Transition to a Sustainable Energy in the U.S.:
Transportation Component

CEE 5910
Engineering Management Project
Final Report

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EXECUTIVE SUMMARY

This report studies the transition of vehicles and infrastructure from current energy alternatives to those that substantially reduce the release of net CO₂ emissions to the atmosphere. The focus is on estimating the extent of new energy sources required to meet the demand in the land, air and water sectors. Each sector was analyzed and presented separately to determine the emerging technologies and better practice techniques for each specific mode of transportation.

Air Transport

International aviation travel is one of the most rapidly growing in CO₂ emissions, with an increase of 42% between 1990 and 2005. This increase is likely to continue due to growth in air travel and lack of stringent regulations to reduce CO₂ emissions in the aviation sector. The total influence of aviation emissions on the climate is significantly greater than that of CO₂ emissions. However, the effect of non-CO₂ aviation emissions on the climate is complex and therefore only CO₂ emissions will be analyzed. There are several CO₂ mitigation strategies available to aviation including aircraft technology improvements, operational changes and alternative fuel usage. Several solutions including the use of winglets, replacing the aging fleet, more efficient decent procedures, preferred routing, taxing on a single unit, the use of gate power rather than auxiliary power units have been proposed to improve aircraft efficiency reducing fuel consumption and ultimately CO₂ emissions. Though there are many technically feasible alternative fuel options available to the aviation sector only one option, biofuel, is a viable alternative to conventional jet fuel. The adoption of these CO₂ mitigation strategies over the next 20 years will result in 32% fuel savings by 2030.

Water Transport

Even though in the past water transportation was not a huge factor in global carbon dioxide emission, recently, the industry is gaining attention due to its increased contribution to carbon emission. In this report, we will provide some basic information about the marine sector, examine the possible current or new technology that can be used to reduce carbon dioxide emission, and build models to predict energy consumptions.

The marine sector can be divided by recreational and freight use, and in the freight area, we have domestic and foreign commerce. In U.S., freight use is the bigger factor for energy consumption. The sector can be broken down by vessel’s use and also be categorized by the vessel type and size. As with the choice of modal transport, marine transportation in U.S is much safer, more energy efficient and has great potential to reduce highway congestion.

Currently, the marine sector has many possible techniques to reduce carbon dioxide emissions. Vessels can have more energy efficient design and equipment to reduce the emission. Also, the industry is still exploring the potential use of biofuel through some ongoing researches such as NOAA’s Green Ship Initiative. As with the idea of using renewable energy, the marine sector is starting to use the technology to save fuel and carbon dioxide emission. One of the notable uses of wind energy is the SkySail system, which is currently in used by MS Beluga SkySails. As for solar energy, many places are using hybrid solar boats to cut the emission and fuel cost such as
the Sydney Harbor ferry boats. Currently, a first-ever solar panel cargo car carrier ship just set sail last year. The industry is not just looking for new ways to save energy but also doing best practices to try to reduce the emission. Therefore, the technology and ways to cut the carbon dioxide emission are emerging in the industry.

As with the modeling part of our analysis, the focus is to create a model to predict energy consumption at 2030 domestically because current international marine data is not complete and accurate. Nations are just starting to put together statistics and data now. We will examine the base case of do nothing and other the scenarios using possible technology to compare the difference.

Overall, this research report should give a complete overview of the marine sector, the emerging technologies involved in the industry, and some possible forecasted scenarios in the future for energy consumption and carbon dioxide emissions.

**Land Transport**

*Freight*

The freight portion of the land transport section first focuses on the fuel consumption inefficiencies of long distance Class-8 freight trucks and the various ways these can be mitigated. Reducing heavy duty truck fuel consumption is important because they consume 60% of all fuel used for freight in the US (Davis, 2003), shadowing every other transportation mode. This section of the report highlights and details how even small improvements in freight truck fuel economy can result in major reductions of CO₂ emissions. Examples of possible efforts include improving the aerodynamic performance of these trucks as well as fine tuning engine specifications.

The second focus is then to gather these possible improvements and predict the long term effect they may have on fuel consumption from the entire US fleet of trucks as well as the corresponding reduction in CO₂ emissions. This is done using models that forecast possible scenarios and their outcomes. It is important to note that these figures offer significance of scale. In the conclusion of this report we provide a simple comparison detailing how implementing fuel saving technologies in the US truck fleet at a modest 2% adoption rate per year can reduce CO₂ emissions by 69 million tons in the year 2030 alone whereas significant changes in airline fuel consumption are modeled to reduce CO₂ emissions by only 530,000 tons in a 22 year span.

*Better Place Concept*

The land sector is also addressed by analyzing the Better Place concept, a battery-electric passenger car network powered solely with renewable energy sources. This private company’s concept is introduced through the perspective of the company itself, third-party reviewers, and the authors. Several key strategies Better Place will deploy are discussed, including their design and operation of an “Intelligent Network,” placing ownership of the batteries in the hands of Better Place, and choosing Israel to receive the first network. With the assistance of several blogs and reviews, limitations and consequences of the concept are discussed, addressing more specifically the difficulties with selling vehicles to customers, standardizing the battery, and
possible increases in vehicle use and congestion. With limited technical information on this new
design, numerical predictions or models cannot be prepared, but the following claims are made:
(1) Better Place is a business and looking to generate revenue and profit as its primary goal; (2)
implementing Better Place networks should be done in populated and developing areas with high
fuel prices and plentiful renewable energy resources; and (3) a significant amount of capital is
required to initiate implementation.
1. INTRODUCTION

1.1 Overview

Compelling evidence reveals that unless something is done to substantially reduce CO₂ emission in the near future, we may be faced with catastrophic climate problems. In the last 50 years alone, world energy production has quadrupled, indicating an ever growing demand and consumption of energy. With this increase in demand, switching to renewable energy becomes essential not only to meet this demand but to mitigate the rising climate problems and solve our problems of presently depleting energy resources as well. Currently, new technology has been produced, such as hybrid cars, which aid in the effort to increase use of renewable energy, but a multitude of information and possibilities have yet to be unearthed and researched. Specifically, the area of transportation is still in development stages and has much untapped potential. This sector accounts for ~25% of energy consumption worldwide and ~27.5% of energy consumption within the United States. Due to the large stake transportation energy consumption has both in the United States and worldwide, it is not only beneficial but necessary to delve further into this field.

1.2 Team Structure

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1.3 Problem

1.3.1 Air Transport

Population increases and the growth of the middle class in developing countries have contributed to increased demand for air travel and freight movement. Some of the main sources of emissions include aircraft exhaust, ground support equipment, and auxiliary power units within aircraft. The increase has placed a demand upon the environment which has not been fully researched to date. In this project it is our intent to further investigate the factors influencing carbon dioxide emissions from aircraft operations. Air transport only accounts for 2% of total global emissions. However, rapid growth in aviation in recent years has led to increased scrutiny. Questions regarding the aircrafts and ground support combustion processes, possible emission reducing strategies and technologies will be explored. We will strive to find which are feasible.

1.3.2 Water Transport

As of now carbon emission from water-based transportation has increased 25% in the last ten years, yet this mode is extremely underdeveloped in terms of significant research in available renewable energy use and technology. On top of this, the total estimation of harmful emissions from shipments is highly varied due to different interpretation of international bunker fuel data.

In this project we intend to further research possible techniques for renewable or alternative energy sources in water transport. We also hope to model carbon footprint in this sector and what effects or improvements are possible for the future. With our increasing wealth of research and information, we plan to forecast possible reactions from the related markets as well as economic effects. Some questions we aim to answer are: Is it possible to retrofit existing fixtures to accommodate these new energy developments? Are these options relevant to vessel life cycles?

1.3.3 Land Transport

Much research has been done on the benefits hybrid cars can have on global warming, but hybrid transportation technology has not yet been fully exploited. Currently, hybrid technology is only being offered for personal cars and light trucks, and the market for them has been doing well. But this neglects a huge source of CO₂ emissions: heavy trucks. In the USA in 2004, heavy duty vehicles (most of which were trucks) contributed about 20% of all transportation GHG emissions.

Our group will do research to see how feasible hybridization of trucks is, both technically and in a business sense. We also plan on searching for new alternatives to reduce truck emissions. Once this information is collected we will create forecast models to help us test the effects changes like these could have on CO₂ emissions from the truck fleet. This information can be extremely helpful especially because changing a truck to hybrid has a much deeper effect on emissions than changing one car to hybrid.
In addition, our group will research the Better Place concept, an electric car network that uses technology available today to reduce oil dependency and increase renewable energy use. We will investigate the key ideas and strategies behind this system, looking directly at the company and third party reviews to establish a foundation. From there, we will attempt to project the effects this concept can have on a larger scale; the impacts on energy use, particularly renewables, and CO₂ emissions.

1.4 Scope of Work

1.4.1 Air Transport

Focus on domestic energy consumption in the air-based sector. We will initially research available energy resources, technologies available, current trends in energy consumption, restrictions and feasibility. With this data, we plan to model potential improvements and any milestones that can possibly be reached in the future. Upon creating a model, we will then see how this fits into the current air-based freight and travel sector. We will compile information in a comprehensive report covering all aspects of air travel including models to forecast energy demand and greenhouse gas emissions. Recommendations of best practices for the aviation industry will be made.

1.4.2 Water Transport

For this section of the project, we plan to focus on domestic energy consumption in the water-based sector. We will initially research new energy resources and technologies available as well as current trends in areas of energy consumption, current technologies, and existing status quo. With this data, we plan to model potential improvements and any milestones that can possible be reached in the future. Upon creating a model, we will then see how this fits into the current landscape of water-based freight and travel aspects of this transportation mode. We will attempt to incorporate any findings we make into a final forecasting model.

1.4.3 Land Transport

We will research the hybridization of freight transporting vehicles, trucks. We will make the key assumption that hybridization of heavy trucks will be technically feasible. We will assess how feasible the technology is, the benefits and challenges involved, and possible plans to incorporate said vehicles into a fleet to reduce greenhouse gas emissions. We will also look into other alternative energies to reduce truck emissions. Also, we will focus on the Better Place concept. We will gather the preliminary information on the company and explain the findings by discussing strategies and limitations with their concept. Recommendations will be given for establishing the concept in the United States or other parts of the world.
2. AIR TRANSPORTATION

2.1 Aviation Sector Overview

Aviation is a critical part of our national economy, enabling the movement of goods and people throughout the world quickly and safely. In 2008, the aviation sector contributed to 3% of global CO₂ emissions. Passenger and cargo operations of just U.S. carriers consumed approximately 18.85 billion gallons of jet fuel. Kerosene-type jet fuel (Jet A & Jet A-1) produces approximately 21.53 lbs CO₂ per gallon burned. Thus, the consumption of this fuel generated approximately 175M Metric Tons of CO₂ emissions. Worldwide international aviation is one of the most rapidly growing sources of CO₂ emissions, showing an increase of 42% between 1990 and 2005. While CO₂ emissions from most other transportation sectors are declining due to the implementation of more stringent control programs, the growth of air travel and the lack of federal control programs have allowed for the continued increase of CO₂ levels within the air transportation sector.

An expectation of strong future economic growth is the main underlying driver of the aviation traffic projections. “Aviation traffic is usually highly responsive to economic growth rates; with increases in economic activity promoting greater than proportional increases in traffic”. A study released in 2004 concludes that “the rise in demand for air travel is one of the most serious environmental threats facing the world”.

“States are required by federal law to reduce ambient levels of criteria pollutants. Given the existence of stringent control programs for other industry sectors, reductions in airport-related air pollution are necessary in order for states to lower emissions to meet air quality and public health goals”. Information generated by this study will hopefully provide a resource and offer strategic suggestions aimed toward the reduction of CO₂ emissions within the air transportation sector.

2.1.1 Greenhouse Effect of Aviation Emissions

The greenhouse effect of aviation emissions is much more complex than the near ground emissions of most other transportation sectors. Atmospheric science has provided us with some knowledge of how gases transform in the atmosphere but there are very few studies that have been able to accurately quantify the effect of high altitude emissions on climate.

High-altitude NOₓ emissions induce tropospheric ozone formation and reduce the atmospheric lifetime of methane. This has obvious implications; methane is a potent greenhouse gas. However, it is hard to say with any certainty by how much the lifetime of methane is reduced and what effect altitude of the emissions has on this transformation.

In addition, particles and water vapor lead to the formation of linear contrails and cirrus clouds under certain conditions. These clouds trap heat in the lower atmosphere similar to CO₂. Though water vapor is traditionally thought of as harmless, many studies estimate the climate effect of H₂O from aviation to be significant. Considering both the water vapor effect and the NOₓ effect, the total influence of aviation on climate is expected to be considerably greater than is suggested solely on the basis of its share of current CO₂ emissions. In a recent study by Omega, a publicly
funded partnership providing insight into the environmental effects of the aviation industry, they estimate that aviation is responsible for 4.7% of the anthropogenic change in global mean temperature.

Due to uncertainty and lack of research into the effect of varying altitudes and behavior of alternative fuels, examining the complete greenhouse effect of aviation is increasingly difficult. In this report we will focus on only CO₂. In the effort to reduce human effect on climate change, CO₂ has been in the political spotlight. It is linked directly with the amount of fuel consumed and it easily quantifiable. On average, 67% of the exhaust from aircraft will be CO₂, H₂O makes up 28%. Figure 1, shown below, summarizes the share of various other exhausted gasses.

![Figure 1 – Aircraft Emission Breakdown](image)

Though the complete effect of the technological improvements discussed in this report may not be fully understood, any reduction in CO₂ will certainly reduce the effect of aviation on climate change.

2.1.2 Emission Inventory

To begin studying the effect of aviation on climate change and inventory of the current emission sources must be established. As mentioned previously in section 2.2, an inventory of items requiring fuel at an airport is a good reflection of the sources of CO₂.

There are three primary energy users at airports: the aircraft, the ground support fleet, and any auxiliary powering units the airport may have installed. Auxiliary powering units (APUs) are generators that make electricity on site to power the electrical system onboard aircraft. While connected to an APU the aircraft does not need to run its turbines just to run lights and other low draw electric units. Ground Support Equipment (GSE) consists of primarily vehicles and equipment that do not leave the airport. They include a host of equipment such as aircraft tugs, air-conditioning units, baggage handlers, loaders, etc. Figure 2 shown below summarizes the share of energy use of all airline activities. It can be easily observed that the primary driving source for CO₂ emissions are the aircraft, producing a total of 98.8% of all CO₂ emissions while APUs and GSEs account for a combined 1.2%. In this report we will highlight opportunities for
improvement from aircraft, APUs and GSEs, however our model will primarily focus on aircraft efficiency and operational improvements, as they are the primary emission sources.

**Figure 2 – Airline 2008 CO\textsubscript{2} Emissions\textsuperscript{7}**

![Airline 2008 CO\textsubscript{2} Emissions](image)

### 2.1.3 Data Limitations: Aircraft

**Aircraft**
The aircraft emissions inventory for operations below 3,000 feet is well known. Fuels dispensed at airports are a reliable data source and the conversion of fuel burned into CO\textsubscript{2} emissions is well understood. Calculating the exact amount of aircraft ground emissions below 3000 feet however involves calculating all four phases of the LTO cycle. Data must include emissions within the Approach, Taxi-Idle, Takeoff, and Climbout phases. In addition, the type of aircraft and age for efficiency purposes must be known. The data file if available would be enormous and the calculations not trivial. In this report we will use the generally accepted percentages illustrated within Figure 2.

**GSEs and APUs**
Greenhouse (CO\textsubscript{2}) gas emission data currently available covering GSEs and APUs is marginal at best. To accurately forecast emissions, the rate of emissions and the amount of activity of each unit must be known. GSEs are generally not licensed to operated on open roads and therefore do not have to comply with the national emissions standards. The lack of required reporting and emissions compliance is responsible for approximately 5 to 20% higher emissions. APUs even go further in complicating issues as current fuel data does not separate out their fuel usage from that of the aircraft. It is however generally accepted that the average emission factor by percentage (GSEs=1.0%) and (APUs=0.2%) are widely accepted and will be used within this report. The breakdown is illustrated in Fig.1. The primary driver for GSE forecast is the forecast of LTOs. This number has grown from 16 billion in 1996 to 22 billion in 2008 with an expected growth to 40 billion in 2030. However, many airlines have begun to convert their GSEs to alternate fuels such as electric and propane. Unfortunately there is little or no data to support the actual numbers.
2.2 Emission Reduction Strategies

Section 2.2 will focus upon the options available for reducing CO₂ emissions at airports. The section is divided into three categories covering Aircraft, GSE’s, and APU’s. Within each category technological and operational options are explored. Examples of technological options include, advances in engine design, new materials, and alternative fuel usage. Examples of operational options include changes in taxiing, takeoffs, and landing procedures.

2.2.1 Aircraft Improvements

Engine

The bulk (>90%) of CO₂ emissions at airports throughout the world are from aircraft engines. Trends in engine performance and efficiency provide evidence of improvements. “Aircraft energy use (fuel per seat mile) over the next 25 years is projected to decrease by over 30% as airlines continue to make improvements.”

Improvements in engine design have been demonstrated by numerous manufacturers. “New aircraft engines are 70% more fuel efficient than 40 years ago and 20% better than 10 years ago.” General Electric and Pratt & Whitney are working together on an engine that would reduce NOₓ by 40% with significant efficiency improvements in fuel burn therefore reducing CO₂ levels.

Aerodynamic Design

The development of new improvements to aircraft aerodynamic efficiency has already lead to greater reductions in CO₂ emissions by reducing the amount of fuel burned. Lacking regulatory pressure or government support, the Greener by Design study predicts an improvement of 30-35% over the next 50 years in fuel burn from improving efficiencies to existing swept wing design aircraft. The biggest single "bolt-on" performance enhancer for airliners has been the blended winglet, developed jointly by Aviation Partners and Boeing in 1999. They have proved to be so popular that more than 1,750 blended winglet systems are in service with at least 100 airlines in more than 40 countries. Modifications times for a Boeing -700 are typically four days for a provisioned wing(no conversion needed) and six days for a conversion, and for a Boeing -800 it takes four and eight days. “The result is reduced drag, which translates directly into improved fuel consumption of between 4% and 6%, and better aerodynamic performance from increased lift.” At a 4% savings in fuel burn, this translates into a CO₂ reduction of approximately 7 Metric Tons in 2008. These savings mean that the return on investment is achieved in a shorter period.

