TRANSPORTATION ENERGY AND CARBON FOOTPRINTS FOR U.S. CORRIDORS

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TRANSPORTATION ENGERY AND CARBON FOOTPRINTS FOR U.S. CORRIDORS

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SUMMARY

Changes in climate caused by changes in anthropogenic (i.e. “man-made”) greenhouse gas (GHG) emissions have become a major public policy issue in countries all over the world. With an estimated 28.4% of these emissions attributed to the transportation sector, attention is being focused on strategies aimed at reducing transportation GHG emissions. Quantifying the change in GHG emissions due to such strategies is one of the most challenging aspects of integrating GHG emissions and climate change into transportation planning and policy analysis; the inventory techniques and methods for estimating the impact of different strategies and policies are still relatively unsophisticated.

This research developed a method for estimating intercity passenger transportation energy and carbon footprints and applied this method to three corridors in the U.S.-- San Francisco/Los Angeles/San Diego; Seattle/Portland/Eugene, and Philadelphia/Harrisburg/Pittsburg. These corridors are all US DOT-designated high speed rail (HSR) corridors. The methodology consists of estimating the number of trips by mode, estimating the direct CO_2 emissions, and estimating indirect CO_2 emissions.

For each study corridor the impacts of different strategies and policies on carbon dioxide emissions were estimated as an illustration of the policy application of the developed methodology. The largest gain in CO_2 savings can be achieved by strategies aiming at automobile emissions, due to its sizeable share as main mode and access/egress mode to and from airports and bus and train stations: an average fuel economy of 35.5 mpg would result in a 38-42% savings of total CO_2 emissions; replacing 25% of gasoline

use with cellulosic ethanol can have a positive impact on CO_2 emissions of about 13.4-14.5%; and a 10% market share for electric vehicles would result in potential CO_2 savings of 3.4-7.8%. The impact of a 20% or 35% improvement in aircraft efficiency on CO_2 savings is much lower (0.88-3.65%) than the potential impacts of the policies targeting automobile emissions. Three HSR options were analyzed using Volpe's long-distance demand model: HSR125, HSR150, and HSR200. Only the HSR150 and HSR200 would result in CO_2 savings, and then just for two of the three corridors: the Pacific Northwest (1.5%) and California (0.6-0.9%). With increased frequency and load factors, a HSR150 system could result in CO_2 savings of 3.3% and 2.1% for the Pacific Northwest and California, respectively. This would require a mode shift from auto of 5-6%. This shift in auto mode share would mainly be a result of pricing strategies. One such pricing strategy, a carbon tax, could have a positive impact on auto diversion towards HSR. However, even a carbon tax of $400/tC, a multiple of 10 compared to today's tax, would not result in a diversion higher than 0.5%. There are no visible CO_2 savings due to this tax. From these results, HSR may not be such an obvious choice, however, with increased ridership and diversions from other modes, CO_2 savings increase significantly due to the lower emissions per passenger mile for HSR. Higher diversion may occur once a HSR rail system is built, as was seen in several other countries. The framework developed in this study has the ability to determine the GHG emissions for such HSR options and increased diversions.

Recommendations and areas for further research to better understand or estimate the CO_2 emission inventories and potential strategy impacts include: improving long-distance demand modeling and data, energy and emissions data, and life-cycle data; analyzing the cost-effectiveness of policies, future scenarios, pricing strategies to divert auto trips to HSR, network effects, other GHGs, and the impact of aircraft emissions at altitude; and including access and egress emissions.

1 INTRODUCTION

Global climate change caused by changes in anthropogenic (i.e. “man-made”) greenhouse gas (GHG) emissions has become a major public policy issue in countries all over the world. With an estimated 28.4% of these emissions attributed to the transportation sector (ORNL, 2008), attention is being focused on ways to reduce transportation GHG emissions by reducing society’s dependence on fossil fuels. In the meantime, the United States is still seeing a growth in daily travel distances, travel frequencies and long distance travel. With respect to long distance travel, estimates indicate that “intercity passenger travel could constitute as much as 25% of total passenger miles of travel by all modes” (Pisarski, 2006).

Strategies for reducing GHG emissions include a range of technologies and actions aimed at changing travel behavior. New vehicle and fuel technologies (e.g. the electric car or biofuels) are likely to be important components of any serious national strategy for reducing emissions over the long term (King, 2008; CEMT, 2006). Shifting travel from low occupant vehicles to higher occupancy vehicles and thus reducing vehicle miles traveled (VMT) is another strategy that has been suggested by many (Davis and Hale, 2007). Others have focused on the potential VMT reduction associated with a transition to more compact urban development (Ewing et al, 2008).

No matter what strategy is adopted, quantifying the change in GHG emissions due to changes in technology or travel behavior is one of the most challenging aspects of integrating GHG emissions and climate change into transportation planning and policy analysis (Schmidt and Meyer, 2009). Although several states and agencies require and have used methods to quantify GHG emissions in their climate plans, the inventory techniques and methods for estimating the impact of different strategies and policies are still relatively unsophisticated (Gallivan, Ang-Olson, and Turchetta, 2009).

1.1 Research Goals and Objectives

This research develops a method for estimating the consumption of intercity passenger transportation energy and the passenger transportation carbon footprint, and applies this method to three corridors in the U.S. The specific research goals are:

1. Assess the current state-of-practice in developing transportation-related carbon emission inventories,
2. Develop a methodology for developing such an inventory that improves the current state-of-practice for intercity passenger transportation,
3. Apply the methodology to three designated high speed rail corridors, and
4. Illustrate the value of the methodology by analyzing a range of commonly discussed CO_2 reduction strategies.

As noted, the methodology will focus on passenger transportation, examining highway, bus transit, air travel and passenger rail travel. The emissions from intercity freight trips are likely to be a significant component of a corridor's carbon footprint, but such travel is not included in this study.

The three corridors selected for application of the methodology are: the San Francisco–Los Angeles–San Diego corridor, the Seattle–Portland–Eugene corridor, and the Philadelphia–Harrisburg–Pittsburg corridor. These corridors are all US DOT-designated high speed rail corridors and were selected in part because high speed rail is believed to become a competitive transportation mode that can reduce carbon emissions.

Estimates made for the year 2008 consist of direct and indirect emissions. Direct emissions include carbon emissions attributable to the liquid and gaseous fuels consumed for highway, bus transit, air, and rail transportation, as well as the carbon emissions associated with the electricity required to operate rail systems within the corridors. Indirect emissions result from the manufacturing process and supply of the vehicles, fuels, and built infrastructures that are required to provide transportation services. A number of recent studies have shown that 'indirect' emissions are a significant percentage of total direct plus indirect vehicle-based emissions, and therefore need to be incorporated into full carbon footprint studies.

In this study the direct and indirect emissions are combined to provide an estimate of the total 'upstream' plus direct CO_2 emissions released in the construction, operation and maintenance of fuels, vehicles, and built infrastructures (roadways, stations, offices, etc) that make passenger travel between metropolitan areas possible. Detailed carbon footprints provide insights into the potential impact of different policies both for individual corridors as well as for federal policies. Questions such as where to apply certain policies (both in terms of mode and geographic area) to gain the largest reductions can be answered using such footprints. In this research three strategies to reduce carbon emissions in the transportation sector will be analyzed: vehicle technologies, fuel technologies, and mode shifts.

1.2 Dissertation Organization

This dissertation is organized in the following manner. Chapter 2 provides a literature review summarizing the current state of knowledge about carbon emissions and climate change, a summary of carbon emissions as they relate to the transportation sector, a discussion of the policy context for GHG emissions, both for the U.S. as well as internationally, and finally a discussion of GHG reduction strategies for the transportation sector. Chapter 3 provides an overview of direct and indirect GHG quantification models and methods as well as a review of the current state of long-distance demand forecasting, as it is needed for quantifying direct emissions from long-distance travel. Chapter 4 presents the methodological framework and the research approach that was used in estimating intercity passenger CO_2 emissions inventories for the three corridors. The impact of different policies and strategies on CO_2 emissions are also presented for each corridor. Finally, Chapter 5 provides conclusions and recommendations, and identifies a number of areas for further research.

2 LITERATURE REVIEW

The literature relating to climate change and greenhouse gas (GHG) emissions is expanding significantly each year as more analysts examine the relationship between the two and the implications for society. Section 2.1 of this chapter summarizes the current state of knowledge concerning carbon emissions and climate change. Section 2.2 summarizes carbon emissions as they relate to the transportation sector. Section 2.3 discusses the policy context for GHG emissions and describes policy efforts in both the U.S. and international. Section 2.4 discusses several GHG emission reduction strategies for the transportation sector, followed by a chapter summary in section 2.5.

2.1 Carbon Emissions and Climate Change

It is not the purpose of this research to describe in detail the relationship between greenhouse gas emissions and climate change. However, it is important as a point of departure to understand some of the basic relationships between greenhouse gas emissions and change in climate. In essence, greenhouse gases freely allow sunlight to enter the Earth's atmosphere. Some of this sunlight is absorbed by the Earth and some is re-radiated back as infrared radiation (heat). Greenhouse gases absorb the infrared radiation trapping heat in the atmosphere, causing increases in the global average temperature (EIA, 2009a).

Greenhouse gases include water vapor, ozone, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Of the GHGs, carbon dioxide is one of the most important anthropogenic contributors to climate change. In 2008, carbon dioxide accounted for almost 83 percent of U.S. greenhouse gas (GHG) emissions (see Figure 2.1). The majority

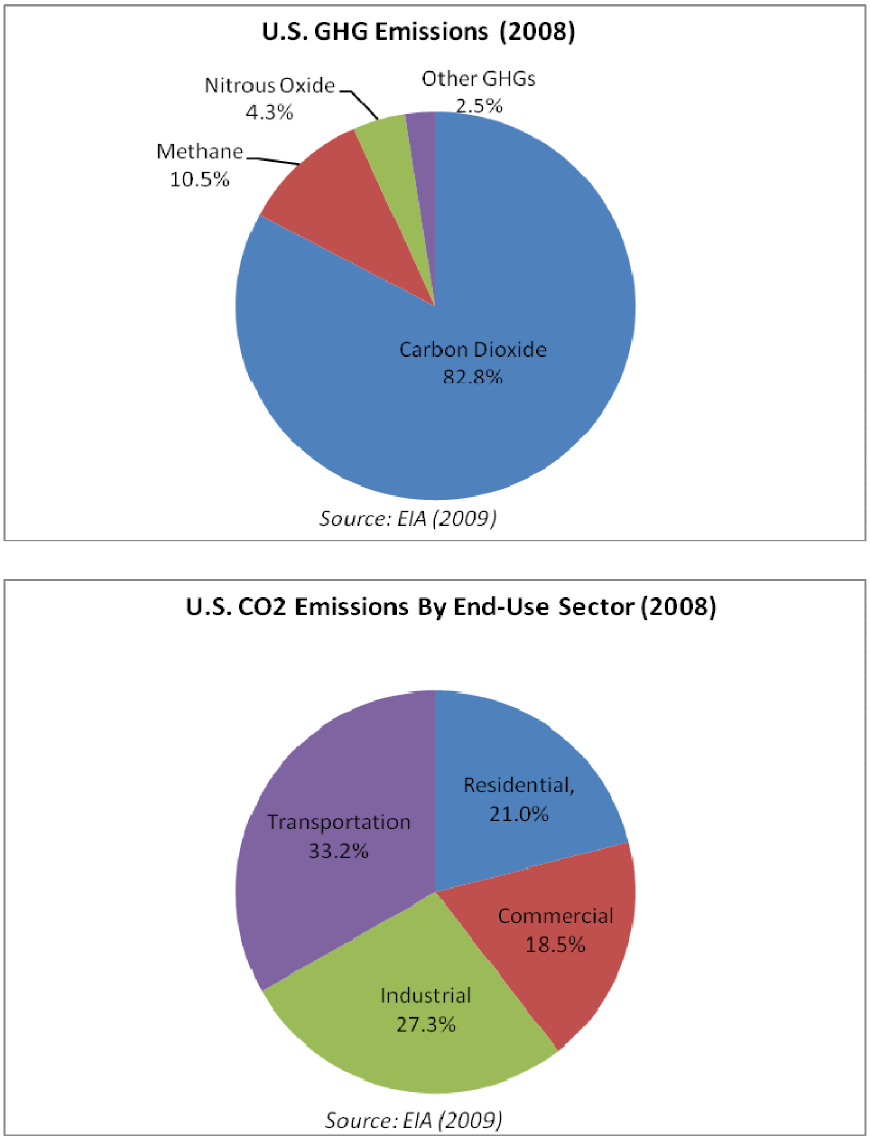

Figure 2.1: U.S. Carbon Dioxide and Greenhouse Gas (GHG) Emissions

of anthropogenic carbon dioxide is emitted when carbon-based fuels, such as coal and oil, are burned for energy for housing, commercial, industrial and transportation needs (Brown, Southworth, and Sarzynski, 2008).

Greenhouse gas emissions have increased over the last decades and are projected to grow even more in the future. According to the Energy Information Administration (EIA), carbon emissions in the United States have increased by almost 1 percent per year from 1980 to 2005 (EIA, 2007a). Emissions from the commercial, residential and transportation sectors increased by more than 25 percent each over this 25-year period (EIA, 2007a). Industrial emissions declined during this period primarily because the United States moved away from energy-intensive manufacturing towards a service and knowledge economy. However, between 2006 and 2030 total U.S. carbon emissions are projected to increase by 16 percent (EIA, 2007b).

Most climate scientists have concluded that climate change represents a serious global risk and that an urgent response is required. According to the latest Assessment Report from the Intergovernmental Panel on Climate Change (IPCC)[1], the average global surface temperature increased 0.74°C [0.56°C to 0.92°C] during the 100 years up to 2005. Its climate model projections indicate that further increases of 1.1 to 6.4°C are likely during the twenty-first century (IPCC, 2007).

Increasing global temperatures present serious challenges–noticeable already–including rising sea levels, extreme weather events, changes to precipitation patterns,

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[1] The IPCC is a scientific intergovernmental body set up by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP). Its task is to provide an objective source of information about the causes of climate change, its potential environmental and socio-economic consequences and the adaptation and mitigation options to respond to it. (Source: http://www.ipcc.ch/)

long droughts, expansion of tropical areas, increasing desertification, changes in agricultural yields, mass species extinction, and changes in disease vectors. The IPCC concludes that “most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations” (IPCC, 2007). Many scientific societies have endorsed the conclusions of the IPCC.

2.2 Transportation Sector Carbon Emissions

As can be seen in Figure 2.1, the transportation sector accounts for one-third of U.S. carbon emissions, or 1925.3 million metric tons of carbon dioxide equivalent[2] in 2008. Residential, commercial buildings and industries account for 26.3 percent and the conversion of primary energy to electricity in the electric power sector is responsible for 40.6 percent (EIA, 2009b). Although this research only focuses on the transportation sector, an effective climate and carbon emissions reduction strategy should include all three sectors.

The transportation sector is not only one of the main sources of carbon emissions, it is also the fastest growing. Between 1990 and 2005 the transportation sector accounted for almost half of the growth in U.S. greenhouse gas emissions. In a business-as-usual scenario, emissions from the transportation sector are expected to continue to grow at the most rapid rate of all sectors between now and 2030 (Gallivan et al, 2008). According to the U.S. Energy Information Administration an increase of almost 40 percent in CO_2

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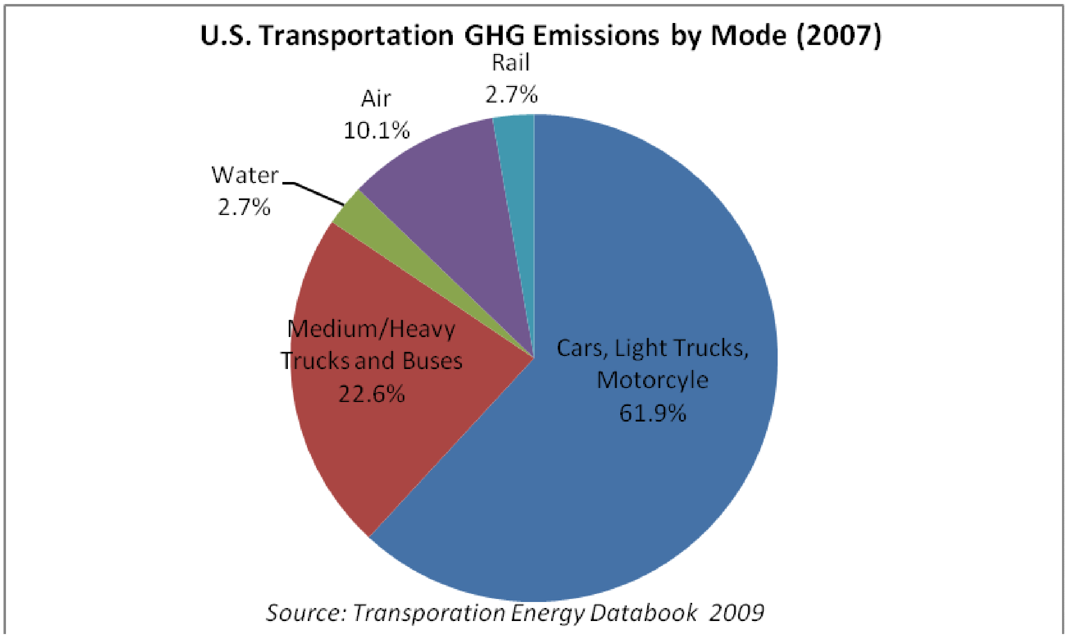
[2] Carbon dioxide equivalent (CO2e) describes the amount of CO_2 that would have the same global warming potential (GWP) as a given type and amount of greenhouse gas. (e.g. 23:1 for converting a gram of methane to a gram of CO2e; 296:1 for converting a gram of nitrous oxide, etc.)

emissions from transportation will be seen over that period (Annual Energy Outlook 2007).

Within the transportation sector, passenger vehicles and light duty trucks are the main source of GHG gas emissions, accounting for roughly 62 percent of the total. Freight, including light duty commercial trucks, account for an additional 20 percent. Figure 2.2 shows the breakdown of transportation emissions for 2007 (based on Transportation Energy Data Book, ORNL, 2009. Table 11-8). The main fuel type consumed in the transportation sector is gasoline, followed by petro-diesel. In 2008, gasoline accounted for 75 percent of vehicle fuel consumption and diesel for 23 percent. Alternative fuels (biodiesel, compressed natural gas, electricity, ethanol, methanol, hydrogen, liquefied natural gas and liquefied petroleum gas) accounted for about 2 percent (EIA, 2009b).

That the transportation sector has seen such rapid increases in GHG emissions is not surprising. Rising wealth and suburbanization following World War II dramatically transformed American driving patterns. The country saw a large increase in daily travel distances and also in the frequency with which households used their vehicles (Brown, Southworth, and Sarzynski, 2008). Between 1970 and 2005, average annual vehicle miles traveled (VMT) per household increased by almost 50 percent – from 16,400 miles to 24,300 miles. Vehicle ownership per household increased from 1.16 to in 1969 to 1.89 in 2001, even though the average household size fell (from 3.14 to 2.57 persons over the same period).



Note: Pipeline not included

Figure 2.2: Share of 2007 U.S. Transportation CO_2 Emissions by Mode

The growth in transportation GHG emissions between 1990 and 2006 was caused by an increase in person and vehicle-miles of travel (VMT) and stagnation of fuel efficiency across the U.S. vehicle fleet. Person-miles traveled by light-duty vehicles increased 39 percent from 1990-2006, ton-miles carried by medium- and heavy-duty trucks increased 58 percent from 1990-2005, and passenger-miles traveled by aircraft increased by 69 percent from 1990-2005. Commercial truck travel increased even more rapidly than passenger travel. The annual growth rate was 3.7 percent for commercial truck travel compared with 2.8 percent for passenger travel. This increased travel has resulted in worsening traffic congestion, higher fuel consumption, and rising carbon emissions (Brown, Southworth, and Sarzynski, 2008).

In addition to increasing wealth, decreasing travel times due to faster transportation have resulted in a significant increase in long distance travel. According to Pisarski (2006), long-distance travel today has reached pre-9/11 levels and growth rates. Estimates indicate that "intercity passenger travel could constitute as much as 25% of total passenger miles of travel by all modes."

Despite several steps taken by governments and agencies, transportation energy use is projected to grow by 0.4 percent annually. This growth could result in an increase of carbon emissions from transportation of 10.3 percent between 2006 and 2030 (EIA, 2008a).

2.3 Policy Context for GHG Emissions Reduction

Concern about greenhouse gases and climate change is not only a recent concern. In 1824, the French physicist Joseph Fourier for the first time described what he called the Earth's "greenhouse effect."[3] It was not until the second half of the 20th century, however, that most scientists were convinced of the seriousness and risks of climate change, and of the role of human activity in exacerbating this effect. In addition, beginning in the 1960s, governments around the world started to take air pollution in general more seriously (due to well publicized air pollution episodes in London and Pittsburgh) and began to establish a legislative and regulatory framework for reducing pollutant emissions from transportation sources. This section reviews international and U.S policies and governmental efforts to reduce GHG emissions. It is important for the U.S. context, however, to place GHG emission reduction efforts in a longer timeline of

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[3] See: http://www.manhattanrarebooks-science.com/fourier.htm

efforts to reduce air pollutants overall. Table 2.1 gives an overview of some of the most significant efforts.

Table 2.1: Major Policy Efforts to Reduce Air Pollutant and GHG Emissions

Year	Action
1955	The Air Pollution Control Act of 1955 is implemented in the U.S.
1963	The Clean Air Act of 1963 passes U.S. Congress
1965	Motor Vehicle Air Pollution Control Act is enacted
1967	The Air Quality Act is enacted
1967	California establishes a clean air agency: the California Air Resources Board (CARB)
1969	Amendments are made to the Clean Air Act to extend authorization for research on fuel efficient and alternative cars and low emissions fuels
1969	U.S. Congress enacts the National Environmental Policy Act (NEPA)
1970	NEPA is signed into law
1970	The Clean Air Act of 1970 passes U.S. Congress
1970	Establishment of the United States Environmental Protection Agency (EPA)
1975	U.S. Congress enacts the Corporate Average Fuel Economy (CAFE)
1977	New amendments to the Clean Air Act of 1970 pass to set realistic goals
1979	First World Climate Conference held in Geneva in February
1979	Establishment of the World Climate Programme
1980	Establishment of the World Climate Research Programme
1988	The United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) form the Intergovernmental Panel on Climate Change (IPCC)
1990	California enacts the Zero Emissions Vehicle (ZEV) Program
1990	The Clean Air Act of 1990 passes U.S. Congress, proposing emissions trading among other things
1990	IPCC publishes its First Assessment Report concluding that surface temperatures have risen 0.3-0.6C over the past century
1990	Second World Climate Conference held in Geneva in October/November
1992	Adoption of the United Nations Framework Convention on Climate Change (UNFCCC)
1993	President Clinton proposes a BTU tax, but it does not pass U.S. Congress
1994	The Climate Change Convention enters into force on March 21

Table 2.1 (continued)

1995	IPCC publishes its Second Assessment Report concluding that evidence suggests "a discernible human influence" on the Earth's climate
1995	The Acid Rain Program (ARP) incepts in response to the Clean Air Act's goal of reducing annual SO_2 emissions by 10 million tons below 1980 levels
1995	Establishment of the Conference of the Parties (COP) the Convention's ultimate authority
1997	COP 3 takes place in Kyoto, Japan in December resulting into the Kyoto Protocol
2005	European Union Emission Trading Scheme Phase 1 starts on January 1
2005	Kyoto Protocol enters into force
2001	IPCC's publishes its Third Assessment Report concluding that newer and stronger evidence indicates that most of the warming observed is attributable to human activities
2001	The United States rejects the Kyoto Protocol
2003	Beginning of the The NOx Budget Trading Program
2007	The Energy Independence and Security Act of 2007 passes U.S. Congress and is signed into law
2007	CAFE standards receive a major overhaul
2007	ARB and the California Energy Commission's Public Interest Energy Research (PIER) Program fund and launch the Plug-in Hybrid Electric Vehicle (PHEV) Center in the University of California
2007	California enacts a low-carbon fuel standard (LCFS) mandate
2007	IPCC publishes its Fourth Assessment Report, bringing new momentum to the climate change debates. The report concludes that the observed increase of global temperatures is "very likely due to the observed increase in anthropogenic greenhouse gas concentrations"
2008	British Columbia and the European Union enact a low-carbon fuel standard (LCFS) mandate
2008	European Union Emission Trading Scheme Phase 2 starts on January 1
2009	Third World Climate Conference held in Geneva in August/September
2009	COP 15 takes place in Copenhagen, Denmark in December. The Copenhagen Accord was not adopted
2009	U.S. President Obama proposes a new national program to regulate fuel economy and greenhouse gas emissions from vehicles
2009	The American Clean Energy and Security Act of 2009 (ACESA), which proposes a carbon emission trading program for the U.S. is passed by the U. S. House of Representatives
2009	China becomes the world's biggest greenhouse gas emitter pushing the U.S. to second place. The US remains ahead on a per-capita basis

2.3.1 International Efforts to Reduce GHG Emissions

The first major international meeting on climate change, the First World Climate Conference, was held in Geneva in February 1979. The conference was attended by scientists from different disciplines and led to the establishment of the World Climate Programme (1979) and the World Climate Research Programme (1980).[4] However, international efforts to more fully understand climate change and how to reduce GHG emissions became organized in the late 80s and early 90s when a number of intergovernmental conferences on climate change were held around the world (UNFCCC, 2000).

