge due to the low efficiency of 26.6 KWH per mile.

Table 6

Emission Values for Route 1 Scenario 2

Electric Barge	
KWH needed	2,447,200
Emission factor	0.000315 Metric tons CO_2 per Kilowatt hour
Barge Emissions	770.9 MT CO_2
Electric Truck	
KWH needed	85,000
Emission Factor	0.000315 Metric tons CO_2 per Kilowatt hour
Truck Emissions	26.8 MT CO_2
Total Emissions: 797.6 MT CO_2	

Another major concern about scenario 2 is that the emissions are greater than the base case scenario so implementing this scenario would move the sponsor company further away from their goal of reducing carbon emissions until the production of electricity becomes carbon neutral.

A sensitivity analysis was completed to determine when scenario 2 would be saving emissions compared to the base case. The efficiency of the barge was tested from 1 KWH/ mile up to 50 KWH/mile in case our original energy assumption was not correct. The other factor that changed was the emissions from producing electricity. To have emission savings with the current efficiency, the grid emissions would have to drop from 0.315 kg CO_2 per KWH to 0.1 kg CO_2 per KWH. If the electric grid production efficiency does not improve, then the efficiency of the tugboat has to go from 26.6 KWH per mile to 5 KWH per mile. It is more likely for the electric grid to reach zero emissions than for the efficiency of the tug to increase fivefold because not many companies are exploring this technology yet and are using hybrid tugs as a transition while battery technology improves.

4.1.3: Route 1 Scenario 3: Hybrid Barge and Electric truck

Due to hybrid tugs being viewed as a step between diesel tugs and electric tugs, we created a scenario to determine if this technology could be implemented currently to provide a transition to zero carbon emissions.

Table 7

Values for Route 1 Scenario 3

Item		Unit
# of TEUs moved a year	1,000	TEUs per year
Cost of Hybrid Tugboat	$18,000,000	$
Cost of Hybrid Tugboat charging	$120,506	$
Yearly maintenance for a Hybrid Tugboat	$25,000	$ per year
Miles covered a year by electric tugboat on electricity	18,400	miles
Efficiency of the Electric Tugboat	26.6	KWH per mile
Rate Per TEU	$323	$ per TEU (assuming 80% of operation is on diesel so used for 800 TEUs)
Cost of Electric Truck	$450,000	$
Cost of Electric Truck Charging Infrastructure	$103,185	$
Yearly maintenance for an electric truck	$7,500	$ per year
Miles covered a year	50,000	Miles
Truck efficiency	1.7	KWH per mile
Cost of Electricity	$0.166	$ per KWH

Hybrid tugs cost less to purchase and operate than fully electric barges because hybrid barges still operate primarily on diesel engines with a few batteries added. Hybrid tugs still need charging infrastructure, but it is less than what is required for a fully electric tug due to having a smaller battery capacity onboard. The capital expense is $18,673,691, and the operating expense is $386,265.04 per year. The operating expense is less than it is for the base case, so it is theoretically possible for the company to earn back its investment due to the savings. However, the payback period is over 850 years, which is not a reasonable amount of time. The other concern is whether there will be emission savings.

Table 8

Emission Values for Route 1 Scenario 3

Hybrid Barge	
Miles	92,000
Emission factor	0.000383 Metric tons CO_2 per Kilowatt hour
Barge Emissions	35.3 MT CO_2
Electric Truck	
KWH needed	85,000
Emission Factor	0.000315 Metric tons CO_2 per Kilowatt hour
Truck Emissions	26.8 MT CO_2
Total Emissions: 62.0 MT CO_2	

In Scenario 3, the emissions are reduced compared to the base case, resulting in an annual decrease of 229 metric tons of CO_2. Considering a 15-year project lifespan, the capital expense equates to $5,437 per metric ton of CO_2 reduction achieved.

4.1.4: Route 1 Cost Comparison

Table 9 shows estimated capital expenses, operating expenses for a year, and the savings in operating expenses compared to scenario 1 for the three scenarios.

Table 9

Capital and Operating Expenses for Route 1

Scenario	Capital expense	Operating Expense	Operating Expense savings per year from Scenario 1
1- Diesel Barge and Truck	$8,150,000	$407,779	–
2-Electric Barge and Electric Truck	$31,759,169	$447,845	$ (40,066)
3- Hybrid Barge and Electric Truck	$18,673,691	$386,265	$21,514

Route 1 scenario 1 has the lowest capital expenditure due to diesel trucks and tugs costing less than the electric or hybrid alternatives. Table 10 shows the assumed cost of the equipment for each of the scenarios.