Aircraft Materials

New body materials have been the focus of research and development for decades. The new Boeing B-787 jet, to fly later this year has achieved radical reductions in weight through the extensive use of composite materials. The Boeing B-787 will contain 50% composite materials. These composites will use graphite combined with epoxy resins for the fuselage. In addition, the wings will include titanium-graphite. Titanium is a very strong light weight metal and graphite is a stable form of carbon. By way of comparison, “about 50% of the weight of a B-777, a Boeing aircraft currently in production, is aluminium. And 12% of the weight of a B-777 is composites.
Yet only about 20% of a B-787 will be aluminium by weight, with 50% of weight taken up by composites.” While these composites are unique today, they may become the standard of tomorrow. In addition, fuel consumption can also be reduced through the use of new materials which are used in conjunction with aircraft. “The use of lighter cargo containers can reduce CO₂ emissions by up to 438 tons based on a fleet of 3,100 passenger planes and 1,000 freight aircraft. The International Air Transport Association advises that every kilogram of weight saved reduces fuel consumption by an average of four percent of the weight carried for an hour.”¹² For example, if an aircraft reduces its weight by 100kg then it will save four kilograms of fuel in each flying hour. Based on just 35,000 new containers, 29 million kg of fuel can be saved and reductions of nearly 88 million kg of CO₂ can be achieved. This is a small fraction of the entire industry. If every airline in the world where to adopt the use of this type of new container, over 400,000 tonnes of CO₂ emissions could be cut.

**Hybrid Systems**

Similar to the technology used in today’s hybrid cars, energy can be captured and stored in batteries. The stored electric then could be used to power in-wheel motor/generators capable of effectively manoeuvring an aircraft. Aircraft require a tug for push back from terminals and require their main engines for taxiing to runways. Currently the technology allows for only push back, however this eliminates the need for ground operations. The technology was developed by Delos Aerospace. “It’s projected to provide fuel savings of 2.4 to 3.4 million dollars a year per (jet, turbofan) aircraft.”¹³ This is the equivalent of approximately 1 million gallons of fuel at $3.00 dollars.

### 2.2.2 Operational Improvements

**Airline Efficiency**

Although a simple idea, operational efficiency can be maximized by making sure each flight is full. This minimizes the amount of CO₂ emissions per passenger. Airlines could use larger aircraft holding more passengers instead of running multiple smaller aircraft serving the same routes. Also using fuller smaller aircraft on less common routes can save considerable amounts of fuel. Airlines could also optimize their fuel burn through properly timing schedules. Flying at off peak hours if even less profitable would avoid congestion and save fuel.

**Single-engine Taxiing**

Most large aircraft have multiple engines of which one or more could be shut down. By operating fewer engines, nearer their maximum output efficiency is maximized. This simple change results in fuel savings and reduced emissions. “A 747 jet consumes more than 500 gallons of fuel taxing (non delayed)-enough fuel to operate a car for a year.”¹⁴

**Tow aircraft to the runway**

Aircraft are typically pushed back from the gate using a tow tractor which maneuvers the aircraft into a safe position to start its engines. If aircraft where towed to the runway there would be a
potential savings in fuel burn emissions. There is however a tradeoff between the combine Tug and APU’s emissions providing air-conditioning and lighting versus aircraft engine emissions. Long haul aircraft at major US hubs such as New York, San Francisco, and Los Angeles currently take an average of 60 minutes from gate to takeoff and burn 2000 gallons of fuel. Tug and APU emissions are approximately half of a taxing aircraft. When all is calculated a savings of 10% is anticipated.

Derated Takeoffs and Approach

Aircraft are designed to take off fully loaded and at maximum thrust. During normal operations most aircraft do not need to apply full thrust in obtaining flight and still staying within safe operating parameters. Full thrust is only needed under extreme conditions. Safe runway lengths, and other airport designs are key in implementing this option. The reduction in thrust correlates directly with the reduction of fuel and CO$_2$ emissions. During approach where aircraft fly a smooth approach into the airport rather than the classical stepped approach, reduces fuel burn. During the 4$^{th}$ Aviation and Environment Summit it was reported that “fuel burn is reduced by 50-150kg for short haul to medium haul aircraft, but also reduces CO$_2$ emissions by 160 to 470kg per flight.”15 In the US there were approximately 11 billion departures and arrivals in 2008. Information about actual in-flight operations is confidential and is not always recorded during flights making it very difficult to gather data.

Reduced Taxi Time

CO$_2$ emissions are high during taxi operations when aircraft engines are operating at greatly reduced efficiencies. A number of options are available in reducing taxi time which correlates into fuel burn savings. One option is to design new airports or ones under construction to allow planes to stay close to the runways and terminals. Another option would be to incorporated measures that would hold an aircraft at the gate until ready for takeoff. In a Business 24-7 article, “research shows that 18% of fuel is wasted every year through airport infrastructure and operational inefficiencies amounting to 120 Million Tons of CO$_2$ emissions worldwide.”16

Point-to-Point Travel

More direct flights reduce the number of miles flown. By utilizing this approach unnecessary air miles are curbed resulting in fuel conservation and emission reductions. “For every 1 billion passenger mile flown by Southwest Airlines, 10 million pounds of CO$_2$ were emitted to the atmosphere compared to the industry average.”17

2.2.3 Support Equipment Improvements

Alternative Fuels – GSEs

Almost 100% of GSEs burn either gasoline or diesel as their primary fuel. Three types of fuels have been used as alternative fuels at airports to reduce GSE emissions. They are (LPG) liquefied petroleum and (CGN) compressed natural gas. The conversions of conventionally fueled GSE’s to LPG or CNG provide significant emission benefits. In addition, the cost of LPG
is half of gasoline. The largest constraint to switching over is the initial capital cost of conversion and the installing of alternate fueling facilities. “Conversions cost for belt loaders and baggage tractors to LPG are about $1,700. For aircraft push backs about $2,700 and gasoline GSE’s to CNG about $5,000.\textsuperscript{18} The cost of a CNG station could be in the range of $750,000 and the loss of physical space (real-estate) may not be feasible. Although this looks bleak many airlines are taking on comprehensive programs of reinvesting in equipment.

<table>
<thead>
<tr>
<th>Table 1 – Alternative Fuel Emissions</th>
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<tr>
<td><strong>Emissions Relative to Gasoline GSE</strong></td>
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<tr>
<td>LPG</td>
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<tr>
<td>---</td>
</tr>
<tr>
<td>HC</td>
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<tr>
<td>CO</td>
</tr>
<tr>
<td>NO\textsubscript{2}</td>
</tr>
<tr>
<td>PM</td>
</tr>
<tr>
<td>CO\textsubscript{2}</td>
</tr>
</tbody>
</table>

United States Environmental Protection Agency

**Electrification**

Onsite emissions benefits from electrification are very positive. No emissions are generated when the piece of GSE equipment is idle. Electric tugs, baggage conveyors and many other machines are now commercially available. Conversions are also readily available. The initial purchase of electric GSE’s can run up to 27% higher than conventional fuel operated equipment, however the cost is recovered through fuel and maintenance savings. The cost of a charging infrastructure must also be taken into consideration. Southwest Airlines has become an industry leader in electrification with 580 pieces of equipment electrified to date. Just this one airline alone reduced their ground support equipment fuel consumption by more than 495,000 gallons of fuel annually. This is the equivalent of reducing CO\textsubscript{2} emissions by more than 10.5 million pounds.

**Auxiliary Power Units Emission Reduction**

Data on APU’s emission factors and aircraft/APU combinations is sparse. These units do not fall under any vehicle class’ emission requirements, and therefore are not subject to any controls or emission certification programs. The only way to subjectively calculate the emission would be based upon the time difference between departures and arrivals. In addition, the use and number of electrified gates is not documented as a whole. Although APU’s are a very small portion (0.2%) of the total aircraft emissions, they still can be reduced. Gate electrification is once again the answer. Fixed Gate designs can reduce emissions from APU’s by allowing gate-based power and air hookups to supply energy directly to the aircraft. Provided that the fixed system is capable of supplying all the aircrafts electrical and air conditioning needs (not currently the case for most fixed systems used today), APU use could be reduced from an average of 45 minutes per layover to approximately 7 minutes for a narrow body jet and from 120 minutes to 7 minutes
for a wide body jet.\textsuperscript{19} An article published by Southwest Airlines has stated “through gate electrification, Southwest has reduced APU fuel consumption by more than 15 million gallons in 2007.”\textsuperscript{20} This the equivalent of 161K Tons of CO\textsubscript{2} reduced by one airline alone.

2.3 Aviation Alternative Fuels

2.3.1 Alternative Fuel Feasibility Analysis

There are a variety of options available as alternative fuels for aviation including biodiesel, methanol, ethanol, Fischer-Tropsch Kerosene, nuclear, hydrogen and liquefied bio-methane. However, all of these options face significant challenges making only a few of these options viable.

*Methanol and Ethanol*

Methanol and ethanol are both alcohols and present similar challenges as alternative jet fuels. Each has an extremely low energy density and specific energy density, meaning there is not enough energy in mass or volume terms.

![Figure 3 – Aircraft fuels energy content per unit volume and weight\textsuperscript{21}](image)

This limits the aircraft to a short range and causes the take-off weight of the aircraft to be too heavy. The use of methanol or ethanol would require aircraft redesign. Ethanol requires a 64\% increase in storage volume for the same amount of conventional fuel and a 25\% larger airplane wing. This would result in a 20\% increase in the airplane’s empty weight. The increased weight of ethanol compared to conventional would result in a 35\% increase in takeoff weight. Since the aircraft engine is designed to handle the heaviest part of the mission, which is takeoff, the engine would require a 50\% increase in thrust. All of this amounts to a 15\% increase in energy use for a 500nmi flight.\textsuperscript{21}
Nuclear

A nuclear powered aircraft was first considered by associates of the Manhattan Project in 1942 for its potential to travel at high speeds with an almost unlimited range. The Nuclear Energy for the Propulsion of Aircraft project was initiated by the United States Air Force in 1946 to develop a high performance nuclear aircraft and a long-range nuclear bomber. In 1951, this project was replaced by the Aircraft Nuclear propulsion program run by the Atomic Energy Commission and the United States Air Force. Early designs suggested that an 80 ton propulsion system, including 5 tons for the reactor and 50 tons shielding system, was required for nuclear powered aircraft. These weight issues, in addition to safety concerns of radiation emission, accidental explosions, and terrorist attacks have rendered nuclear powered aircraft infeasible.

Liquefied bio-methane

Liquefied bio-methane has also been considered for alternative aviation fuel but also faces significant challenges. Although liquefied bio-methane could provide more than a 25% reduction in CO$_2$ emissions, it is still not considered a viable option for aviation due to production limitations in producing large quantities at a low enough cost and with sufficient homogeneity.

Fischer-Tropsch Kerosene

Kerosene can be manufactured using different processes with the most common method being Fischer-Tropsch. The Fischer-Tropsch process is performed in a series of three steps: synthesis gas generation, hydrocarbon synthesis and upgrading. In the first synthesis gas generation step a carboniferous feedstock, such as coal, is converted into synthesis gas. Then a mixture of liquid hydrocarbons and wax are created by catalytically converting the synthesis gas. This step is known as the Fischer-Tropsch process. In the last step, the mixture of hydrocarbons is upgraded to the desired fuels with hydrocracking and isomerization.

Fischer-Tropsch Kerosene is considered a more viable option than methanol, ethanol, nuclear and liquefied bio-methane fuels. FT kerosene can provide significant reductions in CO$_2$ emissions during the fuel combustion process. However, the FT kerosene manufacturing process is extremely energy intensive resulting in life-cycle CO$_2$ emissions twice that of conventional jet fuel. Therefore the FT kerosene manufacturing process must be coupled with renewable energy or carbon sequestration to have CO$_2$ reduction benefits. Currently FT kerosene is viewed as a method to reduce oil consumption rather than reduce CO$_2$ emissions. Advantages of FT kerosene include the elimination of aircraft SO$_2$ emissions, lower particulate emissions and its use as a drop in fuel replacement meaning no aircraft redesign would need to occur. FT kerosene would require the same fuel storage infrastructure and transport as conventional kerosene. In addition to using 100 percent FT kerosene fuel, blends with conventional kerosene can be created. The high thermal stability of FT kerosene could be used to create higher fuel temperatures and increase fuel combustion efficiency. FT kerosene can also be used to improve high altitude operability to due to the fuel’s ability to operate well at low temperatures.

In addition to facing difficulties lowering CO$_2$ emissions on a life-cycle basis, FT kerosene faces other challenges as well. The lower energy density of FT kerosene than conventional kerosene
reduces the maximum aircraft range on long flights. The sulphur-free and low aromatic content of FT kerosene cause it to have poor lubricity, but can be solved with additives. FT kerosene also requires costly new refinery investments.

**Hydrogen**

Hydrogen is considered an important long term aviation fuel, with many estimates put at 50 plus years before the technology can be phased into the market. Hydrogen technology is ideal because it has no end use CO\(_2\) emissions. It can also be derived in many different ways from many different sources. Hydrogen production can be considered a sink for electricity during off peak hours. Hydrogen propulsion technology would prove a great aid in reducing CO\(_2\) emissions, but the technological challenges it faces places hydrogen as a technology of the future. Hydrogen would require significant aircraft redesign. Hydrogen has a lower volumetric density than conventional fuel and as such larger fuel tanks would have to be accommodated. Spherical or cylindrical fuel tanks would are needed withstand pressure differentials. The heavy fuel tanks increase the operating empty weight by 13% for a Boeing 737. However, the fuel is light and therefore decreases the takeoff weight by 5\%\(^{21}\). Aircraft engines are designed for the heaviest part of the mission, takeoff, therefore the reduction in takeoff weight, would allow for the engine to deliver 25\% less thrust and be downsized. Due to insulation and pressurization requirements the fuel storage could not be included in the wings. The aircraft redesign for hydrogen technology is feasible but more development is needed.

Though hydrogen powered aircraft would eliminate CO\(_2\) emissions completely, it would emit water vapor which can be a strong greenhouse gas at high altitudes. Hydrogen emits 2.6 times the water vapor of conventional kerosene.\(^{23}\) The residence time of water in the atmosphere differs significantly from CO\(_2\). The residence time of CO\(_2\) is more than 100 years and independent of altitude. The residence time of water varies with altitude from 3-4 days on the ground up to 0.5-1 year in the stratosphere.\(^{23}\) The greenhouse gas effect of water vapor varies greatly with altitude as well, and is considered to have a larger greenhouse gas effect than CO\(_2\) at higher altitudes. Water is considered to have negligible green house effect below 10 km, and begins to dominate CO\(_2\) as greenhouse gas at 12 km.\(^{24}\) However, if the relative greenhouse gas effect of CO2, H\(_2\)O and NO\(_x\) combined are considered hydrogen has less of an impact than conventional kerosene at all altitudes.
Hydrogen powered aircraft also presents safety concerns as hydrogen air mixtures detonate, but burn out much faster than kerosene fires. There are also supply concerns as an abundant source of energy for electrolysis and large amount of water is needed. Hydrogen technology also presents infrastructure design challenges as more complex ground transportation, handling and distribution infrastructure and storage are required.

**Biodiesel**

Biodiesel may be the most instrumental agent in reducing CO\(_2\) emissions in the aviation sector, as it does not face the significant technological challenges of hydrogen and can more efficiently reduce CO\(_2\) emissions than FT kerosene. Biodiesel is obtained by the esterfication of oleaginous crops such as oilseed rape, sunflowers and soybean. The main production areas of oilseed rape are Canada, China, India and North and West Europe. Oilseed rape requires humid conditions, a long growing season, deep soil and is cold tolerant. Out of the sunflower and soybean alternatives, oilseed rape is the most sensitive to nutrient and water inputs. It can also assist with crop diversification as it can be grown in rotation of cereal cultivation.

The sunflower has the advantage being able to be grown in several different climates including subtropical, temperate, warm temperate and semi-dry climates. The sunflower can also be grown in rotation with small grain cereals such as wheat. The main producers of sunflowers are Argentina, Eastern Europe, USA, China, France and Spain. Currently sunflowers are mostly produced for their oil but also produced as an ornament as well. Oil producing varieties of sunflowers have 40-50% oil be seed mass. The sunflower has less intensive management than oilseed rape and can be grown in areas where oilseed rape cannot.

The soybean is the least sensitive to crop inputs compared to oilseed rape and sunflowers, as there is a reduction of tillage, irrigation, fertilizer and weed control. As a result of lower inputs, production costs, energy consumption and emissions are also reduced. However, soybean produces a lower oil yield per hectare than rape or sunflower. Soybean production for oil may also compete with food supplies as it is a large source of protein for both humans and livestock.
The advantages of biodiesel over conventional jet fuel and other alternative fuels include the fuels ability to reduce life-cycle emissions, biodegradability, and same airplane design. Biodiesel is considered a kerosene “extender” as 10-30% mixtures can be created. One of the main disadvantages of biodiesel is that it freezes at the normal operating temperatures of high altitudes. An additional processing step may be performed to address this challenge. Biodiesel also faces storage issues as it can degrade through oxidation, therefore long term storage must be avoided. The water reactivity of biodiesel also presents storage and pipeline transport issues.

The most significant challenge facing biofuels is its production as plant growth requires a large land area and can interfere with food production. Most countries will be unable to grow their own biofuel feedstock. For example, if Germany were to completely replace its diesel demand with biodiesel, approximately 56.6 million tons would be required. To meet this requirement every crop would have to be replaced with rapeseed and four times the area of Germany’s 11.83 million hectares of arable land would be need. These demands are not only infeasible but would also inhibit Germany’s food production. A similar case holds true for the United States. Supplying only a 15% blend of biodiesel to the US commercial aviation fleet would require 2.04 billion gallons of biofuel a year. Soybeans, the US biofuel feedstock, which produces 60 gallons of biofuel per acre, would require a land area similar to the size of Florida at 34 million acres. Biofuel production should not be ruled out for all countries as Brazil and Ukraine have the land area to supply their energy needs with biofuels. Biofuels may become more appealing in the future as several biofuel feedstocks, such as Jatropha and algae, are being developed with higher energy density requiring less land area and interference with food production.

2.3.2 Alternative Life-Cycle Emission Analysis

Several studies have been performed to determine the energy input required to produce biodiesel. Energy input has varied greatly with the assumptions made in these studies. In 1998, the first comprehensive life cycle study of biodiesel was performed by The Department of Energy National Renewable Energy Lab (NREL) and U.S. Department of Agriculture (USDA) and determined biodiesel had a net energy value of 3.2 to 1. More recent research in 2007 by the NREL and USDA found a higher positive net energy ratio for biodiesel at 3.5 to 1 due to higher soybean yields, less herbicide use and a significant reduction in soybean crushing energy use.