In 1988, the United Nations Environment Programme (UNEP) formed the Intergovernmental Panel on Climate Change (IPCC) together with the World Meteorological Organization (WMO). The task of the IPCC was to give policy makers and the public a better understanding of climate change by assessing 1) the state of existing knowledge, 2) the impacts of climate change on the environment, the economy and society, and 3) potential response strategies. The IPCC published its first report, peer reviewed by leading scientists and experts, in 1990. This report concluded that human GHG emissions are likely causing rapid climate change and global warming, which could have powerful effects on the global environment, ecosystems and society. The report also stated that major international efforts were required to stabilize atmospheric concentrations of greenhouse gases, especially with growing populations and expanding

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[4] See: http://unfccc.int/

economies. The report had an important influence on many policy makers worldwide and greatly influenced the United Nations Framework Convention on Climate Change (UNFCCC), which was adopted in 1992 at the Earth Summit in Rio de Janeiro after the Second World Climate Conference had called for treaty negotiations for climate change in 1990 (UN, 1997). The objective of the UNFCCC was to achieve "stabilization of greenhouse gas concentrations in the atmosphere at a level that would minimize dangerous anthropogenic interference with the climate system."[5] The Climate Change Convention was the result of treaty negotiations by the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change (INC/FCCC), consisting of negotiators from 150 countries. The Committee met for five sessions to finalize the Convention that was adopted and opened for signature in Rio de Janeiro---154 nations signed the UNFCCC.[6]

The 1992 Climate Change Convention did not specify any international emissions reduction targets nor did it set mandatory limits on GHG emissions for countries. It only established "a process for responding to climate change over the decades to come." In particular, it set up a system whereby governments report information on their national greenhouse gas emissions and climate change strategies. This information is reviewed on a regular basis in order to track the Convention's progress. In addition, developed countries agreed to promote the transfer of funding and technology to help developing countries respond to climate change. They were also committed to taking measures aimed at returning their greenhouse gas emissions to 1990 levels by the year 2000." (UN, 1997)

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[5] See: http://unfccc.int/essential_background/convention/background/items/1353.php
[6] See: http://unfccc.int/

The Convention provisions became operational on March 21, 1994 and in 1995 the Conference of the Parties (COP) was established as the Convention's ultimate authority.

The COP has held a series of sessions, including Kyoto in 1997 and Copenhagen in 2009 (see Table 2.2). As of December 2009, UNFCCC had 192 signatory parties. It is important for the context of this research that Kyoto and Copenhagen, be examined in more detail.

Table 2.2: UNFCCC Conference of the Parties and Meeting of the Parties Sessions (Source: UNFCCC)

Year	**Conference of the Parties (COP)/Meeting of the Parties (MOP)**	**City and Country**
1995	COP1	Berlin, Germany
1996	COP2	Geneva, Switzerland
1997	COP3	Kyoto, Japan
1998	COP4	Buenos Aires, Argentina
1999	COP5	Bonn, Germany
2000	COP6	The Hague, Netherlands
2001	COP6	Bonn, Germany
2001	COP7	Marrakech, Morocco
2002	COP8	New Delhi, India
2003	COP9	Milan, Italy
2004	COP10	Buenos Aires, Argetina
2005	COP11/MOP1	Montreal Canada
2006	COP12/MOP2	Nairobi, Kenya
2007	COP13/MOP3	Bali, Indonesia
2008	COP14/MOP4	Poznan, Poland
2009	COP15/MOP5	Copenhagen, Denmark

2.3.1.1 The Kyoto Protocol

COP 3 took place in Kyoto, Japan in December 1997. After intensive negotiations, COP3 adopted the Kyoto Protocol, which established legally binding requirements for developed countries (Annex 1 countries) to reduce GHG emissions. These industrialized countries (and some others) agreed to reduce their collective GHG emissions by 5.2% from 1990 levels between the years 2008-2012 (UNFCCC, 1997a). The actual reductions will have to be much larger than 5%, even up to 20% for developed countries, since current emission levels for most developed countries are much higher than the 1990 levels.[7] As of the end of 2009, 187 nations have signed and ratified the protocol (UNFCCC, 2009d). Each participating country is required to submit annual GHG inventories under UNFCCC and the Kyoto Protocol.

The Protocol gives countries a certain degree of flexibility in how they achieve their emissions reductions by allowing mechanisms like emissions trading, clean development mechanisms, and joint implementation. These mechanisms give Annex 1 countries (developed countries) the option to purchase GHG emission credits from other countries through financial trade, financing projects that reduce emissions in developing (non-Annex I) countries, or from developed countries with excess allowances (UNFCCC, 1997b). These flexible mechanisms give non-Annex I countries that have no GHG restrictions financial incentives to develop projects that reduce emissions to receive and sell carbon credits. In addition, it gives Annex I countries the option to purchase carbon credits instead of reducing emissions domestically. Carbon emissions trading will be discussed in a later section.

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[7] See: http://ec.europa.eu/environment/climat/kyoto.htm

The United States agreed to reduce its total emissions by 7 percent from 1990 levels during the period 2008 to 2012.[8] However, before the Kyoto Protocol was finalized, the U.S. Senate passed the Byrd Hagel Resolutions, which stated (Byrd and Hagel, 1997):

> "(1) the United States should not be a signatory to any protocol to, or other agreement regarding, the United Nations Framework Convention on Climate Change of 1992, at negotiations in Kyoto in December 1997, or thereafter, which would—
>
> (A) mandate new commitments to limit or reduce greenhouse gas emissions for the Annex I Parties, unless the protocol or other agreement also mandates new specific scheduled commitments to limit or reduce greenhouse gas emissions for Developing Country Parties within the same compliance period, or
>
> (B) would result in serious harm to the economy of the United States"

Even though the Clinton Administration symbolically signed the Protocol, the Protocol would not be ratified by the Senate until there was participation by developing nations (CNN, 1997). President Bush did not submit the Protocol to the Senate, and explicitly rejected it, mainly because of economic reasons, the uncertainties he believed were existing in scientific evidence, and the exemption of developing countries, especially China and India (The White House, 2001).

2.3.1.2 <u>The Road To Copenhagen</u>

The Kyoto Protocol left several issues unresolved that were to be discussed at COP6 in the Hague, Netherlands in 2000. COP6 was suspended without agreement mainly due

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[8] See: http://unfccc.int/kyoto_protocol/items/3145.php

to disputes regarding the flexibility of the agreement, the consequences for countries that would not meet their requirements and the role of developing countries (Shah, 2001). COP6 continued a few months later in Bonn, Germany after President George W. Bush had rejected the Protocol. As a result, the U.S. did not participate in the Protocol negotiations. The supporters of the Protocol reached agreement on most of the major political issues including flexible mechanisms, carbon sinks, compliance failure, and financing.[9] COP7 was held in Marrakech, Morocco in 2001 to establish the final details of the Protocol. The Protocol entered into force early 2005 and the first Meeting of the Parties to the Kyoto Protocol (MOP1) was held in Montreal in late 2005, along with COP11.

In 2007, the IPCC published its Fourth Assessment Report, which gave a clear signal that climate change represented a serious global risk. The IPCC concluded that "most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations" (IPCC, 2007). The IPPC report brought new momentum to the UN climate change negotiations and at COP13 in Bali in 2007 all Parties to the UNFCCC (Annex 1 and non-Annex) agreed to step up their efforts to fight climate change. A number of decisions were adopted resulting in the Bali Road Map. In addition, the Parties decided to start negotiations for long-term cooperative action. These negotiations were scheduled to be concluded at COP15 in Copenhagen in 2009 and were to enter into force in 2012 when the Kyoto Protocol commitment period expires (UNFCCC, 2009a).

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[9] See: http://risingtide.org.uk/resources/factsheets/bonn

2.3.1.3 Copenhagen

COP15 had as a major goal establishing a global climate agreement for 2012 and after. However, the ministers and officials from 192 countries participating in the meeting did not succeed in establishing a binding agreement for the post-Kyoto time period.[10] The Copenhagen Accord was drawn up acknowledging that "adaptation to the adverse effects of climate change and the potential impacts of response measures is a challenge faced by all countries" and requiring "enhanced action and international cooperation on adaptation", including both developed and developing countries. The Accord also called for "the collective commitment by developed countries to provide new and additional resources, including forestry and investments through international institutions, approaching USD 30 billion for the period 2010-2012 with balanced allocation between adaptation and mitigation." (UNFCCC, 2009b) However, the Accord was not adopted; the final decision read that the conference of the parties only "takes note of the Copenhagen Accord of 18 December 2009." (UNFCCC, 2009b) As a result the document is not legally binding and further negotiations are needed. The next COP (COP16) has been scheduled in Mexico for late 2010. (UNFCCC, 2009c)

2.3.2 GHG Emissions Policies in the United States

Regulations targeting emissions and air pollution in some form or another have been around for over a hundred years in the United States, tracing back to the Industrial Revolution. Pittsburgh in 1815 and Chicago and Cincinnati in 1881 were the first to

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[10] See: http://unfccc.int/2860.php

implement clean air legislation.[11] Many other cities and regions slowly followed. Most of these regulations focused on pollutant emissions from stationary sources. During the 1940s, smog incidents in Los Angeles and Pennsylvania increased public awareness and concern, but it was not until 1955 that the federal government implemented regulations to deal with this problem at a national level (AMS, 1999). The purpose of the Air Pollution Control Act of 1955 was mainly to make the nation and public officials aware of the environmental hazard related to air pollution. The act did not do much to prevent air pollution, but provided “research and technical assistance”(AMS, 1999). The Air Pollution Control Act of 1955 was the start of a series of clean air and air quality acts that to this day direct public actions on reducing pollutant emissions.

Greenhouse gas emissions were not part of these regulatory initiatives. Until recently, such emissions have been largely ignored as part of U.S. clean air policy. Perhaps the closest that clean air legislation came to affecting GHG emissions was the 1963 Clean Air Act, known as the Motor Vehicle Air Pollution Control Act. These amendments of the original Clean Air Act established standards for automobile emissions (AMS, 1999). In 1969, amendments to the 1967 Air Quality Act extended authorization for research on fuel efficient and alternative cars and low emissions fuels.[12]

The 1970 amendments to the Clean Air Act resulted in a totally rewritten version of the original, leading to the Clean Air Act of 1970. Several emission standards were set, including a standard for motor vehicle emissions limiting CO emissions to 90% from 1970 emissions, to be effective by the 1975 models. In 1990, after a decade of hardly any action regarding the Clean Air Act, the U.S. Congress amended the act again to try to

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[11] See: http://legal-dictionary.thefreedictionary.com/Clean+air

[12] See: http://www.epa.gov/apti/course422/apc1.html

solve air pollution problems. The federal government increased automobile emissions standards and tightened control by setting definite deadlines. This regulation encouraged the use of low-sulfur and alternative fuels, set Reid Vapor Pressure (RVP) standards in order to control evaporative emissions from fuels and required the installment of Best Available Control Technology (BACT) in vehicles to reduce air toxics (AMS, 1999). The 1990 amendments to the Clean Air Act also proposed emissions trading, known as cap-and-trade. Emissions trading policies will be discussed later in more detail.

More recently, several acts and policies have been proposed, including the Clear Skies Act of 2003 and America's Climate Security Act of 2007, both focusing on air pollution and greenhouse gas emissions reduction through cap and trade programs. Neither bill passed Congress. The Energy Independence and Security Act was signed into law on December 19, 2007. The purpose of the act was “to move the United States toward greater energy independence and security, to increase the production of clean renewable fuels, to protect consumers, to increase the efficiency of products, buildings, and vehicles, to promote research on and deploy greenhouse gas capture and storage options, and to improve the energy performance of the Federal Government, and for other purposes” (Rahall, 2007). Although this act did not directly target emissions reductions, it certainly can have an indirect effect.

2.3.2.1 Corporate Average Fuel Economy (CAFE)

One of the most important federal policies affecting GHG emissions is found in the corporate average fuel economy (CAFE) standards. In 1975, two years after the 1973 Arab Oil Embargo, Congress enacted CAFE standards targeting the improvement of the fuel economy of automobiles and light trucks.[13] Ever since its introduction, CAFE has been actively debated and opposed.[14]

Even though CAFE was enacted in 1975, fuel economy standards were first introduced in 1978. The first year standards were for passenger vehicles only and were set at 18 mpg. In 1979, a second category was established for light trucks (initially trucks with a gross vehicle weight rating (GVWR) of less than 6000 pounds, but raised to 8500 pounds in 1980). In 2007, CAFE standards received a major overhaul, the first one in over 30 years. The Energy Independence and Security Act of 2007, signed by President Bush, set a national goal for fuel economy standards of 35 mpg by 2020. This standard applied to all passenger vehicles, including light trucks, and was set above the previously defined targets for CAFE standards.

On March 23, 2009 the National Highway Traffic Safety Administration (NHTSA) implemented a credit trading and transferring scheme, allowing manufacturers to trade credits with other manufacturers or transfer credits between categories. This scheme was believed to mainly benefit foreign auto manufacturers that could import smaller cars in order to offset the less efficient vehicles manufactured domestically.

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[13] See: http://www.nhtsa.dot.gov/portal/fueleconomy.jsp

[14] Recent studies and surveys have shown that fuel economy has become one of the most important factors in consumers' vehicle choice, especially after the fuel price increases from the last few years. In 2007 a survey for the Pew Campaign For Fuel Efficiency found that "Nearly nine-in-ten voters (89%) say that passing a bill to "require the auto industry to increase fuel efficiency…" is an important accomplishment compared to only 11% who said it was not an important accomplishment. In fact, a strong majority (61%) say enacting higher standards would be a *very* important accomplishment" (The Mellman Group, Inc., 2007). That year the Toyota Prius with a fuel efficiency of 55 mpg outsold the top-selling SUV, the Ford Explorer with a fuel efficiency of 17 mpg. Auto manufacturers are now focusing more and more on fuel efficiency and on new technologies like E-85 (ethanol), hybrid-electric and all-electric vehicles.

On May 19, 2009 President Obama proposed a new national program to regulate fuel economy and greenhouse gas emissions, increasing the goal of 35 mpg by 2020 to an average of 35.5 mpg by 2016 (39 mpg for cars and 30 mpg for trucks). A White House Press Release from May 19, 2009 announcing Obama's National Fuel Efficiency Policy stated that "the new rules will not dictate the size of cars, trucks and SUVs that manufacturers can produce; rather it will require that all sizes of vehicles become more energy efficient… [The] new policy will produce environmental benefits that will reduce air pollution from the reduction of greenhouse gas emissions and other conventional pollutants." (The White House, 2009) The new CAFE standards were officially adopted on April 1, 2010.

Despite the different programs and policies, the new national goals for the U.S. are still weak compared to many other developed nations and to industrializing nations such as China. For example, the fleet average for the European Union was 44 mpg in 2008 and 48 mpg for Japan. China's average fuel economy was 37 mpg in 2008 (An and Sauer, 2004).

2.3.2.2 Council of Environmental Quality and NEPA

Congress enacted the National Environmental Policy Act (NEPA) in December, 1969. NEPA was the first major environmental law in the United States and established the future directions for national environmental policies. A major goal of NEPA is better informed decisions and citizen involvement in order to promote the improvement of the environment. Agencies are required to undertake an assessment of the environmental impacts and effects of their proposed actions prior to making decisions. NEPA's requirements apply to all agencies in the executive branch of the federal government. (CEQ, 2007)

Up to 2010, agencies were not required to consider GHG emissions nor climate change factors when conducting environmental assessments. However, on February 18, 2010 the Council on Environmental Quality issued proposed guidance on the consideration of GHG emissions in such assessments that potentially could have a significant impact on how such assessments are undertaken. This proposed guidance had the following major elements (CEQ, 2010):

- If a proposed action would be reasonably anticipated to cause direct emissions of 25,000 metric tons or more of CO_2-equivalent GHG emissions on an annual basis[15], agencies should consider this an indicator that a quantitative and qualitative assessment may be meaningful to decision makers and the public.
- In the agency's analysis of direct effects, it would be appropriate to: (1) quantify cumulative emissions over the life of the project; (2) discuss measures to reduce GHG emissions, including consideration of reasonable alternatives; and (3) qualitatively discuss the link between such GHG emissions and climate change.
- Agencies should consider quantifying those emissions using the following technical documents:
  - For quantification of emissions from large direct emitters: 40 CFR Parts 86, 87, 89, et al. Mandatory Reporting of Greenhouse Gases; Final Rule, U.S. Environmental Protection Agency (74 Fed. Reg. 56259-56308).
  - For quantification of Scope 1 emissions at Federal facilities: Greenhouse gas emissions accounting and reporting guidance that will be issued under Executive Order 13514 Sections 5(a) and 9(b) (http://www.ofee.gov)
  - For quantification of emissions and removals from terrestrial carbon sequestration and various other project types: Technical Guidelines, Voluntary Reporting of Greenhouse Gases, (1605(b) Program, U.S. Department of Energy (http://www.eia.doe.gov/oiaf/1605/))

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[15] CEQ does not propose this reference point as an indicator of a level of GHG emissions that may significantly affect the quality of the human environment, as that term is used by NEPA, but notes that it serves as a minimum standard for reporting emissions under the Clean Air Act.

- For proposed actions that are not adequately addressed in the GHG emission reporting protocols listed above, agencies should use NEPA’s provisions for inter-agency consultation with available expertise to identify and follow the best available procedures for evaluating comparable activities.
- Analysis of emissions sources should take account of all phases and elements of the proposed action over its expected life, subject to reasonable limits based on feasibility and practicality.
- Within this description of energy requirements and conservation opportunities, agencies should evaluate GHG emissions associated with energy use and mitigation opportunities and use this as a point of comparison between reasonable alternatives.
- This would most appropriately focus on an assessment of annual and cumulative emissions of the proposed action and the difference in emissions associated with alternative actions.
- An agency may decide that it would be useful to describe GHG emissions in aggregate, as part of a programmatic analysis of agency activities that can be incorporated by reference into subsequent NEPA analyses for individual agency actions. In addition, Federal programs that affect emissions or sinks and proposals regarding long range energy, transportation, and resource management programs lend themselves to a programmatic approach.
- Among the alternatives that may be considered for their ability to reduce or mitigate GHG emissions are enhanced energy efficiency, lower GHG-emitting technology, renewable energy, planning for carbon capture and sequestration, and capturing or beneficially using fugitive methane emissions. In some cases, such activities are part of the purpose and need for the proposed action and the analysis will provide an assessment, in a comparative manner, of the alternatives and their relative ability to advance those objectives.

2.3.2.3 State and Regional GHG Initiatives in the U.S.

Several states or regions within the U.S. have, independently from the federal government, initiated and implemented their own strategies or regulations to improve air quality and/or reduce greenhouse gas emissions. California, known for its more aggressive environmental regulations, established its own clean air agency in 1967, the California Air Resources Board (CARB), a department within the California

Environmental Protection Agency (Cal/EPA). California was the only state that had an established Environmental Protection Agency before the Clean Air Act passed Congress. Once the Clean Air Act passed, other states were required to either follow federal standards or the CARB standards, but were not allowed to set their own standards like California.[16] The main mission of ARB is to "promote and protect public health, welfare and ecological resources through the effective and efficient reduction of air pollutants while recognizing and considering the effects on the economy of the state."[17]

California has taken several legislative steps towards reducing greenhouse gas emissions through programs focusing on clean cars, clean fuels, renewable energy and caps on polluting industries. In the transportation sector such regulations and programs include the Alternative Fuel Vehicle Incentive Program, the Zero Emissions Vehicle (ZEV) Program, and Low-Carbon Fuel Standards.

The Alternative Fuel Vehicle Incentive Program (AFVIP), also known as Fueling Alternatives, is funded by ARB. The program provides rebates to Californians who purchase eligible alternative fuel vehicles in order to promote use and production of such vehicles. The rebate program, which was allocated a total of approximately $1.8 million, is administered by the California Center for Sustainable Energy (CCSE). Qualifying vehicle types include all-electric vehicles, plug-in hybrid electric vehicles, hydrogen fuel cell vehicles, and alternative fuel vehicles (e.g. Compressed Natural Gas (CNG) vehicles) (ARB, 2008).

To promote the mass commercialization and the use of zero emission vehicles, California enacted the ZEV Program in 1990. The program and the regulations have been

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[16] See: http://www.arb.ca.gov/

[17] Idem

modified several times over the years and according to ARB it "has spurred many new technologies that are being driven on California's roads."[18] Since its introduction several sub-categories within The ZEV Program were created (ARB, 2004):

- LEV (Low Emission Vehicle): The least stringent emission standard for all new cars sold in California beyond 2004.
- ULEV (Ultra Low Emission Vehicle): 50% cleaner than the average new 2003 model year vehicle.
- SULEV (Super Ultra Low Emission Vehicle): 90% cleaner than the average new 2003 model year vehicle.
- PZEV (Partial Zero Emission Vehicle): Meets SULEV tailpipe standards, has a 15-year / 150,000 mile warranty, and zero evaporative emissions.
- AT PZEV (Advanced Technology PZEV): Meets PZEV standards and includes ZEV enabling technology.
- ZEV (Zero Emission Vehicle): Zero tailpipe emissions, and 98% cleaner than the average new 2003 model year vehicle.

In 2007, ARB and the California Energy Commission's Public Interest Energy Research (PIER) Program funded and launched the Plug-in Hybrid Electric Vehicle (PHEV) Center in the University of California, Davis to provide "technology and policy guidance to the state, and to help solve research questions and address commercialization issues for PHEVs."[19] In 2010, state standards are to be strengthened to ensure that automakers will make sufficient investments in clean vehicle technologies that will help to electrify the transportation system.

In 2007, California was the first in the world to enact a low-carbon fuel standard (LCFS) mandate. British Columbia and the European Union followed with similar

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[18] See: http://www.arb.ca.gov/msprog/zevprog/background/background.htm

[19] See: http://phev.its.ucdavis.edu/

legislation in 2008.[20] Several bills have been proposed at the federal level in the U.S. to establish a national low-carbon fuel standard based on California's LCFS model, but as of late 2010 none have been approved.

California's Low Carbon Fuel Standard (LCFS) was designed to "provide a durable framework that uses market mechanisms to spur the steady introduction of lower carbon fuels. The framework establishes performance standards that fuel producers and importers must meet each year beginning in 2011" (ARB, 2009). The LCFS should result in a reduction of at least 10 percent in the carbon intensity of California's transportation fuels by 2020, a reduction needed to achieve the state's mandate of reducing GHG emissions to 1990 levels. In addition to GHG emissions reduction, "the LCFS is designed to reduce California's dependence on petroleum, create a lasting market for clean transportation technology, and stimulate the production and use of alternative, low-carbon fuels in California." (ARB, 2009)

On April 23, 2009, ARB approved the specific rules for the LCFS that will go into effect in January 2011. The regulation takes effect incrementally, but increases significantly beginning in 2015 (Buchanan, 2009).

In the northeastern United States, the Regional Greenhouse Gas Initiative (RGGI)[21] has been formed consisting of states and provinces wanting to reduce greenhouse gas emissions.[22] The RGGI is designing a carbon cap and trade program for power plants.

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[20] See: http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+20081217+ITEMS+DOC+XML+V0//EN&language=EN#sdocta5 and http://www2.canada.com/vancouversun/news/business/story.html?id=23e7f256-4ebc-4468-974a-c4219d78b13b&p=1

[21] See: http://www.rggi.org/home

The Western Climate Initiative (WCI)[23] is an initiative by states and provinces in the west and in Canada to "identify, evaluate, and implement policies to tackle climate change at a regional level", independent of their national governments.[24] WCI is working on laying a foundation for an international cap and trade program involving the United States and Canada. The initiative requires partners to set regional emission reduction goals and to develop a market-based strategy to achieve that goal. This multi-sector program is said to be "the most comprehensive carbon-reduction strategy designed to date" and will include transportation when fully implemented.[25]

The Midwestern Greenhouse Gas Reduction Accord (MGGRA) is a regional agreement to reduce greenhouse gas emissions 18-20 percent below 2005 levels by 2020 and 80 percent by 2050 though a recommended cap-and-trade program.[26] The program will be multi-sector, including transportation fuels, and only entities that emit more than 25,000MTCO$_2$e on an annual basis will be capped. The MGGRA was signed on June 8, 2009, but has yet to be implemented (EIA, 2009b).

2.4 GHG Reduction Strategies for the Transportation Sector

Two primary categories of strategies have been identified for transportation-related efforts to reduce GHG emissions, those relying on market influences to change travel behavior and those directly attempting to reduce the amount of vehicle miles traveled

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[22] The participating states and provinces are Maine, New Hampshire, Vermont, Connecticut, New York, New Jersey, Delaware, Massachusetts, Maryland, Rhode Island, Prince Edward Island, Newfoundland and Labrador.