Table 10

Cost of Route 1 Equipment

Equipment	Cost
Diesel Truck	$150,000
Electric Truck	$450,000
Diesel Tug	$8,000,000
Electric Tug	$31,000,000
Hybrid Tug	$18,000,000

With the diesel truck being one-third of the price of an electric truck, there needs to be a savings in the operating expense to have the investment in the technology be worthwhile. Looking at Table 9, it can be seen that there are no monetary savings for scenario 2 compared to scenario 1, so the money spent on the technology will never be paid back. This can be explained by the low efficiency of the electric tug, meaning much electricity needs to be purchased, and that exceeds the cost of diesel needed to power the tug.

Just having savings in operating expenses does not make a business case for the scenario. There needs to be a reasonable payback period for the investment needed. With no savings for the electric barge and electric truck scenario, we will not look at payback periods for it. The current payback period of 867 years sounds unreasonable for practical purposes, so we tried to figure out how the payback period would change if part of the capital expense was paid by a grant. To lower the payback period under 100 years, 90% of the capital expense needs to be covered by other funds. This is still not a good payback period, so there is not a strong economic case for the current efficiency of the barge. If the efficiency of the barge is increased from 26.6 KWH per mile to 5 KWH per mile, the payback period can be reduced to 21 years with grants covering 90% of the capital expenditure.

4.1.5: Route 1 Emissions

Table 11 is a comparison in emissions for each scenario and the savings in emissions compared to Scenario 1.

Table 11

Emissions for Route 1

Scenario	Emissions per year (MT)	Emissions savings per year from scenario 1 (MT)
1- Diesel Barge and Truck	291	–
2-Electric Barge and Electric Truck	797.64	-506.64
3- Hybrid Barge and Electric Truck	62.03	228.97

At present, only the hybrid case yields emission savings, primarily due to the emissions associated with electricity generation. However, if one were to assume a future transition to a zero-emission grid, it would be feasible to calculate the cost per metric ton of CO_2 saved in comparison to the diesel case. Table 12 shows the amount per MT CO_2 saved for scenarios 2 and 3.

Table 12

$ per MT CO_2 saved for Route 1

Scenario	Current Grid Emissions	If 0 emissions from grid
2-Electric Barge and Electric Truck	–	$7,276 per MT CO_2 saved
3- Hybrid Barge and Electric Truck	$5,437 per MT CO_2 saved	$4,278 per MT CO_2 saved

The amount of money needed to be spent per MT CO_2 saved seems high so it would be harder to win a grant for these cases.

4.2: Route 2

Route 2 is only served by trucks with a route of 100 miles from the coastal port to the inland warehouse. A trip is considered from the port to the warehouse and back. Due to this route only being served by trucks, there are only two scenarios to consider: 1) diesel truck and 2) electric truck.

4.2.1: Route 2 Scenario 1: Base Case Diesel Truck

This route relies on only a diesel truck, so the only capital expense in this scenario is the cost of a diesel truck.

Table 13

Values for Route 2 Scenario 1

Item		Unit
# of TEUs moved a year	250	TEUs per year
Cost of Diesel Truck	$150,000	$
Yearly maintenance for a diesel truck	$15,000	$ per year
Miles covered a year	50,000	Miles
Truck efficiency	6.5	Miles per Gallon
Diesel price	$5.17	$ per gallon of diesel

The emissions from this scenario are viewed as the base case for the route because that is what is currently used.

Table 14

Emissions for Route 2 Scenario 1

Truck	
Miles covered	50,000
Emission Factor	0.004854 MT CO_2 per TEU Mile
Truck Emissions	242.7 MT CO_2

Due to diesel trucks being one of the most inefficient modes of transport compared to barge and truck, the emission for moving 250 TEU is 242.7 MT CO_2.

4.2.2: Route 2 Scenario 2: Electric Truck

Scenario 2 uses an electric truck which costs three times what a diesel truck costs to purchase and requires an electric charging station as well.

Table 15

Values for Route 2 Scenario 2

Item		Unit
# of TEUs moved a year	250	TEUs per year
Cost of Electric Truck	$450,000	$
Cost of Electric Truck Charging Infrastructure	$103,185	$
Yearly maintenance for an electric truck	$7,500	$ per year
Miles covered a year	50,000	Miles
Truck Efficiency	1.7	KWH per mile
Cost of Electricity	$0.166	$ per KWH

The operating expense for an electric truck is $21,610 a year meaning that there is a savings of $33,159 compared to the base case, so there is a possible economic case for the technology. The payback period for the capital expense is 16.7 years which is higher than most companies are looking for and higher than the estimated 15-year life of the electric truck.