In addition, to being one of the most viable alternative aviation fuels bio-jet fuel also affords one of the largest reductions in CO₂ emissions compared to jet fuel. Liquid hydrogen from water and nuclear power provides the largest reduction, with almost zero CO₂ emissions relative to conventional jet fuel, as seen in the graph below.
Bio-jet fuel affords a 40% reduction in CO₂ emissions compared to conventional jet fuel.²¹ Biodiesel is a great alternative fuel to aid in the reduction in CO₂ emission however; it cannot assist in completely reducing these emissions.

### 2.4 Aviation Emissions Model

#### 2.4.1 Method

The growth of miles traveled by air has been steadily growing linearly since 1996. In 2008 the total miles traveled by U.S. Carriers exceeded 8.1 billion miles. Although interrupted by 9/11 and the current market recession, historical data before 1996 suggests an underlying linear growth trend we expect to return after 2009. Figure 6 below, illustrates out projection of miles traveled to 2030.

At the same time the number of miles traveled has been increasing, the efficiency of the aircraft has also been increasing. By combining the miles traveled with the fuel use from 196 to 2008, we can compute a miles per gallon metric to measure aircraft efficiency. Figure 7 shown below
is the computed average fuel economy. From the graph, we find that the average fuel economy over the last 12 years has increased 1.6% yearly.\textsuperscript{27}

![Figure 7 – MPG Increase 1996-2008](image)

In order to estimate the effect of various impacts on the emission of CO\textsubscript{2} from the aviation industry, a model was constructed to account improving efficiencies, operational changes, and biofuel blending. A case incorporating all three reduction strategies was also created.

First a base case was established. The Intergovernmental Panel on Climate Control (IPCC) published a report on the forecasting of CO\textsubscript{2} emissions from aircraft where they estimated, that efficiency would improve by 1.3% per annum to 2010, then 1.0% per annum to 2020, and 0.5% per annum thereafter. We chose to use this as the base case for our calculations. Our model was forecast out to 2030.

The first scenario we explored was the effect of increased aircraft efficiency. In our case based on the collection of estimates in our literature review, we chose to double the annual base case efficiency increases. The technology to obtain these increases is available today however the cost of implementation is often a prohibiting factor. For this reason, we understand doubling efficiency to be an extreme case. However as we will show later, in order to stabilize the emissions from the aviation sector major changes are necessary. Motivated by a carbon cap and trade system or stricter management of the aviation industry in general, we believe the efficiency improvements in our model are possible.

The second input the model allows is the effect of the implementation of the operational changes outlined in section 2.2.2. We believe that with increased concern over the environmental effects of the aviation industry that major operational changes might be once again under consideration. Because the changes do not require intense infrastructure upgrades in most cases and simple policy changes are all that is necessary, we estimate the impact of operation changes would be phased in over the next two years with an effect equivalent to increasing aircraft efficiency by 5% per annum until 2010. Once the optimal policies are in place, we expect the efficiency gains to return to the base case of 1.5% per annum to 2020 and 0.5% per annum thereafter.\textsuperscript{28}
The third reduction strategy modeled is the blending of biofuel with jet fuel. From literature we estimated a linear growth of the biofuel blending increasing at a rate of 0.5% per annum. In this case the efficiency of the aircraft was left at the base case and a direct replacement of the fuel was modeled with a life-cycle CO\(_2\) ratio of 50%, meaning that a gallon of fuel replaced by biofuel would reduce the CO\(_2\) emitted by 50%.

2.4.2 Results

The effect of increasing efficiency to double the current rate, had the most significant effect on the CO\(_2\) in the year 2030. By increasing the efficiency of the aircraft, the industry could save 53.8 billion gallons of fuel over the next 22 years. This amount to a reduction of 530,000 metric tons of CO\(_2\) from the atmosphere. Figure 8 illustrates the fuel savings over time.

Through operational changes, the aviation industry could save roughly 30 billion gallons of fuel, and reduce CO\(_2\) emissions by 340,000 metric tons. Figure 9 shows the savings year by year.
Biofuel blending by replacing 33.8 billion gallons of jet fuel over the next 22 years, would save approximately 520,000 metric tons of CO$_2$. Figure 10 shows the reduction of jet fuel by biofuel replacement.

The combination of the three reduction strategies results in a significant reduction in both fuel consumption and CO$_2$ emitted. Through the year 2030, the total amount of fuel consumed is able to remain steady as the number of miles travels continues to increase. It is important to note that combination of the three strategies is not simply the sum of the savings. The operational improvements combine with the efficiency improvements for the years 2009 and 2010, then efficiency is equal to the efficiency only scenario thereafter. Biofuel blending is also added the reduced efficiency actually reduces the per gallon CO$_2$ impact of the jet fuel replacement. Figure 11 shows the effect of all three solutions versus the effect of each solution individually.
Figure 12 shows the CO₂ levels out to 2030. The fuel savings and CO₂ savings vary a little due to the life-cycle ratio of the biofuel. If a gallon of biofuel had no life-cycle greenhouse gas emissions as opposed to 50% of jet fuel, then the curves would look identical. By the year 2030, the airline industry could be using 32% less fuel per year compared to the base case.
3 WATER TRANSPORT

As of 2006, water transport makes up 5% of U.S. Domestic Energy consumption\(^\text{29}\). Though this is considerably less than the automobile transportation sector, reducing as much harmful emissions as possible can still be beneficial.

3.1 Sectors

The water transport mode is divided into two areas, recreational and freight. Recreational makes up 17.14% of the water transport mode energy consumption while the last 82.86% is from Freight transport.\(^\text{29}\)

<table>
<thead>
<tr>
<th>Category</th>
<th>Rated Power</th>
<th>Displacement per Cylinder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>&lt;37 kW</td>
<td>any</td>
</tr>
<tr>
<td>Commercial C1</td>
<td>&lt;5 liters</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>≥37 kW</td>
<td>≥5 liters and &lt; 30 liters</td>
</tr>
<tr>
<td>C3</td>
<td>≥30 liters</td>
<td></td>
</tr>
<tr>
<td>Recreational C1</td>
<td>≥37 kW</td>
<td>&lt;5 liters</td>
</tr>
</tbody>
</table>

Sectors within water transport are differentiated in multiple ways. One possibility is by engine type and capacity. Diesel engines versus spark-ignition engines are given varying emission standards and are found on different types of boats. Sectors can also be defined by purpose and engine capacity. Engine capacity is grouped by category as shown in Table 2. For example, a cruise liner would be category Recreational C1 since it has a recreational purpose with power and displacement ≥ 37 kW and <5 liters respectively.\(^\text{30}\) Finally, sectors of water transport can be distinguished by category and tier for emission standard purposes. The category is the same categories as aforementioned, while tier pertains to the year a boat was made. Tier (Table 3) is essential for implementing emission standards. Newer boats have stricter emission standards.

<table>
<thead>
<tr>
<th>Tier</th>
<th>Rulesmaking</th>
<th>CFR</th>
<th>Effective Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 2</td>
<td>Phase 2 Emission Standards for New Nonroad Spark-Ignition Nonroad Engines at or below 19 Kilowatts (published March 30, 1999, 64 FR 15208)</td>
<td></td>
<td>2001 to 2007, depending on engine size</td>
</tr>
</tbody>
</table>
Though it is possible to divide the water transport mode by multiple criterions, the most common way to differentiate areas of this mode is by purpose and engine type, more specifically, domestic/foreign commerce and private/public recreation.

### 3.1.1 Domestic Commerce

Vessels of domestic commerce usually fall into the C1 and C2 category which means the engines are typically diesel engines with power greater than or equal to 37 kW and displace zero to 30 liters per cylinder\(^30\). These vessels are also used for commercial purposes of domestic freight.

Domestic commerce makes use of the waterway network in the United States. The four main areas of the U.S. network are the coastwise waterways, inland waterways, the great lakes, and bays/ports. The coastwise waterway refers to the routes taken along both coasts of the United States, especially between Alaska and the western U.S. coast. The inland waterway refers to navigable waters within the contiguous United States. Majority of the network focuses on the Mississippi river, especially with the Mississippi River system and the Gulf Intracoastal Waterway. The Intracoastal Waterway runs for most of the length of the eastern American coast and runs from the Atlantic Ocean to the Gulf coasts of the United States. Great lakes refer to the waterway made by the five Great lakes. Bays and ports refer to the water inlets that allow for boats to dock.

A wide variety of commodities are transported, most of which are dense, heavy products that do not spoil. The top three commodities shipped domestically in the United States are petroleum products, coal, and sand/gravel/stone. A complete list is given in Table 4.

<table>
<thead>
<tr>
<th>U.S. Domestic Commodities</th>
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<tbody>
<tr>
<td>Pulp and Waste Paper</td>
</tr>
<tr>
<td>Waste and Scrap, NEC</td>
</tr>
<tr>
<td>Coal Coke</td>
</tr>
<tr>
<td>Non-Ferrous Ores &amp; Scrap</td>
</tr>
<tr>
<td>Sulfur, Clay and Salt</td>
</tr>
<tr>
<td>Forest Products, Wood &amp; Chips</td>
</tr>
<tr>
<td>All Manufactured Equipment</td>
</tr>
<tr>
<td>Prim. Manufactured Goods and Manufactured Goods</td>
</tr>
<tr>
<td>Iron Ore and Scrap</td>
</tr>
<tr>
<td>Chemical and Related Prod</td>
</tr>
<tr>
<td>Crude Petroleum</td>
</tr>
<tr>
<td>Food and Farm Products</td>
</tr>
<tr>
<td>Sand, Gravel, and Stone</td>
</tr>
<tr>
<td>Coal</td>
</tr>
<tr>
<td>Petroleum Products</td>
</tr>
</tbody>
</table>

Table 4 lists items from least traded to most popularly traded in the year 2004. Data was collected listing the exact millions of short tons of each quantity traded. This data was charted as shown in Figure 13. From the chart, it is shown that the greatest quantities of items moved serve as a huge focal point of domestic U.S. water transport due to the disparity in quantity shipped between the two ends of the list. It is interesting to note that the highest amount of products
shipped is petroleum, and as the country weans itself off non-renewable energy sources, this may also have an effect on the water transportation industry.

![Figure 13 – Comparison of U.S. Domestic Commodities by Mil. Short Tons](image)

3.1.2 Foreign Commerce

Foreign commerce typically includes waterborne import, export, and in-transit trade. Typically, vessels involved in foreign commerce fall in the C3 category, since it is necessary to be able to withstand harsh ocean-going forces. C3 category engines generally have power greater than or equal to 37 kW and displace greater than or equal to 30 liters per cylinder. Ocean-going vessels are typically diesel engines.

This research focuses mainly on domestic energy consumption and emission since data on foreign energy emission is sparse. Due to international bunkers at ports, no official means has been established to track energy use toward national totals. Totals are beginning to be recorded in May 2009. Since no accurate measure of energy has been instated, records have high variability. Data is available regarding tons of commodities shipped internationally.

3.1.3 Private Recreation

Private recreation generally involves smaller, spark-ignition vehicles, though some privately owned recreation vehicles do have diesel engine types. These vehicles are generally in category small with less than 37 kW of power.
3.1.4 Public Recreation

This sector mainly involves cruise liners. These cruise liners are in its own category, recreational c1, having greater than or equal to 37 kW of power but only displacing less than five liters per cylinder.\textsuperscript{30}

Public recreation also contributes a great deal to the energy use of the water transportation mode. No specific data is provided about this area of water transport. Though it does make a contribution to energy consumption in the water transport mode, the main focus of current data collection is on domestic commerce and foreign commerce. Both public and private sectors of recreational boat combine to make up 17.4\% of energy use in the water transportation sector, as aforementioned.\textsuperscript{29} Though the total energy consumption of this sector is evident, specific breakdown between private and public sectors are not available.

3.2 Vessels

In order to better understand marine transportation capabilities in terms of where and how new energy emission improvements can be implemented, it is necessary to understand what vessels are in use, the lifespan of these vessels, and the current standard of emission regulation. Knowing the landscape before an endeavor gives a better idea of what direction to head next, especially in terms of improving energy emission.

3.2.1 Types

The first distinction of marine vessels is by size. Vessels greater than or equal to 10,000 dead weight tons (DWT) are typically considered ocean-going or lake-going vessels. These vessels include tankers (transporting liquids), containerships, dry bulk vessels, roll on-roll offs, double hulls, product ships, general ships, gas ships, and combo ships (gas and dry cargo). Aside from this are smaller vessels that typically move on smaller waterways. These smaller vessels include tugs, dry barges, ferries, tank barges, and double-hull tank barges. Since inland waterways are considerably smaller than coastal water ways, only smaller vessels usually navigate these waters.

Of these boats, the main two types of power sources are diesel fuel engines and spark-ignition engines. Spark ignition engines are generally smaller in size as aforementioned, mainly found in private recreational boats. Diesel engines are most common, found in both large and small vessels, especially cargo and ocean-going vessels.

3.2.2 Lifespan

Since much of this research involves possible new technology for existing marine vessels, it is important to know the lifespan of an average boat, since this might give an indication of how quickly the new technology would get adopted. Also knowing the average age of a boat, gives an idea of range of old technology currently exists and gives a better idea of how energy efficient methods should be executed.
In the data of vessel ages provided by the U.S. Department of Transportation Maritime Administration, a distinction was made between U.S. Flag ships versus U.S. built ships that flew the U.S. Flag. Ships are registered under nations called “Flag States,” which deems the boat to have a certain nationality. Flag states are responsible for ensuring vessels conform to international laws, follow maritime security, and protect the marine environment. Not all boats need to be built in the country it is registered under. Thus, U.S. flag ships follow U.S. regulation.

U.S. flag ships built in the U.S. have an average age of 20.2 years which is slightly higher than general U.S. flag ships, 18.6 years. From this average, 57.8% of U.S. built U.S. flag ships are older than 20 years, and 50.4% of general U.S. flag vessels are older than 20 years.

As proposed in the introduction section, this report endeavored to research possible barriers in technology adoption into the current market due to the long lifespan of average vessels. A new possibility being developed takes the lifespan of vessels into account. This development is the retrofitting of vessels, usually 30-50 years old, with new energy efficient technology. Thus, it is possible to reduce carbon emission in not just newly built vessels but existing vessels as well. Retrofitting will be further discussed in section 3.4.2.

3.2.3 Emission Regulations

Current carbon emission standards are non-existent. Any existing regulations focus on air pollutants such as carbon monoxide, nitrous oxides, hydrocarbons, and particulate matter. Any regulations currently in place are based on category (involving the size and capacity of the engine) and tier (year boat made).

3.3 Energy

3.3.1 Modal Comparisons

Compared with rail and truck transport, the water mode is the most energy efficient. With current technology, one barge moves one ton of cargo 576 miles per gallon, while one semi-trailer truck moves one ton of cargo 155 miles per gallon. Along these lines, one unit trains moves one ton 413 miles per gallon. Not only is the water mode more energy efficient, but the carrying capacity of a standard 15-barge tow far outstrips both rail and truck modes. One standard 15-barge tow carries is equivalent to the carrying capacity of 1050 semi-trailer trucks and 2 unit trains. These results are summarized in Figure 15 and 16.
3.3.2 Modal Benefits

Though the marine transport mode offers the best energy efficiency and carrying capacity compared to truck and rail modes, truck and rail modes offer different benefits that make it a competitive option to marine transport.

Currently, the truck mode has the highest contribution towards energy consumption and carbon emissions. Highway transportation makes up 81% of U.S. domestic energy consumption, a staggering value compared to the 5% contributed from water transportation and 2% from rail. The enormous use of highway transportation has contributed to increased highway congestion as well as increase in automotive accidents. Despite these negative aspects, the truck transport system has one huge benefit, the sheer size of its network provides for multitude of options in terms of route efficiency, saving time and money. The rail transport network offers similar benefits as the truck transport mode, though the rail network is not as comprehensive as the truck network yet still much larger than the waterway system. It is evident in Figures 16, 17 and 18 that the current U.S. waterway system pales in comparison.

Despite the smaller state of the U.S. waterway network, domestic marine transport still has its own benefits. The marine transport mode has huge unrealized potential. With some effort, the waterway system can be developed further along with transferring more freight burden from the truck mode to the water transport mode. This transfer of cargo would reduce highway
congestion, decrease energy consumption of non-renewable energy in the truck transport mode, and decrease accidents common to the truck transport mode.

3.3.3 Flags of Convenience

A final factor affecting accurate measures of U.S. water transport modal energy consumption is due to Flags of Convenience (FOC). Defined as registry offered by a flag state which allows non-national or foreign vessels to register to fly its flag, this causes a discrepancy in energy data since some vessels register under foreign countries but operate within the U.S. FOC differs from general U.S. flag ships because even though U.S. flag ships may not necessarily be built in the
U.S., U.S. flag ships have adopted the U.S. as its nationality and continue to operate in the U.S. An example of a boat under a FOC would be an U.S. boat operating in the U.S. flying a flag from the Cayman Islands.

Two types of FOC exist. The first deals with ocean-going vessels that sail internationally under a FOC. These vessels are dubbed “merchant vessels” and contribute to international carbon emission totals. As of 2008, the International Transport Workers’ Federation has named 33 flags as FOC21. The United States currently has 446 merchant vessels greater than or equal to 1,000 gross Tons operating under FOC.36 Second of these two types concerns vessels which sail domestically in a country that it is not registered under but instead is registered under a FOC. This practice is a greater concern since this contributes directly with a nation’s carbon emission total. As of now, no data is available stating the exact number of U.S. vessels in this second type of FOC.

Multiple reasons cause a ship owner to operate under FOC, mainly for lower costs, more relaxed crewing requirements, less vigorous regulation, and performing illegal operations. This creates huge concern in terms of possible misrepresentation of actual national energy consumption levels in the marine transport mode, danger to crews, and the illegality of possible vessel operations.

For this research, errors created by FOC are assumed to be negligible. Though unrealistic, our models work with data provided by the U.S. Department of Transportation. Improving energy records both domestically and internationally is a definite recommendation for future development and improvement of the water transportation mode.

3.4 Technology

With the knowledge of marine transportation sector and the understanding of marine transportation benefits, we should now know a little bit better the reason that marine transportation is growing substantially each year recently, and we have to look for ways to reduce the emissions from the industry. The big issue is how we can possibly decrease emissions by using alternative fuels, renewable energy or even some combination of various technologies. This section examines the current and/or possible technology that can be used in the industry.