[23] See: http://www.westernclimateinitiative.org/

[24] The participating states and provinces are California, Montana, New Mexico, Oregon, Utah, Washington, British Columbia, Manitoba, Ontario, and Quebec.

[25] See: http://www.westernclimateinitiative.org/the-wci-cap-and-trade-program

[26] The participating states are Iowa, Illinois, Kansas, Michigan, Minnesota, and Wisconsin, as well as the Canadian province of Manitoba.

(VMT), energy consumed, and CO_2 emitted. In both cases, estimating the expected reduction in GHG emissions requires one to have a means of inventorying existing emissions.

2.4.1 Market-Based Emission Reduction Strategies

As has been discussed in previous sections, market-based instruments (MBIs), such as emission trading (cap-and-trade programs), and pollution charges (carbon tax), are gaining momentum as important policy mechanisms for greenhouse gas emissions reductions, both internationally as well as within the United States. However, their application on a national or international scale has been limited. MBIs are broadly defined as “regulations that encourage behavior through market signals rather than through explicit directives regarding pollution control levels or methods.” (Stavins, 1998) Examples of MBIs targeting emission control are tradable permits and pollution charges. These instruments, if designed well, make use of market forces as opposed to conventional command-and-control approaches: “they encourage firms (and/or individuals) to undertake pollution control efforts that both are in those firms' (or individuals') interests and that collectively meet policy goals.” (Stavins, 1998) Such instruments provide flexibility in terms of how policy goals are being achieved.

According to Stavins (1998), the two biggest advantages that market-based instruments have over traditional command-and-control approaches are:

1) Cost effectiveness: “Rather than equalizing pollution levels among firms (as with uniform emission standards), market-based instruments equalize the incremental amount that firms spend to reduce pollution (their marginal cost)”, and
2) Dynamic incentives for technology innovation and diffusion: “with market-based instruments, it always pays firms to clean up a bit more if a sufficiently low-cost method (technology or process) of doing so can be identified and adopted.”

The next sections will discuss two types of MBI: carbon emission trading and carbon taxes. Examples of an application of such strategies will be presented.

A carbon tax is a price-based instrument charging a fee for the amount of pollution emitted by a source. This type of tax is called a Pigovian tax, charged on a non-market activity that generates negative externalities. This tax gives the emitter an incentive to reduce emissions until the cost to reduce more emissions is equal to the tax rate (Stavins, 1998). The challenge with such tax systems is identifying an effective tax rate. Ideally, it should be equal to the social cost of the emissions: the marginal cost of emitting one extra ton at any point in time. However, the response from the entities subject to the tax needs to be considered (Stavins, 1998). According to the report 'Policy Options for Reducing CO_2 Emissions' from the Congressional Budget Office (CBO)' a carbon tax will "place an upper limit on the cost of reducing emissions, but the total amount of CO_2 that would be emitted in any given year would be uncertain"(CBO, 2009). The 2007 IPCC report presents peer-reviewed estimates of the average social cost of carbon emissions of $43/tC for 2005 with a standard deviation of $83/tC. This wide range is mostly explained by uncertainties in climate change science, different valuations of impacts, and discount rates (IPCC, 2007).

Under an Emission Trading Scheme (cap-and-trade system), companies are issued emission allowances, which gives them the right to emit a certain amount of a pollutant. The total amount of allowances issued cannot exceed a certain level of emissions (a cap), thus placing an upper limit on the total emissions. Under a cap-and-trade system, companies that emit more greenhouse gases than allowed can do two things. First, they can decrease their emissions by changing their production process, implement different technologies, or produce less. Second, they can buy allowances from companies that emit less than they are allowed to. This process is shown in Figure 2.3. Theoretically those companies that can reduce emissions most cost-effectively will do so, resulting in emission reduction at the lowest cost to society. Unlike a fixed tax rate, the cost of the emissions reduction will fluctuate based on energy markets, demand, weather, and technologies available (Stavins, 1998; CBO, 2009).

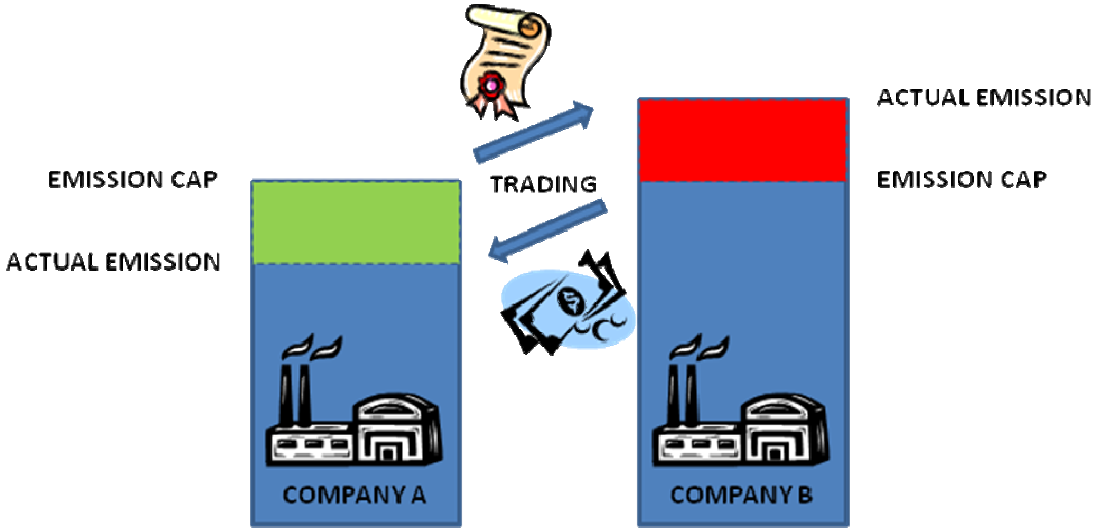

Figure 2.3: Carbon Emission Trading (adopted from www.ecofys.nl)

Stavins (1998) states that even though pollution taxes and tradable permits appear to be symmetric in theory and are both targeting emission reduction by giving emitters incentives, there are significant differences in actual implementation:

- Permits fix the level of pollution control while charges fix the costs of pollution control.
- In the presence of technological change and without additional government intervention, permits freeze the level of pollution control while charges increase it.

- With permit systems as typically adopted, resource transfers are private-to-private, while they are private-to-public with ordinary pollution charges.
- While both charges and permits increase costs on industry and consumers, charge systems tend to make those costs more obvious to both groups.
- Permits adjust automatically for inflation, while some types of charges do not.
- Permit systems may be more susceptible to strategic behavior
- Significant transaction costs can drive up the total costs of compliance, having a negative effect under either system, but particularly with tradable permits
- In the presence of uncertainty, either permits or charges can be more efficient, depending upon the relative slopes of the marginal benefit and marginal cost functions and any correlation between them

The CBO study (CBO, 2009) compares different policy designs including a carbon tax and a cap-and-trade program. One of their main concerns is the before mentioned uncertainty regarding the cost (and the potential variability of the cost) of emissions reductions regarding the cap-and-trade strategy.

Europe has shown most progress in implementing carbon taxes and greenhouse gas trading schemes. In the 1990s a carbon/energy tax was proposed EU wide, but did not pass due to opposing industries (OECD, 2005). This did not stop individual countries from gradually implementing carbon tax structures. In 1990, Finland was the first country to implement a carbon tax; Sweden, Denmark and Norway followed soon thereafter. A few years later the Netherlands (1996) and Slovenia (1997) followed. At the end of the decade Germany (1998) and the U.K. (2000), two of the largest European economies, had implemented carbon taxes as well, resulting in an annual tax bill of 25 billion Euros (Andersen, 2008).

The European research project, Competitiveness Effects of Environmental Tax Reforms (COMETR)[27], conducted a comprehensive study to estimate the effect of carbon

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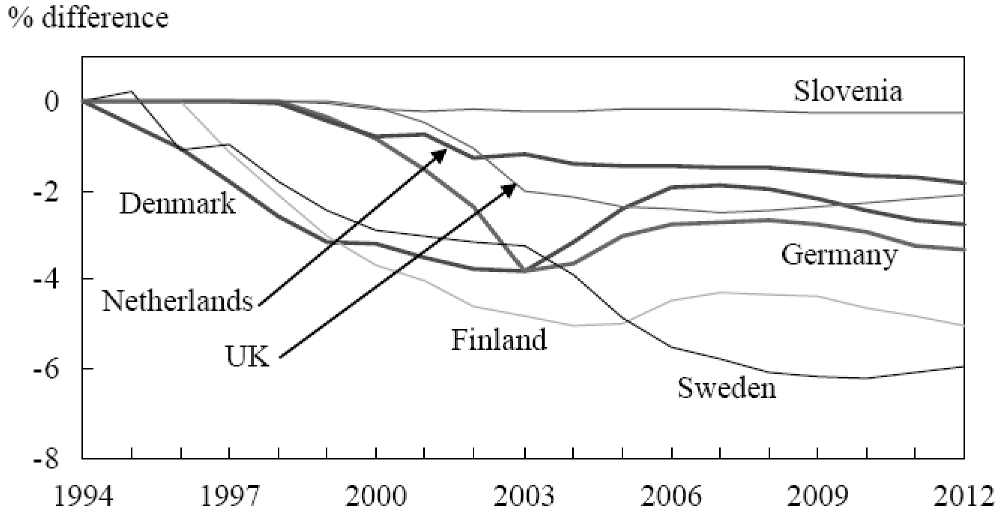
[27] See: http://www2.dmu.dk/cometr

taxes on fuel consumption. The project developed a model to disentangle the impacts from the tax and applied it to the seven European countries that implemented carbon taxes first in order to get a firm ex-post assessment and future forecasts. The results shown in Figure 2.4 indicate the effect of a carbon tax on fuel demand relative to a business-as-usual case. Six countries show a reduction in fuel demand. On average the reduction in demand was 2.6% in 2004, with Finland and Sweden showing the largest effect. According to Andersen (2008) “the size of the reduction in fuel demand is dependent on: the tax rates imposed; how they are applied to the various fuels and fuel user groups; how easy it is for fuel users to substitute between the various fuel types and non-fuel inputs; and the scale of the secondary effects resulting from changes in economic activity.”



Note(s) : % difference is the difference between the base case and the counterfactual reference case.
Source(s) : CE.

Figure 2.4: The Effect of Carbon Taxes on Fuel Demand (Andersen, 2008)

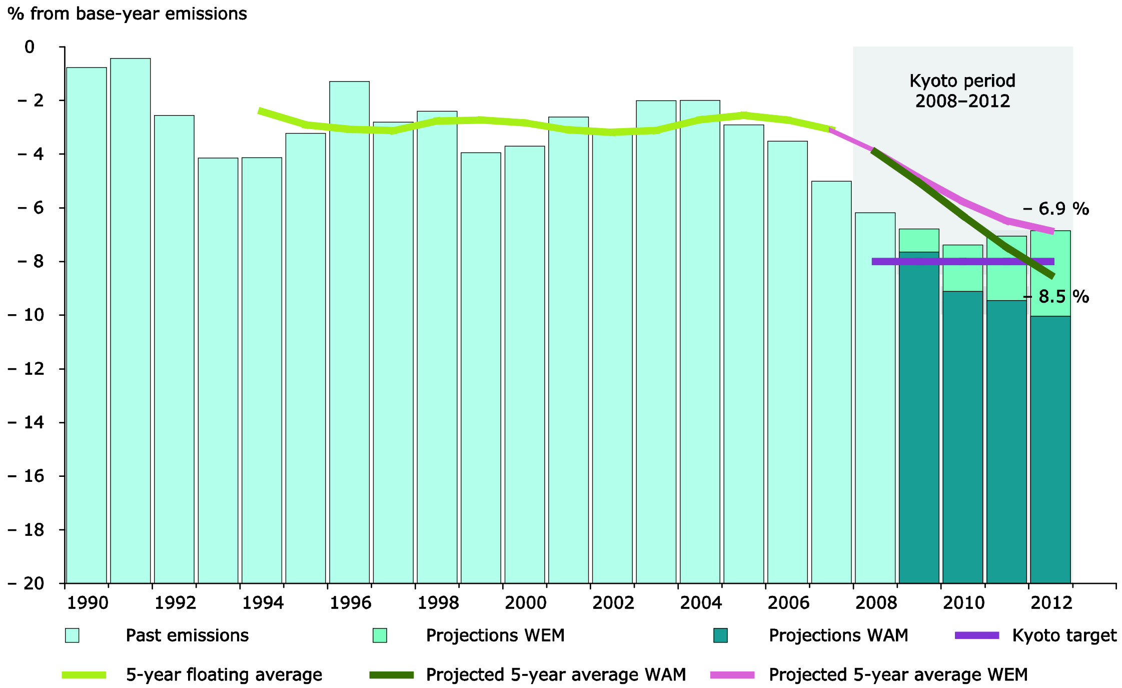
In the United States, an energy/carbon tax was first proposed by President Clinton in 1993--the BTU tax. Such a tax would focus on fossil fuels, methanol and ethanol, and domestic and imported electricity produced from hydro power and nuclear energy based on its heat content. The proposed tax was essentially an economy-wide energy tax, although wind, solar, geothermal and biomass sources of energy were exempted. The proposed BTU tax was never adopted. Instead, the BTU tax was replaced by a 4.3-cent increase in the gasoline tax. Several carbon tax proposals have been presented to Congress since that time, but none have been adopted to date. (Milne, 2008)

At a local level, two areas have currently adopted a carbon tax structure: Boulder, Colorado and the Bay Area, California. In Boulder, the Climate Action Plan Tax was approved in 2006, imposing a tax on end-users of electricity. The tax revenue is used to finance the city’s climate action plan. This program aims to reduce GHG emissions to seven percent below 1990 levels by 2012. In California the Bay Area Air Quality Management District implemented a greenhouse gas tax in 2008. This charge is estimated to generate an annual revenue of $1.3 million which will be used for the District’s climate programs. (Milne, 2008) The California Air Resources Board proposed the idea to implement a statewide carbon tax on polluting industries. This would be the first state in the U.S. to do so. Agreement with industries, oil companies, and utilities has yet to be reached. (Young, 2009)

With respect to emissions trading, the European Union Emission Trading System (EU ETS) is the largest multi-national, cap-and-trade scheme for greenhouse gases in the world and is a landmark environmental policy. It was designed and implemented to achieve the GHG reduction targets under the Kyoto Protocol: an annual average of 8%

reduction from 1990 levels for 2008-2012. The program now covers over 12,000 installations in the 27 EU countries and six major industrial sectors: electric power, oil refineries, coke ovens, metal ore & steel, cement kilns, glass, ceramics, paper & pulp. Covered entities emit around 45% of total carbon dioxide emissions in the EU and allowances valued at $23 billion in 2006. More than 1 billion metric tons of emissions were traded that year. Emission allowances are given out for a period of time, called the Trading Period. This way, irregularities in CO_2 emissions due to extreme weather can be neutralized by allowing emitters to bank their allowances. The first phase Trading Period started on January 1, 2005. Phase 2 began in 2008 to cover the Kyoto Protocol period and Phase 3 will start in 2013 targeting emission reductions of 21% from 2005 levels by 2020. Starting in 2012, the airline industry will be included in the EU ETS as well. (Pew Center, 2007; Ellerman, 2008; CBO, 2009; Parker, 2010)

Although the EU ETS has had a positive effect on reducing GHG emissions, projections from the European Environment Agency (EEA) show that the EU-15 existing measures will result in a 6.9% reduction from 1990 level, rather than the 8% reduction agreed to under the Kyoto Protocol (see Figure 2.5). Further actions are required and changes to the current trading scheme have been proposed, including permit auction, central allocation rather than national allocation plans, and including other GHGs. These changes have not been finalized yet and are not likely to become effective until the third Trading Period (Parker, 2010).



Note: WEM: with existing measures (measures implemented or adopted). WAM: with additional measures (planned measures).

Figure 2.5: GHG Trends and Projections EU-15 (EEA, 2009)

Carbon emissions trading programs have been proposed several times in the United States, but no such program has been implemented. Two of the most recent proposals that include a federal GHG cap-and-trade program are the American Clean Energy and Security Act of 2009 (ACESA), which was passed on June 26, 2009, by the U. S. House of Representatives and a bill passed by the Senate Environment and Public Works Committee in November 2009 (EEA, 2009). ACESA's proposed program would take effect in 2012, requiring total GHG emission reductions of 17 percent below 2005 levels by 2020 and 83 percent by 2050. The bill passed by the Environment and Public Works Committee tightened this requirement to 20 percent below 2005 levels by 2020. In addition to federal proposals, state-level and regional efforts to develop a trading program are under way, including the Regional Greenhouse Gas Initiative (RGGI) and the Western Climate Initiative (WCI) discussed in earlier sections and the state of California (CBO, 2009).

It should be noted that emissions trading programs and strategies that have been used in the United States (such as for acid rain and SO_2 reductions) have mainly focused on large point source GHG emissions (e.g. power plants). Including transportation emissions in a tax or trading program has been proposed by several, but according to the Pew Center (2007) it remains politically challenging to implement. However, as noted earlier, transportation is the fastest growing source of GHG emissions and it is likely that sooner or later the transportation sector will be included in tax or trading programs.

2.4.2 Transportation Emission Reduction Strategies

Reducing GHG emissions from the transportation sector usually focuses on three main strategies: improved vehicle fuel efficiency, improved fuels, and a reduction in vehicle miles traveled (VMT), either through mode shift or a decrease in travel demand. As mentioned before, high speed rail could play a significant role in GHG emissions as well.

2.4.2.1 Vehicle Fuel Efficiency

For the short term, fuel efficiency is considered to have the most potential for reducing carbon emissions. In 2007, the British Treasury commissioned a review, led by professor Julia King, to examine vehicle and fuel technologies that could help to de-carbonize road transport over the next 25 years. The final report, published in March 2008, recommended policy and strategies for government, business and consumers, to reduce CO_2 from road transport in the next years. According to King, almost complete decarbonization of road transport is, in the long term (by 2050), a realistic ambition. The cost will be significant but manageable and delay would be dangerous and much more expensive. Also according to King, the key areas for action include reducing vehicle emissions and producing cleaner fuels. King states that even in the short term significant CO_2 emission reductions can be achieved through the use of already available technologies, and by making smart choices about our driving behavior. She observed that "moving low-carbon technologies from the "shelf to the showroom […] could reduce per kilometre emissions of new vehicles by as much as 30 per cent within five to ten years" (King, 2008). Both demand and supply are currently delaying deployment and therefore a strong focus on ensuring a market for these low emission vehicles is needed. For the medium term, King's recommendations are, in addition to vehicle technologies, aimed at fuel technologies, mainly the further development of biofuels. In the longer term it is very likely that electricity and hydrogen will be the main scope for de-carbonizing fuels as well as through new biofuels with low productive land requirements. (King, 2008)

In a 2006 policy brief, The European Conference of Ministers of Transport (ECMT) came to similar conclusions. The recommendations relating to CO_2 emission reduction policies, based on a review of progress made in OECD countries, stated that, although many countries currently tend to focus on high cost measures like promoting biofuels, "for the short and medium term, policies that target fuel efficiency offer most potential for reducing CO_2 emissions." (CEMT, 2006) According to ECMT, carbon and fuel taxes are the ideal measures for addressing CO_2 emissions. Other possible measures included vehicle taxation, vehicle and component standards, incentives for more efficient logistic organization and support for eco-driving and. "For the long term, more integrated transport and spatial planning policies might contain demand for motorised transport. Ultimately higher cost energy sources, including clean energy carriers such as hydrogen and electricity, produced from renewable energy sources, or from fossil fuels with carbon sequestration and storage, will be required if there are to be further cuts in transport sector CO_2 emissions" (CEMT, 2006). Vehicle efficiency and alternative fuels have been emphasized by the IPCC as well as key mitigation practices for the transportation sector (IPCC, 2007).

Despite improved automotive engine technologies, vehicle fuel efficiency gains in the U.S. have leveled off since the mid-1980s. The main reason is that improved technologies have been canceled out by the demand for more powerful and larger vehicles, especially sports utility vehicles (Brown, Southworth, and Sarzynski, 2008). As noted earlier, a new national program to regulate fuel economy and greenhouse gas emissions, increasing the goal of 35 mpg by 2020 to an average of 35.5 mpg by 2016, was recently implemented (The White House, 2009). Revised fuel economy standards for small trucks as well as medium and large commercial trucks are also being analyzed by the federal government. Significant increases in vehicle fuel economy appear both feasible and justifiable (Brown, Southworth, and Sarzynski, 2008).

In 2009 the International Air Transport Association (IATA) published a Technology Roadmap providing "a summary and assessment of technological opportunities for future aircraft. It looks at technologies that will reduce, neutralise and eventually eliminate the carbon footprint of aviation" (IATA, 2009)

IATA's first findings based on an assessment of a broad scope of technologies show that:

- “The most significant aircraft efficiency gains are expected from new engine architectures (open rotor, geared turbofan, counter-rotating fan, etc.) and from natural and hybrid laminar flow, which are all candidates for use in new aircraft types by 2020.
- Numerous smaller improvements, like winglets and reduced-weight components, can be implemented into current series or even retrofitted.”

Although premature, the rough estimates of the total CO_2 emissions reduction potential are, according to IATA, “consistent with a number of studies estimating the overall efficiency improvement in the next decades. The results of these studies range between 20 and 35% emissions reductions for new aircraft in 2020 compared to their predecessors, achieved mainly from the engine type and the use of laminar flow. The TERESA project results give IATA and airlines the confidence that sufficient innovation potential exists to achieve the estimated overall targets.”

2.4.2.2 Alternative and Improved Fuels

The U.S. transportation sector is primarily powered by gasoline, followed by diesel, which together accounted for 98 percent of the vehicle fuel consumption in 2008 (EIA, 2009b). On an energy basis, diesel is slightly more carbon intensive than gasoline (at 19.95 TgC per QBtu compared with 19.34 TgC per QBtu for gasoline), although diesel engines are generally more energy-efficient than gasoline engines. Improvements in fuels and technology have the potential to reduce transportation carbon emissions substantially. According to Brown, Southworth, and Sarzynski (2008), “Cellulosic ethanol and biodiesel may prove to be important low-carbon fuel alternatives to gasoline and diesel. For example, replacing one-quarter of projected gasoline use with cellulosic ethanol—a replacement rate viewed as achievable within 25 years— could cut carbon emissions by 15 to 20 percent.” Hybrid electric systems that are recharged in off-peak hours by low-carbon electricity are another promising alternative. “Metropolitan areas are particularly well suited to low-carbon options because the capital investment needed to establish new refueling infrastructures is more economically feasible in high-density environments.” In a press release on June 17, 2010,[28] Nancy Gioia, Ford's director of global electrification, stated that between 10% and 25% of Ford’s global sales volume will be electrified by 2020. Of those vehicles, “70% will be hybrids, another 20% to 25% will be plug-in hybrids and the rest will be all-electric vehicles.” Nissan's expectations for electric vehicles are even higher; they expect that “more than 10% of its entire fleet will be all-electric by 2020.” Nissan plans to launch a 100-mile range electric hatchback, the Nissan Leaf, in December 2010.[29]

The source of the electricity used to power vehicles, especially trains in the short term, will have a major effect on the GHG emissions. In 2008, renewable energy accounted for almost 10 percent of the energy used in the United States. According to Clean Edge, a research and publishing firm devoted to the clean-tech sector, the global clean-energy market is projected to grow from $144.5 billion to $343.4 billion, or more than 100%, from 2009 till 2019 (Clean Edge, 2010). Although there are no federal requirements for electric utilities to generate a specified minimum percentage with eligible sources of renewable electricity, President Obama has called for “a goal of 10 percent renewable

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[28] http://www.freep.com/article/20100617/BUSINESS01/6170412/1002/business/Ford-Electrics-could-be-25-of-2020-fleet

[29] Ibid

energy use by power producers by 2012 and 25 percent by 2025" (Sklar, 2009). The U.S. House of Representatives has set a goal of 15 percent by 2020.

2.4.2.3 VMT Reduction Strategies

The ECMT examination of policies for CO_2 emissions reduction so far adopted by OECD governments shows that policies for reducing demand for transport have been largely ignored. Several studies have been undertaken that look at the potential VMT reduction from a variety of strategies. According *Growing Cooler* (Ewing et al., 2008) "since 1980, the number of miles Americans drive has grown three times faster than the U.S. population, and almost twice as fast as vehicle registrations. In line with VMT increases, automobile commute times have risen steadily, especially in metropolitan areas" (Ewing et al., 2008). Ewing et al. (2008) state that a large share of the VMT increase "can be traced to the effects of a changing urban environment, namely to longer trips and people driving alone." Our built environment has been developed towards an automobile dependent environment with little focus on public transit and walking (Ewing et al., 2008). Although it takes time to change the built environment, denser, mixed-use development could be an effective strategy to reduce VMT and thus carbon emissions. Improving and promoting transportation modes, other than car, while discouraging car use, could have a positive effect as well.