Table 16

Emissions for Route 2 Scenario 2

Electric Truck	
KWH needed	50,000
Emission Factor	0.000315 Metric tons CO_2 per Kilowatt hour
Truck Emissions	26.8 MT CO_2

Based on the current emissions from the grid and the estimated efficiency of an electric truck there can be a saving of 215.9 metric tons of CO_2 a year. Due to electric truck technology not being widespread yet, the efficiency might not be accurate, so a sensitivity analysis was completed. With the current grid emissions, the efficiency could be as inefficient as 10 KWH per mile and still have 85 MT of CO_2 emission reduction per year.

4.2.3: Route 2 Cost Comparison

One of the biggest concerns for making a business case is if the sponsor company is able to make the money back that they invest into the new technology from savings from the base case. The current payback period for scenario 2 is 16.7 years. Using a grant to cover part of the capital expense can decrease the payback period to where it is more attractive for the company to invest.

Table 17

Route 2 Cost Comparison

Scenario	Capital expense	Operating Expense	Operating Expense savings per year from Scenario 1
1- Diesel Truck	$150,000	$54,769	–
2-Electric Truck	$553,185	$21,610	$33,159

If a grant covers the charging equipment, then the payback period would be reduced to 13.57 years. To get to a payback period of 5 years the grant would need to cover 70% of the capital expense.

4.2.4: Route 2 Emissions Comparison

With the goal to reduce the carbon emission from the base there is a saving by implementing an electric truck due to it having a lower emission factor than a diesel truck. Another way to determine if a scenario is viable is to look at the $ per metric ton CO_2 reduction. With the current emission from the grid, the $ per metric ton CO_2 will be $170.8. If the grid goes to zero, it is reduced to $152 per MT CO_2.

Table 18

Emissions Comparison for Route 2

Scenario	Emissions per year (MT)	Emissions savings per year from scenario 1 (MT)
1 - Diesel Truck	242.7	–
2 - Electric Truck	26.8	215.9

4.3: Route 3

Route 3 can be served by train and truck. Two scenarios were created to compare the technology:

- Scenario 1 uses a diesel train to an inland port and then a diesel truck to the distribution center
- Scenario 2 uses an electric train to the inland port and then an electric truck to the distribution center

Route 3 has 225 miles covered by the train from the coastal port to an inland port. Then the truck covers 25 miles out to a warehouse and 25 miles back to be ready to pick up the next TEU.

4.3.1: Route 3 Scenario 1: Base Case Diesel Train and Diesel Truck

This scenario is the base case for the route due to this technology being already used on this route. Table 19 shows the values for capital and operating expenses for scenario 1.

Table 19

Values for Route 3 Scenario 1

Item		Unit
# of TEUs moved a year	1,000	TEUs per year
Cost of Diesel Locomotive	$2,000,000	$
Yearly maintenance for a Diesel Locomotive	$300,000	$ per year
Rate per TEU for train	$459.94	$ per TEU
Cost of Diesel Truck	$150,000	$
Yearly maintenance for a diesel truck	$15,000	$ per year
Miles covered a year	50,000	Miles
Truck Efficiency	6.5	Miles per Gallon
Diesel price	$5.17	$ per gallon of diesel

The values are used to calculate the capital expense for having one train and one truck to move 1,000 TEUs a year. The capital expense is $ 2.15 million, with most of the cost coming from a diesel locomotive. The annual operating expense is $814,709 with most of the cost coming from the rate per TEU for the train which represents how much it would take to fuel the train but likely includes a markup to help the rail company make a profit.

The other important piece of the model is the calculation of emissions for the scenario to determine if the other scenarios produce a reduction in carbon dioxide emitted. Table 20 shows the values that feed into the emission part of the model for Route 3 Scenario 1.

Table 20

Emission Values for Route 3 Scenario 1

Train	
Miles covered	225,000
Emission factor	0.000687 MT CO_2 per TEU Mile
Train Emissions	154.6 MT CO_2
Truck	
Miles covered	50,000
Emission Factor	0.004854 MT CO_2 per TEU Mile
Truck Emissions	242.7 MT CO_2
Total Emissions: 397.3 MT CO_2	

Most of the emissions from this scenario come from the diesel truck because trains are more efficient than diesel trucks per TEU mile.

4.3.2: Route 3 Scenario 2: Electric Train and Electric Truck

This scenario changes the train and truck to electric. The cost of the train increases by $3 million and then the electric train and truck both require electric charging equipment.