3.4.1 Ship Design and Equipments

One of the ways and the first step to reduce carbon dioxide emission is through the use of energy efficient ship design and equipments. One example is the usage of the bulbous bow. Using the bulbous bow can reduce wave resistance to the ship, so it can improve the ship’s fuel efficiency. One of the possible forms of the bow is called The Inui bow, which was developed by Takao Inui from Japan during the 20th century, and it is commonly used on huge commercial cargo or commerce ships. This Inui bow can decrease 5% of the fuel consumption at ship’s normal cruising speed.37 As of now, more of this form is applied to the smaller cargo ships. According to a U.S Navy’s report to Congress, a study has estimated that using a bow form onto an Arleigh Burke (DDG-51) class destroyer could possible cut the fuel consumption by 3.9%. Figure 19 is a picture of DDG-51’s bulbous bow design.37
Another way to increase energy efficiency is to use stern flaps. Stern flaps are small pieces of equipments that are installed at the rear of ships to increase the hull’s bottom surface. It can reduce the wave resistance working against the ship. According to the same report to Congress, tests have shown that the stern flaps could decrease fuel consumption about 6 to 7.5 % on DDG-51 class destroyers. Figure 20 is the illustration of DDG-51’s stern flaps.

While using different designs and adding on additional parts can reduce the fuel consumption and thus the carbon dioxide emission, using more energy efficient turbines for the engine is also a good tool to try to reduce the fuel consumption. As of right now, the navy ships are using simple-cycle gas turbines. WR-21 intercooled recuperated gas turbines, developed by the French, U.S., and U.K governments together during 1991 to 2000, could potentially save about 25-30% of fuel consumption, even though the installation and maintenance cost may be a bit higher. Many other highly efficient turbines are used and being developed as well for use not
just in military but also in other parts of water transportation such as recreational and commerce use.

Using the electric-drive propulsion system and fuel cell technology could also reduce carbon dioxide emissions. The electric-drive propulsion system could allow the ship’s turbines to run at the most fuel-efficient speed for increasing amount of time. The implementation of the fuel cell technology could potentially save fuel consumption by generating electricity to power the ship as opposed to powering through combustion of fuel.

3.4.2 Alternative Fuel

Besides using energy efficient ship design and equipment, alternative fuel is also a good way to possibly reduce carbon dioxide emission. There have been many practices and discussions of using biofuels in land transportation. If biofuel can be used in cars, it should also be applicable to the marine transportation sector. As mentioned in previous parts from aviation transportation, biofuel is made from oil of soybeans and cooking oil, and it has great lubricity and produces cleaner injector as well as the detergent effect and the lower cost involved compared to the regular diesel. In this report, we would look specifically at National Oceanic and Atmospheric Administration (NOAA)’s green ship initiative project. In this project, the primary objective is to research and develop a way for vessels to use B100 (100%) soy biodiesel as opposed to the B20 biodiesel, which is a blend of the petroleum diesel and biodiesel. The project started in 1999, and it achieved its primary goal of getting ships to use B100 in 2006. Figure 21 and 22 below shows two of the three ships that successfully use B100 only.

![R/V Huron Explorer](image)
This project is different from some other projects involving biodiesel because it tries to retrofit vessels that are 30 to 50 year old to use B100. Unlike some of the other projects that have new vessel to accommodate engineered bio-products, the researchers try to change the mechanical and electrical system on the ship so that they can use B100. This initiative project would provide good practical ways and fundamental work for other old large fleet that would want to convert to the use of biodiesel later.

After the researchers made three ships that completely run on B100 biodiesel, they are going to examine the effects of B100 on engines, find and come up with ways to decrease nitrogen oxide emissions from the use of biodiesel, and explore possible ways to apply ethanol in small boats.

3.4.3 Renewable Energy: Wind

Another possible emerging technology to reduce carbon dioxide emission for marine transportation is the use of the wind. We can use the huge kites and skysails to help propel the ship to reduce the use of fossil fuel. There are several companies that are trying to develop the system. In this report, we mainly focus on the SkySail system that is developed by the Germany-based firm.

The SkySail concept is simple. Basically, the ship would have a huge towing kite propulsion system that helps to share the burden of fuel. The system is made up of three major components, which includes the huge towing kite with rope, a launch and recovery system, and a control system. Figure 23 below is the illustration of the SkySail system.
The towing kite would have size area about 150 to 600 m$^2$ depending on the size of the ship, and the rope may be up to 500 meters long. Usually the kites are operating at 200 to 300 meters high from the ship. The launch and recovery system involves the winch and the force transmission point. It is a mechanism that allows the ship to put up the kites before the ship sets sail, and the recovery system works the same but reverse way. The following Figure 24 shows the process of the launch.

Then, the control pad and the control system are keys to the SkySail steering system. The control pad is the direct link between the kite and the rope, and it serves to monitor the change of the aerodynamic profiles and change directions and path if needed. The control system is just like the autopilot function of the airplane. It can tell which way the kite should turn based on the signals sent from the control pad. It acts as the centerpiece of the steering system.

According to the SkySail company, this system can cut fuel consumption by 15 to 35%, and 50% if optimal wind condition exists. The skysail system can not only operate with downwind, but also can perform with courses up to 50 degree to the wind. Therefore, this is a good technology to try to reduce the amount of carbon dioxide emissions.

This system is not just a concept but is actually in practice at the moment. Beluga Shipping, a Bremen-based shipping company, has a project called WINTECC, which costs about 4.1 million Euro dollars with part of the funding from Europe Union. The project is essentially about using
this SkySail system on a cargo ship called MS Beluga SkySails. This ship is in operation today and being used by DHL and US Navy to transport goods and supplies. According to Beluga, this ship saves about 20% of the fuel consumption and potentially saving about $1500 fuel cost a day. Figure 25 below is the picture of MS beluga SkySails.41

Some advantages of using this skysail system as opposed to sail masts are lower installation and maintenance costs, maximum wind power, stability of the ship, and usual loading and unloading process. According to one article cited in Navy’s report to Congress, the cost to install the sail masts and to increase the strength of the hull for a cargo ship is around 10 million Euro dollars (which is about $12.5 million). Even though the article does not talk about the size of the ship, it generalizes the installation cost for the cargo ship group. On the other hand, according to Navy’s report to Congress, SkySail states that it can install the skysail system with around 0.4 mil euros to 2.5 million euros depending on the size of the ship.37 Also, according to the National Post figures and SkySail company, the skysail system can achieve maximum power compared to the sail masts because wind strength increases with altitude.42 Since the towing kite is operating at around 100 meter to 300 meter, it would definitely have more power than regular sail masts. Also, the kites would minimize the heeling of the ship compared to using regular sail masts. Therefore, the towing kite provides better stability to the ship. In addition, if sail masts are installed on the ship, they are going to take up cargo space on the deck of the ship, and they may interfere with loading and unloading procedures. Additionally, Sail masts need to be sufficiently high for it to work optimally, and installing a high mast will add to the cost as well. However, the towing kite system would never have that problem because it is high up in the sky, and it has a recovery system at the front of the ship that can bring the kite down.

In conclusion, using wind technology such as the SkySail system is a promising way to reduce carbon dioxide emission, and it is an emerging technology due to successful pilot testing of the MS Beluga SkySails.
3.4.4 Renewable Energy: Solar

Besides using wind to reduce the emission, we can also use apply the solar technology to do the same. Currently, there are many boats or vessels that apply the solar technology to decrease emission. For example, as of right now, Sydney harbor at Australia is using solar sailor hybrid-powered ferry boat that was developed by Solar Sailor Holdings Ltd. According to the company, these ferry boats that are for inner harbor runs can possibly save up to 50% of the fuel consumption depending on the length of the trip. Figure 26 is the picture of a solar sailor hybrid-powered ferry boat.

Figure 26 – Solar Sailor Hybrid-Powered Ferry Boat

Another emerging area of the solar technology is its application to large cargo ships as opposed to smaller boats previously. Recently, Auriga Leader, a 328 solar panel ship jointly developed by Nippon Yusen K.K and Nippon Oil Corp, set sail in December 2008. It serves as a car carrier and is used by Toyota. This cargo ship’s capacity is 6400 cars. According to the companies, the 328 solar panels cost about 150 million yen to install (about $1.68 million). This solar panel power system is capable of producing 40 kW², and as of right now, the system can save about 6.5 to 7% for the fuel consumption used for lighting and other systems in the ship and only about 0.2% to 0.3% fuel consumption saving to the propulsion system. It is not a significantly huge number. However, it is one of the first huge cargo ships trying out solar energy. Therefore, the application of solar energy on other huge ocean-going cargo vessels may be possible in the near future after the launch of this Auriga Leader. Figure 27 below shows the picture of the ship.
3.4.5 Possible Zero Emission Design

All marine technologies discussed before in this report are all already in use or starting to emerge. What if we find a way to use all the technology in a single vessel? Well, the result is an almost zero emission concept design ship called E/S Orcelle. It is a car carrier ship design developed by Wallenius Wilhelmsen, a Scandinavian shipping company. The ship would be capable of carrying about 10,000 cars, 50% more than today’s car carrier ship. Also, the ship would use a wide range of technological combinations such as wind, solar, wave, fuel cell, electricity, and mechanical power. According to the Navy’s report to Congress, the company believes that a ship with part of this ship’s features would be possible by 2010 and that this design may become a reality by 2025. Figure 28 shows the concept design of E/S Orcelle.
3.5 Best Practices of Marine Transportation

With many possible emerging technologies and ways to reduce carbon dioxide emission, we should not forget that sometimes doing simple things can actually produce great benefits as well. According to C40 Cities website, which is an organization site that includes 40 largest cities in the world with same common commitment to try to work on climate change issues, there are many seaports in various cities and countries doing the best practice of trying to reduce carbon dioxide emissions.48

One best practice port from C40 Cities group is Goteborg, Sweden. The city reduces port-side emissions, including carbon dioxide, nitrogen oxide, sulfur dioxide and other pollutants, by up to 97% using the simple system called Onshore Power Supply. Traditionally, when ships are parked at the port, they still use diesel to run their engines to power the ship and the system. This would produce large amount of the emissions just by the ships parking at the port. However, as of right now, ships are using the Onshore Power Supply system, and with this system, the ships simply just use cities electricity power grid system to power their ships and the system. Of course, there would be more installation and maintenance costs on cities’ power grid system; however, the results of reducing emissions are great.48

Another city with best practice is Seattle, United States. Seattle’s port reduces emissions by 29% annually, using the same concept of onshore power supply system as the port at Goteborg. The third group of ports using a similar system is the 21 ports from United Kingdom. They also reduce emissions by using the plug-in of the city electricity grid when ships are parking.48

Therefore, cities which require ships simply to use the onshore power supply system could actually have significant impact at reducing carbon dioxide emissions. Sometimes, reducing carbon dioxide emission can be achieved through existing technology and be more energy efficient.
3.6 Current Trends and Projections

The sectors within the water-transport mode and the current technology that have been used by the industry have been introduced, and the possible techniques for alternate renewable energy sources are studied based on the technical feasibilities and their impact in the previous sections. Before building the forecast model, understanding current trends of domestic marine transportation is very important. This section also presents the results of the projection of waterborne freight in the recent studies. The forecast model that was built for this paper will be discussed in the next section.

3.6.1 Current Activity and Trends

U.S. demand for freight transportation has been rising steadily, and forecasts show continued growth over the next several decades. According to Bureau of Transportation Statistics, in 2001, 22 percent of ton-miles of freight were increased from the 2.61 trillion ton-miles of nation’s domestic freight moved in 1990 with an annual growth rate of 2.0 percent. However, the modal share of domestic waterborne freight was declining from 1990 to 2001, from 32 percent of ton-miles to 20 percent of ton-miles (Figure 29).49

Figure 29 – Domestic Freight Modal Share of Ton-Miles, 1990 and 200149

U.S. Army Corps of Engineers, Waterborne Commerce of the United States, provides the trend of U.S. waterborne freight tonnage for both domestic and foreign (imports and exports) in Figure 30. Foreign trade accounts for 58 percent of waterborne tonnage, with import tonnage nearly 2.7 times more than export tonnage. Even though domestic waterborne tonnage fell 9 percent and waterborne export tonnage fell by 15 percent between 1990 and 2003, the total waterborne freight tonnage has actually increased by 11 percent since 1990 because waterborne imports grew by 67 percent.31
From the U.S. economic point of view, according to TRANSEARCH, the freight productivity returns from deregulation, the capacity investments made in the 1970s and 1980s, and the introduction of just-in-time logistics are diminishing. There are relatively few opportunities for further expansion of road freight since congestion is increasing, especially in metropolitan areas. It will cause domestic waterborne freight begins to rise for the coming decades.  

3.6.2 Projections from Recent Studies

According to the United States Department of Transportation, Federal Highway Administration (FHWA), the contribution of freight transportation to air quality problems in future years depends on two major factors: the rate of growth in freight movement and changes in the emissions characteristics of trucks, locomotives, ships, and aircraft. There are some recent studies have developed projections of freight transportation demand by mode are included water transport. According to the forecast results from ICF Consulting and American Association of State Highway and Transportation Officials (AASHTO), domestic waterborne freight is expected to remain relatively flat, ton-mile growth rates is only 0.7 percent. FHWA provides the comparison of domestic freight demand forecasts from those studies in Table 5.

<table>
<thead>
<tr>
<th>Source (Units) Period</th>
<th>Historic Data</th>
<th>Forecasts (compound annual growth rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Historic Data</td>
<td>Economic Forecast</td>
</tr>
<tr>
<td>Truck</td>
<td>3.9%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Rail</td>
<td>3.6%</td>
<td>1.9%</td>
</tr>
<tr>
<td>Water</td>
<td>-2.5%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Air</td>
<td>5.2%</td>
<td>4.4%</td>
</tr>
</tbody>
</table>
3.7 Forecast Model

The energy consumptions of domestic recreational and tour marine are relatively small, and it is difficult to get reliable data on international freight. Therefore, our forecast model only focuses on the domestic marine freight industry, consisting of three parts: canal and waterway shipping in the interior, Great Lakes shipping, and coastal shipping. According to the recent studies presented in section 3.6.1, marine freight transportation is growing in the following decades with the U.S. economy and population growth.

Our model was built to correlate to the expected growth with U.S. GDP under the assumptions in section 3.7.1. The forecast methodology and the results of forecast are discussed in section 3.7.2. The options of renewable energy and the possible techniques that may be implemented to reduce the fuel consumption and emissions are discussed in section 3.7.3. Section 3.7.4 presents the results of savings in 2030. Section 3.7.5 also presents the results based on the forecast of ICF Consulting.

3.7.1 Assumptions

When modeling the domestic marine freight, the following assumptions were made:

- The projection of energy use is based on an upturn in domestic marine freight from 2006 to 2030. Reasons for a possible upturn are: the saturation of the road network, and high fuel prices, leading to strain on shipping by truck; the desire for less energy-intensive ways of shipping. However, this is not the only possible outcome for the next 20 years, but the only outcome for this model.
- Along with an upturn in domestic marine freight, the model also incorporates improving delivered fuel efficiency in Btu per ton-mile, which is different from the trend for 1970 to 2005 as shown in Figure 31. The trends fluctuated up and down but did not show sustained improvement. The predicted improvement is due to the impact of ongoing higher cost of fuel and desire across the economy to improve energy efficiency.

![Figure 31 – US Domestic Marine Energy Intensity](image)
• The most important factor influencing freight transportation is the gross domestic product (GDP). The model uses the GDP forecast from previous year final report: Pathways to Reduced Transportation CO₂ in the Year 2050. Figure 32 shows the forecast for the GDP values through 2050 with the equation of the exponential trendline.

![Figure 32 – US Domestic GDP Forecast Graph](image)

- From 2006 to 2030, ton-miles traveled of marine freight can be predicted from GDP annual growth rate based on the exponential trendline.
- Using the historic data between 1970 and 2005 from U.S. Army Corps of Engineers, Waterborne Commerce of the United States
- If any of the assumptions is changed, then the outcome of the modeling work would look quite different.

3.7.2 Forecast Methodology

Calculating ton-miles traveled for marine freight is a critical step for the success of this model, since fuel consumption is dependent on the parameter, and fuel use is generally proportional to emissions of greenhouse gases. The spreadsheet model for domestic marine freight is shown in Table 6. The calculations for each column are discussed in this section in the following steps.

<table>
<thead>
<tr>
<th>Year</th>
<th>Distance Traveled (billion ton-miles)</th>
<th>Ton-miles per gallon % change</th>
<th>Fuel (billion gallons)</th>
<th>CO₂ Emission (billion lbs)</th>
<th>Ton-miles per gallon</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>607.9</td>
<td>1.0%</td>
<td>2.24</td>
<td>49.62</td>
<td>271.98</td>
</tr>
<tr>
<td>2007</td>
<td>625.4</td>
<td>1.0%</td>
<td>2.28</td>
<td>50.54</td>
<td>274.70</td>
</tr>
<tr>
<td>2008</td>
<td>643.3</td>
<td>1.0%</td>
<td>2.32</td>
<td>51.47</td>
<td>277.45</td>
</tr>
<tr>
<td>2009</td>
<td>661.7</td>
<td>1.0%</td>
<td>2.36</td>
<td>52.42</td>
<td>280.22</td>
</tr>
<tr>
<td>2010</td>
<td>680.6</td>
<td>1.0%</td>
<td>2.40</td>
<td>53.39</td>
<td>283.03</td>
</tr>
<tr>
<td>2011</td>
<td>700.1</td>
<td>1.0%</td>
<td>2.45</td>
<td>54.37</td>
<td>285.86</td>
</tr>
<tr>
<td>2012</td>
<td>720.1</td>
<td>1.0%</td>
<td>2.49</td>
<td>55.37</td>
<td>288.71</td>
</tr>
</tbody>
</table>
Calculating Ton-Miles Traveled

Using the GDP exponential equation, \( y = (7E-184)x^{56.683} \), it is possible to predict the GDP from 2006 to 2030. Letting \( x \) equal to the year of the GDP and plugging this in to the equation, the value of GDP will be calculated. The average annual percentage change for the GDP between 2006 and 2030 is about 2.85%. Since the ton-miles traveled is correlated with the GDP trend, the model uses the annual percentage change of the GDP for each year to predict the ton-miles traveled from 2006 to 2030. The result is shown in Figure 33.
Calculating Energy Efficiency

As of 2006, water transportation accounts for 5 percent of U.S. domestic energy consumption. While marine vessels are becoming more fuel-efficient over time, growth in freight activity has in some cases outpaced these efficiency improvements. The assumption is made that energy efficiency is growing 1% each year from 2006 to 2030. The growth rate of energy efficiency is less than the percentage change for the ton-miles traveled, since domestic marine demand is increasing faster than the improvement of energy efficiency. Convert Btu to gallons for the energy of diesel fuel by dividing by 138,700. Thus, the new unit for energy efficiency will be ton-miles per gallon. Figure 34 shows the forecast for energy efficiency.