The 2009 study *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions* (Cambridge Systematics, 2009), provides an analysis of the effectiveness and costs of almost 50 strategies and combinations of strategies that focus on the reduction of travel activity and on improving transportation systems operations. The VMT reduction strategies considered by *Moving Cooler* are (Cambridge Systematics, 2009):

- Pricing and taxes. Strategies raise the costs associated with the use of the transportation system, including the cost of vehicle miles of travel and fuel consumption. Both local and regional facility-level pricing strategies (e.g., congestion pricing) and economy-wide pricing strategies (e.g., carbon pricing) are considered.
- Land use and smart growth. Strategies focus on creating more transportation-efficient land use patterns, and by doing so reduce the need to make motor vehicle trips and reduce the length of the motor vehicle trips that are made.
- Nonmotorized transport. Strategies encourage greater levels of walking and bicycling as alternatives to driving.
- Public transportation improvements. Strategies expand public transportation by subsidizing fares, increasing service on existing routes, or building new infrastructure.
- Ride-sharing, car-sharing, and other commuting strategies. Strategies expand services and provide incentives to travelers to choose transportation options other than driving alone.
- Regulatory strategies. Strategies implement regulations that moderate vehicle travel or reduce speeds to achieve higher fuel efficiency.

The study found that implementation of the strategies analyzed, without economy-wide pricing, could achieve annual GHG emissions of as high as 24 percent less than the projected baseline for 2050. Strong economy-wide pricing measures could generate GHG reductions far beyond this. Some of the strategies that contribute most to GHG reductions, according to the study, are local and regional regulatory and pricing strategies that increase single occupancy vehicle travel costs, educational strategies to promote eco-driving behavior resulting in better fuel efficiency, and smart growth and land use strategies that reduce travel distances (Cambridge Systematics, 2009).

The recently published Congressional report *Transportation's Role in Reducing U.S. Greenhouse Gas Emissions* (USDOT, 2010), attempts to objectively evaluate “potentially viable strategies to reduce transportation greenhouse gas (GHG) emissions.” One of the groups of strategies evaluated is ‘Reduce Carbon-Intensive Travel Activity’. These strategies would reduce VMT by “reducing the need for travel, increasing vehicle occupancies, and shifting travel to more energy-efficient options that generate fewer GHG emissions.” The VMT reduction strategies evaluated in this study and their potential impact on GHG emissions according to the study are (USDOT, 2010):

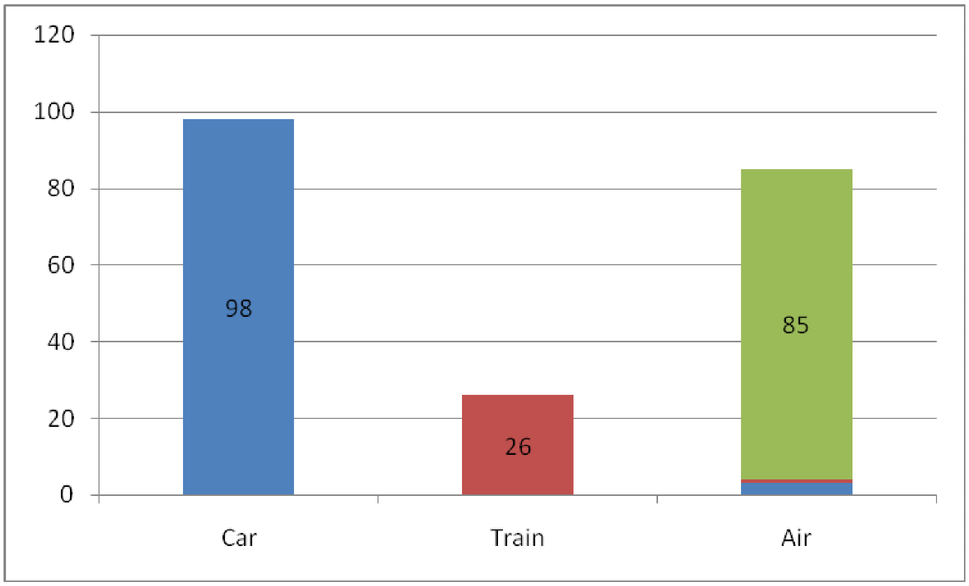
- Transportation pricing strategies, such as a fee per vehicle-mile of travel (VMT) of about 5 cents per mile, an increase in the motor fuel tax of about $1.00 per gallon, or pay-as-you-drive insurance—if applied widely—could reduce transportation GHG emissions by 3 percent or more within 5-to- 10 years. Lower fee or tax levels would result in proportionately lower GHG reductions.
- Significant expansion of urban transit services, in conjunction with land use changes and pedestrian and bicycle improvements, could generate moderate reductions of 2 to 5 percent of transportation GHG by 2030. The benefits would grow over time as urban patterns evolve, increasing to 3-to-10 percent in 2050. These strategies can also increase mobility, lower household transportation costs, strengthen local economies, and provide health benefits by increasing physical activity.
- Studies based on limited European experience suggest that “eco-driving” strategies to teach efficient driving and vehicle maintenance practices could potentially reduce emissions by as much as 1-to-4 percent. However, this would require comprehensive driver training as well as in-vehicle instrumentation. As such, the European findings may not be replicable in the United States.

The study assesses the total collective impact of these carbon-intensive travel activity reduction strategies on U.S. transportation GHG emissions “could range from 5-to-17 percent in 2030, or 6-to-21 percent in 2050.”

2.4.2.4 High Speed Rail

Given the potential interest in high speed rail in the corridors studied in this research, it is important to describe current knowledge concerning its potential CO_2 reduction. Over the past several decades high speed rail has gained popularity all over the world as an alternative intercity passenger travel mode to air and highway. Figure 2.6 compares the total CO_2 emissions from transporting one passenger between the Berlin and Frankfurt city centers in Germany. It shows the potential CO_2 savings as travelers switch to rail. In this figure, going by rail is on average 4 times more efficient than taking the car and more than 3 times better than taking the plane. Note that this graph applies to Germany where cars have higher fuel efficiencies than in the U.S., so the savings would be even higher for travel between U.S. cities.

High speed rail has experienced significant growth, especially in Europe and Japan. Policies, technologies, and investments have resulted in an increasing role for rail travel in the European transportation network. Trains are capturing an increasing share of the rail–air market in many city pairs within 400 miles (Sheck, 2009). Individually and



Note: Plane emissions include travel to and from the airport. They are not increased to take account of the effect of emissions at high altitude. (Source: http://www.uic.org/homepage/FactandFig%2011-08.pdf)

Figure 2.6: Kg CO_2 (1 person Berlin – Frankfurt, 545 km (340 miles)

collectively, European nations are investing heavily in passenger rail. EU transportation development funds have been very helpful to smaller countries, whereas in countries like Spain, "four percent of the GDP has gone to improving infrastructure for almost a decade. Ireland is investing over 6 billion Euros to improve its national rail network from 2006–2015" (Sheck, 2009). Travelers in Japan have been riding high speed trains for more than four decades already. The first high-speed train, the Shinkansen, started operation just before the 1964 Tokyo Olympics. Now, this high-speed network contains of almost 1550 miles of track, with train speeds of up to 186 mph.

Although the U.S. passenger railroad system is lagging behind the European and Asian networks, the popularity of rail, and particularly high-speed rail, is increasing. A 2009 U.S. Department of Transportation news release stated that "the Secretary released new data today indicating that Americans drove 3.6 percent less, or 9.6 billion miles fewer, in July 2008 than July 2007. Since last November, Americans have driven 62.6 billion miles less than they did over the same nine-month period last year. Meanwhile, she said, "transit ridership is up 11 percent, and in July, Amtrak carried more passengers than in any single month in its history" (Capon, 2009). Of course, the major reason for this shift was the economic recession, which was taking hold in 2007.

In April 2009, President Obama and Vice President Biden released a strategic plan outlining their vision for high-speed rail. The plan identified $13 billion in federal funds -- $8 billion in the Recovery Act and $5 billion requested in the President's budget -- to jump-start a potential world-class passenger rail system and set the direction of transportation policy for the future. "Everyone knows I'm a big believer in our nation's rail system – I've devoted a big part of my career doing what I can to support it – and I'm proud that this Administration is about to transform that system fundamentally," said Vice President Biden. "Thanks to an $8 billion investment from the Recovery Act, we're going to start building a high-speed rail system that will loosen the congestion suffocating our highways and skyways, and make travel in this country leaner, meaner and a whole lot cleaner" (FRA, 2009).

In June 2009 the US High Speed Rail Association (USHSR)[30] was established for the purpose of advancing a high speed rail system across America. It is their vision to have a 17,000-mile national high speed rail network by 2030 featuring 220 mph electric trains. This vision is shown in Figure 2.7.

(Source: http://www.ushsr.com)

Figure 2.7: USHSR's High Speed Rail Network Vision

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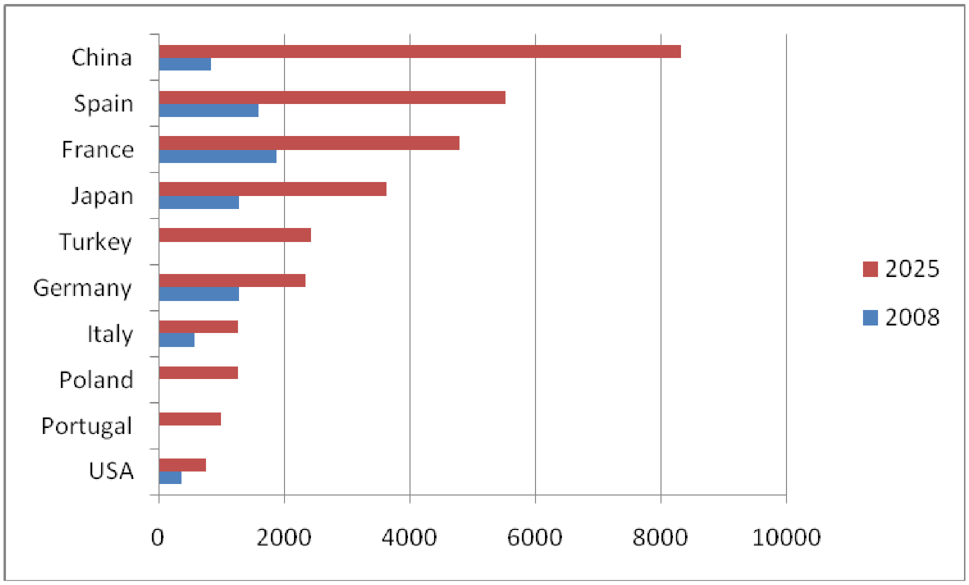
[30] http://www.ushsr.com/

Figure 2.8 shows the current and planned kilometers of high-speed track for several countries that are actively pursuing high-speed rail. Despite increased interest in the U.S. the graph shows that the U.S. growth does not match either European or Asian plans.



(Source: http://www.uic.org)

Figure 2.8: Kilometers of High-Speed Rail Track, 2008 vs. 2025

2.5 Summary

Each of the opportunities to reduce carbon emissions from the transportation sector requires public and private sector involvement. Transportation planning and policy activities can make a significant contribution to these strategies. Climate change is starting to be considered in transportation planning and policy-making by several state Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs). The level of incorporation varies widely though. In some planning documents climate change appears as specific goals, policies, strategies or performance measures, where other plans merely recognize that climate change is an issue that relates to transportation (Gallivan et al, 2009). According to Gallivan et al (2009). “most transportation agencies are not currently seeking to incorporate climate change adaptation measures into long range planning”. In addition, while greenhouse gas (GHG) emissions are likely to be reduced as travelers switch to high speed rail from other modes of travel, little modeling has been done to estimate this potential impact in the U.S. (CNT, 2006). Quantifying the GHG emissions and potential savings therefore needs to receive more attention to better inform the transportation planning and policy-making process.

3 ESTIMATION OF GREENHOUSE GAS EMISSIONS

Quantifying GHG emissions is a key component of considering climate change in transportation planning and policy-making. In order to reduce emissions effectively, current and future emission levels need to be known as well as the potential impacts of various policies and strategies on emissions (e.g. the impact of a carbon tax or a cap-and-trade program on mode shifts). Agencies face several questions about appropriate tools, methodologies, and data (Gallivan et al, 2009).

Several methods exist to develop a transportation GHG emission inventory, but most are of limited use for MPO planning and strategy analysis. Most inventories are developed by fuel type, based on fuel sales data by state or country (Gallivan et al, 2009), including IPCC's guidelines for a national inventory.[31] The main drawback with this methodology is that there is no distinction between different modes, vehicle types, and geographic areas. This breakdown is required for relevant strategy analysis. Other methods use local inspection and maintenance data to develop registration and mileage accumulation or use VMT data, usually compiled for transportation network planning (Heiken et. al., 1996). A Harvard study by Glaeser and Kahn (2008) used the National Household Travel Survey (NHTS) "which contains information on gasoline usage associated with travel by private automobile, family characteristics, and zip code characteristics." Although their study distinguishes road and rail traffic, and focuses on regional levels, it only includes two modes and does not distinguish fuel types. Like most other methods, freight is not addressed separately in their study.

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[31] http://www.ipcc.ch/

Most studies only measure “direct” or tailpipe emissions associated with traffic movements. However, a number of recent life-cycle analysis (LCA) studies of alternative vehicle/fuel technologies indicate that the “indirect” emissions that result from supplying the vehicles, the fuels, and the built infrastructures that are required to provide transportation services are of a similar order of magnitude as the direct emissions, and therefore ought to be incorporated into carbon footprinting studies if policy making is to be fully informed (DeLucci, 2003; ANL, 2009; EPA, 2006; Chester and Horvath, 2008; The Climate Registry, 2008; Green Design Institute, 2009; Natural Resources Canada, 2009). These indirect multipliers are found to vary a good deal across modes of travel, and affect metropolitan areas differently, depending on the mix of travel modes.

Because of the different methods used for estimating GHG emissions, data consistency appears to be a problem. According to Gallivan et al. (2009), MPOs rely heavily on local VMT estimates in developing regional transportation GHG inventories. “Such local inventories are very likely to be inconsistent with state-level inventories. If and when regions are required to meet certain VMT or transportation GHG reduction goals, state and regional inventories would provide conflicting bases for performance measurement” (Gallivan et al., 2009). It is therefore important that reliable and consistent transportation GHG inventories be developed at the regional level with both direct and indirect emissions included.

3.1 Forecasting Long-Distance Personal Travel

To estimate direct emissions from long-distance travel it is important to know travel activities between cities or within corridors. According to the 1995 American Travel

Survey, the last long distance passenger travel survey by the federal government, over 1 billion personal trips to destinations within the United States were made by U.S. households. An additional 41 million trips were made to other countries totaling 827 billion miles of travel, or about 25% of all person miles of travel in the nation.[32] Today, a lack of recent data prevents proper accounting, but all indications are that this long distance travel activity has grown substantially over the past 15 years. Proper accounting is required to get a proper understanding of how and where much of this activity is taking place. This is important to know in order to estimate the effectiveness of policies (e.g. on greenhouse gas emissions) and to invest wisely in transportation systems.

This section discusses the current status-quo of long-distance passenger travel demand modeling and presents a review of the literature. This review has served as input to a long-distance personal travel database collection and modeling roadmap prepared by Oak Ridge National Laboratory for the Office of Highway Policy Information in the Federal Highway Administration, U.S. Department of Transportation, and can be found in Southworth and Sonnenberg (2009). The literature scan covers a number of nationwide modeling activities in both the United States and abroad, as well as a number of recent statewide and multi-state corridor modeling efforts in North America.

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[32] http://www.bts.gov/publications/1995_american_travel_survey/us_profile/entire.pdf

3.1.1 National, Statewide and Major Corridor Travel Studies

In the U.S. currently there is no single database and no established method of modeling long distance passenger travel movements either across the entire country or across a single state.[33] A search for useful past experience leads to three study types:

1. National models developed in other countries: a number of countries, notably in Europe, have developed and now maintain national travel models. Most of these models (see the reviews and studies reported by de Jong, Gunn, et al, 2000; Lundqvist and Mattson, 2001; Zhang, 2009) include both passenger and freight components, and most combine estimates of short and long distance tripmaking components.
2. A number of states in the U.S. have developed, or are in the process of developing, their own long distance travel models, seeking to capture travel across their borders as well as between their major metropolitan areas and counties (see FHWA, 1999; Horowitz, 2006).
3. A third set of studies focus their attention on specific long distance, high volume travel corridors, with the most recent corridor studies in the U.S. and Canada focused on the analysis of high speed rail feasibility (Bhat 1995, 1997; Cambridge Systematics Inc., 2006; Volpe Center, 2008), a topic of growing interest worldwide.

Table A.1 in Appendix A lists a number of the more recent studies by type, between them covering the principal types of long distance travel demand models currently in use. This includes models developed in the U.S. and Canada, in Europe, and in a number of other countries. Approaches vary considerably in behavioral content, spatial specificity, scope of analysis and intended use.

Zhang (2009) provides a technical review of past models. For discussion purposes he suggests a classification of models along the lines shown in Figure 3.1, although many of

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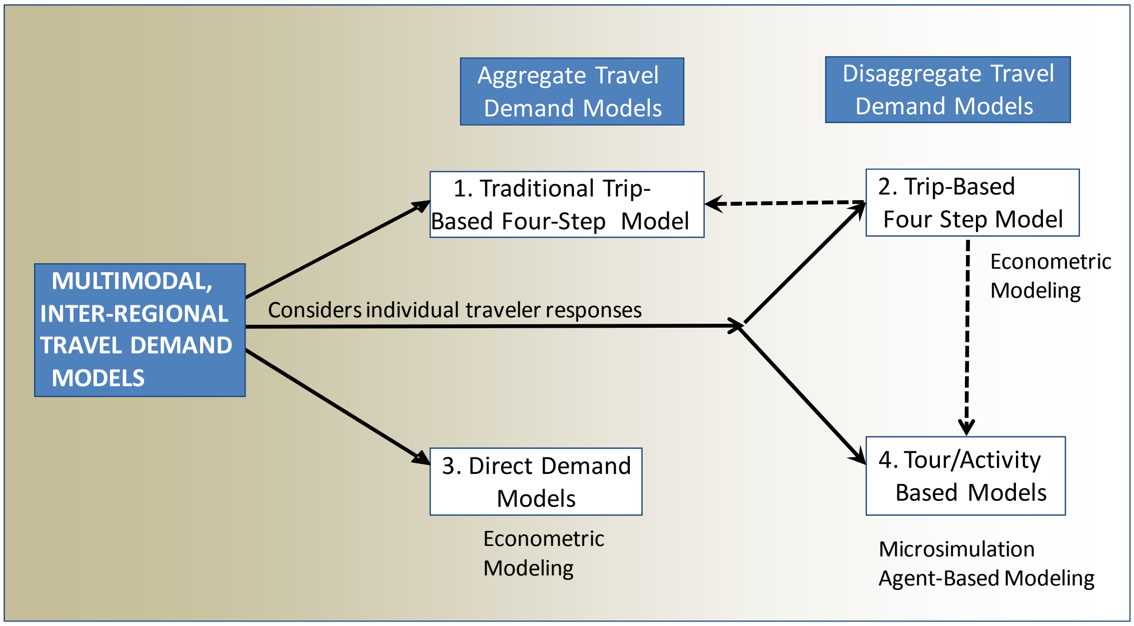
[33] In contrast, the DOT's Freight Analysis Framework, or FAF Program has served this purpose for freight movements since 1998.[33]
http://ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm

the national and statewide models referenced use two or more of the above approaches at some stage in their generation of mode and trip purpose specific flows.

As with most travel demand modeling, the most popular approach is some variation of the four step urban transportation planning model (Box 1 in Figure 3.1), moving sequentially from trip generation (trip frequency) through trip distribution (destination) and modal choice to route choice (traffic assignment), but with a growing reliance on the use of 'disaggregate' demand models based on the analysis of individual traveler and/or household responses for the purposes of estimating the travel demand elasticities associated with trip-making costs and other level of service (LOS) variables (Box 2 of Figure 3.1). Most of the models in Table A.1 include all four traditional sub-models, with some of the European models also including a separate auto ownership model (see Zhang, 2009, Tables 1 and 2 for additional details of selected models).



(modified, based on Zhang, 2009, Fig.1)

Figure 3.1: Categorization of Multimodal Inter-Regional Travel Demand Analysis Methods

A broad classification of trips into business and non-business travel has been common in U.S. studies (see Asiabor, Baik and Trani, 2007), whereas some of the European models include more detailed travel purpose categories, especially within non-business purposes. For example, the factors that determine choice of mode as well as the location, number, and duration of out-of-home destinations differ when considering family vacation travel, versus recreational trips that do not involve an overnight stay away from home. Within each of these trip purposes, and for a given geographic context (national, statewide/regional, corridor) the explanatory variables used by the models fall under three groupings: trip/tour logistics characteristics, traveler socio-demographics, and level of transportation service. The most common long distance modes analyzed are auto (car), air, rail and bus. A few models make a distinction between conventional rail and high speed rail. With increasing interest in high speed rail development in the U.S. this distinction could become an important one. Modeling the use of shorter-range small aircraft transportation systems has also been a recent topic in the U.S. Some of the models listed in Table A.1 also split car into ‘car driver’ and ‘car passenger’. This separation reflects the interaction among individuals that participate together in certain activities. For long-distance travel, especially for recreational and vacation trips, this joint participation may play a significant role. This is where disaggregate, activity-based modeling of household travel needs can prove advantageous (see below).

To date nearly all of the disaggregate demand models have been based on the theory of traveler utility maximization or generalized cost minimization, and use multinomial, nested, and mixed logit or similar forms of econometric model, each based on fitting a the model to a set of revealed (RP) and/or stated preference (SP) responses obtained from a survey of individual travelers or households. The strength of these models is their ability to include a wide range of both traveler attributes as well as transportation service attributes, the former either by developing separate model calibrations for specific traveler categories, or using dummy variables (e.g. income group dummies), the latter by inclusion of extra terms within the traveler's utility function. A key attribute of these models is the form and content of these traveler utility functions, which typically include travel time and monetary expenditures (air, bus or rail fares, auto rental or owner operating costs) as well as responses to frequency of service offered and its on-time reliability (see Table A.1).

The other two general modeling categories shown in Figure 3.1 refer to less popular forms. The first type (Box 3) is termed direct demand modeling (DDMs) in the transportation literature. These models attempt to explain travel frequency, mode, destination and other attributes of personal tripmaking in a single estimation step, and in most cases to date have tried to accomplish this using aggregate, planning level data. This approach avoids the complexities and conceptual issues associated with determining how (and in what if any sequence) people organize their travel decisions, but usually does so at the price of statistical accuracy and model goodness of fit. It appears to be most useful when applied to corridor-specific studies, in which the variety of tripmaking choices in more limited and the data is typically more reliable than that used in statewide or nationwide studies (see Volpe Center, 2009, for example).

The models located in Box 4 of Figure 3.1 represent a growing trend in travel demand modeling: the treatment of tripmaking as part of a person's or a household's daily travel activity profile. An improved theoretical as well as empirical basis is being sought here by treating travel as one set of choices that, along with other choices (such as where to live, what recreational and employment activities to pursue) help to define a person's, and a family's life style.

Also based on modeling using disaggregate, individual traveler response data, this approach has yet to see a truly dedicated application to long distance travel forecasting. Most models reviewed in Table A.1 started as trip-based models: effectively estimating each trip as if it involved a completely separable decision-making process. However, a movement from trip-based modeling towards a more travel activity-based modeling approach can be distinguished in the travel literature in general, and especially among the European models that incorporate a long distance travel component. The majority of these activity-based models are disaggregate demand models, including the European-wide model TRANS-TOOLS. (The STREAMS model on the other hand is an aggregate European-wide model). A feature of such models is the substitution of individual trips as the units of behavioral interest with daily trip-tours. To be of value to long distance travel analysis, this approach needs to be extended to multi-day, out-of-home travel tours linked to a traveler's household/family structure and business/employment practices.

The most promising uses of this activity-based approach are currently tied to the use of microsimulation as an alternative method for aggregating the results of disaggregate travel demand models, making use of today's high speed computing to cost-effectively generate many thousands, or millions, of individual trips, summing over these simulated trips to produce aggregate population level O-D flow matrices that can be matched to a set of base year planning totals (e.g. to the total number of long distance recreational trips made by households in a given region in a given income class).

Microsimulation offers a good deal more flexibility than traditional aggregation methods (see Miller, 2003). By also taking advantage of recent developments in agent-based modeling (ABM), micro-simulated trips can be created after generating synthetic travel “agents” in the form of individual travelers and their families/households. Using microsimulation to replicate travel decisions, ABM allows a population of autonomous travelers or households to interact among themselves to determine what types of travel to engage in, basing individual behaviors on a person’s current socio-economic status, his or her objective, and history of past actions.

Like microsimulation, ABM supports a bottom-up approach to estimating travel activity patterns, and as such seems well suited to travel activity systems in which individual tripmaking behaviors can be aggregated, sometimes yielding unexpected system-level effects known as emergent behaviors (see Sanford Bernhardt, 2007). That is, a microsimulation/ABM approach allows all of the many variables affecting long distance travel decision-making shown in Figure 3.1 to interact in ways that more artificially structured modeling frameworks have not been able to do. These methods also make it easier than traditional four step models to replicate such events as multi-stop, multi-day travel activity tours of the sort often associated with vacation or “road warrior” business travel.