Table 21

Values for Route 3 Scenario 2

Item		Unit
# of TEUs moved a year	1,000	TEUs per year
Cost of Electric Locomotive	$5,000,000	$
Cost of Electric Locomotive charging	$400,000	$
Yearly maintenance for an Electric Locomotive	$230,000	$ per year
Miles covered a year by electric Locomotive	225,000	miles
Efficiency of the Electric Train	9.65	KWH per mile
Cost of Electric Truck	$450,000	$
Cost of Electric Truck Charging Infrastructure	$103,185	$
Yearly maintenance for an electric truck	$7,500	$ per year
Miles covered a year	50,000	Miles
Truck Efficiency	1.7	KWH per mile
Cost of Electricity	$0.166	$ per KWH

The capital expenses are $5,953,185 to obtain the vehicles and the charging equipment required. The operating expense is $612,187 per year which is less than the base case scenario and saves $202,522 so it is possible for the company to earn back the investment from the savings from the base case. The major part of the spending comes from the electricity for the train.

Table 22

Emission Values for Route 3 Scenario 2

Electric Locomotive	
KWH needed	2,172,150
Emission factor	0.000315 Metric tons CO_2 per Kilowatt hour
Barge Emissions	684.2 MT CO_2
Electric Truck	
KWH needed	85,000
Emission Factor	0.000315 Metric tons CO_2 per Kilowatt hour
Truck Emissions	26.8 MT CO_2
Total Emissions: 711.0 MT CO_2	

The major concern about Scenario 2 is that the emissions are greater than the base case scenario due to how much electricity is needed to operate the train. To figure out when Scenario 2 would be saving emissions compared to the base case, a sensitivity analysis was completed. The efficiency of the train was tested from 2 KWH/ mile up to 50 KWH/ mile in case our efficiency assumption was not correct. We also tested the emissions from producing electricity. If the grid emissions remain at 0.315 kg CO_2 per KWH then to save emissions the efficiency needs to be 5 KWH per mile or better. If the efficiency remains around 10 kwh/mi then the emission of the grid needs to be reduced to 0.15 kg CO_2 per KWH.

4.3.3: Route 3 Cost Comparison

Table 23 shows the estimated capital expenses, operating expenses for a year, and the savings in operating expenses compared to the base scenarios.

Table 23

Capital and Operating Expenses for Route 3

Scenario	Capital expense	Operating Expense	Operating Expense savings per year from Scenario 1
1 - Diesel Train and Truck	$2,150,000	$814,709	–
2 - Electric Train and Electric Truck	$5,953,185	$612,187	$202,522

The base case has the lowest capital expense because the vehicle technology costs less, and there are no charging facilities needed. The savings helps the business get its investment back. The payback period is 29.40 years. Getting a better payback period requires better efficiency or grant funding. If the efficiency stays the same, obtaining a payback period of less than 10 years requires at least 70% of the funding coming from grants.

4.3.4: Route 3 Emissions Comparison

In Table 24, there is a comparison in emissions for each scenario and the savings from the base case scenario.

Table 24

Emission Comparison for Route 3

Scenario	Emissions per year (MT)	Emissions savings per year from scenario 1 (MT)
1- Diesel Train and Truck	397.3	–
2-Electric Train and Electric Truck	711.0	-313.7

Scenario 2 has more emissions from the base case so does not provide a good business case because it does not match the goal of the sponsor company unless the emissions from the grid decrease. If the efficiency stays the same, then the grid emissions need to drop to 0.15 kg CO_2 per KWH. If the grid decreases to 0, then for a 15-year life it costs $999.00 for each metric ton of CO_2 reduced from the diesel base case.

Chapter 5: Discussion

Chapter 5 discusses the results of the feasibility study that has been conducted for the different scenarios under the three corridors. We will examine and highlight the most significant findings and explore the implications of these findings on the Company's future investment decisions.

5.1: Costs and Emissions

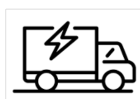
The high cost of investment needed to make the current delivery system ready for the transition to reduced emissions will create a significant gap between what the customer is currently paying and what the future costs would likely be under the new scenarios. As presented in Chapter 4, both Route 1 and Route 3 do not appear to be sufficiently prepared as yet for the green transition due to the extensive capital investment required. The excessively long payback periods render them unsuitable from a business perspective.

We summarize our findings in Figure 2 and see that the first case employing an electric tugboat and electric truck under Route 1 is unfavorable from both cost and emissions point of view. However, the favorability of the route is enhanced if a hybrid tugboat is used in place of an electric tug. But even for this case, the extremely high payback period renders the case impractical. A large portion of the capital expenditure will have to be covered by funds and grants to see a reasonable figure for the payback period. The dollar amount to be invested per MT CO_2 saved seems so high that it will be hard to convince the stakeholders of the practicality of this case.