Calculating Energy Consumption

To calculate energy consumption, divide ton-miles traveled by the energy efficiency. The unit of energy consumption used is billion gallons as shown in Figure 35.
Calculating Carbon Dioxide Emission

CO₂ emissions from a gallon of diesel = 2,778 grams x 0.99 x (44/12)
= 10,084 grams = 10.1 kg/gallon
= 22.2 pounds/gallon

Based on the conversion above, to calculate carbon dioxide emission is just simply multiplying fuel consumption with 22.2, and the pounds of carbon dioxide emission is determined as shown in Figure 36.

Figure 36 – Domestic Marine CO₂ Emission Forecast

3.7.3 Options for Potential Savings

Several current and/or possible technologies that can be used for marine freight were discussed in Section 3.4. To improve the model, three options are chosen to present the results. Among the renewable energy possibilities, solar energy is chosen instead of wind energy, since it is not feasible to use the SkySail system for the domestic marine freight. For alternative fuel, biodiesel is chosen and only focuses on B100 (100%) soy biodiesel. The third option is the scenario that combines renewable energy with alternative fuel.

Option 1: Renewable Energy: Solar Energy

Solar energy is a clean and abundant source, but it is also a very expensive alternative when compared with other energy systems. Today, some ships are trying solar energy. Therefore, solar energy could grow further as more technological breakthroughs in energy storage and power conversion help make it more economically viable. The model assumes the percent of ship using solar energy will increase 1% each year from year 2007 to 2030. The result of the modeling would change if the assumption is changed. Table 7 shows the result of spreadsheet model for the base case improved by using solar energy.
### Table 7 – Base Case Model Improved by Solar Energy

<table>
<thead>
<tr>
<th>Year</th>
<th>Replace Energy by %</th>
<th>Fuel (billion gallons)</th>
<th>CO2 Emission (billion lbs)</th>
<th>Ton-miles per gallon</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>0.0%</td>
<td>2.24</td>
<td>49.62</td>
<td>271.98</td>
</tr>
<tr>
<td>2007</td>
<td>1.0%</td>
<td>2.25</td>
<td>50.03</td>
<td>277.48</td>
</tr>
<tr>
<td>2008</td>
<td>2.0%</td>
<td>2.27</td>
<td>50.44</td>
<td>283.11</td>
</tr>
<tr>
<td>2009</td>
<td>3.0%</td>
<td>2.29</td>
<td>50.85</td>
<td>288.89</td>
</tr>
<tr>
<td>2010</td>
<td>4.0%</td>
<td>2.31</td>
<td>51.25</td>
<td>294.82</td>
</tr>
<tr>
<td>2011</td>
<td>5.0%</td>
<td>2.33</td>
<td>51.65</td>
<td>300.90</td>
</tr>
<tr>
<td>2012</td>
<td>6.0%</td>
<td>2.34</td>
<td>52.05</td>
<td>307.14</td>
</tr>
<tr>
<td>2013</td>
<td>7.0%</td>
<td>2.36</td>
<td>52.44</td>
<td>313.55</td>
</tr>
<tr>
<td>2014</td>
<td>8.0%</td>
<td>2.38</td>
<td>52.83</td>
<td>320.13</td>
</tr>
<tr>
<td>2015</td>
<td>9.0%</td>
<td>2.40</td>
<td>53.21</td>
<td>326.88</td>
</tr>
<tr>
<td>2016</td>
<td>10.0%</td>
<td>2.41</td>
<td>53.59</td>
<td>333.82</td>
</tr>
<tr>
<td>2017</td>
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<td>2.43</td>
<td>53.97</td>
<td>340.95</td>
</tr>
<tr>
<td>2018</td>
<td>12.0%</td>
<td>2.45</td>
<td>54.34</td>
<td>348.27</td>
</tr>
<tr>
<td>2019</td>
<td>13.0%</td>
<td>2.46</td>
<td>54.71</td>
<td>355.79</td>
</tr>
<tr>
<td>2020</td>
<td>14.0%</td>
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<td>363.53</td>
</tr>
<tr>
<td>2021</td>
<td>15.0%</td>
<td>2.50</td>
<td>55.42</td>
<td>371.49</td>
</tr>
<tr>
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<td>16.0%</td>
<td>2.51</td>
<td>55.77</td>
<td>379.67</td>
</tr>
<tr>
<td>2023</td>
<td>17.0%</td>
<td>2.53</td>
<td>56.11</td>
<td>388.08</td>
</tr>
<tr>
<td>2024</td>
<td>18.0%</td>
<td>2.54</td>
<td>56.44</td>
<td>396.75</td>
</tr>
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<td>2025</td>
<td>19.0%</td>
<td>2.56</td>
<td>56.77</td>
<td>405.66</td>
</tr>
<tr>
<td>2026</td>
<td>20.0%</td>
<td>2.57</td>
<td>57.09</td>
<td>414.84</td>
</tr>
<tr>
<td>2027</td>
<td>21.0%</td>
<td>2.59</td>
<td>57.40</td>
<td>424.29</td>
</tr>
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<td>2.60</td>
<td>57.70</td>
<td>434.03</td>
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<tr>
<td>2029</td>
<td>23.0%</td>
<td>2.61</td>
<td>58.00</td>
<td>444.06</td>
</tr>
<tr>
<td>2030</td>
<td>24.0%</td>
<td>2.63</td>
<td>58.28</td>
<td>454.40</td>
</tr>
</tbody>
</table>

**Option 2: Alternative Fuel: Biodiesel (B100)**

Currently, the most used fuel in marine freight transportation is diesel fuel. Emissions of GHG are generally proportional to fuel consumption. One gallon of diesel emits 22.2 pounds carbon dioxide. A ship operating on using B100 will emit about 75% less carbon dioxide than that of one consuming standard diesel fuel. Thus, the amount of CO₂ emission produced per ton-miles traveled by a ship using biodiesel is simply the amount for standard diesel for that multiplied by 25%. The model assumes the percent of ship using B100 will increase 0.5 % each year from year 2009 to 2030. The result of the modeling would change if the assumption is changed. Table 9 shows the result of spreadsheet model for the base case improved by using B100.
Table 8 – Base Case Model Improved by B100

<table>
<thead>
<tr>
<th>Year</th>
<th>Replace Energy (by %)</th>
<th>Fuel (billion gallons)</th>
<th>CO2 Emission (billion lbs)</th>
<th>Ton-miles per gallon</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>0.0%</td>
<td>2.24</td>
<td>49.62</td>
<td>271.98</td>
</tr>
<tr>
<td>2007</td>
<td>0.0%</td>
<td>2.28</td>
<td>50.54</td>
<td>274.70</td>
</tr>
<tr>
<td>2008</td>
<td>0.0%</td>
<td>2.32</td>
<td>51.47</td>
<td>277.45</td>
</tr>
<tr>
<td>2009</td>
<td>1.0%</td>
<td>2.34</td>
<td>52.03</td>
<td>283.05</td>
</tr>
<tr>
<td>2010</td>
<td>1.5%</td>
<td>2.37</td>
<td>52.78</td>
<td>287.34</td>
</tr>
<tr>
<td>2011</td>
<td>2.0%</td>
<td>2.40</td>
<td>53.55</td>
<td>291.69</td>
</tr>
<tr>
<td>2012</td>
<td>2.5%</td>
<td>2.43</td>
<td>54.32</td>
<td>296.12</td>
</tr>
<tr>
<td>2013</td>
<td>3.0%</td>
<td>2.46</td>
<td>55.11</td>
<td>300.62</td>
</tr>
<tr>
<td>2014</td>
<td>3.5%</td>
<td>2.50</td>
<td>55.90</td>
<td>305.20</td>
</tr>
<tr>
<td>2015</td>
<td>4.0%</td>
<td>2.53</td>
<td>56.70</td>
<td>309.86</td>
</tr>
<tr>
<td>2016</td>
<td>4.5%</td>
<td>2.56</td>
<td>57.51</td>
<td>314.59</td>
</tr>
<tr>
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<td>2.59</td>
<td>58.33</td>
<td>319.41</td>
</tr>
<tr>
<td>2018</td>
<td>5.5%</td>
<td>2.63</td>
<td>59.16</td>
<td>324.31</td>
</tr>
<tr>
<td>2019</td>
<td>6.0%</td>
<td>2.66</td>
<td>59.99</td>
<td>329.30</td>
</tr>
<tr>
<td>2020</td>
<td>6.5%</td>
<td>2.70</td>
<td>60.84</td>
<td>334.37</td>
</tr>
<tr>
<td>2021</td>
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<td>2.73</td>
<td>61.70</td>
<td>339.53</td>
</tr>
<tr>
<td>2022</td>
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<td>2.77</td>
<td>62.56</td>
<td>344.78</td>
</tr>
<tr>
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<td>63.44</td>
<td>350.12</td>
</tr>
<tr>
<td>2024</td>
<td>8.5%</td>
<td>2.84</td>
<td>64.32</td>
<td>355.55</td>
</tr>
<tr>
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<td>9.0%</td>
<td>2.87</td>
<td>65.21</td>
<td>361.08</td>
</tr>
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<td>2.91</td>
<td>66.12</td>
<td>366.71</td>
</tr>
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<td>10.0%</td>
<td>2.95</td>
<td>67.03</td>
<td>372.43</td>
</tr>
<tr>
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<td>10.5%</td>
<td>2.98</td>
<td>67.95</td>
<td>378.26</td>
</tr>
<tr>
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<td>3.02</td>
<td>68.88</td>
<td>384.19</td>
</tr>
<tr>
<td>2030</td>
<td>11.5%</td>
<td>3.06</td>
<td>69.82</td>
<td>390.22</td>
</tr>
</tbody>
</table>

Option 3: Solar Energy and Biodiesel (B100)

This option assumes option 1 and option 2 are being used at the same time with the same assumptions mentioned for each option. Table 9 shows the result of spreadsheet model for the base case improved by using solar energy and B100.

Table 9 – Base Case Model Improved by Solar Energy and B100

<table>
<thead>
<tr>
<th>Year</th>
<th>Replace Energy (by %)</th>
<th>Fuel (billion gallons)</th>
<th>CO2 Emission (billion lbs)</th>
<th>Ton-miles per gallon</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>0.0%</td>
<td>2.24</td>
<td>49.62</td>
<td>271.98</td>
</tr>
<tr>
<td>2007</td>
<td>0.0%</td>
<td>2.25</td>
<td>50.03</td>
<td>274.70</td>
</tr>
<tr>
<td>2008</td>
<td>0.0%</td>
<td>2.27</td>
<td>50.44</td>
<td>283.11</td>
</tr>
<tr>
<td>Year</td>
<td>Increase</td>
<td>Fuel Consumption</td>
<td>Fuel Cost</td>
<td>Total Cost</td>
</tr>
<tr>
<td>------</td>
<td>----------</td>
<td>------------------</td>
<td>-----------</td>
<td>------------</td>
</tr>
<tr>
<td>2009</td>
<td>1.0%</td>
<td>2.27</td>
<td>50.45</td>
<td>291.90</td>
</tr>
<tr>
<td>2010</td>
<td>1.5%</td>
<td>2.27</td>
<td>50.65</td>
<td>299.50</td>
</tr>
<tr>
<td>2011</td>
<td>2.0%</td>
<td>2.28</td>
<td>50.83</td>
<td>307.37</td>
</tr>
<tr>
<td>2012</td>
<td>2.5%</td>
<td>2.28</td>
<td>51.00</td>
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<tr>
<td>2013</td>
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<td>324.00</td>
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<td>2014</td>
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<td>51.30</td>
<td>332.79</td>
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<td>51.55</td>
<td>351.39</td>
</tr>
<tr>
<td>2017</td>
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<td>2.29</td>
<td>51.66</td>
<td>361.24</td>
</tr>
<tr>
<td>2018</td>
<td>5.5%</td>
<td>2.29</td>
<td>51.75</td>
<td>371.49</td>
</tr>
<tr>
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<td>2.29</td>
<td>51.82</td>
<td>382.15</td>
</tr>
<tr>
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<td>2.29</td>
<td>51.88</td>
<td>393.25</td>
</tr>
<tr>
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<td>51.92</td>
<td>404.82</td>
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<td>51.90</td>
<td>456.37</td>
</tr>
<tr>
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<td>51.84</td>
<td>470.74</td>
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<td>51.77</td>
<td>485.78</td>
</tr>
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<td>51.67</td>
<td>501.54</td>
</tr>
<tr>
<td>2029</td>
<td>11.0%</td>
<td>2.24</td>
<td>51.56</td>
<td>518.07</td>
</tr>
<tr>
<td>2030</td>
<td>11.5%</td>
<td>2.23</td>
<td>51.42</td>
<td>535.42</td>
</tr>
</tbody>
</table>

3.7.4 Savings Results

Figure 37 illustrates the results of fuel savings with three potential options discussed in section 3.7.3. The highest line represents the base case, the second highest line represents the base case improved by B100, the third highest line represents the base case improved by solar energy and the lowest line represents the base case improved by both solar energy and B100. For the base case, the fuel consumption is increasing about 50% in 2030 comparing to 2005, a large amount. However, the line that represents both solar energy and B100 use is almost flat from 2005 to 2030, which indicates that using solar energy and B100, fuel consumption will stay the same in 2030.
Figure 38 illustrates the results of carbon dioxide emission saving with three potential options discussed in section 3.7.3. Since carbon dioxide emission is generally proportional to fuel consumption. The lines look similar to Figure 37, except the line of using B100 is slightly closer to the line of base case. The reason is B100 still have 25% carbon dioxide emission. The lowest line combined the savings from both solar energy and B100.
Figure 39 shows the percentage savings of fuel savings and carbon dioxide saving from each option in 2030.

![Figure 39 – Forecast Fuel and CO2 Emission Savings in 2030](image)

### 3.7.5 Alternative Forecast Results

Section 3.6.2 discussed the projections from recent studies and Table 6 presents forecasted growth rates for water freight from both AASHTO and ATA that are significantly lower than the growth rate of GDP. Considering the existence of these forecasts, this section presents an alternative scenario that is more conservative in its forecast. Instead of using the GDP forecast growth rate (2.8%), this scenario uses the estimated ton-mile growth rate (0.7%) from AASHTO and ICF and keep the 1% improvement in energy efficiency from the previous model. Figure 40 shows the estimated ton-miles traveled from 2006 to 2030.

![Figure 40 – Domestic Marine freight volume forecast](image)

Since the percentage change of energy efficiency is a little greater than the ton-mile growth rate, the fuel consumption of the alternative scenario is actually slightly decreasing from 2006 to 2030. Figure 41 shows the comparison of fuel consumption forecasts of both models, which shows a big difference between them.
Figure 42 illustrates the results of fuel saving with three potential options discussed in section 3.7.3 for the alternative scenario. The fuel consumption of the base case is almost flat from 2005 to 2030. By using the option that using solar energy and B100, fuel consumption will be reduced by 50% in 2030.

Figure 43 illustrates the results of carbon dioxide emission saving with three potential options discussed in section 3.7.3 for the alternative scenario.
Figure 43 – Domestic Marine CO2 Emission with Renewable Energy Forecast (Alternative Scenario)
4 LAND TRANSPORT: FREIGHT TRANSPORT

The main goal of this section is to determine the current situation, problems and inefficiencies with freight trucks; then find possible solutions and the effects these may have on total fleet fuel consumption, with the goal of lowering total CO$_2$ output, both of which are directly proportional.

4.1 Land Freight Overview

4.1.1 Mode Dominance

As shown in figure 29, land freight is by far the most widely used freight mode in the US, when measured by tonnage, total freight value, or fuel consumption. Intercity trucking makes about 1/3 of domestic ton miles, and this value grew 4.9% from 1990 to 2001. Rail seems to be the dominant transport in the US with 47% of ton-miles in 2001, but this would be inaccurate because rail generally transports bulk goods like coal for very long distances.

Figure 44 shows the general increase in ton-miles transported throughout the different sectors (except for marine). During this time period the growth of ton-miles for trucking has been 3.9% annually.\textsuperscript{52}

![Figure 44 – Domestic Freight Ton-Miles, 1990 - 2003](source: Bureau of Transportation Statistics, National Transportation Statistics 2004)

Trucking accounts for 65% of total tons moved and over 75% of the value of goods is shipped by trucks.\textsuperscript{55} Freight shipment values by mode are shown in figure 44 above. Trucking even accounts for most of the “Parcel, USPS, or courier” slice in the pie, the second largest, because trucks often move this shipments value as well. It is clear from this chart that the US economy is completely dependent on the trucking industry.
In order to give a scale to these percentages, it is useful to point out that this 75%+ of value movement in the US corresponds to 215 billion miles traveled in 2002.53

4.1.2 Fuel/Energy Use

Typically, truck consumption is quoted in gallons of fuel used. This will later be converted to emissions because fuel consumption and greenhouse gas emissions are proportional to each other. Figure 46 below shows energy use by transportation sector in 2000. Trucks account for 18% of total fuel consumption. Once we take away passenger fuel consumption, and other fuel use not related to freight, we find that this 18% is equal to 60% of all fuel used for freight in the US.54
4.1.3 Classification of Trucks

Trucks are split into eight different classes, according to weight. These classes can be further split into three general categories in order to ease classification, as shown in figure 47.

Figure 47 – Truck Class Break Down

Class 1-2 trucks are comprised of mostly passenger trucks. These include SUVs and pickup trucks as well as vans. Class 3-6 trucks are trucks like garbage trucks, delivery trucks, city buses, and other trucks of this general size. Class 7-8 trucks are the heaviest-duty. These include concrete mixers and fire engines, but most in this category are Class 8 tractor trailers. The emphasis of this paper lies in this category.

4.1.4 Fuel Economy

Figure 48 shows that average fuel economy for combination trucks has not changed in the past 30 years. This fact when paired with the sheer size of the trucking industry indicates that there is much room for improvement in this sector. Fuel economy has not changed for this class of truck because of lack of demand for new technologies to be implemented in these trucks. On top of this, manufacturers face risks partly due to generally low fuel prices. There is also a lack of fuel economy information for specific models.

Figure 48 – Average Class 8 Fuel Economy 1980-2007
4.2 Improvements on Fuel Economy

4.2.1 Currently available improvements

Because tractor-trailers account for two-thirds of all fuel spent by trucks\textsuperscript{56}, simple improvements based on currently available technologies are of utmost importance when choosing where to focus efforts to increase fuel economy. The following table lists technologies identified by Vyas with their corresponding potential fuel economy gains.\textsuperscript{57} Incremental costs of adding these technologies are also listed, although these can vary depending on truck model and age as well as the specific addition added.