3.1.2 Demand Modeling in Practice: Mixed Method, Multi-Step Models

Over the past three decades it has become an increasingly common practice to use hybrid aggregate/disaggregate demand modeling frameworks in transportation planning studies (hence the dashed line from Box 2 back to Box 1 in Figure 3.1). These frameworks try to offer the best of both worlds: a behavioral basis for determining representative traveler utility functions and their associated travel cost elasticities, tied to a mechanism for expanding the resulting disaggregate demand model's results to match regional travel activity totals.

To date the most ambitious effort to construct a complete four step long distance transportation planning model for U.S. long distance to date is attributable to researchers at the Virginia Polytechnic Institute and State University, whose TSAM (transportation systems analysis model) produces estimates of annual long distance trips by air and auto on a county-to-county basis (Baik et al, 2008). With an initial focus on air travel, the TSAM framework starts with a set of survey-based long distance trip frequencies (measured in person round-trips) broken down according to state of origin (from the 1995 American Travel Survey). These purpose-specific (i.e. business and non-business) trip rates are multiplied by a set of exogenously supplied and household income stratified U.S. county population estimates (and forecasts). County-based trip attractions are similarly expanded using a trip rate x total county employment for business trips, and a trip rate x employment in service industries for non-business trips. These Os and Ds are then distributed between U.S. county pairs using an aggregate spatial interaction model and an iterative proportional fitting routine to match county-to-county O-Ds to survey expanded, state-specific tripmaking totals.[34]

Step three in the process, modal choice, is solved as a two step disaggregate nested logit model, which assigns each O-D flow to either the air taxi, commercial airline, or

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[34] A two state estimation process is used, due to ATS data limitations. First, a state-to-state spatial interaction model is calibrated, then these O-Ds are distributed between individual county pairs using a Fratar method constrained to state O-D totals.

automobile mode after first determining the average or ‘composite’ cost of commercial air travel options by solving a logit model for travel between each O-D pair’s most common embarkation-debarkation airport pairings. Asiabor, Baik and Trani (2007) describe this modeling as well as the application of a mixed logit model to the same data. They also illustrate the use of door-to-door travel cost functions that incorporate airport access and egress as well as airport waiting time and flight delay costs: and the difficulties of getting accurate data on trip origination and destination locations for this purpose from past surveys. Finally, traffic route assignments for the commercial air travel are estimated using travel time and fare-based disutility functions to calibrate a multinomial logit model of alternative airport-to-airport routes selections. This is done by fitting the O-D-M flows from the mode choice model to alternative airport-to-airport routes, using aggregated data on reported route traffic volumes from official and commercial sources data sources.[35]

The TSAM framework exemplifies the effort required at the present time in combining a broad range of data sources and modeling techniques to obtain a set of spatially disaggregated long distance O-D-M(ode)-P(urpose) travel matrices for the entire United States. Similar multi-stage and multi-sourced travel modeling frameworks are being used in the EU and elsewhere. Of these, the MYSTIC, STEMM, STREAMS and TRANS-TOOL modeling systems listed in Table A.1 have been applied on a continental scale in Europe, that is, on a geographic and population scale similar to that required of a U.S. long distance modeling system. Also of note, these and a number of the more

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[35] The air taxi model, for which data on travel costs is more limited, uses a Monte Carlo distribution simulation model to carry out its assignments.

elaborate national travel models are also moving towards a merger of passenger and freight forecasting methods in order to capture a complete set of transportation sector activities, as well as to assign mixed passenger-freight traffic volumes to regional and national networks (and perhaps also to consider the benefits associated with greater use of mixed passenger-freight service options: see Southworth and Wigan, 2008). Finally, some of the non-U.S. modeling systems listed in Table A.1 are beginning to explore feedback loops between the traffic network assignment stage of the modeling process and the effects of any congestion costs captured in this step on the generation as well as the distribution and choice of mode used by long distance trip makers. With high levels of traffic congestion, and hence travel delays, expected in many U.S. travel corridors (based on the historical growth in multimodal travel volumes), this is a modeling enhancement that may become essential if federal or other analysts wish to study the potential effects of future traffic flow bottlenecks on overall network performance.

An additional study of interest here is the agent-based microsimulation model of intercity trip frequency and destination choice by Epstein et al. (2009), developed for the purpose of understanding the spread of pandemic diseases such as avian and swine flu. Applied to each household and each person in the U.S, the model employs a micro-level implementation of the gravity model to simulate individual-level intercity travel decisions based on a zip-code level origin-destination system. Also in the U.S., microsimulation of long distance tripmaking is used in the Maryland statewide model (see Zhang, 2009), and in the modeling of household travel in Oregon (Donnelly et al, 2009). Agent-based modeling approaches have also been demonstrated in large-scale networks by Zhang and Levinson (2005).

Finally, a category of long distance travelers not represented in U.S. household surveys is foreign visitors, notably foreign tourists. Limited analysis of the within-U.S. travel activity patterns of these visitors appears to have been carried out. The TSAM framework discussed above does offer one beginning in this area, modeling international passenger enplanements (produced and attracted) at the nation's 66 international airports, using regression based on gross domestic product and historical enplanement data for 9 world regions (Baik et al, 2008). While detailed air travel data on these travelers is collected from all of the commercial airlines making stops at U.S. airports, as part of the Office of Airline Statistics'‘T-100' (International Segments) database,[36] data on how these travelers move around the country once they leave the air travel system is not collected; data on the traveler's principal (or at least first) destination should be reported on their landing declaration.

3.1.3 Assessment of Current Modeling Practice

Miller (2003) provides an excellent summary of, and suggestions for, needed improvements in long distance travel demand modeling that is still relevant today. The following list of modeling needs draws directly from his list, while adding to and commenting further on it:

- *Limitations on O-D and Trip Purpose Details*: this is the single greatest weakness of all efforts to model long distance travel to date, with the limited sample size of passenger and household surveys preventing expansion of estimates on a sound

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[36] http://www.bts.gov/programs/airline_information/

statistical basis to anything but rather broad regional O-D matrices, and in many cases also to rather broad trip purpose categories.

- *Treatment of Access and Egress Modes:* The effects on access/egress mode availability and user perceived costs (including inconvenience as well as monetary and time costs) need to be better captured in both our datasets and demand models. Miller (2003) points to the use of nested logit modeling as one means being used to capture such costs in a theoretically consistent manner. All O-D travel costs should be "door-to-door" costs. If multi-destination trip tours are modeled these costs should be put on a home-back-to-home tour cost basis.
- *Treatment of Travel Costs and LOS Attributes:* Extensions of traveler disutility or generalized cost functions are needed that go beyond the 'fare, time and service frequency' approach. These cost functions should be allowed to vary according to the types of trips or tours being made: by trip purpose, by number of days away from home, and by number of travelers in the group, etc.
- *Alternatives to Discrete Choice Modeling:* To date many of the choices simulated by microsimulation /ABM methods still rely heavily on the partial travel choice probabilities generated by logit or similar discrete choice, disaggregate demand (TG, TD, MC, TA) models. In the future alternative rule-based choice systems might also be explored, taking advantage of the less restrictive functional forms these methods make possible. Support for such methods will, however, require supporting data collection efforts, including more in-depth study of how travelers make long distance travel decisions.

- *Making Traffic Congestion Endogenous to The Modeling Process:* The effects of increased traffic volumes on traffic congestion-induced delays needs to be modeled explicitly if policy analysis is to place reliance on a national or regional model's ability to evaluate the effects on traveler benefits of adding or removing significant modal capacity. Feedback from the traffic route assignment stage of a model to the other steps in the traditional four step modeling process (i.e. the TG, TD, MC steps) is one way to do this. Other, less computationally intensive ways also need to be explored.
- *Alternatives to a Trip-Based Approach to Behavioral Response:* While the number of trips between places is an important planning input, the behavioral basis for generating these volumes needs to be tied closer to the daily and seasonal activity patterns of travelers who often organize their long distance travel activities in the form of multi-destination out-of-home trip tours. Household characteristics need more attention here, notable where leisure trips are concerned.
- *Foreign Visitor Trips:* More attention needs to be given to modeling the travel activity schedules and destinations of foreign visitors, principally those of foreign tourists.

Many of the shortcomings of current models are closely tied to the limitations of existing datasets. Much past “travel modeling” has in fact been focused on filling gaps in current data sources, or on finding ways to cope with limitations on the travel as well as traveler details provided by past household surveys. Due to the current status of long-distance travel models and the lack of sound data, Southworth and Hu (2010) addressed the importance of developing an American long distance personal travel data and modeling program and prepared a roadmap for the Federal Highway Administration (FHWA). Further research and development activities are ongoing.

3.2 Indirect Emission and Long-Distance Personal Travel

A number of recent life-cycle analysis (LCA) studies of alternative vehicle/fuel technologies started to include “indirect” emissions in their estimates. It was emphasized, however, that these indirect emissions estimates were approximate. Not only is the state-of-the-art in calculating such indirect emissions in its early stages as far as most transportation modes are concerned, no two major studies have adopted the same set of steps to measure these emissions, or made the same assumptions regarding energy consumption rates from the individual activities they include in their “cradle-to-grave” LCA methodologies.

To date, the most comprehensive LCA of passenger transportation in the U.S. has been completed by Mikhail Chester and Arpad Horvath at the University of California, Berkeley (Chester and Horvath 2008, 2009a and 2009b). Other studies and models (Delucchi, 2003, The Climate Registry, 2008, Green Design Institute 2009, ANL 2009, MacLean and Lave, 2003) have analyzed single modes, specific phases or particular externalities, but none have performed a complete LCA including multiple modes, vehicles, infrastructure, and fuel inventories. Chester and Horvath’s method quantifies energy inputs and emissions associated with the entire life cycle of the fuels, vehicles, and also many of the built infrastructures (roadways, tracks, terminals, depots, parking structures, offices, etc) and other support activities (notably insurance) required to support these vehicle movements. They accomplish this using a combination of the two most common forms of LCA: a highly detailed process model that quantifies each of the resource inputs and environmental outputs at each stage in the vehicle, fuel, or infrastructure production process, and an economic input-output analysis that integrates traditional I/O modeling with environmental databases to produce an inventory analysis of the entire supply chain associated with a product or service (see Hendrickson et al, 1998; Green Design Institute, 2009). The environmental performance is calculated for each component in the mode's life cycle, and is then normalized per passenger-kilometer-traveled (PKT). Detailed analyses and data used for normalization can be found in Chester and Horvath (2008 and 2009). Their results can be used to factor up the direct vehicle activity-based emissions to a more complete representation of the life-cycle CO_2 emissions associated with each transportation mode. They conclude that "Current results show that total energy and greenhouse gas emissions increase by as much as 1.6X for automobiles, 1.4X for buses, 2.6X for light rail, 2.1X for heavy rail, and 1.3X for air over operation."

The following chapter describes a research approach for estimating direct and indirect GHG emission for transportation. This approach includes individual modes and vehicle types at the corridor, rather than national or local, level. The method only includes passenger transportation and distinguishes highway, transit (all different modes), air travel, and passenger (high-speed) rail. Estimates are made for emissions within three corridors with a maximum length of 400 miles for the year 2008. Passenger travel between metropolitan areas has been growing rapidly and it would be interesting to know how a mode shift from air and highway to less polluting modes would affect carbon emissions.

These estimates provide a database from which emission reduction opportunities will be identified and the impacts of different technologies and policies will be estimated. Based on these estimates, policy recommendations can be developed.

4 METHODOLOGY

This section describes the conceptual framework and the research approach that will be used to develop a methodology for estimating an intercity passenger GHG emissions inventory and the approach to assess the impact of different technologies and policies. The methodology was developed with a special focus at the corridor level.

4.1 Conceptual Framework

A method for quantifying transportation GHG emissions would include a full lifecycle analysis for all transportation modes, both passenger and freight transportation. Rather than just analyzing end-use emissions (i.e. emissions from fuel consumed for powering vehicles) it is important to include upstream and downstream emissions as well. A full lifecycle assessment (LCA) of transportation emissions should take into account all emissions from the key components that make up the nation’s transportation system: vehicles, fuels, and infrastructure (EPA, 2006).

EPA distinguishes three lifecycle stages in which emissions occur (EPA, 2006):

> 1. Upstream Emissions – Upstream emissions are those that occur before a product is used, including extraction of raw materials, processing, manufacturing, and assembly. Sources of upstream emissions include any fuel combustion associated with these processes, as well as “fugitive” emissions, such as venting and/or flaring of natural gas from oil wells or natural gas plants.
>
> 2. Direct Emissions – Direct emissions occur during the operation and maintenance of vehicles.
>
> 3. Downstream Emissions – Downstream emissions occur at the end of the lifecycle and are associated primarily with disposal. Sources of downstream emissions include fuel combustion used during disposal, collection of municipal solid waste, and landfills.

Figure 4.1 displays the conceptual framework for a detailed lifecycle assessment of transportation GHG emissions based on the modes, components and stages mentioned above.

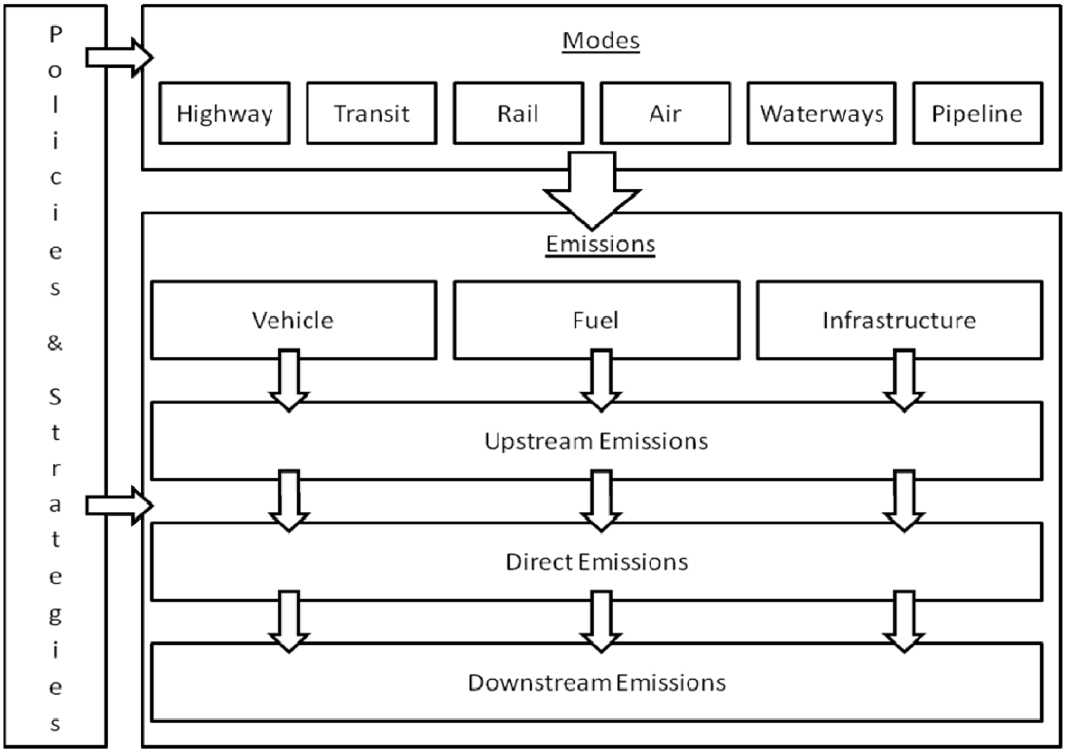

Figure 4.1: Conceptual Framework

A lifecycle assessment of transportation emissions can be useful in evaluating policies and strategies. This approach is increasingly used to compare emissions from different fuel types (EPA, 2006), but can also be applied to comparison of different vehicle technologies, and differences across transportation modes. The policy component is shown in Figure 4.1 as well.

4.2 Research Framework

This research will focus on passenger transportation only and will analyze emissions from passenger highway, bus transit, passenger rail, and passenger air. Freight modes are not included, so waterways and pipelines as a whole are outside the scope of this research. The lifecycle assessment will include three key components: vehicles, fuel and infrastructure. Recent results from the LCA literature are used to combine direct and indirect emissions on a per vehicle mileage basis, producing an estimate of the total "upstream" (EPA, 2006) plus direct CO_2 emissions from intercity travel activity. These indirect emissions estimates are approximate at this stage. Not only is the state-of-the-art in calculating such indirect emissions in its early stages as far as most transportation modes are concerned, but no two major studies have adopted the same set of activities to measure these emissions, or made the same assumptions regarding energy consumption rates from the individual activities they include in their "cradle-to-grave" LCA methodologies. Using selected values from the recent literature the research results are meant to be illustrative of the range of CO_2 emissions likely to be occurring. Downstream emissions (e.g. disposal of vehicles, oil products and infrastructure) are not included. The framework for this research is shown in Figure 4.2 as colored blocks.

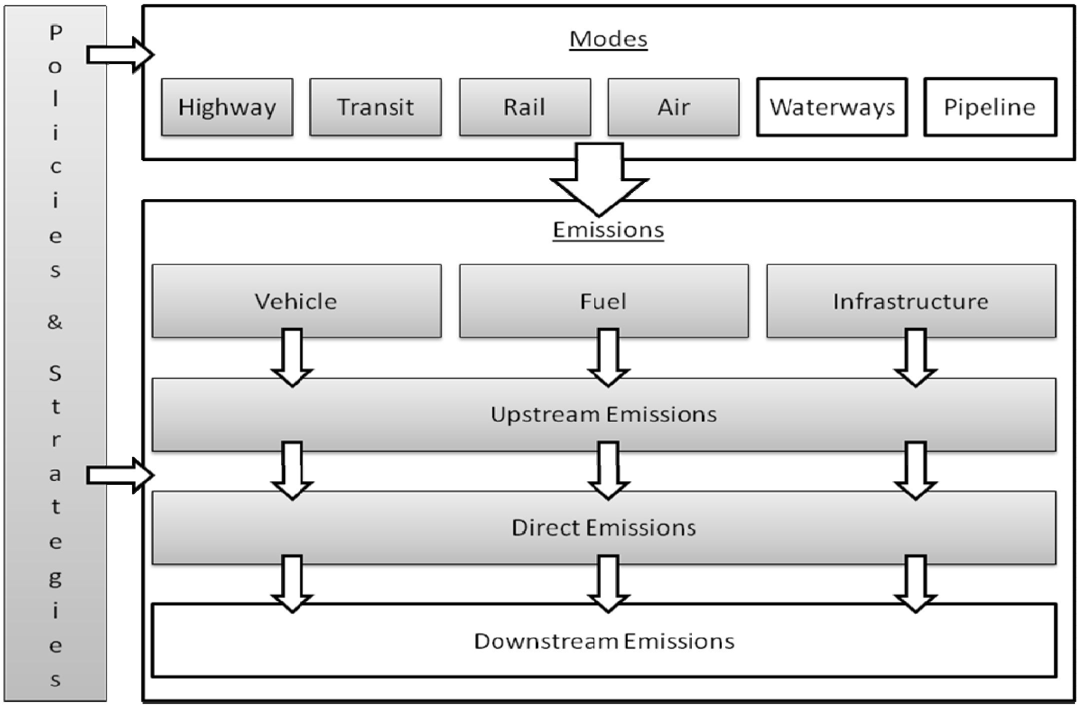

Figure 4.2: Research Framework

4.3 Research Approach

The research approach consists of six steps as shown in Figure 4.3.

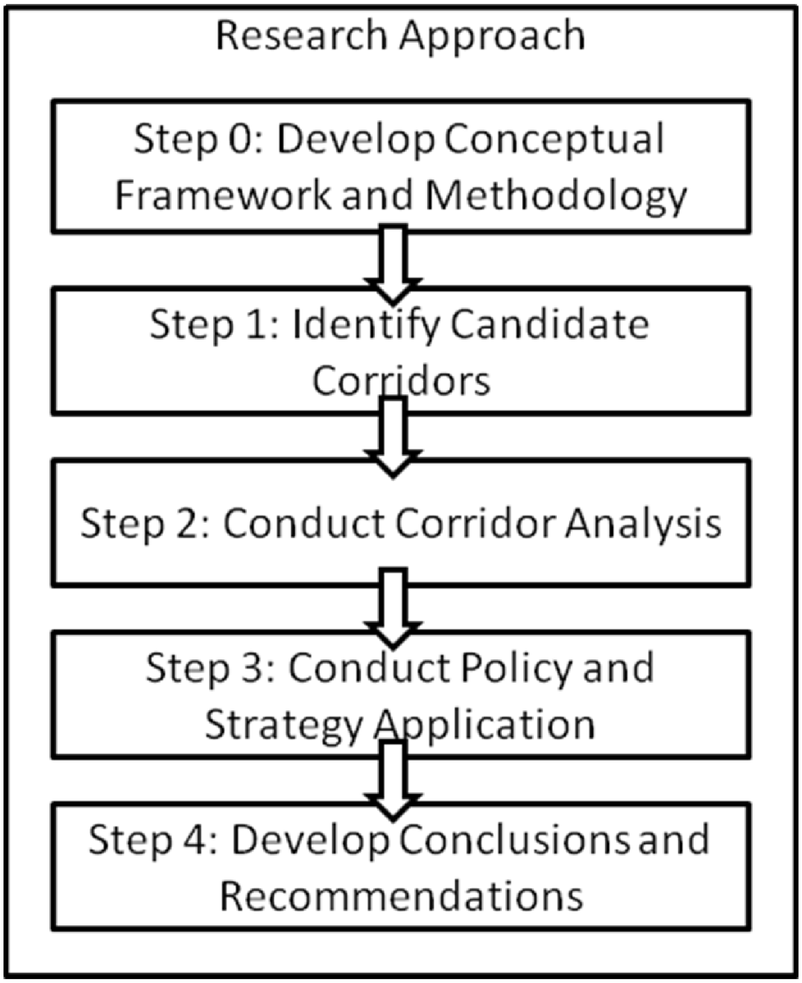

Figure 4.3: Research Approach

4.3.1 Step 0: Develop Conceptual Framework

The conceptual framework for a full lifecycle assessment for transportation emissions has been discussed above, as has the framework that will be used for this research. Based on this conceptual framework the methodology for developing intercity passenger transportation CO_2 emission inventories was developed. This methodology is shown in Figure 4.4 and was used for the analysis of several corridors and policy applications in the next steps.

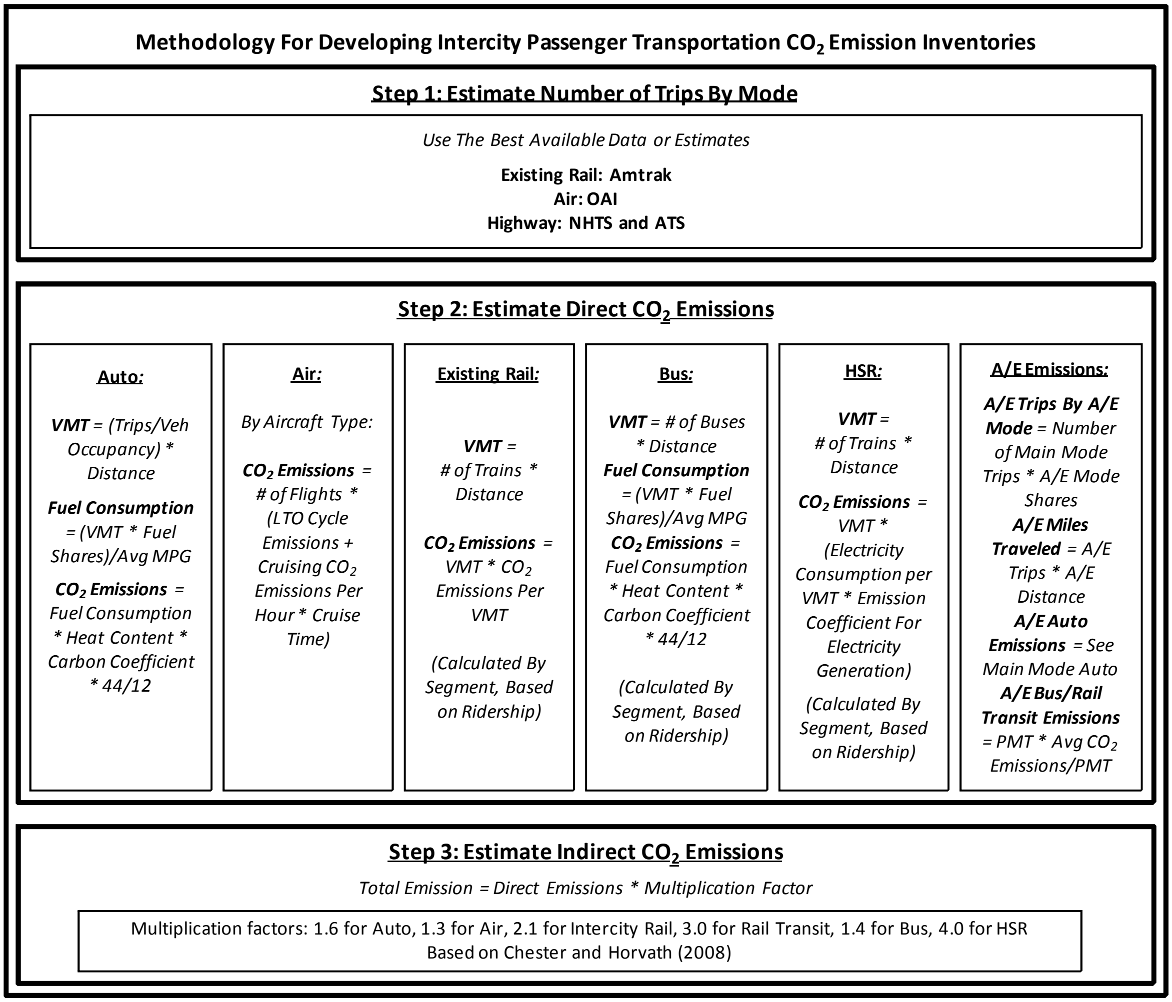

Figure 4.4: Methodology For Developing Intercity Passenger Transportation CO_2 Emission Inventories

4.3.2 Step 1: Identify Candidate Corridors

The methodology is developed with a special focus at the corridor level. Because of the increased interest in high-speed rail and its potential to reduce transportation GHG emissions, the three corridors selected for this study are federally designated high speed rail corridors. There are 11 such corridors in the U.S. (see Figure 4.5). Most of these corridors are still in the planning stages.