We also notice that Route 3 leads to a further increase in emissions, which defeats the very purpose of setting up an alternate route for cargo delivery. Of all the scenarios presented, Route 2 provides favorable returns on both cost and emissions and seems to be the low-hanging fruit that can be easily targeted to begin the journey toward Green Corridors. Even the payback period (16.7 years) is the least for this case out of all the cases analyzed. If a grant can be utilized to cover part of the capital expense, it can decrease the payback period further, making it a more attractive business case.

Figure 2

Alternative Routes: Emissions and Cost Comparison

ROUTE	SCENARIO	MODE	EMISSIONS REDUCTION ACHIEVED OVER BASE CASE	COST REDUCTION ACHIEVED OVER BASE CASE	PAYBACK PERIOD (in years)
1	Electric Tugboat + Electric Truck		✗	✗	
	Hybrid Tugboat + Electric Truck		✓	✓	800+
2	Electric Truck		✓	✓	17
3	Electric Locomotive + Electric Truck		✗	✓	29.4

Comparing the routes directly in terms of per TEU is not always the best way to compare because each route covers a different amount of miles so a better comparison is per TEU mile. Table 25 has the comparison of all of the routes and all of the scenarios.

Table 25

Comparison of Emissions Per TEU and Cost Per TEU Across Routes

Route and Scenario	Emissions per TEU (MT CO_2 /TEU)	Emissions per TEU mile (MT CO_2 /TEU mile)	Cost per TEU ($/ TEU)	Cost per TEU mile ($/ TEU mile)
1 - Base Case Diesel Tugboat and Diesel Truck	0.291	0.00205	$951.1	$6.70
1- Electric Tugboat and Electric Truck	0.798	0.00562	$2,565.1	$18.06
1- Hybrid Tugboat and Electric Truck	0.062	0.00044	$ 1,631.2	$11.49
2 - Base Case Diesel Truck	0.971	0.00353	$259.1	$0.94
2 - Electric Truck	0.107	0.00039	$234	$0.85
3 - Base Case Diesel Train and Diesel Truck	0.397	0.00199	$958.04	$4.79
3 - Electric Train and Electric Truck	0.711	0.00356	$1,009.07	$5.05

If the routes and scenarios are compared by looking at just cost per TEU then it appears that it is more efficient to use a tugboat and truck than a train and truck but when looking at the cost per TEU mile then the train and truck looks more attractive. Route 3 covers more distance so not considering distance makes it an uneven comparison.

When comparing the alternate scenarios with the base case over each route, we find that only Route 2 makes for a successful case in terms of reduction in cost per TEU. If the alternate scenario leads to an increase in cost per TEU rather than a decline, the company might look into avenues to fill in this gap created between what the company is currently paying and what the future costs to them will be. Some of the options to fill in these gaps are exploring policy options like government grants and incentives, incorporating carbon pricing mechanisms and understanding the customer willingness to share the cost of decarbonization.

5.2: Carbon pricing

Nations around the world have started incorporating carbon pricing as part of their overall climate strategy to reduce greenhouse gas emissions and encourage decarbonization. Carbon pricing places a price on emissions, which incentivizes individuals and businesses to reduce their emissions or enhance removals. This policy tool helps integrate the costs of climate change into economic decision-making, which can lead to changes in production, consumption, and investment patterns.

The primary driving force behind the growing demand for carbon credits is the voluntary climate targets set by corporations. These targets typically require ambitious decarbonization efforts throughout the company's value chain, along with compensation or neutralization of any remaining emissions.

Companies are developing a mechanism termed internal carbon pricing (ICP) to put a value on their carbon emissions in a way that drives transition towards a greener future. ICPs have been reported at a wide range of values, spanning from USD 0.8 to USD 6,000/tCO2e. However, the majority of reported ICPs fall below the recommended range of USD 50-100/tCO2e, which economists say is necessary to achieve the temperature goals outlined in the Paris Agreement. Out of the approximately 950 companies that have disclosed their ICPs to CDP, a not-for-profit charity that runs the global disclosure system for investors, companies, cities, states and regions to manage their environmental impacts, 68% currently implement a price of USD 50/tCO2e or less, and an additional 18% implement a price between USD 50 and USD 100/tCO2e. Fewer than 100 companies have disclosed that they are currently implementing a carbon price above USD 100/tCO2e (World Bank, 2022).

For the purpose of this study, we have incorporated the sponsor company's internal carbon price. Building the dollar value of the carbon emission reduction into the economic feasibility model opens opportunities to reduce the long payback period by offsetting some portion of the costs involved in the development of the green corridors.

5.3: Utilizing government funds and policies

Effective utilization of government incentives and subsidies can be integral to offset some of the costs associated in the electrification of the fleet in the green corridors and in installing EV charging infrastructure, especially in areas/routes where the potential to cut down carbon emissions by adopting electric vehicles is higher.