<table>
<thead>
<tr>
<th>Aerodynamics</th>
<th>Fuel Economy Gain</th>
<th>Year of Introduction</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>cab top deflector</td>
<td>2.0%</td>
<td>current</td>
<td>$750</td>
</tr>
<tr>
<td>gap closing</td>
<td>2.5%</td>
<td>2005</td>
<td>$1,500</td>
</tr>
<tr>
<td>trailer edge curvature</td>
<td>1.3%</td>
<td>2005</td>
<td>$500</td>
</tr>
<tr>
<td>pneumatic blowing</td>
<td>5.0%</td>
<td>2010</td>
<td>$2,500</td>
</tr>
<tr>
<td>Rolling Resistance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>low RR tires</td>
<td>3.0%</td>
<td>2005</td>
<td>$1,098</td>
</tr>
<tr>
<td>super singles</td>
<td>3.0%</td>
<td>2008</td>
<td>$1,098</td>
</tr>
<tr>
<td>pneumatic blowing</td>
<td>1.2%</td>
<td>2015</td>
<td>$500</td>
</tr>
<tr>
<td>Transmission</td>
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<td>$1,000</td>
</tr>
<tr>
<td>Auxiliaries</td>
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<td></td>
</tr>
<tr>
<td>electrical auxiliaries</td>
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<td>$500</td>
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<tr>
<td>fuel-cell auxiliaries</td>
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<td>Engine</td>
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<td>$500</td>
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<tr>
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<td>improved injectors etc</td>
<td>6.0%</td>
<td>2007</td>
<td>$1,500</td>
</tr>
<tr>
<td>thermal management, etc.</td>
<td>10.0%</td>
<td>2010</td>
<td>$2,000</td>
</tr>
<tr>
<td>vehicle mass</td>
<td>5.0%</td>
<td>2005</td>
<td>$2,000</td>
</tr>
</tbody>
</table>

As is shown in the table, engine improvements are the most important to be made, when considered together. Increasing cylinder pressure, reducing engine friction, improving thermal management, and improving injectors would together contribute a 22\% increase in fuel economy. Many of these improvements are extremely simple to make, where the only problem for the truck owner would be initial costs of buying the products. For example, the “super singles” row in the table refers to changing the dual tire configuration on semis to single tires. Easy to change tires are already in the market called Michelin-X One tires. These are simple improvements because they do not involve any changes to the axles of the truck, except for simply changing the tires. Although there is concern in the truck driver community about the safety of using single tires instead of doubles because of the possibility of blowouts, Michelin has conducted tests with tractor trailers as well as concrete mixers and has found no difference in steering ability from double tires to their single tires. This is one factor why these improvements
have not been made across the board, but with more availability of test data proving that these new tires are just as safe, drivers should more readily accept these cost saving changes.

Some changes listed in the table are more difficult to implement than ones discussed above. “Thermal management” improvements, although potentially significant, can be more expensive and prohibitive to implement. These improvements involve reducing the wasted heat produced by the engine. “Vehicle mass” improvements can be very reasonable for new trucks coming off the assembly line; but for trucks already in commission, significantly reducing the overall weight of a truck can be a difficult or economically infeasible task. Aerodynamic improvements seem to be of the easiest to implement and most obvious changes to make. These are largely add-ons to trucks and thus can be installed on any truck new or already in use.

4.2.2 Hybridization

Hybridization has been shown to be a viable option for improving fuel economy in trucks that are used for stop-and-go driving style. These include garbage trucks and in-city delivery trucks as well as buses, all of which drive short distances (relative to class-8 combination trucks). Hybridization is viable for these because the constant stopping allows the hybrid system to recuperate the otherwise lost energy into battery storage.

Tractor trailers instead travel very long distances at very constant speeds and do not stop very often. Although there are a few models of hybrid class-8 combination trucks, data of these are largely unavailable due to their as of yet novelty. Based on light-duty hybrids, some savings are expected even if the heavy duty vehicles do not stop often. Even so, it will be some time until enough data is available to determine the economic feasibility of hybrid class-8 trucks. Because of this, the modeling that follows focuses on improvements to be made with currently available technologies.

4.3 Fuel Economy Forecasts

The following models were made assuming a reasonable scenario in order to determine the fuel and CO2 savings that are possible by implementing the different technologies discussed above.

4.3.1 Assumptions

Assume a 2% adoption rate for all technologies. This means that on year one of implementation, 2% of the entire US fleet adopts the technologies and thus the corresponding fuel savings are applicable for that percentage of the fleet. On year two, 4% of the entire fleet will have the technologies. The model assumes that this adoption rate continues through the entire evaluation period (through 2030).

Another assumption is that the increase in fuel economy will be taken from a baseline forecast that assumes that fuel consumption will continue to increase. This was determined using the TREND() function in Microsoft Excel.
4.3.2 Results

Figure 49 below shows, for illustrative purposes, the effect of Aerodynamic improvements alone on total fleet fuel consumption following the constraints described above. This is meant to give an idea of how just one technological change can affect total fuel consumption over time. The difference in slope fairly dramatic for an improvement that reduces fuel consumption by 10%, as listed in Table 10 under aerodynamic improvements (sum of all aerodynamic improvements).

Figure 49 – Fuel Consumption with Aerodynamic Improvements

Figure 50 below shows the effects of all possible fuel economy improvements being implemented. This includes aerodynamic improvements, engine improvements, rolling friction reduction, mass reduction, and transmission improvements. This totals to a 47% fuel economy increase for the trucks that implement all of the technologies.

Figure 50 – Fuel Consumption 1996-(Forecasted)

It is worth mentioning again, that the improvements shown above for “All Except Engine” are in fact improvements modeling a hybrid solution, but these results are very uncertain. Hybridization
was assumed to cut fuel consumption by 50% in order to come up with this forecast line. The graph is for the illustrative purpose of the following concept: even if hybridization of class 8 trucks increases efficiency by 50%, which is unlikely, other improvements not including hybridization can have almost as much of an impact on fuel economy.

Putting aside hybridization, the effects of the other improvements (and a 2% yearly adoption rate) can be seen in the pie chart, figure 51 below. The entire pie is equal to the forecasted fuel consumption in a business as usual scenario, whereas the blue area is the forecasted fuel consumption in the modeled scenario with 2% adoption rate of improvements that achieve a 47% improvement on fuel economy.

![Figure 51 – Forecasted Fuel Savings for Year 2030](image)

Fuel economy can be greatly improved using simple technologies that are currently available as well as economically feasible for class-8 tractor trailer trucks. Improvements identified by Vyas can improve fuel economy by 47% in class-8 trucks, and when this is forecasted to 2030 we can expect a 19% saving of fuel in this year (compared to the expected fuel usage in 2030). The fact that these trucks are long distance travel only reduces the attractiveness of hybrid technology for this class. CO2 reductions are proportional to fuel savings and are equal to

\[(\text{gallons of diesel fuel saved}) \times (22.2 \text{ lb CO2/gallon diesel}) = 138 \text{ billion pounds of CO2}\]

Because these savings are simple to achieve (from a technology standpoint) and incredibly significant due to the size of the US land freight fleet it is of utmost importance that measures are taken to increase fuel economy in the ways outlined above.
5 LAND TRANSPORT: BETTER PLACE CONCEPT

5.1 Overview

“Better Place is working to build an electric car network, using technology available today. Our goals? Sustainable transportation, global energy independence, and freedom from oil”

-www.betterplace.com

A typical electric car uses an electric motor powered with batteries to provide motion to the wheels for propulsion. A motor controller manages the amount of power delivered from the batteries to the electric motor, which is determined by the driver pressing on the accelerator pedal. Advantages of electric cars compared to the conventional internal combustion engine vehicles (ICEVs) include their lower operating and maintenance costs, increased overall energy efficiency (gas-powered vehicle run on average 20% efficient, electric vehicles are 20 to 25% efficient, considering 70 to 85% efficiency of electric motors and 33% efficiency of electricity generation at power stations with 9.5% loses over transmission), and reduced carbon dioxide and other pollutants emissions. With needed improvements in the electric vehicles technology, disadvantages include its limited range, lack and need for infrastructure, and additional safety concerns introduced by corrosive chemicals and high voltage electrical systems in vehicles.

Better Place is a venture-backed private mobility operating company, uniting batter-electric passenger vehicles with renewable energy to create a zero-emission transportation solution and end the world’s dependence on oil. Founded in October 2007 by Shai Agassi, Israel and Denmark agreed within six months, by January and March 2008, respectively, to adopt the Better Place model and “transform their transportation infrastructure from oil-based to renewable energy and significantly reduce harmful emissions,” beginning in 2011. Shortly after, other national and state governments, including Denmark, Australia, Hawaii, California, and Ontario, Canada have arranged to also adopt an electric vehicle infrastructure from late 2011 onwards. It is a goal of Better Place not to just better gas mileage or reduce emissions, but put an end to vehicle emissions entirely. They believe this is fully achievable, utilizing technology that currently exists and partnering with automakers, battery manufacturers, energy companies, and governments.

Figure 52 – Better Place Concept: Battery-Electric Sedan and Wind Turbines
The vision of Better Place relies on four pillars; plug, people, planet and prosperity. They think “the plug we use to charge our electric cars, the people who drive those cars, the planet we live on, and out mutual prosperity are all interconnected.” When plugging into a “smart” service, we can eliminate our oil addiction. The people who drive the cars are going to be the same, but what can change is how much they pay, how they benefit, and how they feel. The planet can be a “better place” as we strive for independence from oil, reduce greenhouse gases, and expand the market for renewable energy. To build this infrastructure, a carbon-free environment is created, generating new jobs and sustainable solutions that are prosperous for the environment and future generations.

5.1.1 Electric Car Infrastructure

The components of the Better Place electric car infrastructure are comprised of five main components: the electric car, battery technology, charge spots, battery exchange stations, and renewable energy. They will be automated by Better Place’s “Intelligent Network” software to enable easy use and enhance the customer’s experience.

(Images in this section are from www.betterplace.com)

Better Place will not make the vehicles, as they will partner with major automakers to offer a greater selection of vehicles. For no reason other than a high interest, the first automaker to collaborate with Better Place is Renault-Nissan, who is tooling up a 2 million car manufacturing line in Turkey. Other automakers are looking to partner as well, yet none have been announced to this date. Similar to the gas-powered cars we drive today, the electric cars will look and perform nearly the same, except quieter, more efficient, less likely to breakdown or require major maintenance.

The battery technology that will be used is lithium ion. The re-chargeable battery has long been in use, and in the last decade, the efficiency and lifespan of the lithium ion batteries have significantly improved due to the demand of cellular phones, laptop computers, and power tools. These advances have been incorporated into electric vehicle batteries to produce a rechargeable lithium ion battery that “can reliably deliver driving distances of over 100 miles on a single charge and replenish themselves at approximately one minute per minute of drive.” As these batteries are becoming mass-produced, economies of scale have driven down costs and lead to even more technical improvements. Currently, the lithium-ion battery partner is Automotive Energy Supply Corp. (AESC), a joint venture between Nissan, NEC of Japan, and A123 Systems.

Charging spots, or plug-in points, are to be available for use in parking garages, retail spaces, street curbs, and homes of the drivers,
so that a car can recharge when the software instructs it to. They are the regular point of interface between the car and the power grid to keep batteries topped off. Designed to be perfectly safe and weatherproof, these charge spots function at 3.3 kW and 6.6 kW, interacting only with vehicles equipped. When a vehicle parks at a charging spot, the on-board software instructs the link-up and charges until the battery is full, so the driver doesn’t have to do anything.

For trips beyond the range of a charged battery, fully automated battery exchange stations will be deployed. When a car’s battery is depleted or almost depleted, instead of waiting for the battery to recharge at a charging spot, a driver can pull into an exchange station, where the depleted battery is removed and a fully-charged replacement battery is installed, in less than 80 seconds (this does not include drive in a drive out time). Using the same latches that hold 500 pound bombs in place on bombers, the battery attaches underneath the car. This process is also automated making it more efficient and convenient for a user than a conventional gas station. It is not expected for exchange stations to be used on a frequent basis by users as most of today’s driving is within 40 miles of the home. A video of an exchange can be viewed on Better Place’s website, which was released early-May 2009.

To match the increased demand of electricity induced by the adoption of an electric vehicle network, Better Place will implement their zero-emission solution, and supply this newly created demand solely with renewable energy. This will not only ultimately reduce pollution, but accelerate the adoption of renewable energy by further creating a working demand for it. Currently, utility companies are hesitant to invest in renewable energy, as it poses issues with storage and consistency. The electric car infrastructure will act as a repository for excess electricity, acting as a storage unit when more electricity is being produced than needed, and potentially feeding the grid during peak loads. This transition is not expected to happen immediately, if at all.

5.1.2 Business Model

The business model of Better Place works similar to that of a cell phone company. Consumers pay cell phone service provides for minute-by-minute access to their towers or satellites, and pay comparatively little for the actual phone themselves. Basically, one purchases airtime and not the real device. Better Place applies this same model to transportation, where the phone is now an electric car, the satellites and towers are the recharge or exchange stations, and the network is the grid itself. Instead of purchasing minutes, one now purchases miles. Better Place owns the batteries, buys clean electricity, and sells either miles or kilometers to drivers to provide a clean, affordable, and convenient solution to transportation. They will operate the electric recharge grid that brings this all together. This network will be the ultimate moneymaker for Better Place, as they will purchase electricity in bulk from solar arrays and wind farms at an undisclosed
controlled price set by a long-term contract, and resell it to customers at a higher price to account for costs other than the actual electricity and generate profits.

During the years 2008 and 2009, Better Place has been and will continue deploying and testing its framework in a variety of launch markets. They plan on deploying hundreds of thousands of vehicles annually, anticipating achieving tipping-point saturation in early markets within 10 years of rollout.

5.1.3 Leadership Team

- Shai Agassi  Founder and CEO
- Idan Ofer  Chairman of the Board
- Charles Stonehill  Chief Finance Officer
- David Kennedy  General Counsel
- Moshe Kaplinsky  CEO, Better Place Israel
- Evan Thornley  CEO, Better Place Australia
- Jens Moberg  CEO, Better Place Denmark, and Head of Business
- Kiyotaka Fujii  President, Better Place Japan, and Head of Business Development, Asia Pacific
- Lawrence Seeff  Head of Business Development, Americas

5.1.4 Investors

- Acorns to Oaks II
- Esarbee Investments Canada
- GC Investments LLC
- Israel Cleantech Ventures
- Israel Corp.
- Maniv Energy Capital
- Morgan Stanley
- Musea Ventures
- Ofer Group
- VantagePoint Venture Partners
- Varikra Partners
- Wolfensohn & Co.

5.2 Key Strategies

The authors have identified several key strategies Better Place will deploy that they hope will enable them to succeed, compared to the failed attempts to develop an electric car infrastructure in the past. Relying on the advancements in technology since the last electric vehicle networks were attempted, and these key strategies, Better Place plans to launch their network in 2011 in Israel, then Denmark by 2012, and Australia, Hawaii, and the San Francisco bay area onward, with other locations in the talks as well. The three key strategies identified and
to be discussed are Better Place’s design and operation of their “Intelligent Network,” placing the ownership of the battery in Better Place’s hands, and choosing Israel to test their network.

5.2.1 Intelligent Network

Plug-in points and exchange stations will be on the current electricity grid, but Better Place will control them with their “intelligent network.” Renewable energy, which varies in loads, has to carefully be monitored and possibly stored, to match demands and prevent overloads. Better Place, which is founded by software people, are building a system that can do just that by controlling how much charge goes in, when it goes in, and if it comes out of the cars. This will be the main day-to-day operation of Better Place: operating the entire electric car infrastructure through a control-center with their originally designed software. Evan Thornely, CEO of Better Place Australia, says “that is what we know how to do. We’ve got a bunch of guys who build and sold three software companies before they started here.” This will provide several benefits to Better Place and its users.

Each car will be equipped with an intelligent computer that connects to the “intelligent network” and notifies the driver multitudes of information. The connection will monitor driving patterns and gather information to build statistics on how much charge is needed and when it’s needed. From the network-control center, Better Place will manage how much and when charge goes in, and possibly if it comes out. This will eliminate wasted energy and make for a valuable customer to renewable energy suppliers. Also, Better Place will be a partner of utility companies, sharing charge from renewable sources, giving them a place to store energy, and helping to feed the grid during peak times.

Other benefits of the “intelligent network” brought to the drivers include the vehicles being cheaper to insure, better connected to the world, and other incentives that could come with responsible driving. Since the network knows the location and information of a car at all times, if someone tries to steal it, Better Place could shut the vehicle down and locate it, making a Better Place vehicle theft-proof, and therefore cheaper to insure. Also, since the “intelligent network” is in constant communication with the car, the intelligent computer in the car could have some innovative features, such as downloading TV content, pre-ordering food, or browsing the internet using one of the several monitors throughout the car. Last, since the network monitors one’s driving, it could tell for example if someone is actually a person who doesn’t speed, as opposed to a person who speeds but never gets caught. This information reported to one’s insurance company might result in incentives.

Closely monitoring people driving at all times might raise concern, as people want their privacy and don’t want to feel like they are being watched under a microscope. Better Place says there will be a range of privacy protocols and protections in place, making the comparison to cell phone carriers and ISP. They claim people will always be informed as to what can be done and what they agreed to. They believe the benefits provided by the “intelligent network” far outweigh any major concerns such as the privacy issue.
5.2.2 Battery Ownership

To reduce the up-front cost of the car and provide additional benefits, Better Place will own the battery installed in Better Place-compatible vehicles. Considering a major drawback of the electric vehicle compared to the gas-powered vehicle is its greater cost due to the necessity of expensive batteries, Better Place’s strategy is to absorb this cost up-front to make the initial purchase of an electric vehicle more attractive.

Figure 53 – First Prototype Electric Sedan using a Lithium Technology Corporation Battery

A consumer will purchase or lease the electric car, but subscribe to energy, which includes the use of a battery pack and being charged on a per miles or kilometers driven basis. It is expected that not every customer will pay the same price for the miles or kilometers they drive, similar to a cell phone contract where not everyone pays the same price for the minutes used. They might even help pay for the cost of the car should a driver agree to drive enough. Better Place will make back the cost of the battery, and other amenities used, like charge points or exchange stations, in the energy that drivers purchase through the lifetime of the battery or vehicle, customer contracts, or some other means never disclosed.
Figure 55 – Current Battery Pack, with Vehicle Connector

Additional benefits of placing battery ownership with Better Place include recycling and updating worn-out or out-dated batteries. Lithium ion and other rechargeable batteries have a certain number of charges until they start to lose capacity and eventually are useless. This is measured as a batteries’ lifecycle, which is defined as the number of complete charge-discharge cycles a battery can perform before its normal capacity falls below 80% of its initial rated capacity, usually between 500 to 1200 cycles. By Better Place owning the battery, as it becomes worn-out or out-dated, they can easily notify the user to bring his or her vehicle to a battery exchange station for a new battery. After Better Place acquires the worn-out or out-dated battery, it can be repurposed for other needs, such as a hospital emergency power pack, or the raw materials, (lithium, phosphate, and others) can be mined out and repackaged into new batteries.