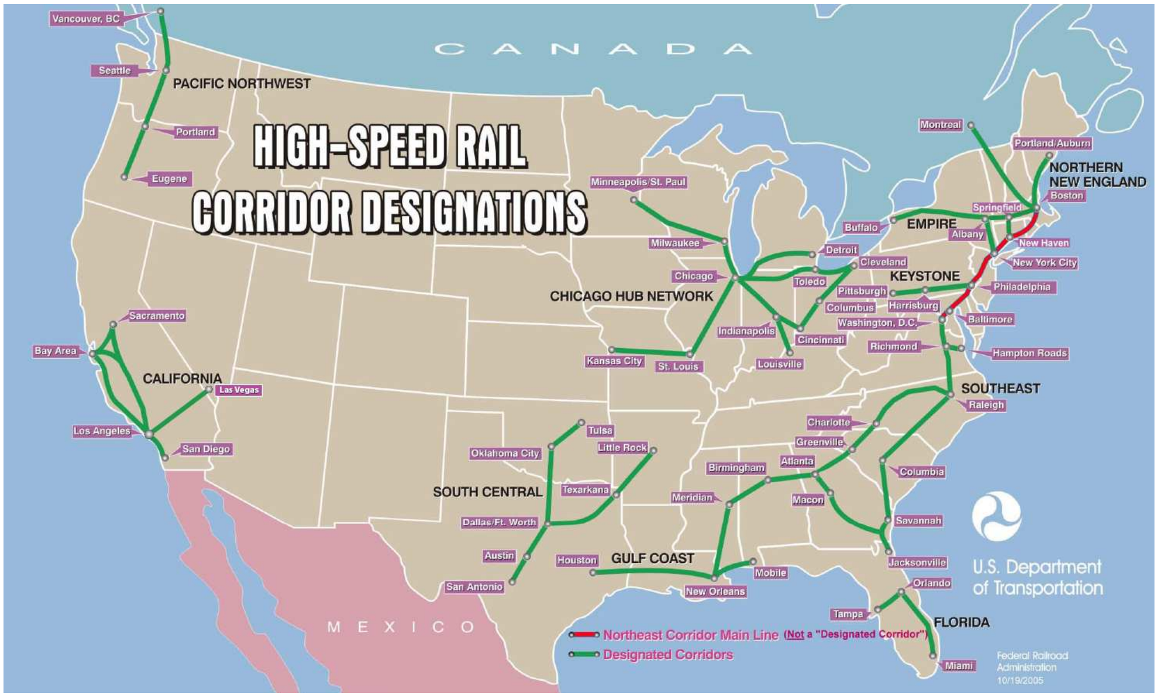

Figure 4.5: U.S. Designated High-Speed Rail Corridors

In addition to being a designated high-speed corridor, the three corridors were selected based on a maximum distance of 400 miles and data availability. The selected corridors are:[37]

1. **California.**

   California is pursuing continued improvements to existing passenger rail corridor services and a new high-speed rail (HSR) system. Since the 1980s, the State of California and Amtrak have made significant investments in equipment and facilities to develop three passenger rail corridor services: the San Joaquins (Bay Area/Sacramento–Central Valley, with bus connections to L.A.); Capitols (San Jose–Oakland–Sacramento–Auburn); and Pacific Surfliners (San Luis Obispo–L.A.–San Diego). In 2008, total intercity ridership on California's state-supported corridor trains–at 5.5 million–accounted for one fifth of Amtrak's passenger-trips nationwide. A strategic plan was prepared for improvement of the Pacific Surfliner Corridor from Los Angles to San Diego eventually running at speeds of up to 110 mph.

2. **Pacific Northwest**

   Designated as a high-speed rail corridor in 1992, this 466-mile route houses Amtrak corridor and long-distance trains, Sounder commuter services in the Seattle region, and the freight trains of the owning railroad companies (Union Pacific and BNSF). Amtrak's Cascades service links Eugene and Portland, Oregon with Tacoma and Seattle, Washington and Vancouver, British Columbia. Since its 1992 designation, the FHWA and FRA have jointly allocated $8.395 million for grade crossing improvements in this corridor, primarily between Portland and Seattle. Between 1994

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[37] Corridor description from: http://www.fra.dot.gov/Pages/203.shtml (last viewed on October 9, 2010)

and 2007, Washington (with participation from Oregon) invested a total of some $700 million from all sources to upgrade track and signal systems, renovate stations, and purchase trains to operate on the Pacific Northwest Corridor. Incremental improvements are planned to eventually support 110 mph service with greater frequencies on the Portland–Seattle–Vancouver portion of the corridor.

3. Keystone

The designated Keystone Corridor consists of two very different segments: Harrisburg–Philadelphia (Amtrak owned) and Harrisburg–Pittsburgh (Norfolk Southern owned). *East of Harrisburg:* Sharing some of the operating characteristics of the Northeast Corridor (NEC) main line, the Amtrak-owned and -operated Philadelphia–Harrisburg segment (104 miles) is a mature passenger corridor, with frequent intercity trains (14 round trips per average workday, most of which operate on the NEC beyond Philadelphia to New York) and commuter trains for part of the route near Philadelphia. This line has multiple tracks, full electrification, and almost complete grade separation from the highway grid. The remaining three public highway grade crossings on the Philadelphia–Harrisburg segment are being eliminated with current projects. Amtrak is planning additional improvements. Speed on the line is now up to 110 mph. Station improvements and new construction are being pursued at Lancaster and Elizabethtown. *West of Harrisburg:* In contrast with Amtrak's portion of the Keystone Corridor, the segment between Harrisburg and Pittsburgh is a heavy-duty freight railroad, owned and operated by Norfolk Southern (NS), with only one passenger train round trip per day, the Pennsylvanian (New York–Pittsburgh), over its mountainous topography.

Emissions are quantified for door-to-door travel in these corridors in detail. Modes to be analyzed include auto, bus, passenger rail and air.

4.3.3 Step 2: Conduct Corridor Analysis

Estimating intercity passenger GHG emissions inventories requires an extensive travel activity data set, a validated and established method of modeling long distance passenger travel movements either across the entire country or across a single state, and reliable data on life-cycle emissions. As has been discussed in Chapter 3, the state-of-practice of long-distance modeling in the U.S. is not sufficient for detailed analysis, data is scarce, and the state-of-the-art in calculating indirect life-cycle emissions is in its early stages as far as most transportation modes are concerned. Nonetheless, it is useful to use the best available data to demonstrate the proposed framework and model structure and to conduct a life cycle assessment of GHG emissions within the three corridors identified in step 1. The specific characteristics for each corridor will be taken into account. If possible, local detailed data was used. When better models and data become available, these should be used in the proposed framework and structure.

For highway (automobile, intercity bus), passenger rail and air travel, carbon dioxide emissions were estimated. The estimated emissions were based on life-cycle emissions, so in addition to end-use carbon emissions, fuel, vehicle, and infrastructure production emissions were taken into account. The UC Berkeley study by Chester and Horvath formed the basis for calculating these upstream emissions.

The main steps and data sources used for estimating intercity travel activities and emissions were:

1. Estimate 2008 AMTRAK ridership for city pairs within the corridor based on ridership by distance data provided by Amtrak for this study and Amtrak boardings data for each station
2. Estimate the number of trips for highway modes based on the results from step 1, 2008 OAI air travel activity data, and published average mode shares based on NHTS data.
3. Estimate direct “base-case” carbon dioxide emissions from travel activities by using published numbers on fuel efficiency, btu and carbon contents
4. Estimate indirect carbon dioxide emissions by using results from published life-cycle analysis studies.

The following sections explain these steps in more detail and present the results for the three corridor analyses using the steps above.

4.3.3.1 Step 2.1: Estimating 2008 AMTRAK ridership

For this study Amtrak provided ridership data by distance intervals of 100 miles for each of its routes. In addition, number of boardings and alightings data was available for each station on the different routes. Each city/station pair was categorized based on the 100 miles distance intervals and the number of boardings were used in a gravity model to estimate the ridership between the city pairs as follows:

$$T_{ij} = G_{ij} / \sum G_{\text{all city pairs}} * \text{Total Ridership For Distance Interval}$$

Where G is the gravity model used:

$$G_{ij} = (B_i * B_j)/d_{ij}^{\beta}$$

Where
B_i = Number of boardings and alightings in city i
B_j = Number of boardings and alightings in city j
d_{ij} = distance between city i and city j

β = parameter of transportation friction. The β value was calibrated to estimate ridership with a 90% accuracy. For the Cascades Route $\beta = 1$; Coast Starlight $\beta = 0.5$; Pacific Surfliner $\beta = 0.05$; Keystone $\beta = 0.1$; Pennsylvanian $\beta = 1.5$

If a station served more than one Amtrak route, the number of boardings and alightings for each of those routes was estimated based on total ridership ratios between the different routes. Table 4.1 presents the different Amtrak routes for each major city in the study corridors. For the California corridor, the Oakland train station was analyzed instead of San Francisco, since there is no direct train from San Francisco to Los Angeles.

Table 4.1: Amtrak Routes by City

Amtrak Routes By City/Station	
City	**Routes**
Eugene	Coast Starlight; Cascades
Portland	Coast Starlight; Cascades; Empire Builder
Seattle	Coast Starlight; Cascades; Empire Builder
Pittsburgh	Pennsylvanian; Capitol Limited
Harrisburg	Pennsylvanian; Keystone
Philadelphia	Pennsylvanian; Cardinal / Hoosier State; Acela Express; Keystone; Crescent; Carolinian/Piedmont; Northeast Regional; Silver Service/Palmetto; Vermonter
San Francisco/Oakland	Coast Starlight; San Joaquin; Capitol Corridor
Los Angeles	Southwest Chief; Texas Eagle; Pacific Surfliner; Coast Starlight; Sunset Limited
San Diego	Pacific Surfliner

Source: Amtrak (www.amtrak.com)

The system is assumed to be closed, meaning that, over time, the number of trips from city i to city j equals the number of trips from city j to city i. According to BTS data[38], national business travel accounted for 16% of all long distance travel in 2001 (2001 NHTS). According to the 1995 American Travel Survey (ATS), national business travel accounted for 22% [39]. In this study the 2001 share will be used and this share is assumed to apply to rail travel as well. The Amtrak Ridership estimates for the three corridors are shown in Table 4.2.

Table 4.2: Amtrak Ridership Pacific Northwest, Keystone and California Corridors

City Pair	Distance (miles)	Total Ridership (2008)	Business Ridership
Pacific Northwest			
Eugene – Portland	124	23,648	3,783
Portland – Seattle	186	86,203	13,792
Eugene - Seattle	310	4,757	761
Keystone			
Pittsburgh –Harrisburg	249	5881	940
Harrisburg – Philadelphia	104	35157	5625
Pittsburgh – Philadelphia	353	5000	800
California			
San Francisco – Los Angeles	381	1718	274
Los Angeles – San Diego	121	123395	19734
San Francisco – San Diego	502	898	143

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[38] http://www.bts.gov/publications/america_on_the_go/us_business_travel/html/entire.html

[39] http://www.bts.gov/publications/1995_american_travel_survey/us_profile/index.html

4.3.3.2 Step 2.2: Estimating number of trips for highway and air modes

As has been discussed in Chapter 3, currently there is no single database and no established method of modeling long distance passenger travel movements either across the United States or across a single state. From the recent examples of long distance travel demand studies presented in Chapter 3, the Volpe model seems to be most suitable for this study to estimate trip diversions when a new mode is implemented, but this model is not sufficient to estimate the absolute base number of trips by mode for the corridors in this study. To estimate the number of air trips, air activity data from the Office of Airline Information (OAI) was used. The results from step 2.1, the OAI air activity data, and published average mode shares served as a basis to estimate the number of trips for automobile and bus.

Table 4.3 shows the OAI Market trips for 2008 for the Pacific Northwest Corridor, the Keystone Corridor and the California Corridor. Business travel is assumed to account for 16% of all trips.

Table 4.3: OAI Air Market Trips (2008)

Total Trips Air - Pacific Northwest			
From\To	**Eugene**	**Portland**	**Seattle**
Eugene	0	54,572	58,057
Portland	57,357	0	435,449
Seattle	54,841	430,964	0

Business Trips Air - Pacific Northwest			
From\To	**Eugene**	**Portland**	**Seattle**
Eugene	0	8,732	9,289
Portland	9,177	0	69,672
Seattle	8,775	68,954	0

Total Trips Air - Keystone			
From\To	**Pittsburgh**	**Harrisburg**	**Philadelphia**
Pittsburgh	0	8,233	348,520
Harriburg	8,207	0	61,499
Philadelphia	330,120	58,563	0

Business Trips Air - Keystone			
From\To	**Pittsburgh**	**Harrisburg**	**Philadelphia**
Pittsburgh	0	1,317	55,763
Harrisburg	1,313	0	9,840
Philadelphia	52,819	9,370	0

Total Trips Air - California			
From\To	**San Francisco**	**Los Angeles**	**San Diego**
San Francisco	0	1,240,567	644,993
Los Angeles	1,240,152	0	241,242
San Diego	668,152	274,714	0

Business Trips Air - California			
From\To	**San Francisco**	**Los Angeles**	**San Diego**
San Francisco	0	198,491	103,199
Los Angeles	198,424	0	38,599
San Diego	106,904	43,954	0

The 2008-9 NHTS data does not give us any insight into modal trips by distance for trips longer than 31 miles. Therefore published 2001 NHTS numbers are used. According to the 2001 NHTS nearly 94% of the 100 to 249 mile business trips are by personal vehicle. In the 250- to 499-mile range, the personal vehicle's share of trips declines to 67%, while the airplane accounts for 31% of the trips. The ratios between OAI data and the estimated Amtrak ridership were used to calculate rail share for each corridor and the remainder was attributed to bus. Table 4.4 presents the ranges of mode shares used.

Table 4.4: Mode Shares Business Trips

Mode Shares - Business Trips (%)				
Distance (miles)	**Auto**	**Air**	**Rail**	**Bus**
100-249	94	3.5-4.5	1.3-2	0.5
250-499	67	31-32	0.5-1.3	0.5

The report ‘America on the Go’ (BTS, 2006) provides insight on mode shares for non-business trip purposes, which formed the basis for the estimation. Rail is based on the OAI/Amtrak ratio, and bus shares are adjusted to not exceed Greyhound’s capacity. This resulted in much lower bus shares than the national average (2%), but this can be explained by the fact that rail mode is an alternative for the corridors in this study, but is not currently an alternative for most parts of the U.S. The results are shown in Table 4.5.

Table 4.5: Mode Shares Non-Business Trips

Mode Shares - Non Business Trips (%)				
Distance (miles)	**Auto**	**Air**	**Rail**	**Bus**
100-249	96-97	1.5-2.75	0.75-1	0.5
250-499	90	8.25-9.5	0.75-1.25	0.5

Based on these mode shares the number of trips for the auto and bus modes and the total number of trips for each corridor was calculated. The air data served as the reference point, since this is the most reliable of the available data. The results for the three corridors are shown in Figure 4.6 and Table B.1 in Appendix B.

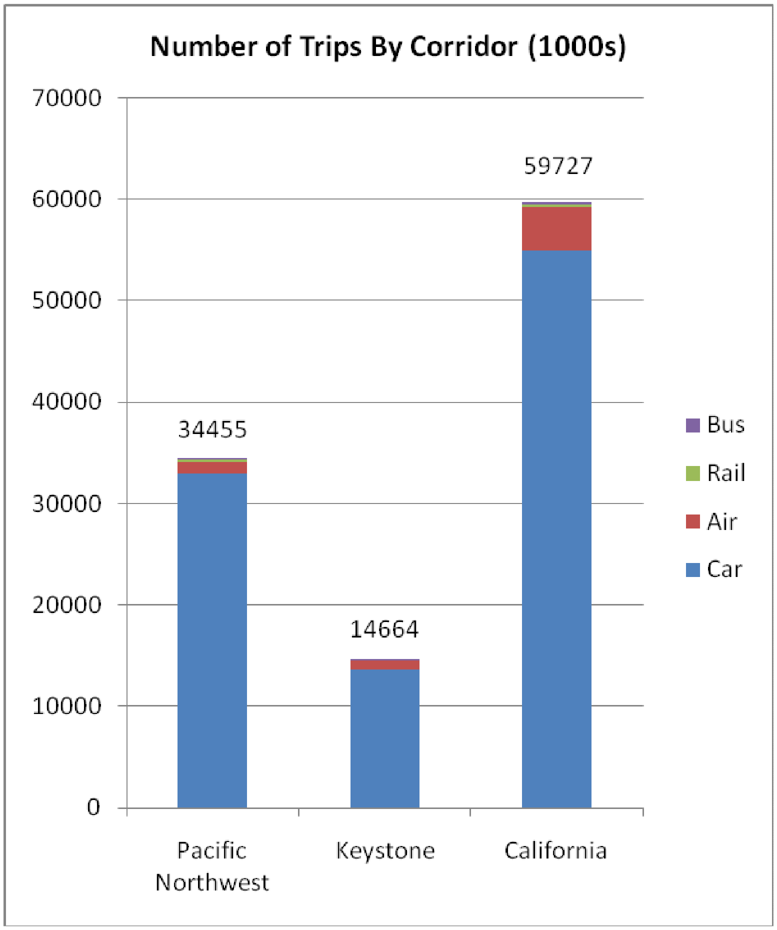

Figure 4.6: Total Number of Trips by Corridor

4.3.3.3 Step 2.3: Estimating direct "base case" carbon dioxide emissions

The results from step 2.2 formed the basis for estimating the direct transportation energy and carbon emissions for each mode.

Auto

For the calculation of automobile fuel consumption, two data sources were used. Oak Ridge National Laboratory's (ORNL) Transportation Energy Data Book[40] and FHWA's Highway Statistics Publications were used for the calculation of the average fuel consumption for cars. Table A.1 in the Transportation Energy Data Book reports the following automobile fuel shares:

Auto Fuel Shares (2008)	
Gasoline	0.728
Gasohol	0.267
Diesel	0.005

Highway Statistics reports a 2008 average miles traveled per gallon of fuel consumed of 19.7 mpg. Based on EPA's city and highway tests, this average is adjusted by a factor of 1.15 to reflect highway driving, resulting in 22.65 mpg. This average mpg was used for all three fuel types and was assumed to apply nationwide. By doing this the differences in the fuel mix across regions were not captured. These differences are taken to be comparatively small, especially when compared to other possible sources of variation in the available data.

The calculations in step 2.3 resulted in total passenger trips. For the calculation of the energy consumption and carbon emissions, vehicle miles are needed, which was calculated as follows:

Vehicle Miles Traveled = Passenger trips/Avg Vehicle Occupancy * distance between city pairs

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[40] http://cta.ornl.gov/data/Index.shtml

According to the 2001-2 NHTS the average vehicle occupancy for intercity travel is 1.6 passengers per vehicle.[41] By multiplying the vehicle miles by the fuel shares and dividing these values by the average mpg's, the number of gallons of fuel consumed for each city pair was calculated.

For the calculations of Btus and carbon emissions, published numbers for the heat and carbon content for different fuels were used. For gasohol the same values were used as those for gasoline[42]. These numbers are presented in Table 4.6.

Table 4.6: Default Energy and Carbon Content Coefficients

Heat Content for Fuels (Btu/gal)			
Gasoline	Diesel	Gasohol	LPG/Propane
125,000	138,700	120,900	91,300
Carbon Coefficients (Tg/QBtu)			
Gasoline	Diesel	Gasohol	LPG/Propane
19.34	19.95	19.34	16.99

By multiplying the total gallons of fuel consumed by the net heat content, the total Btus for each city pair were calculated. Multiplying these numbers by the carbon coefficients (reported in Table 4.6 as Tg/QBtu, or Teragrams per Quadrillion Btu) gives the

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[41] U.S. Department of Transportation, Bureau of Transportation Statistics. *National Household Travel Survey 2001*
http://www.bts.gov/programs/national_household_travel_survey/

[42] This approach was based on the description and carbon content numbers reported in the US Energy Information administration's (EIA) "ANNEX B. Methodology for Estimating the Carbon Content of Fossil Fuels" (2002), which reports gasohol as part of its average gasoline carbon content per Btu estimate.
http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/LHOD5MJQ62/$File/2003-final-inventory_annex_b.pdf

transportation carbon footprint for each city pair. Results were multiplied by 44/12 to convert from carbon to carbon dioxide (CO_2).

These steps result in the automobile emissions for the three corridors presented in Figure 4.7 and in Table B.2 in the Appendix.

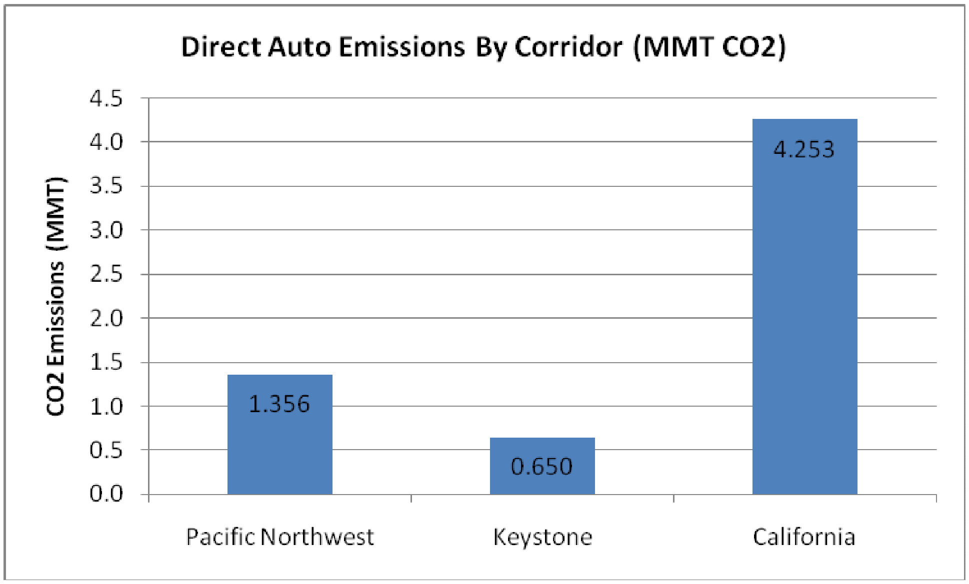


Figure 4.7: Automobile Emissions (in million metric tones)

Air

For the calculations of the air passenger transportation-related CO_2 emissions, published data on aircraft and engine specific emissions during landing and take-off cycles (LTO) and during cruising was used. These values were multiplied by the number of flights and by the cruise time, respectively. Only direct flights have been considered for this study, except for the Harrisburg-Pittsburgh connection, where there were none. The best connecting flights from Harrisburg to Pittsburgh and Pittsburgh to Harrisburg connect in Washington Dulles International Airport. For this city pair the emissions calculations were therefore split up into the two segments. For each segment the ratios between the number of trips for Harrisburg-Pittsburgh and the number of trips for Harrisburg-Washington and Pittsburgh-Washington were used to estimate the emissions that can be allocated to the Harrisburg-Pittsburgh travelers. Note that for the other city pairs in the study corridors all emissions for each flight were allocated to the city pair trips. By doing this, the fact that other connecting travelers, traveling through a city, may be on the flight as well is being ignored. Not enough data was available at this time to consider those trips. Table 4.7 summarizes the flight activity for the three corridors. For Harrisburg-Pittsburgh an aircraft combination is given, reflecting the connecting flights through Washington Dulles.