Under the Inflation Reduction Act (IRA), which is perhaps the most significant legislation to accelerate transportation electrification in U.S. history, a new tax credit, known as Section 45W, has been created to allow commercial electric vehicles (EVs) to qualify for tax credits for the first time ever until the end of 2032. The credit amount per qualified commercial EV is either 30% of the sales price or the incremental cost of the vehicle, whichever is less. The incremental cost refers to the difference between the purchase price of the EV and a comparable internal combustion engine vehicle. The tax credit is limited to $7,500 for vehicles with a gross vehicle weight rating (GVWR) of less than 14,000 lbs, and $40,000 for vehicles with a GVWR of more than 14,000 lbs. To be eligible, the vehicle must be used for business purposes, and there are no requirements for battery or mineral sourcing under Section 45W. *(Inflation Reduction Act Impacts on Electric Vehicles | Electrification Coalition*, n.d.)

If this grant can be utilized for the deployment of electric trucks on the alternate corridors, the payback period can be further reduced by cutting down on the high initial capital expenditure.

5.4: Limitations and Challenges

The current model does not take into account the longer lead times and potential delays associated with intermodal transport, which might lead to a build-up of inventory holding costs for the customers. Efficient coordination and communication between different modes of transportation become critical in addressing this challenge of potential delays by coordinating frequency and scheduling.

The government policy and regulatory landscape is another arena that can play a significant role in promoting or hindering the general adoption of green corridors. While the current federal government has introduced incentives and regulations to encourage EV adoption, the long-term stability of these policies is prone to uncertainty due to policy changes that might occur when a different political party comes to power.

As the use of plug-in electric vehicles increases, there will be a growing need for a network of electric vehicle supply equipment (EVSE) that can power these vehicles. The costs associated with purchasing, installing, and owning these non-residential EVSEs will be a significant parameter to consider for companies aiming to electrify their diesel fleets. The installation costs will vary depending on the location of the charging station and the existing electrical infrastructure, which might favor some specific routes over others. Another factor to consider, in addition to the initial installation costs, is that there will be ongoing maintenance and operational costs, such as electricity costs, network fees (if applicable), and upkeep of the charging equipment. Ongoing maintenance of electric vehicles is a major challenge as there are not sufficient service centers to support the maintenance and repair demands that will arise with the growing use of electric vehicles. Factors like limited availability of spare parts, technological complexity, and access to sufficient electricity to charge a fleet of heavy-duty trucks are poised to make the use of electric vehicles less efficient as compared to regular gasoline-powered vehicles.

5.5: Further avenues for improvements

A potential key enabler towards building more efficient intermodal corridors is factoring in how synchromodality will give more opportunity for customers to get their cargo delivered in a timely manner.

The concept of synchromodality has different definitions in the industry. However, one of the most accepted definitions is “a multimodal strategy that incorporates the flexible choice of freight transportation modes into shippers’ management of supply chain processes” (Dong et al., 2018, p. 47). Being able to switch between modes of transportation allows companies to take advantage of lower-emission modes when they align with their schedules. Trains and barges are known to be more cost-effective and produce fewer emissions than trucks, but trains and barges do not have the flexibility that trucks do in terms of frequency, scheduling, and quantity (Dong et al., 2018). The Port of Virginia is a suitable place to employ synchromodality due to having access to a barge going to Richmond, a train line running to the Inland Port, and proximity to many of the major highway systems on the East Coast.

To achieve effective synchromodality, the system requires open communication between all the carriers and shippers on the network, allowing volumes to switch between modes. The network volumes need to be high enough and stable to be able to have economies of scale for train and barge transportation. (Dong et al., 2018) Pre-requisites for an effective synchromodality system include encouraging the practice that there is infrastructure in place to allow synchromodality to occur and the proper technology to allow the sharing of information between different parties (Singh, Van Sinderen, and Wieringa, 2016).

The modeling of synchromodal transport is relatively new, and most models focus on the operational method. The three main methods for modeling synchromodality are binary, flow, and state space (Larsen, 2022). Binary modeling occurs when binary variables are used to show whether a group of containers is matched with a mode. Flow models are similar to binary models but instead allow groups of containers to be separated, giving more flexibility to the model. State space modeling is more complex and uses discrete time difference equations for a set time period to describe the flows between different locations (Larsen, 2022).

Chapter 6: Conclusion

The findings of this report open a pathway toward the prospective routes for setting up Green Corridors in the future. In this chapter, we present recommendations on the feasibility of implementing these alternate routes. We also discuss potential areas for future research, which along with the findings from this report, can accelerate the adoption of green corridors and help in transitioning towards a more sustainable future.