5.2.3 Testing Charging & Exchange Stations in Israel

Implementing the Better Place plan requires a massive network of battery charging spots and exchange stations to keep vehicles powered, as well as an appropriate location to test its feasibility. Better Place vehicles are equipped with an on-board computer that will inform the driver on the remaining power supply and can direct the driver to the nearest charging spot or exchange station. According to an Evan Thornley interview, to fully charge a battery, it would take about eight hours, and a swap at a battery exchange station would take about three minutes. It isn’t expected that anyone will ever need to fully charge, as they shouldn’t be fully depleting their battery too often, and if at times it does come close, they will probably just go to a battery exchange station anyway. Customers will be billed not necessarily at the plug or exchange, but possibly once a week, once a month, or however else they chose to arrange to pay for the miles or kilometers they drove. This is the main source of revenue for Better Place, controlling and profiting off the power they sell to their customers.

To work out all the kinks, optimize the model into practice, and start generating a profit, Better Place needed a proper location to implement its first network and infrastructure. Based on the driving habits and distances between major locations, certain markets were better suited for implementing and testing this network. Comparably to the U.S., where 90% of car owners drive
less than 45 miles per day, Israel is characterized as an ideal location for an electric vehicle infrastructure to meet the transportation needs of most of the population. The country is 300 miles north to south, and less than 100 miles at its widest points, with its three major cities, Tel Aviv, Haifa, and Jerusalem, all within 100 miles of each other. Also, the vehicle density of the nation, which is over 120 vehicles per km of road, and still growing, is highly favorable for a new car infrastructure, compared to the United States, which has a vehicle density of 40 vehicles per km of road. Data on Israel’s transportation sector is displayed below in Table 11, 12, and Figure 56, 57, & 58, taken or derived from the Israel Central Bureau of Statistics.

Table 11 – Israel Physical Transport Data

<table>
<thead>
<tr>
<th>Year</th>
<th>Length of Paved Roads (km)</th>
<th>Licensed to Drive (thousands)</th>
<th>Private Vehicles (thousands)</th>
<th>Commercial Vehicles (thousands)</th>
<th>Total Vehicles (thousands)</th>
<th>Kilometers Traveled (million km/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>9,290</td>
<td>439</td>
<td>148</td>
<td>66</td>
<td>266</td>
<td>5,892</td>
</tr>
<tr>
<td>1975</td>
<td>10,278</td>
<td>713</td>
<td>280</td>
<td>96</td>
<td>419</td>
<td>9,232</td>
</tr>
<tr>
<td>1981</td>
<td>11,810</td>
<td>1,049</td>
<td>454</td>
<td>96</td>
<td>539</td>
<td>11,604</td>
</tr>
<tr>
<td>1985</td>
<td>12,760</td>
<td>1,316</td>
<td>614</td>
<td>115</td>
<td>776</td>
<td>14,058</td>
</tr>
<tr>
<td>1990</td>
<td>13,199</td>
<td>1,699</td>
<td>803</td>
<td>154</td>
<td>1,015</td>
<td>18,668</td>
</tr>
<tr>
<td>1995</td>
<td>14,751</td>
<td>2,222</td>
<td>1,112</td>
<td>247</td>
<td>1,459</td>
<td>30,633</td>
</tr>
<tr>
<td>2000</td>
<td>16,450</td>
<td>2,679</td>
<td>1,397</td>
<td>310</td>
<td>1,831</td>
<td>36,482</td>
</tr>
<tr>
<td>2005</td>
<td>17,591</td>
<td>3,116</td>
<td>1,626</td>
<td>351</td>
<td>2,107</td>
<td>41,729</td>
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<tr>
<td>2007</td>
<td>17,870</td>
<td>3,281</td>
<td>1,779</td>
<td>358</td>
<td>2,284</td>
<td>44,996</td>
</tr>
</tbody>
</table>

Figure 56 – Number of Private and Total Vehicles on the Roads in Israel by Year
Table 12 – Calculated Israel Transport Statistics

<table>
<thead>
<tr>
<th>Year</th>
<th>Drivers / Length of Road (drivers / km)</th>
<th>Pri. Vehicles / Length of Road (vehicles / km)</th>
<th>Total Vehicles / Length of Road (vehicles / km)</th>
<th>Drivers / Km Travelled per year (drivers/mill km)</th>
<th>Pri. Vehicles / Km Travelled per year (vehicles/mill km)</th>
<th>Total Vehicles / Km Travelled per year (vehicles/mill km)</th>
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</thead>
<tbody>
<tr>
<td>1970</td>
<td>47.26</td>
<td>15.93</td>
<td>28.63</td>
<td>74.51</td>
<td>25.12</td>
<td>45.15</td>
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<tr>
<td>1975</td>
<td>69.37</td>
<td>27.24</td>
<td>40.71</td>
<td>77.23</td>
<td>30.33</td>
<td>45.39</td>
</tr>
<tr>
<td>1981</td>
<td>88.82</td>
<td>38.44</td>
<td>45.64</td>
<td>90.40</td>
<td>39.12</td>
<td>46.45</td>
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<td>1985</td>
<td>103.1</td>
<td>48.12</td>
<td>60.82</td>
<td>93.61</td>
<td>43.68</td>
<td>55.20</td>
</tr>
<tr>
<td>1990</td>
<td>128.7</td>
<td>60.84</td>
<td>76.90</td>
<td>91.01</td>
<td>43.01</td>
<td>54.37</td>
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<td>1995</td>
<td>150.6</td>
<td>75.38</td>
<td>98.91</td>
<td>72.54</td>
<td>36.30</td>
<td>47.63</td>
</tr>
<tr>
<td>2000</td>
<td>162.9</td>
<td>84.92</td>
<td>111.3</td>
<td>73.43</td>
<td>38.29</td>
<td>50.19</td>
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<td>2005</td>
<td>177.1</td>
<td>92.43</td>
<td>119.8</td>
<td>74.67</td>
<td>38.97</td>
<td>50.49</td>
</tr>
<tr>
<td>2007</td>
<td>183.6</td>
<td>99.55</td>
<td>127.8</td>
<td>72.92</td>
<td>39.54</td>
<td>50.76</td>
</tr>
</tbody>
</table>

Figure 57 – Number of Drivers and Vehicles per Length of Paved Road in Israel

Figure 58 – Drivers and Vehicles per Kilometers Driven per Year in Israel
Currently, the Israeli government and an increasing number of companies are working with Better Place to launch the electric vehicle network by 2011. Before any vehicles are even marketed, 500 initial charge points and exchange stations are to be set up and tested in Tel Aviv, Haifa, and Jerusalem, covering the heart of Israel, from the Mediterranean waters to the center of the country. Currently, Israeli venture capitalists, who are listed Section 5.1.4, have contributed more than $400 million to fund the infrastructure development. Also fleet companies are lining up, where a press release from February 23, 2009 announced 19 leading Israeli companies as the first corporate fleet customers, giving them priority in purchasing Better Place electric cars after they are finished being designed, installed, and tested in Israel.

Starting to generate a profit is possibly the most important factor for Better Place’s success, as they are a business first. After they develop Israel, they must have the capital to develop infrastructure in other parts of the world, and offer competitive prices. Choosing Israel is key, as gas prices have recently risen to over $7.00 a gallon, making it extremely profitable to just undercut the price of gasoline with a cheaper energy, electricity from renewable sources. Since Better Place is a private company, they don’t necessarily have to disclose their earnings, and may never let anyone know just how cheap they are getting their energy for, and how bad their customers are being taken advantage of. As long as the driver is paying less for filling up electric than gas, they won’t necessarily mind, and allow Better Place to generate profits. They will likely move to other parts of the world with high gas prices, potential for renewable energy, and desire for electric vehicles. Given the potential for lots of renewable energy at a low cost, targeting markets with high gas prices will enable Better Place to maximize their profit by continuing to just undercut the price of gasoline. It is no surprise that Denmark is next, whose price of gas is almost at $6.00 per gallon. Governments may step in at point to prevent people from overpaying too much and being taken advantage of, limiting Better Place’s profitability, but this will likely be determined by a contract pre-arranged with Better Place and legalities. Also, if Better Place’s concept proves to be successful, it is almost certain other car manufactures and competitors will step in, resulting in a more competitive market, and lower prices. Despite the United States low gases prices, choosing certain regions in the U.S. is understandable, as these governments have the funding which they’ve agreed to contribute to help Better Place set up the infrastructure, so it’s not as great of a risk.

5.3 Limitations & Consequences

The following are critiques on the limitations and consequences of the Better Place concept. These are some of the expected issues Better Place might face when implementing their network in Israel and other parts of the world. The authors formulated these ideas, and several blogs have been found that discuss some of these same critiques. In addition, Better Place is made up of software engineers, who are often over-confident in their ability to understand transportation systems, and more issues may arise with their design and implementation than expected.

5.3.1 Selling the Idea to the Customer

Better Place has been able to sell their idea to governments, investors, and car and battery manufacturers, but now as they try to penetrate markets, they must sell their idea to the people
who matter the most, the customers. Despite the moral benefits of reducing vehicle emissions to none by driving a Better Place vehicle, drivers will likely only make the change from gas to electric in mass quantities if the price is right. The cost of an electric vehicle is known to be higher, as it practically replaces two metal containers, a cheap gas tank and an engine, a series of hollow tubes, valves, and joints, with expensive chemical-filled batteries and an electric motor, a precise combination of costly metals. Better Place has already reduced the largest expense of the vehicle by taking ownership of the battery, absorbing its up-front cost. The company is still yet to disclose the actual cost of a Better Place vehicle, such as the eRogue in Figure 59, or the eMegane in Figure 60, but it is expected that it will be fairly competitive with a similar gasoline-powered model.

Even if the price is attractive, the transition from driving a gas-powered to an electric-powered vehicle must be easy. First, battery-electric vehicles have a limited range compared to a gas-powered car, which can get over 400 miles on a single tank. Also, due to the limited range, the driver has to constantly charge their vehicle when parked, and get used to plugging in often. Figuring about 5 to 10 seconds to un-plug or plug-in, multiple times a day, which compared to waiting at a gas station for a few minutes once a week, the use of plugs might take some additional patience and getting used to. Better Place expects drivers to have their car plugged in when not driving on the roads at all times since its an energy storage device that can be used during peak times to help feed the grid. Even for brief stops, Better Place will know when the car is off and not plugged in, so they may charge a premium to subscribers to incline them to plug their car in when not in use, at all times. For example, a basic package might charge $1 for every hour over 10-hours in a month that the car is not in use and unplugged, giving customers a
little le-way. However, someone who forgets to plug-in often might see a higher bill than expected at the end of the month. This is a hidden cost to users that might be very unattractive.

These powerful electric cords also might frighten people, and Better Place is well aware of that. Tal Agassi, Better Place’s global manager for infrastructure and the founder’s brother, mentioned “we want to make the cord smaller and thinner, so it’s more like USB cord or a cord you use on your computer… It’s all about making people comfortable with the idea of using electricity in your car.” This is a very unrealistic goal, as a charge of that magnitude couldn’t travel through such a small input. To make it a little more comforting, there is a blue Better Place logo that glows when the plug is in and electricity is flowing. In addition, the regenerative braking has a different feel and might take some time getting used.

Also, Shai Agassi might be targeting the wrong market. He is off promoting how his vehicles won’t only reduce emissions, but eliminate them, making it extremely attractive for the environmentally conscious consumer. However, with the expected arrival of plug-in vehicles such as Chevy’s Volt, entering the market by 2010, these vehicles will reduce emissions by 70% to 90%, possibly making a much more attractive vehicle including all other factors like range, costs, drivability, and need for no new infrastructure. Simply saying these cars still rely on oil won’t necessarily cut it, as transportation only constitutes up to 30% of the world’s energy consumption, and we will still be faced with oil-dependency issues even if Better Place vehicles emerge.

5.3.2 Battery Swapping and Standardization

One of the greatest technical issues with Better Place is their need to settle on a standard battery due to their battery swapping advantage. Setting themselves apart from previous attempts at an electric vehicle infrastructure, Better Place is giving their vehicles the ability to quickly swap out its battery for a fully charged one. This required for one battery format to be settled on so all cars coming in and out of an exchange stations have the same battery, and need the same battery, in the same spot, making the exchange much simpler. As the optimal location for an electric car’s battery or the battery type has not even been settled yet, several issues arise, which is the reason only one car manufacturer has been willing to partner with Better Place and invest in manufacturing cars with a standard battery format, risking this will be the best technology for the next ten years.

The infrastructure costs of setting up enough plug-in points is huge, and spanning an area with multiple $500,000 battery swapping stations just adds that much more. First, it is challenged that the cost of a battery swapping station is just $500,000. To operate the station, there must be extra batteries on hand to meet the demands of the customers who expect a fully charged battery right away. The demands must be met at peak times, not on average over the course of a day. Considering it takes 3 hours to fully recharge a battery (and the batteries coming in will likely need full recharging), and each exchange takes on average 2 minutes including drive in and drive out time, the number of batteries each station should have on hand is 90. Assuming the cost to Better Place for each battery is as low as $10,000 (it is unknown what the actual cost is), this means just the batteries they must have on hand is $900,000, and that’s a station with just one exchange spot. Even estimating a reasonable demand to be half that, this is still $450,000. For
Better Place to state their swapping stations are just $500,000, they are not including the price of the batteries they must have in “inventory.” Technically, the inventory cost doesn’t have to be included in pricing the building of a structure, but the inventory for Better Place really isn’t the batteries, but the charge in the batteries. The actual batteries themselves should be considered part of the structure, as without them, there is no place to store the this charge, the inventory, and the swapping station won’t operate unless these excess batteries are in place to be fully charged when users pull in.

Furthering the financial issues with the Better Place battery swapping infrastructure, it works best with just one type of battery size and shape. Even with just one battery type, the exchange station is very costly, as well as the excess batteries that must be on hand. However, an SUV, which is much larger than say a sports or compact car, will likely have a greater energy demand, as well as having more space for a larger battery. Better Place is now faced with a dilemma of offering multiple battery types for a variety of vehicles, or settling on one battery type, which limits the variety. For the former, it much more costly, as the exchange stations now must have multiple types of batteries on hand, which would require more advanced swapping arms or additional battery specific spots.

With Better Place and Renault-Nissan investing in the infrastructure and cars that have quick battery swap ability, they are betting on the battery charging technology not advancing too significantly in the near future. Many feel the limited range of the battery-electric vehicle will be solved with rapid chargers. Although a depleted battery can’t be swapped for a fully charged one in less than a minute, there currently is technology that could recharge 80% of a battery in just 10 to 15 minutes. This technology is looking to improve to fully recharge the battery in under 5 minutes. If this does emerge soon, or a battery that could store over 200 miles worth of charge, Better Place will likely join on, and utilize the newer battery technologies, but it would likely make their exchange stations and excess batteries obsolete, a enormous financial waste.

Other minor issues with Better Place’s battery standardization have been found on multiple blogs discussing the concept. First, some are worried about the quality of the battery they receive for the one they swap out. Knowing how batteries have a life-time, and some drivers will irresponsibly use their batteries just as they abuse their vehicles, after a certain amount of time on being on the road, not every battery will be the same. Some worry that they would swap out a good battery for a lower-grade or older one, which holds less charge, reducing their mileage until their next swap. This pretty much makes swapping a gamble. Also, some are worried about the theft of the batteries themselves. Since the batteries are able to easily swap in and out with a mechanical arm, this could make for an easy theft item as well. A few hundred pound lithium-ion battery pack could be worth a lot of money, at least for a little while. One last issue is Better Place using lithium-ion as their battery. Lithium-ion batteries don’t necessarily do well in the sun, and it will be interesting to see how they hold up in Israel. Some even feel the exchange itself is dangerous, as it could result in electrocution or fire.

5.3.3 Lack of Concern for Congestion

Another issue with Better Place’s concept is their lack of concern for congestion, another key problem facing many nation’s transportation infrastructures. Where most emissions reductions
have come from improved technology, several efforts have also coincided with reducing the amount of vehicle miles traveled or the number of vehicles on the road, and rarely do these efforts look to increase the two. Some methods might be non-technological such as promoting carpooling with an HOV-lane or increasing the coverage of public transit, which reduces congestion as well. Until the emergence of Better Place, there was yet to be a plan that tries to reduce emissions and actually increase the number of vehicles on the road, encouraging congestion. Since Better Place will be offering more attractive rates to those who drive more, Better Place is actually promoting more and individualized vehicle use, showing no concern for congestion, and simply trying to maximize their profit by having as many Better Place vehicles on the road purchasing their energy. Even though they are trying to convert drivers from gasoline to electric vehicles, which is good in reducing carbon emissions, better rates offered to those who drive more will incline the customers to possibly over-predict their amount of driving in fear of paying an expensive premium (like going over the allotted minutes for a cell-service) and incline them to use up all their miles to continue paying the lower rate. So the trips gasoline drivers might not take, such as a 20 minute walk, might be taken by Better Place drivers since they want to use up miles and consider their driving harmless to the environment.

5.4 Authors’ Claims

Better Place is a Business. They claim their concern is to end the world oil-dependency, but in actuality, they are concerned with generating a profit and quickly monopolizing the passenger vehicle infrastructure in multiple countries. The transportation sector only constitutes 25% of the energy consumption worldwide, so clearly Shai Agassi’s efforts won’t end the world-oil dependency since many other sectors rely on oil, though it could move the world the right direction. With Better Place purchasing and reselling renewable energy to the drivers, they will easily profit by controlling all factors with their “intelligent network.” Overall, Better Place is looking to create, “a company controlling a world network of charging stations would become so profitable so quickly that it could subsidize its customer’s electric cars,” emerging in even the toughest markets once the capital structure is in place. One blog comment, by paulwesterberg, put it well, stating “PB [Project Better Place] is about making money by locking you into a multi-year contract with a high monthly fee but low up front costs like the way that cell phone companies make obscene profits.”