Table 4.7: Daily Plane Counts By City Pair

Plane Count by City Pair - Pacific Northwest

	Eugene			**Portland**			**Seattle**		
	Dash 8 Q400	Embraer 120	Canadair 700	Dash 8 Q400	Embraer 120	Canadair 700	Dash 8 Q400	Embraer 120	Canadair 700
Eugene	0	0	0	4	4	0	4	0	0
Portland	3	5	0	0	0	0	20	12	2
Seattle	4	0	0	20	12	2	0	0	0

Plane Count by City Pair - Keystone

	Pittsburgh					**Harrisburg**		**Philadelphia**				
	Airbus 319/320	Embraer 170/175 - CRJ700	Boeing 737	Boeing 757	Embraer 145 + Embraer 170/CRJ700	Dash 8 Q400	Embraer 170 + Embraer 145	Dash 8 Q400	Airbus 319/320	Embraer 170/175 - CRJ700	Boeing 737	Boeing 757
Pittsburgh	0	0	0	0	0	0	4	0	3	4	7	1
Harrisburg	0	0	0	0	4	0	0	9	0	0	0	0
Philadelphia	2	4	7	2	0	9	0	0	0	0	0	0

Plane Count by City Pair - California

	San Francisco				**Los Angeles**						**San Diego**					
	Airbus 319/320	CRJ700 /900	Boeing 737	Boeing 757	Airbus 319/320	Embr 120	Embr 140	CRJ700 /900	Boeing 737	Boeing 757	Airbus 319/320	Embr 120	Embr 140	CRJ700 /900	Boeing 737	Boeing 757
San Francisco	0	0	0	0	19	0	0	2	16	4	8	0	0	0	10	3
Los Angeles	19	2	18	4	0	0	0	0	0	0	0	10	12	14	0	0
San Diego	9	0	10	2	0	10	12	14	0	0	0	0	0	0	0	0

The aircraft-specific emission and fuel data are summarized in Table 4.8.

Table 4.8: Aircraft-specific emissions and fuel consumption

Aircraft Specific Emissions			
Aircraft Type	**LTO cycle CO_2 Emissions (kg/LTO)**	**Fuel Flow Cruising (kg/hr)**	**CO_2 Emissions Cruising (kg/hr)**
Airbus 319/320	2,560	2,600	8,190
Boeing 737	2,905	2,377	7,488
Boeing 757	4,110	3,120	9,828
Canadair 700/900	2,070	1,680	5,292
De Havilland Dash 8 Q400	945	1,000	3,150
Embraer 120	945	1,000	3,150
Embraer 140/145	1,500	850	2,678
Embraer 170/175	2,070	1,680	5,292
Embraer 190	2,700	2,500	7,875

Sources:
IPCC (1996)
Romano et al. (1997)
http://www.airlines-inform.com/commercial-aircraft/SAAB-340.html
http://www.aerospace-technology.com/projects/crj700/specs.html
http://www.airsimmer.com/support/index.php?showtopic=1072
http://cf.alpa.org/internet/alp/1999/mayQ400.htm
http://www.airliners.net/aviation-forums/tech_ops/read.main/145284/
http://www.flyvip.ru/eng/index.php?option=accatalog&Itemid=3&func=show&info=mnf&objid=8
http://www.b737.org.uk/techspecsdetailed.htm
http://www.airbaltic.com/public/fleet.html
http://www.pprune.org/african-aviation/294265-crj900-demonstrator-fajs-2.html

The results for CO_2 emissions from passenger air travel for the Pacific Northwest, the California and the Keystone Corridor are shown in Figure 4.8 and Table B.3.

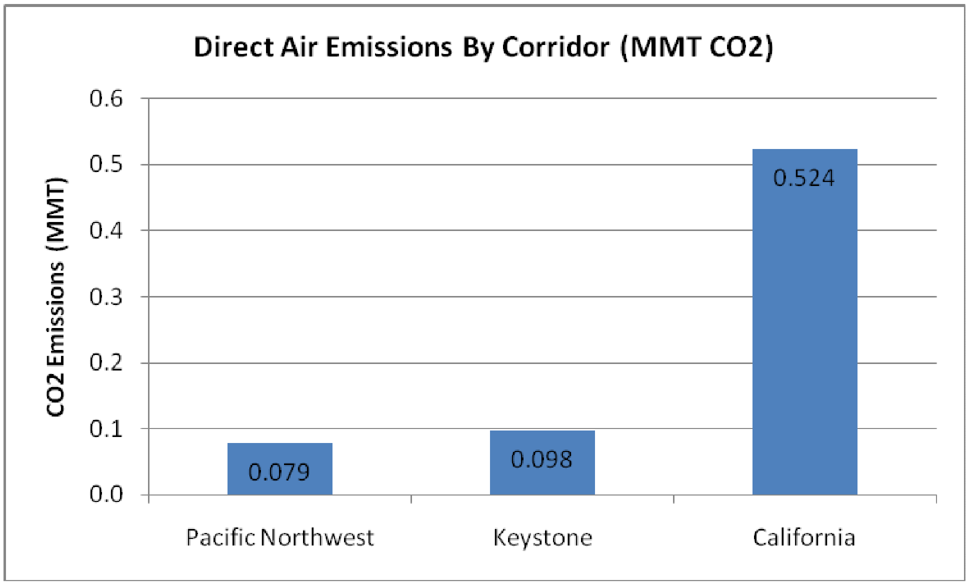


Figure 4.8: Air CO_2 Emissions (million metric tonnes)

Rail

Existing passenger rail CO_2 emissions are based on most commonly used diesel powered trains. Chester and Horvath (2008) estimated the operational CO_2 emissions per VMT for Amtrak's Caltrain at 11.4 kg/VMT. These numbers formed the basis for calculating emissions of the Amtrak trains in the corridors in this study. Within the study corridors, the same train service passes through all three cities in the corridors. Therefore, emissions have been calculated by segment, based on the ratio between passengers traveling from A to B and passengers traveling from A to C through B. By doing this, the emissions for each city pair were estimated proportionally to their share of ridership on a particular train. Even though the trains stop at several other stations in between two cities as well, this ridership has not been taken into consideration for the emission calculation due to lack of data.

The results for CO_2 emissions from passenger rail travel for the three corridors are shown in Figure 4.9 and Table B.4.

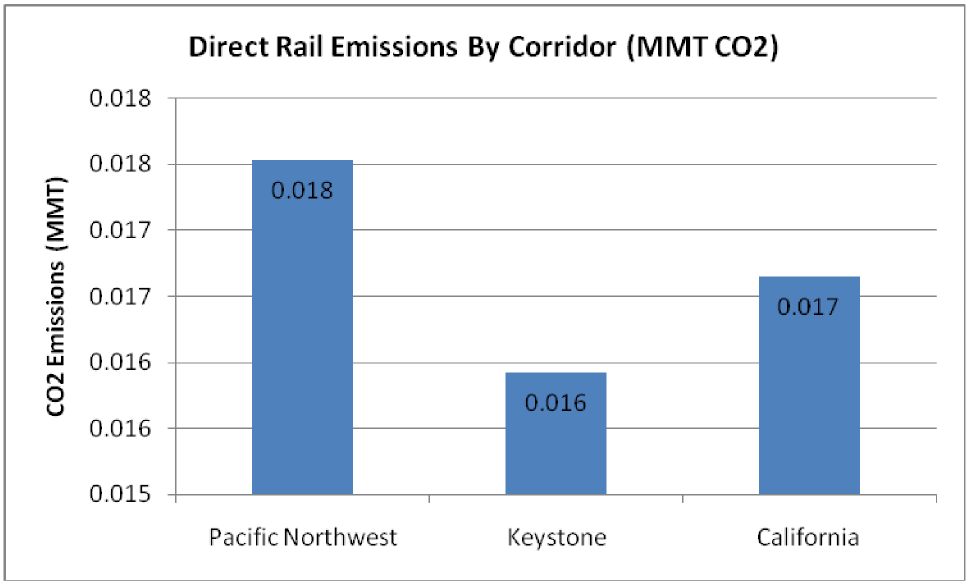


Figure 4.9: Rail CO_2 Emissions (million metric tonnes)

Bus

The emissions for bus travel were calculated in a similar way to auto emissions. According to the Eno Transportation Foundation (2007), fuel use for intercity buses is 100% diesel. According to FHWA's Highway Statistics Publications the average fuel consumption for buses is 6.1 mpg.

The bus VMTs can be calculated by multiplying the number of buses by the distance. Following the steps discussed in the auto section, the CO_2 emissions for bus travel can be calculated. Similar to rail, bus services pass through all three cities in the corridors. Bus emissions were therefore, similar to rail, estimated proportionally to the ridership share for a given city pair by segment.

The results for the three corridors are shown in Figure 4.10 and Table B.5.

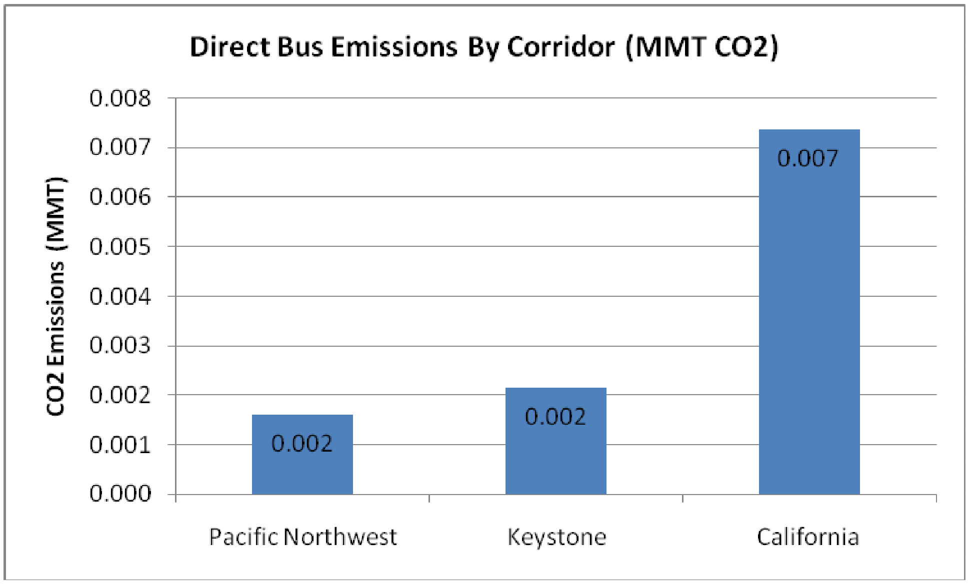


Figure 4.10: Bus CO_2 Emissions (million metric tonnes)

High Speed Rail

Emissions associated with High Speed Rail (HSR) travel are based on electric rail service. Chester and Horvath (2008) estimated the operational electricity consumption for the Swedish X2000 high speed rail system at 32 kWh/VMT. By multiplying this consumption by the GHG Emissions coefficient for electricity generation (See Table 4.9) the emissions per VMT were calculated for each corridor. Multiplying this by distance and number of trains gave the emissions for each corridor. Like existing rail and bus, HSR emissions for each city pair were calculated proportional to their ridership share.

Table 4.9: GHG Emission Coefficient for Electricity Generation

CO_2 Emission Coefficient Electricity Generation	
State	kg CO_2/kWh
Washington	0.123
Oregon	0.184
Pennsylvania	0.557
California	0.301

Source: EIA (2008b) Table A-1
For the Pacific Northwest Corridor, the average for Washington and Oregon was used to calculate emissions

High speed rail emissions for each corridor are presented and further discussed in 'Step 4: Conduct Policy and Strategy Application'.

Access and Egress Transportation Emissions

For the modes air, rail, HSR and bus, it is important to incorporate the emissions from traveling to and from the airport or station into the carbon emissions inventory. Access and egress emissions were calculated based on the mode share used for transportation to and from airports and stations for each city. A 2008 report from the Airport Cooperative Research Program (Coogan, 2008) provides a summary of ground access services to

America's airports for major cities. The ACRP's findings were used in this study to estimate transportation activity by mode to and from the airports and stations in the corridors. For cities that were not included in the ACRP report (Eugene, Pittsburgh and Harrisburg), averages for the region were used. For cities that do have rail transit, but not to the airport (Pittsburgh, Los Angeles and San Diego), estimates were made for A/E mode shares to train and bus stations based on averages from cities that do have rail transit to the airport. The mode shares for 2008 for the study corridors are presented in Table 4.10.

Table 4.10: Access and Egress Mode Shares

Access/Egress Mode Shares (%)			
City	**Highway**	**Bus/Van**	**Rail**
Eugene	91[a]	9[a]	0[a]
Portland	90	4	6
Seattle	89	11	0
Pittsburgh	94 (93)[a,b]	6 (4)[a,b]	0 (3)[a,b]
Harrisburg	94[a]	6[a]	0[a]
Philadelphia	93	4	3
San Francisco	77	16	7
Los Angeles	87 (83)[b]	13	0 (4)[b]
San Diego	91 (87)[b]	9	0 (4)[b]

Source: Coogan (2008)
[a] Estimated based on region
[b] A/E mode shares for Rail/Bus as main mode are in parenthesis if different than Air

These shares were multiplied by the total number of trips for each main mode (air, rail, bus) to get the number of access and egress trips by A/E mode by Main Mode. The number of trips were then multiplied by the average A/E distance to get the A/E Passenger Miles Traveled (PMT) by A/E mode. The average A/E distance was based on city size, and number and location of airport/stations. Distances to bus and train stations are assumed to be the same. The average A/E distances for main modes air, bus and rail for each city are presented in Table 4.11. The total A/E distances for a city pair (origin + destination) is the sum of A/E distance for each city.

Table 4.11: Access and Egress Distances

Access/Egress Distances (miles)		
City	**Main Mode Air**	**Main Mode Rail/Bus**
Eugene	15	10
Portland	20	15
Seattle	25	15
Pittsburgh	25	10
Harrisburg	15	10
Philadelphia	20	15
San Francisco	15	10
Los Angeles	30	20
San Diego	20	15

The emissions for A/E mode auto were calculated the same way as has been described in the section on auto as main mode, using VMT, fuel shares, average MPG, heat contents and carbon coefficients. The emissions for A/E mode bus and rail were calculated by multiplying the PMT for each mode by published data on carbon emissions per PMT for both modes (bus/van: 100gC/PMT; rail transit: 40gC/PMT (Chester and Horvath, 2008)). This average does not take into consideration the differences per city, for example, in electricity mix.

The total direct access and egress emissions as well as the share of these emissions compared to the main mode emissions are presented in Figure 4.11 and Table B.6.

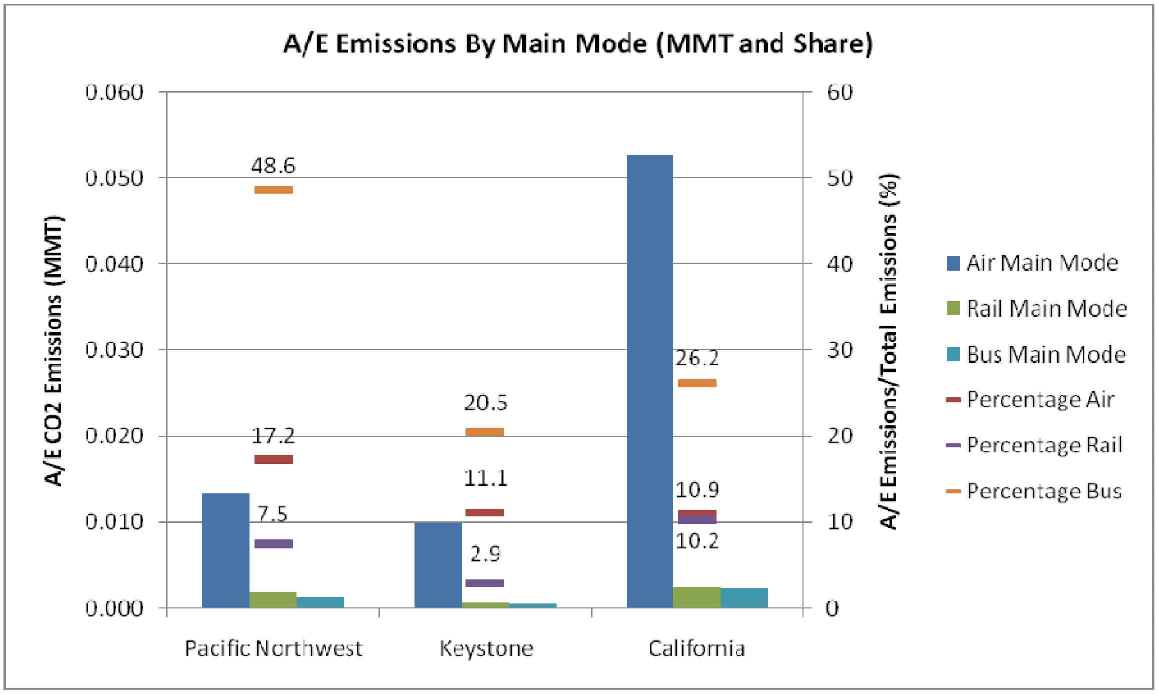


Figure 4.11: Access and Egress CO_2 Emissions by Main Mode (million metric tones and share).

The results show that the A/E emissions especially account for a very large share of total emissions for main mode bus (about 20-50%). Since the A/E distance and mode share for rail and bus were assumed to be the same, this much larger share must be a result of the lower emissions per passenger for bus than for rail (and air). The A/E distances and A/E mode shares are more favorable for the Pacific Northwest corridor than for the California and Keystone corridor, so the higher A/E emissions share for the Pacific Northwest can be a result of lower bus emissions in this corridor. For all three corridors the same bus type with the same fuel efficiency was used, so the lower bus emission solely come from the shorter travel distances in this corridor compared to the others.

The A/E emissions share for main mode air range from 11-17%. As can be seen from Table 4.11, the A/E distance to airports is generally longer than for Rail/Bus resulting in higher A/E emissions. As mentioned above, the A/E distances and A/E mode shares are more favorable for the Pacific Northwest corridor, so, like bus, the higher share for the Pacific Northwest can be a result of lower aircraft emissions in this corridor. These lower emissions are a result of the shorter flight distances for the Pacific Northwest Corridor compared to the California and Keystone corridor and of the aircrafts used in this corridor. The main aircraft used in the Pacific Northwest corridor are the Dash 8 and the Embraer 120, which have among the lowest emissions of all aircraft types used in the three study corridors (see Table 4.8).

The A/E emissions share for rail is the lowest, meaning that, with all A/E characteristics for each different main mode being very similar, the emissions for rail are the highest per passenger. With increased ridership and higher load factors, this can change significantly in favor of rail emissions.

4.3.3.4 Step 2.4: Estimating indirect carbon dioxide emissions

The life-cycle assessment results reported by Chester and Horvath (2008) were used to factor up the direct vehicle activity-based emissions to a more complete representation of the life-cycle CO_2 emissions associated with each transportation mode. Their method quantifies energy inputs and emissions associated with the entire life cycle of the fuels, vehicles, and also many of the built infrastructures (roadways, tracks, terminals, depots, parking structures, offices, etc) and other support activities (notably insurance) required to support these vehicle movements. They accomplish this using a combination of the two most common forms of LCA: a highly detailed process model that quantifies each of the resource inputs and environmental outputs at each stage in the vehicle, fuel, or infrastructure production process, and an economic input-output analysis that integrates traditional I/O modeling with environmental databases to produce an inventory analysis of the entire supply chain associated with a product or service (see Hendrickson et al, 1998; Green Design Institute, 2009). They conclude that "Current results show that total energy and greenhouse gas emissions increase by as much as 1.6X for automobiles, 1.4X for buses, 2.6X for light rail, 2.1X for heavy rail, and 1.3X for air over operation." Looking at the report by Chester and Horvath in more detail, the emission factors for electricity generation are off by about 30%, most likely due to electricity generation energy losses due to efficiency. This especially affects the indirect emission factor for modes using electricity as direct power source. The factor 2.6 for light rail is therefore adjusted to reflect this 30% difference and a factor of 3.0 was used in this study. Even though electricity is used in some form for the other modes' lifecycles, the effect is much smaller and the upstream factors are therefore not adjusted.

"Downstream" emissions, including the emissions resulting from any form of materials re-cycling or salvage operations were not included in any of these numbers. They are expected to be quite small compared to the rest of each mode's LCA emissions.

The total emissions (direct + indirect) for each corridor are presented in Figure 4.12 below and in Table B.7 and B.8.

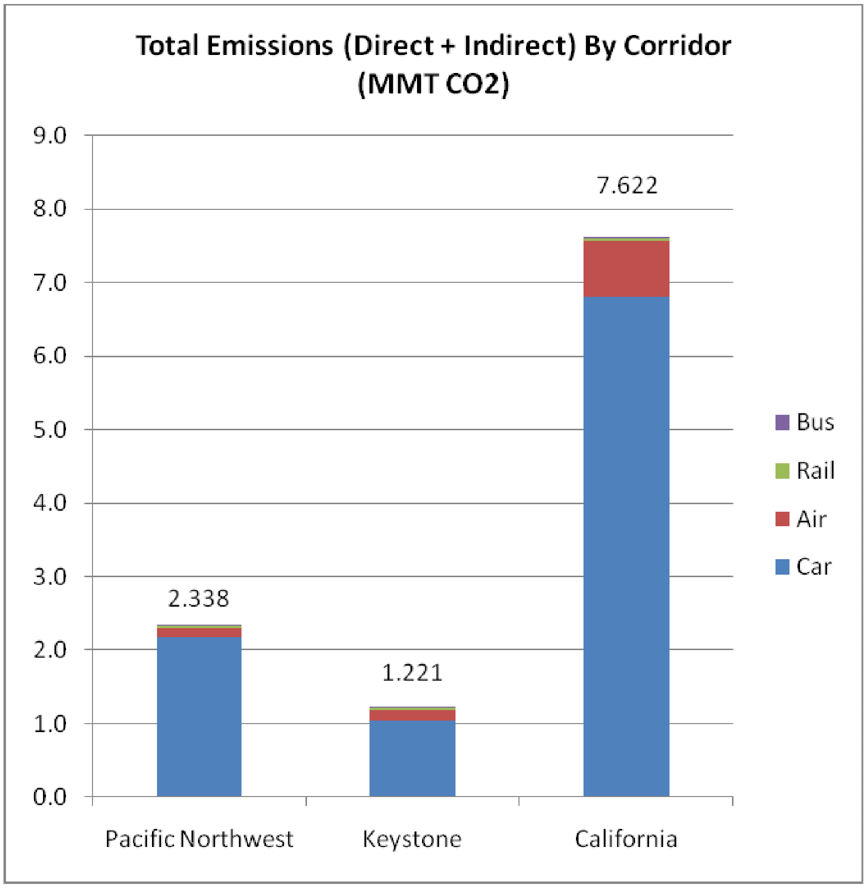
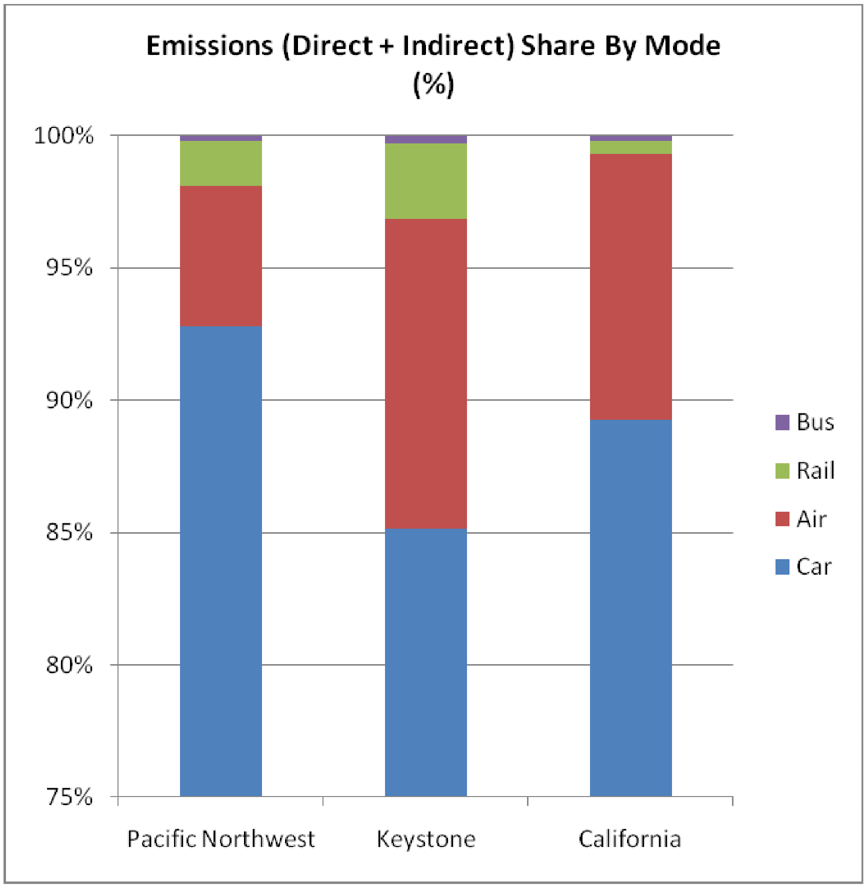


Figure 4.12: Total Direct and Indirect Emissions by Corridor



4.13: Share of Total CO_2 Emissions (Direct + Indirect) By Mode By Corridor

As can be seen from Figure 4.12, the total emissions in the Pacific Northwest corridor are almost twice as much as the Keystone corridor and California is more than six times higher than Keystone. Figure 4.13 shows that the share of auto emissions is the highest for the Pacific Northwest corridor (about 93%) compared to Keystone (85%) and California (89%). Air emissions account for 5% of the total emissions for the Pacific Northwest corridor, 12% for the Keystone corridor, and 10% for the California corridor. These differences, especially regarding the Pacific Northwest, are mainly a result of the different travel distances in the corridors resulting in different auto and air shares. In addition to that, the aircraft types used in each corridor contribute to the difference. In the

Pacific Northwest corridor the main aircraft types in operation are propeller aircrafts (Dash 8 and Embraer 120) while the Keystone and California corridors mainly operate jet aircrafts (Boeing 737, Airbus 319/320, Canadair 700). The propeller aircrafts emit less CO_2 than the jets. Regarding rail the California corridor has the lowest share of total emissions, mainly because the rail service between San Francisco and Los Angeles is very scarce with only one train a day.