6.1: Management Recommendations

a. Transition to electric trucks: The most cost efficient and easiest transition for the company is using electric trucks in place of diesel trucks for inland delivery over Corridor 2. This scenario seems to be the most favorable from both future returns and emissions reduction perspectives. The sponsor company should invest in electric trucks and leverage government funding and incentives to reduce the payback period.

b. Explore future investments: While electric barges and electric trains are currently unsuitable investment options in the near term, the sponsor company should continue to monitor battery technology developments and leverage economies of scale to drive down the costs associated with these investments in the future. They should also collaborate with stakeholders to develop reliable electricity supply sources, set up necessary charging infrastructure, and generate ample customer demand for such services.

c. Share risk and burden: Risk and burden sharing across the Green Corridor will be important to bridge the gap of 'Total Cost of Ownership' that arises with the adoption of these alternate pathways to green transportation. The sponsor company should collaborate with stakeholders to develop risk-sharing mechanisms and explore opportunities to share the burden of investments and operational costs.

6.2: Future Research

While this report provides a cost-emission analysis over the three selected routes, there are still many avenues for future research that could build and expand upon our findings. Some potential areas for further investigation that can guide future decision-making include factoring in inventory holding costs in the model, exploring the use of alternative fuels besides electricity, and expanding the model to include all the emissions from the port to the warehouse.

It would be worthwhile to consider the cost of holding TEUs due to the lower frequency of the train and barges compared to trucks. The inventory holding cost, which is not necessarily taken on by a shipping company but by the shipper, might cause some shippers to rely on traditional trucks due to the faster shipping speed. This holding cost will be different for every customer depending on how much more inventory they might need to hold due to slower shipping. It would also be a good idea to explore what mechanisms can be used to encourage customers or end consumers to opt for these greener routes.

Exploring the use of alternative fuels like hydrogen, biofuels, and natural gas is another area of future research. Extensive research and exploration is already underway in different parts of the world to facilitate this transition to a low carbon future. FLAGSHIPS, a project being funded by the EU, involves several partners who are working together to develop hydrogen fuel cells for two demonstration vessels that will be used for commercial purposes. Their goal is to create a barge and a container vessel that are fueled by green hydrogen, which will pave the way for cleaner water transportation in Europe.

Hydrogen produced through renewable energy is poised to be the most environmentally friendly fuel. It has potential for future shipping applications if liquefied, but due to its low energy density, significant storage space is required.

Hydrogen powered tugs open up the doors to yet another exciting possibility. In May 2022, Astilleros Armón shipyard in Navia, Spain, launched the Hydrotug, the world's first hydrogen-powered tugboat. Incorporating the latest EU Stage V emissions after treatment, the BeHydro engines have passed the factory acceptance tests (FAT) conducted by Lloyd's Register. These engines, rated at 2 MW each, power the Hydrotug, making it the first vessel to utilize them (Marine Log, 2021).

Liquefied natural gas (LNG) is being used as a transportation fuel at various ports for quite some time now. In 2009, the Port of Los Angeles Board of Harbor Commission allocated up to $44.2 million in Port funding to purchase clean trucks. With contributions from local, state, and federal regulatory agencies, as well as private investment, over 900 LNG or compressed natural gas (CNG) trucks were put into service at the Port. The Port is also supportive of the use of LNG as a marine fuel (Sustainable World Ports, n.d.).

LNG-powered tugboats can help in emission reduction as LNG is a cleaner-burning fuel than diesel fuel. This means that LNG-powered tugboats produce fewer emissions of pollutants such as nitrogen oxides (NOx), sulfur dioxide (SO2), and particulate matter. (American Petroleum Institute, 2015)

Some examples of LNG powered tugboats currently in use include Borgøy and Bokn, owned by Buksér og Berging AS, a Norwegian tugboat company and Ishin which is owned by Mitsui O.S.K. Lines, a Japanese shipping company.

The alternate fuel pathway needs to be assessed from economic, technical, and regulatory points of view. Biofuels like ethanol and biogas can be produced domestically and have the potential to enhance energy security. Developing a clear outline of the anticipated alternative fuel demand and production possibilities is, however, crucial for this transition to take place.

Expanding the model to include emissions from the port is another area of future exploration that can help reduce emissions over the entire supply chain. This exercise is likely to provide a better view of all of the emissions from when the TEU leaves the ship to when it gets to the warehouse, allowing decisions to be made to reduce emissions over the whole trip and not just the last move to the warehouse.