Implementing Better Place networks should be done in populated and developing areas, with high fuel prices. Better Place has strategically chosen Israel and Denmark as its first two locations, looking to be operating by 2011 and 2012, respectively. The United States is not necessarily a prime location to adopt the Better Place concept relatively soon on a country wide scale. However, several locations in the U.S. that have their own incentives and are looking to bring Better Place in to their region within the next five years. Hawaii, which is separated from the continental U.S., and pretty much its own entity, is looking at Better Place since they are plentiful in renewable energy, and their grid isn’t as complicated to reconfigure as it would be for the entire continental U.S.. The San Francisco bay area is also looking to adopt the Better Place concept, as they already have renewable energy feeding their grid and State policies soon to enforce the requirement of zero emissions vehicles on the road. As U.S. drivers are used to relatively low gas prices and little limitations with their driving, and the U.S. electric grid is a
problem on its own which must be solved before renewable energy could be added in grand scale to feed passenger transportation, Better Place should realize the U.S. is an extremely risky venture unless gas prices significantly rise. A recommendation for where Better Place should focus is China, where “electric cars are expected to sell briskly to an emerging middle class that has never owned a car and thus is presumably less conditioned to feel range anxiety.” China, which has a more primitive electric grid than the U.S., making it difficult to feed with renewable energy, at least has a population that won’t be as resistant to the electric vehicle limitations since most don’t have a car to begin with, and a limited range car is likely better than none.

No matter what country or location Better Place looks to implement its system, it is likely that major funding will be required. As additional car manufacturers join in, they will likely look for help in updating their lines for the standard battery. As consumers look to make the change to driving electric, they will likely look for subsidies or tax credits in purchasing a revolutionary car. And the actual areas that look to Better Place to set up the infrastructure, Better Place will likely ask for funding to make it possible. As Better Place is looking to generate profits to enable global conquest, if they show success in their test markets, meaning other areas want their network and profit was generated, they should be able to afford setting up the infrastructure on their own. However, Better Place will likely move to the next most profitable location, which might include competing governments bidding against each other as to who will contribute the most.
6 CONCLUSION

6.1 Air Transport

Through our discussion of the various options to reduce aviation’s CO₂ emissions, there are three general conclusions to be drawn.

First, a regulatory framework with an environmental focus is needed in the aviation industry. The cost cutting and market driven solutions to increase efficiency are not enough to mitigate growing emission trend. Other forcing factors such as carbon regulation or stricter aviation emission regulation are needed if the U.S. aviation sector is expected to halt its growth of CO₂ emissions.

Secondly, before any recommendations are made about changing high altitude flight patterns, more studies need to be done on the effect of high altitude water vapor and NOₓ emissions need to be funded. However there are many operation procedures that clearly could help save fuel, and a review of the operational procedures with CO₂ emissions in mind can offer significant benefits.

Lastly, although a stabilization of CO₂ can be achieved with aggressive policies, to this day there are no zero emission scenarios for air travel in the near future. Possibly later down the road, biofuel which uses as much energy as it provides may be an option. Advancement in this area is getting a lot of attention but there are many hurdles in the way to commercial scale implementation of biofuel as a jet fuel displacement as outlined in section 1.3. Policy encouraging the development of advanced biofuel for aircraft is one of the few options the aviation industry will have if it intends to mitigate the industries effect on climate change.

6.2 Water Transport

After completing the forecast model, it is possible to reach a 33% reduction in emissions by 2030 using a combination of the renewable energy and alternative fuel discussed. However, this is not the only possible outcome for the next 20 years. If assumptions are changed, then the results would look quite different.

The model shows that the demand of domestic water freight transportation is growing about 2.85% each year from 2006 to 2030. The growth rate is much higher comparing to 0.7% growth rate from ICF Consulting estimation. Since the model is just given a picture of the future with the assumptions, as the technologies become more developed, the model can be updated to include more accurate estimates of the percentage use and the improvement of the efficiencies of the alternatives.

This model only focuses on domestic marine freight since lack of data on international freight. The data on international freight are beginning to be recorded in May 2009. The model can be updated to include the international marine freight after the data is collected and adding other options for potential savings such as wind energy.
The model was created under the assumption that the industry would use these options to reduce carbon dioxide emission only. However, this is absolute not the only consideration in the reality. A deeper research on economic feasibility of the more sustainable options is needed. Whether or not these savings options can be implemented in a way that is economically acceptable by the end user is very important. Also, the safety issues of using these options need to be considered as well. Lastly, the model implemented with further cost-benefit analysis would help to forecast a more realistic outcome.

6.3 **Land Transport**

6.3.1 **Freight**

The freight section of this report serves to pinpoint currently available technologies that are able to reduce, in any amount, the consumption of fuel and thus the creation of harmful greenhouse gasses. The possible reductions in fuel consumption these technologies can offer were then amalgamated in order to find the composite reduction effect they can have if implemented. These reductions were calculated using a reasonable adoption rate of 2% per year for the entire US fleet, in order to provide realistic and feasible results. There are a few conclusions to be made after the discussion on possible improvements and their effects on the US trucking fleet.

Fuel economy can be greatly improved with simple changes to existing trucks as well as economically feasible changes to new trucks being produced. These changes, although seemingly simple, offer the opportunity for the largest currently feasible reduction in greenhouse gasses. In order to picture this, we offer a more explicit comparison of scale. Our report shows that doubling aircraft fuel economy until the year 2030 can stop the emission of 530,000 metric tons of CO$_2$ to the atmosphere during the total span of those years. Though significant, we also found that if every year an extra 2% (not the whole fleet at once) of the trucks in the US increase their fuel economy by 47% we stop 69,000,000 tons of CO$_2$ from being emitted, in the year 2030 alone. The technologies that produce this 47% increase in fuel economy in trucks is available, feasible to implement, and in many cases simple and inexpensive.

It is possible that these savings can be augmented by other changes in the status quo of the truck driving industry. Bio fuel use as well as a more widespread use of auxiliary power units may serve to bolster the CO$_2$ savings identified in this report. Because of the lack of fuel efficiency regulation in this country, as well as most others, policy changes that force companies and private truck owners to make the proposed changes are the key to ensuring the successful implementation of these technologies and subsequent reduction in greenhouse gas emissions.

6.3.2 **Better Place**

Better Place is a private company designing and hoping to operate an electric car network powered by renewable energy sources with the intention of eliminating emissions from the personal transportation sector and help end the world’s oil dependency. Deploying a widespread infrastructure of charging points and battery swapping stations, Better Place will test launch its concept in Israel starting in 2011, relying on their “Intelligent Network,” standardized batteries, and choice of prime markets for implementation. Two complications with the concept that might
lead to its failure include a possible resistance from selling Better Place vehicles to customers and relying on a swappable standard battery format, which has a high associated cost as extra batteries must be on the road, and risks battery charging technology won’t improve in the upcoming years. The Better Place concept can succeed in the test markets, enabling Better Place to generate profits and expand to other regions of the world. They will either have a head start on any competitor, and possibly “take over the world,” but this is unlikely as governments should keep a potentially monopolistic company in check, and other car manufactures would likely develop a similar model that can compete with Better Place, even with the belated start.

6.4 Recommended Topics for Future Research

- Behavioral Changes vs. Chemistry: Aircraft emissions inventory for operations below 3000 feet is well known. Fuels dispensing at airports are a reliable data source and the conversion of fuel burned into CO\(_2\) emissions is well understood. However, due to the uncertainty and lack of research into the effects of varying flight altitudes and behavior above 3000 feet, examining the complete greenhouse effect of aviation would be interesting. Although the amount and mitigation of CO\(_2\) production is important, many other chemical reactions happen within the atmosphere due to aircraft emissions. What are the chain reactions? Most aircraft fly at altitudes of 8-13km. Why? What is the effect of NO\(_x\)? Does it act as a catalyst in the presence of sun? Does flying at night (lack of sun) within the rain (high humidity) make a difference? More research into the behavioral changes we can make within the flight area above 3000 feet would be interesting. Can we change chemistry through behavior?

- For future teams to work on marine transportation sector, we propose the idea of keeping track of the new international marine data and the bunker fuel data because it was very hard for us to find good data on that area, so we did not create model for international marine sector. Nations are just starting to put together the data recently, so it is very possible to have good data on international data. We think that it is important not just to look at what is happening domestically but also looking at the whole world as well.

- It would also benefit this area if we could possibly look into the role of policy in affecting implementation of the technology we researched.

- Adoption rates is also another area that might help in further understanding the realistic nature of the models presented in this project. Will CO\(_2\) reduction really continue at the rate we projected? What role do adoption rates play in this?

- Looking specifically into the effects of biofuels on the level of fuel consumption and greenhouse gas emissions of the US land freight industry.

- The effects of alternative power units (APUs) on overall truck fleet fuel consumption. This may be interesting but difficult because it involves determining the rest patterns of truck drivers.

- The Better Place concept can be further looked in to as the company continues to develop and more technical information is disclosed. Within the next two years, the company
should be operating, giving actual data for costs, vehicle limits, and energy demands. This and other information can be used to develop models and projections for the concept in the U.S., on a much grander scale than Better Place’s initial markets. Also, one can research this concept by surveying potential customers and gauging their interest. It would be interesting to see how the structure and questioning of the survey affects responses. One survey can be simple, just discussing the benefits of switching to the Better Place network would have on the typical driver, and the other can be more negative to the concept, disclosing all costs associated and possible risks. This is probably more of a social science than engineering problem, but it would still tie well into projecting how Better Place might roll-out in the U.S., and what needs to be done to ensure success. Last, the concept can be researched by looking specifically into its and competing technologies and their futures, noting Better Place’s adaptability, or if a better concept will emerge. If one is expected, what is it?

- All sectors can be researched from a user’s perspective. The products and solutions that are available to users are researched in this report, but understanding what really makes the users (airlines, ship owners, truck drivers, etc.) make the transition could be further identified. This could either entail looking at historical improvements, and what the appeal was, or conducting an informative survey given to the users to better understand their desires and intentions. Each sector, fleet, and/or vehicle size, may be interested in something different, whether it be a quick improvements, cheap improvements, or improvements that are only substantial. For example, delivery services, like Fed Ex, might be interested in quick and cheap improvements at any time, but an oil tanker might only be interested in substantial improvements, regardless of cost, since taking the ship out of commission for a day is extremely costly anyway.
APPENDIX A: PERSONAL REFLECTIONS

Wilson Huang

From the start of the project, I wanted to learn more about transportation sector’s transition to sustainable energy. In this project, my role is to research about new or current technologies that are used by the marine transportation industry. To my surprises, there are many ongoing researches and just-starting new technology for the marine transportation to reduce carbon dioxide emissions. This project gave me a better understanding of the marine sector, as well as some information about the land and aviation sector when I look over the report and the presentation with the group. Overall, the group’s dynamic is good, and the marine subgroup’s teamwork is great. From this project, I also had some experience of coming up with model to predict energy use and consumptions with and without the alternatives to reduce emissions. Therefore, I feel like this project not only improves my knowledge about the transportation sector and its ways to try to reduce emissions but also provides a good experience for teamwork.

Chih-Yu Kuo

My sub-group focused on marine transportation, which was a very new topic for us at the beginning, since none of us have done any research about it before. Also, the previous year’s report didn’t cover a lot about marine transportation. Thus, we spent a lot of time on research for the first few weeks. Everyone shared what we have found during weekly meeting, so we can learn about the information from different areas and also know everyone’s progress. My task was looking for the existed projection model from the recent studies and also collecting useful data to build our own marine forecast model. Prof. Vanek also guided us different methods of forecasting and provided us useful information. We have tried to use one point data of international marine to forecast, but we found it was unreliable, so our model only focused on domestic marine freight, and we also use the existed projection to build an alternative scenario model for comparison. It was interesting that the forecasts results are so different between our model and the alternative scenario model, it might be we are too optimistic about the marine trend will have an upturn correlated to the growth rate of GDP, or the projection form recent studies was too conservative. The only thing we can do is to keep tracking the trend and have more research to improve the current forecast model to be more accurate. It is a good experience for me to work on the research project with other people. I have learned a lot not only about the research topic but also learned how to work with other teammates from different backgrounds.

Daniel Menendez

Working on this project gave me a solid opportunity to build upon different concepts that I have learned about before. I worked on the land freight section of the team, and though it was a difficult experience to learn how to do in depth research through a large amount of scholarly journals on my own, it still worked out. The fact that this project was mostly research based made it a difficult challenge but one that in the end provided everyone in the group a chance to do something that most of us had not been very exposed to before.
Land freight was an interesting topic to research and I learned many new things about the subject and actually have a much better grasp of what exactly the problem is and more importantly the incredible scale of it. I thought that the research I did was useful and provided a good summary and a good proposal of available technologies, although I have seen that not everyone would agree that this part contributed anything new. To me, all of this information was new and so I carried on doing research in order to compile a set of information that I found useful and enlightening. Future groups should be careful not to take anything for granted, and somehow make sure that their research will be putting forth new information, in order to avoid frustration at the end. Another observation/recommendation is that a group should not be lopsided. If there are sub teams that have very different sizes, this can create a lack of support for smaller teams.

I also learned from this project that the modeling of new scientific implements is a very grey area. There really is no way to tell what will happen without having incredible sources of funds to do incredibly large research projects that may still end up incorrect. I learned that many models are done just by finding possible or probable scenarios and then comparing those to other ones in order to find the most reasonable. It seems to be a lot less exact of a science, which was a strange feeling at first, but exciting as well. In the end, I enjoyed working with my group and wish everyone the best of luck.

Cherish Scott

This project has afforded me the opportunity learn an immense amount about reducing carbon emissions in areas not commonly discussed, air and water sectors. With our research I gained great insight into the easy fixes and the extreme challenges that we face in reducing our carbon footprint and addressing climate change. I also learned the importance of the need to keep your eye on the bigger picture and fully understand the carbon impact of multiple sectors and their mitigation strategies. As all carbon reductions are not politically and economically feasible, this is the only way to appropriately allocate resources.

Throughout this project I learned the importance of setting and adhering to reasonable self imposed deadlines, to ensure that work is completed and compiled in a timely manner. This experience has also taught me the importance of creating meeting agendas to ensure the efficient use of time. Our engaging discussions helped create and address new questions in our research. Overall, I have truly enjoyed working with this project team as I have learned a lot from our research, discussions and working together.

Nick Szabo

Upon entering the course I was aware of many “terms” such as greenhouse gasses, emission reductions, alternative fuels, and PHEV’s. Unfortunately, there meanings where never fully understood beyond a definition. Truthfully there was not much thought given to the worlds energy demands and climate problems. You see, I received my Bachelors 30 years ago when this was not an issue…or was it? As the semester’s research continued it became apparent just how naive I had been. There was an enormous amount of information and exciting new technological
avenues to be developed in our efforts to mitigate potential future energy usage problems and reduce CO2 emissions. I worked upon the airline transportation sector and found that only slight changes in daily operations made significant positive impacts. Many questions are unanswered; however I take away a greater understanding of our worlds transportation demands and their possible solutions.

As with any group there are many dynamics. Diverse educational fields, ethnicity, and general personal interest all played a role in what should have been difficult. The end result was a strong dynamic group with many ideas that produced an exciting learning environment, a fantastic report, and most importantly…we had fun! I will take this opportunity to say “Nice Job everyone…You Guys are awesome”. We all gained from our personal and professional interactions. We obtained an extensive amount of knowledge within the transportation sector and hope that others will benefit from our research report.

Stephen Teijeiro

As a graduate student, this semester’s project focusing on transportation, energy and the environment seemed like a perfect capstone for all my academic research in the area. A report covering carbon reducing technologies in transportation sectors other than personal transportation was especially appealing. What I quickly learned was though the news and research papers tout new technology as being able to save us from the effects of global warming, often times the market conditions and implementation feasibility vary significantly from sector to sector. Talking about these differences in our large group prompted fascinating discussion, however when trying to compile a complete report, naturally one considers if the report should have been broken into multiple reports.

Working closely with my peers taught me that effective organization and communication between the group members is very important. A good plan can save a lot of time and effort especially when trying to coordinate 8-9 people over the course of a semester. Having periodic reviews of the material we collected was very helpful. In the end, we made a strong case for the technical feasibility of the reducing CO2 emissions from the transportation industry in all sectors. The report will hopefully help others investigating climate issues and help inform discussion makers of the opportunities and challenges related to climate change in the transportation sector.

Jennifer Y. Yao

From the onset of this project, I knew virtually nothing about renewable energy and energy emissions. Understanding this lack of knowledge, I sought to gain a better understanding of the existing energy network, the status quo for transportation modes, and current trends towards improved energy use. Finally, I desired to immerse myself in the world of “green.”

Overall, I definitely accomplished my goal. I volunteered to be part of the marine transportation sub-group, since it was the most obscure mode in my eyes. I also volunteered to do research on the existing status the water mode. Since I did not know anything about energy efficiency or the
transport networks existing in the U.S., this role suited me best. After this semester’s research, I have come out with an expansive and comprehensive understanding of the air, land and marine networks. I also have a good understanding of the barriers of the marine, land, and rail networks, and that the best way to overcome these barriers is to use different modes to supplement the other.

What I will take away from this project is not only a deep understanding of each network, but I have an awareness of the effort needed to improve the planet’s current environmental problems. Having researched for a semester, I can understand that my effort is only the tip of the iceberg, and I will definitely stay attuned to the developments towards renewable energy, energy efficiency, and reducing energy emission.

Jonathan Zacherman

Coming into this project, I wasn’t sure what to expect, other than I would be working with a group with some transportation and/or energy oriented focus. I really enjoyed the first month of learning some background information on the two fields, and getting the opportunity to work as a team and formulate our research questions and objectives, while satisfying the needs of the Professor. We agreed it was best to take three directions between the land, air, and water sector. I think worked well for the air and water groups, who interacted much more readily since their research was reliant on each other’s, but not as much for the land. This was likely due to Daniel and myself focusing on two separate entities; freight practices and a passenger vehicle concept. Still, more could have possibly done to receive help, possibly from the members in the water and air groups who didn’t seem as overwhelmed, and this should have been realized sooner rather than later.

I highly enjoyed learning about the other topics and researching the Better Place concept, despite the limited technical information that was available. I found this redirected my focus from trying to formulate a model and projections of the concept in the United States, but more discussing the strategies the company will deploy and how they might run into difficulties, which was all that was disclosed up to this point. Interacting with team members and Prof. Vanek, and being able to talk through what I was thinking while performing the research, was a delight and extremely helpful to keeping my thoughts and ideas organized and realistic.

Also, I found I got just as much of a learning experience, if not more, acting as team leader. Coming into the M. Eng management program, I was very interested in getting leadership/management experience, and commanding a team of seven smart and hard-working classmates throughout the semester really gave me that opportunity. I learned the importance of staying organized and prepared for meetings, and how essential an effective communication line is when managing a large group. I would have been interested in receiving feedback from my team members, but considering no one asked for my removal, I guess I didn’t do too bad.
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