REFERENCES

American Petroleum Institute (2015). LNG greenhouse gas emissions guidelines. https://www.api.org/~/media/files/ehs/climate-change/api-lng-ghg-emissions-guidelines-05-2015.pdf

Craig, A. J., Blanco, E. E., & Sheffi, Y. (2013). Estimating the CO2 intensity of intermodal freight transportation. *Transportation Research Part D: Transport and Environment*, *Vol 22*, 49–53. https://doi.org/10.1016/j.trd.2013.02.016

Dong, C., Boute, R., McKinnon, A., & Verelst, M. (2018). Investigating synchromodality from a supply chain perspective. *Transportation Research Part D: Transport and Environment*, *61*, 42–57. https://doi.org/10.1016/j.trd.2017.05.011

Electrification Coalition. (n.d.). Inflation Reduction Act Impacts on Electric Vehicles. https://electrificationcoalition.org/work/federal-ev-policy/inflation-reduction-act/

Environmental Sustainability | Port of Virginia. (n.d.). The Port Of Virginia. https://www.portofvirginia.com/who-we-are/environmental-sustainability/

Environmental Defense Fund. (2017). The EDF Green Freight Handbook. Retrieved from https://supplychain.edf.org/resources/the-green-freight-handbook/

Environmental Protection Agency. (2022). Inflation Reduction Act. Retrieved from https://www.epa.gov/system/files/documents/2022-10/inflation-reduction-act-presentation.pdf

Global Maritime Forum. (2021). The Next Wave: Green Corridors. Retrieved from https://www.globalmaritimeforum.org/content/2021/11/The-Next-Wave-Green-Corridors.pdf

Greene, D., & Plotkin, S. (2011). *Reducing Greenhouse Gasses from U.S. Transportation.* Arlington, Virginia. Pew Center on Global Climate Change https://www.researchgate.net/publication/263039824_Reducing_Greenhouse_Gases_from_US_Transportation

International Maritime Organization. (n.d.). Reducing greenhouse gas emissions from ships. Retrieved from https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx

Larsen, R. (2022, September 16). *Real-time Co-planning in Synchromodal Transport Networks using Model Predictive Control (thesis). Repository TU Delft*. TU Delft. Retrieved October 2022, from https://repository.tudelft.nl/islandora/object/uuid:6b36a004-0b37-417c-a77a-ab423a19cbb9?collection=research.

MacHaris, C., Van Mierlo, J., & Van Den Bossche, P. (2007). Combining Intermodal Transport With Electric Vehicles: Towards More Sustainable Solutions. *Transportation Planning and Technology*, *30*(2–3), 311–323. https://doi.org/10.1080/03081060701395618

Marine Log. (2021, May 17). World's first hydrogen-fueled tugboat launched. https://www.marinelog.com/technology/worlds-first-hydrogen-fueled-tugboat-launched/

Massport (n.d) https://www.massport.com/massport/media/newsroom/massport-announces-goal-to-be-net-zero-by-2031/

Nutraceutical Business Review. (2021, March 31). Beneo barge investment to cut CO2 emissions. Retrieved from https://www.nutraceuticalbusinessreview.com/news/article_page/Beneo_barge_investment_to_cut_CO2_emissions/175645

Port Authority of New York and New Jersey. (n.d.). Environmental Initiatives. Retrieved from https://www.panynj.gov/port-authority/en/about/Environmental-Initiatives.html

Port Houston. (n.d.). Port Houston Environmental Report. Retrieved from https://porthouston.com/stewardship/environment/report/

Port of Los Angeles. (n.d.). Zero Emissions Technologies. Retrieved from https://www.portoflosangeles.org/environment/air-quality/zero-emissions-technologies

Richmond Marine Terminal (RMT) | Port of Virginia. (n.d.). https://www.portofvirginia.com/facilities/richmond-marine-terminal-rmt/

P. Singh, M. van Sinderen, and R. Wieringa. Synchromodal transport: pre-requisites, activities and effects. In *Proc. of International Conference on Information Systems Logistics and Supply Chain*, pages 1–4, Bordeaux, France, 2016.

https://www.researchgate.net/publication/327691841_Synchromodal_Transport_Pre-requisites_Activities_and_Effects

Sustainable World Ports. (n.d.). Port of Los Angeles. Clean Marine Fuels Working Group. https://sustainableworldports.org/clean-marine-fuels/about-our-cmf-working-group/cmf-members/port-of-los-angeles/

The White House. (2022, September 14). Fact Sheet: President Biden's Economic Plan Drives America's Electric Vehicle Manufacturing Boom. Retrieved from https://www.whitehouse.gov/briefing-room/statements-releases/2022/09/14/fact-sheet-president-bidens-economic-plan-drives-americas-electric-vehicle-manufacturing-boom/

World Bank. (2022). State and Trends of Carbon Pricing 2022

http://hdl.handle.net/10986/37455