4.3.3.5 Summary of Assumptions and Caveats

The above results must be treated as approximate and descriptive in nature. The analysis was based on the use of readily available data sets and models and the accuracy of the estimates is therefore dependent on such inputs. In particular, the accuracy of the final carbon estimates depends heavily on the following factors and assumptions:

- the consistency across the various regions of the country in mode shifts
- the lack of detailed data on especially the number of intercity highway trips
- the lack of sophisticated long-distance demand models
- the average mpg for autos was used for all three fuel types and is assumed to apply nationwide. By doing this the differences in the fuel mix across regions are not captured. These differences are taken to be comparatively small, especially when compared to other possible sources of variation in the available data
- only direct flights were considered for this study, except for the Harrisburg-Pittsburgh connection, where there were none

- the average electricity consumption for the trains in the study corridors is assumed to be the same as Amtrak's Caltrain in California. Reliable energy consumption and emissions data was difficult to find
- bus shares in the corridors are assumed to be much lower than the national average since rail is an alternative mode in the corridors in this study and is not for a large part of the U.S.
- data on access and egress mode shares is relatively scarce for most cities and estimates were based on airport access and egress mode shares. These are assumed to be the same for train and bus stations in most cases
- the state-of-the-art in calculating indirect emissions is in its early stages as far as most transportation modes are concerned
- downstream emissions from the disposal of vehicles and infrastructure are not included in the estimates
- air emissions were estimated independently from the altitude where they occur. By doing this the potential difference in impact of emissions in atmosphere, troposphere, and stratosphere are not captured.

4.3.4 Step 3: Conduct Policy and Strategy Application

For the three corridors analyzed in step 2, the potential impacts of various policies and strategies on emissions were estimated. The detailed analyses provided the opportunity to analyze policies and strategies within a given corridor and to compare potential impacts between different corridors. The main policy areas examined were vehicle and fuel technologies and mode shifts, for example as a result of introducing HSR or carbon taxes. The focus will be mainly on auto, air and rail modes.

As has been discussed in Chapter 2.4.2, new and improved vehicle and fuel technologies are expected to make major contributions to GHG emissions reductions. Some technologies even have the potential to reduce direct emissions by almost 100% in the long-term, e.g. biofuels and electric vehicles using renewable energy. This study only focuses on technologies and strategies that are could be implemented within the next 10-20 years.

Based on Chapter 2, the policy questions that will be answered in this step of the analysis for each of the three corridors were:[43]

1. What impact will an average fuel economy of 35.5 mpg have on carbon emissions?
2. What impact will a 10% market share for all-electric vehicles have on carbon emissions?
3. What impact will a 25% gasoline use replacement with cellulosic ethanol have on carbon emissions?

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[43] Note that for all policies/technologies it is assumed that they are indeed possible and that the technologies will be competitive.

4. What impact will a 20-35% improvement in aircraft emissions have on carbon emissions?
5. What impact will the introduction of high-speed rail have on carbon emissions?
6. What impact will a carbon tax have on carbon emissions?
7. What type of policy has the largest potential impact and where?

The analysis of impacts of various policies and strategies on emissions will not look at cost-effectiveness, although such analyses are very important to decision making. The vulnerability of the U.S. economy will have a significant impact on the transportation financial situation, increasing the need for cost-effective measurements. Further research on the cost-effectiveness of the different policies and strategies is clearly needed.

4.3.4.1 <u>What impact will an average fuel economy of 35.5 mpg have on carbon emissions?</u>

As has been discussed in previous sections, the automobile is the main mode of intercity transportation with a mode share of more than 95% of long distance trips up to 249 miles. In addition to that, the automobile is also the main mode for access and egress transportation to and from airports and bus and train stations, accounting for over 90% mode share for most cities. Strategies targeting automobile emissions therefore have great potential to achieve significant emission reductions.

The impact of President Obama’s fuel economy goal of 35.5 mpg on total carbon emissions in the study corridors has been analyzed compared to the base case with no HSR. Even though the fuel economy goal was set for 2016, this study analyzed carbon emission savings for the base year 2008, i.e. it examined savings that could have been achieved if the average fuel economy for 2008 was 35.5 mpg, instead of 19.7 mpg. Although greater fuel efficiency could result in savings for the consumer and a lower cost per mile, in this analysis the cost of automobile travel was not adjusted, mainly due to the assumption that the loss in tax revenue due to fuel efficient vehicles will be offset by other transportation pricing strategies like VMT-based pricing. The potential impact for the Pacific Northwest, the Keystone and the California corridors are shown Figure 4.14 and Table C.1 in Appendix C.

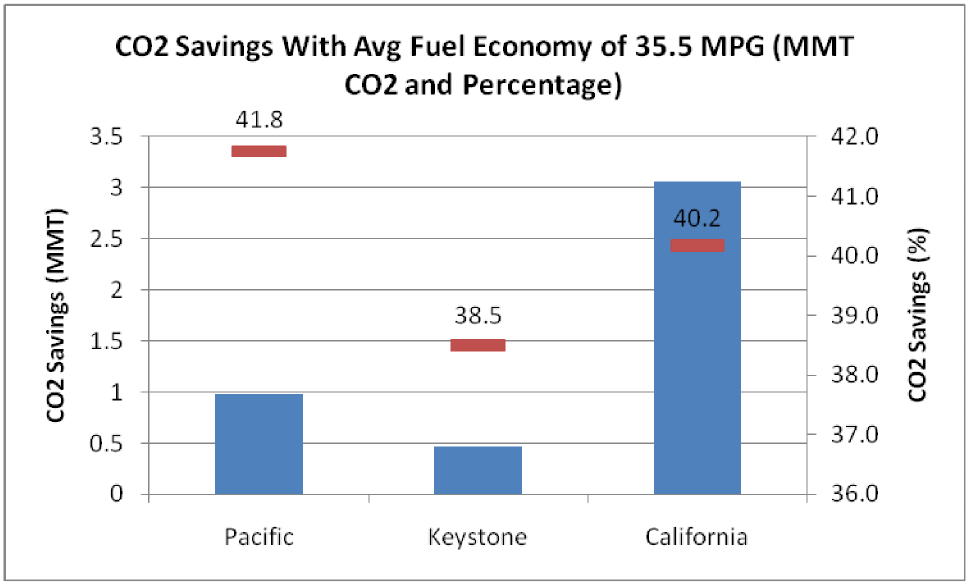

Figure 4.14: CO_2 Savings With Average Fuel Economy of 35.5 mpg (total and percentage)

The CO_2 emissions savings from an average fuel economy of 35.5 mpg ranges from 0.5 to 3 million metric tones CO_2 or about 38-42% of total emissions within each corridor. The total savings are the highest for the California corridor, since the total emissions, and thus potential savings, are much higher in this corridor than in the Pacific

Northwest and Keystone corridor. From Figure 4.13 in Step 2.4, it can be seen that the share of auto emissions is the highest for the Pacific Northwest corridor, and therefore the percentage savings is higher for this corridor than for the others as can be seen in Figure 4.14.

4.3.4.2 What impact will a 10% market share for all-electric vehicles have on carbon emissions?

Nissan's expectations for electric vehicles are that “more than 10% of its entire fleet will be all-electric by 2020” (see Chapter 2). All-electric vehicles do not have tailpipe emissions, however, the emissions from electricity generation have to be incorporated in the analysis to make a fair comparison. Today Nissan’s electric car, the Leaf, has a 42 kWh battery pack and a 100 mile range, resulting in 0.42kWh/mile energy consumption. Multiplying this by 10% of the total VMT gave the total energy used by electric cars. The GHG emissions were calculated by using EIA’s emission coefficients for electricity generation by state (see Table 4.9).

It should be noted that the range of electric cars that are on the market today is only 50-100 miles. These electric cars would not be suitable for long-distance trips so great improvements need to be made in order for the electric car to compete with fuel-powered cars for intercity trips. For this analysis the assumption was made that it is possible to increase the ranges of electric cars significantly in the near future and that a 10% market share will be achievable for long-distance traveling as well. The cost per mile as well as the upstream emissions factor were assumed to be the same for electric and gas-powered cars.

The potential impact for the three corridors is shown in Figure 4.15 and Table C.2.

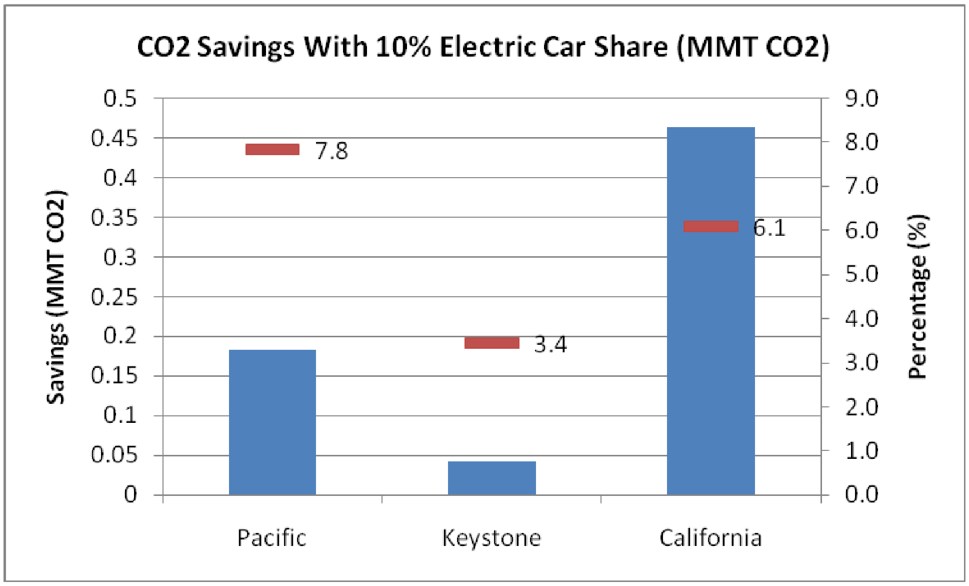

Figure 4.15: CO_2 Savings by Corridor with 10% market share for electric cars (total and percentage)

A 10% market share for electric vehicles results in potential CO_2 savings of 3.4-7.8% for the three study corridors. As can be seen in Figure 4.15, a 10% market share has the largest impact on CO_2 savings for the Pacific Northwest and the lowest impact in the Keystone corridor. This is a result of two corridor characteristics. First of all, the large share of auto emissions for the Pacific Northwest compared to the other corridors, causes auto related policies/strategies to have the largest impact in this corridor, as was the case with the MPG increasing policy discussed above. Secondly, the emission coefficients for electricity generation differ quite a bit among the three corridors. The Pacific Northwest has the lowest amount of GHG emissions per energy output since a lot of power is generated from renewable sources (especially hydropower), while Pennsylvania has the highest amount of GHG emissions per energy output (mainly coal-based power generation). California's emission coefficient lies in between. This greatly effects the overall savings for electric vehicles and results in the fact that the impact in the Keystone corridor is less than half the size of the impact in the Pacific Northwest corridor.

4.3.4.3 What impact will a 25% gasoline use replacement with cellulosic ethanol have on carbon emissions?

As has been mentioned in Chapter 2, cellulosic ethanol may prove to be an important fuel alternative to gasoline and diesel which could cut CO_2 emissions significantly. Cellulosic ethanol is produced from grasses, wood, or non-edible parts of plants. Although corn-based ethanol is easier and less expensive to produce, cellulosic biomass is cheaper to produce than corn, because it requires less energy input, fertilizer and herbicides. Its net GHG reduction is therefore higher than corn-based ethanol. In addition, cellulosic ethanol causes less soil erosion and improved soil fertility compared to corn-based ethanol; cellulose can be grown all over the world and is not used for food; and unlike corn, cellulose poses fewer threats to biodiversity.[44]

Although some studies argue that corn ethanol has a negative net energy value, the majority of studies published in the last 10 years show a positive net energy value for corn ethanol (Wang, 2007). Life-cycle analysis at Argonne National Laboratory (Argonne's Greenhouse gases, Regulated Emissions and Energy use in Transportation (GREET) Model) shows that, per energy unit (BTU), corn ethanol could reduce GHG emissions by 19% to 52% compared to gasoline. According to GREET's calculations,

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[44] http://genomicscience.energy.gov/biofuels/benefits.shtml

cellulosic ethanol can offer an even greater benefit: an 85% reduction in GHG emissions per energy unit compared to gasoline (Wang, 2007).

For this study GREET's findings for GHG reduction from cellulosic ethanol compared to gasoline were used to estimate the potential impacts of replacing one-quarter of gasoline use with cellulosic ethanol for the three study corridors. The gasoline and ethanol comparison and the CO_2 savings were analyzed on a energy unit basis (BTU), since one gallon of gasoline contains more energy (125,000 BTU) than one gallon of ethanol (84,100 BTU). The BTU and CO_2 emissions from 25% of the direct gasoline use was therefore first calculated. Since GREET's comparison is based on a well-to-wheel analysis the upstream emissions from gasoline production and transportation will need to be factored in. A factor 1.2 was used which reflects both GREET's analysis as well as Chester and Horvath's. The result gave the CO_2 emissions for 25% of the gasoline use in the corridor. Since cellulosic ethanol shows an 85% reduction in GHG emissions per energy unit, this result was multiplied by 0.15 to get the CO_2 emissions from the ethanol use. In order to still incorporate the upstream emissions from vehicle manufacturing and maintenance, roadway construction, etc., the upstream factor 1.4[45] was used to estimate ethanol's direct + indirect CO_2 emissions. For this analysis the fuel shares for gasohol and diesel were kept the same.

The potential impacts of replacing one-quarter of gasoline use with cellulosic ethanol for the three study corridors are shown in Figure 4.16 and Table C.3.

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[45] Note that this factor is lower than the 1.6 used for the other auto indirect calculations. This is because the factor for fuel production and transportation is included in the gasoline and ethanol comparison already.

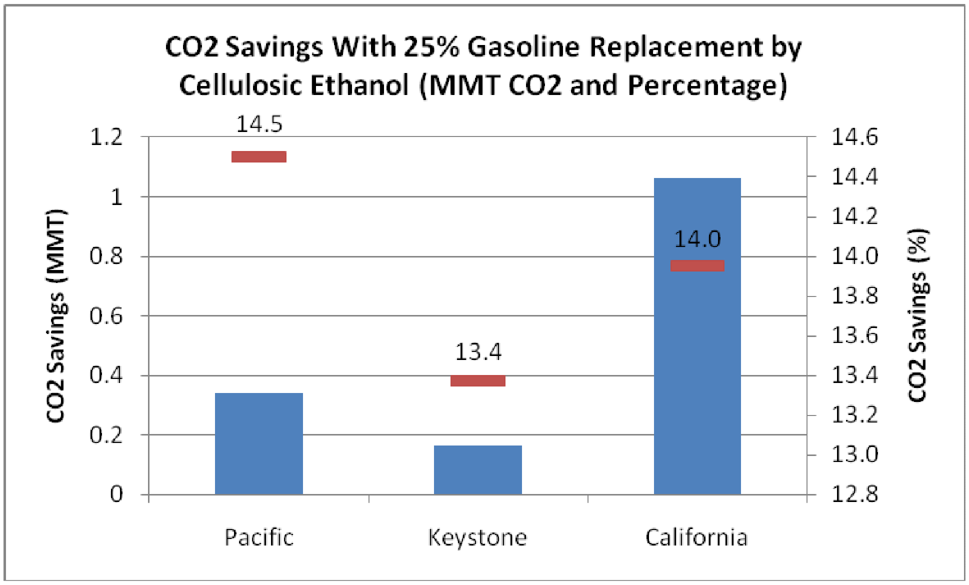

Figure 4.16: CO_2 For 25% Gasoline Replacement With Cellulosic Ethanol

Replacing 25% of gasoline use with cellulosic ethanol can have a positive impact on CO_2 emissions of about 13.4-14.5%. Like the previous two policies, this impact is the greatest in the Pacific Northwest corridor due to the overall share of auto emissions in this corridor. The differences between the three corridors are similar in size as with the MPG improvement policy, since the emissions resulting from ethanol production were assumed to be the same for all three corridors. For the electric vehicle strategy, the power source and its emissions *were* adjusted for each corridor, resulting in larger differences between the three corridors. Total savings are the highest for the California corridor again, due to the current total travel activity and emission in this corridor.

4.3.4.4 What impact will a 20-35% improvement in aircraft emissions have on carbon emissions?

According to IATA, the CO_2 emissions reduction potential range is between 20 and 35% for new aircrafts in 2020 compared to existing planes, achieved mainly from the engine type and the use of laminar flow. Although a 20-35% reduction is significant, including the access and egress emissions as well as all emissions from the other modes will decrease its impact on the emissions as a whole by a very large factor. The potential impacts for the three corridors are shown in Figure 4.17 and Table C.4.

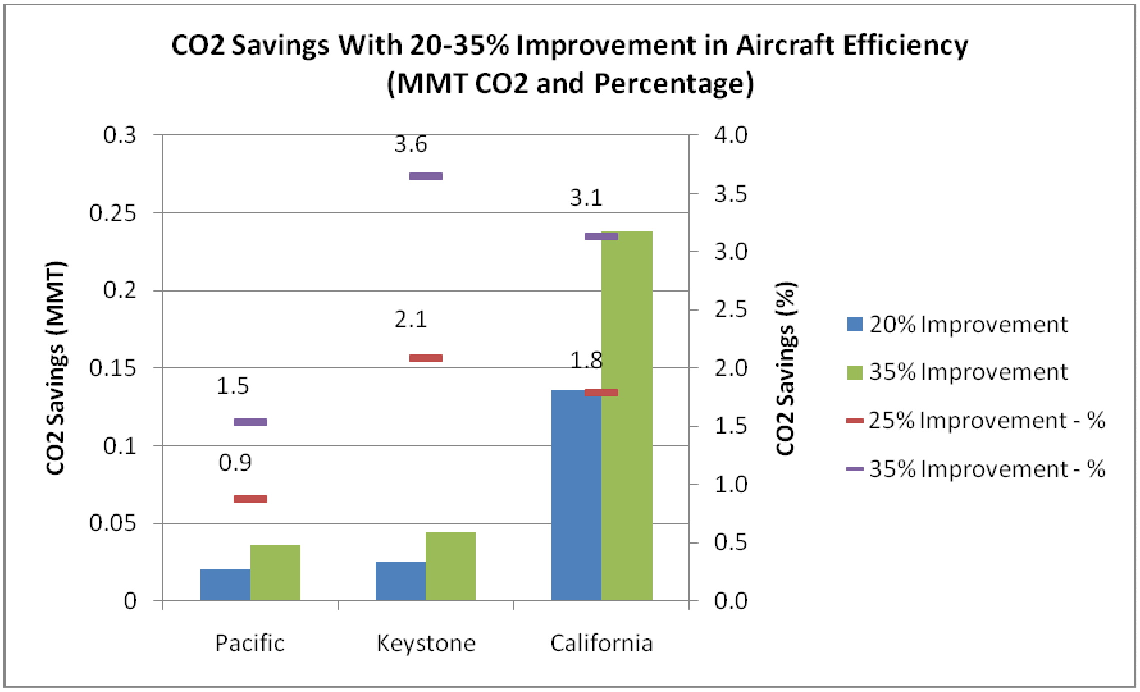

Figure 4.17: CO_2 Savings by Corridor With 20% and 35% Aircraft Efficiency Improvements

The impact of a 20% or 35% improvement in aircraft efficiency is much lower than the potential impacts of the policies targeting automobile emissions, due to the fact that air emissions are only about 5-10% of total emissions, compared to 85-93% for automobile emissions. The impact of these improvements in aircraft efficiencies is the greatest in the Keystone corridor. This is a result of the larger air emissions share in the Keystone corridor compared to the other corridors.

4.3.4.5 What impact will the introduction of high-speed rail have on carbon emissions?

As has been discussed in Chapter 2 and as has been experienced in Europe and Japan, high speed rail can result in considerable CO_2 savings within corridors if large numbers of travelers switch to rail. Modeling this potential shift to rail would be the first step in the analysis of the potential savings but as has been discussed in Chapter 3, the current status-quo of long-distance passenger travel demand modeling shows many shortcomings. Despite the lack of good models and data, the impact of high-speed rail on carbon emissions in the study corridors was analyzed in this section.

The Volpe model seems to be most suitable for this study's estimation of mode shifts when a new HSR mode is implemented, and when new policies and strategies are being analyzed, for several reasons: 1) the model was developed with a focus on the corridor level, 2) the model includes all major passenger transportation modes including HSR, 3) the model includes variables like access and egress time, frequency, etc. and 4) extensive documentation of the model is available.

A quick overview of the methodology is given below. A detailed description of the model, the input variables, and the methods of estimating the input variables can be found in Appendix A of Volpe's report 'Evaluation of High-Speed Rail Options in the Macon-Atlanta-Greenville-Charlotte Rail Corridor' (Volpe Center, 2008).

Volpe's methodology employs a logit-type diversion (mode split) model structure that operates on *each sub-market separately*. The general form of the diversion model is:

$$\% \text{ Divert} = e^{U_{hsr}} / (e^{U_{hsr}} + e^{U_{exist\ mode}})$$

where, U_{hsr} is the utility of HSR travel, $U_{exist\ mode}$ is the utility of the existing mode of travel, and e is the exponential operator.

The utility functions and input variables for Volpe's mode split model are as follows:

- Air Utility = EXP (Cost * Cost Coefficient + LH Time * LH Time Coefficient + A/E Time * A/E Time Coefficient + Wait Time * Wait Time Coefficient + Mode Constant).

- Auto Utility = EXP (Cost * Cost Coefficient + LH Time * LH Time Coefficient + Short Distance Penalty* Short Distance Penalty Coefficient + Mode Constant).

- Bus Utility = EXP (Cost * Cost Coefficient + LH Time * LH Time Coefficient + A/E Time * A/E Time Coefficient + Wait Time * Wait Time Coefficient + Mode Constant).

- Existing Rail Utility = EXP (Cost * Cost Coefficient + LH Time * LH Time Coefficient + A/E Time * A/E Time Coefficient + Wait Time * Wait Time Coefficient + Mode Constant).

- HSR Utility = EXP (Cost * Cost Coefficient + LH Time * LH Time Coefficient + A/E Time * A/E Time Coefficient + Wait Time * Wait Time Coefficient + Mode Constant).

Cost – Car cost is based on AAA estimates of cost per mile for automobiles. Air, Rail and Bus cost is the sum of fares and A/E cost. Fares (business and non-business) were obtained from DOT's Office of Aviation Analysis' Consumer Airfare Report, Amtrak and Greyhound. A/E cost is based on A/E time and city sizes.

LH Time – Line Haul Time data was obtained from MapQuest, Official Airline Guide (OAG) schedules, Greyhound and Amtrak

A/E Time – A/E Time (business and non-business) is based on a city's congestion index, provided by TTI, the number of airports or stations in the city and the size of the terminal to incorporate terminal time.

Wait Time – Wait time is based on the schedule delay concept and is calculated as follows: Wait Time = 0.25*16.5/Frequency, where 16.5 is the number of hours of operation per day.

Short Distance Penalty – Short Distance Penalty is "used to capture the increased disutility of using [other modes than car] for short trips. Out of vehicle time increases relative to line haul time as trip lengths become shorter." It is calculated as (Access/Egress Time + Wait Time)/Distance in hundreds of miles for business trips and as (Access/Egress Time + Wait Time)/ (Access/Egress Time + Wait Time +Line Haul Time) for non-business trips.

Table 4.12 presents the utility coefficients.

Table 4.12: Volpe's CFS Model Utility Coefficients

	Business			
	Air	Rail	Bus	Auto
Cost	-0.0275	-0.0563	-0.0603	-0.0140
LH Time	-1.3963	-0.8811	-0.6211	-0.3667
A/E Time	-1.5498	-2.1805	-2.2475	-0.5501
Wait Time	-0.8038	-1.0573	-1.2422	-0.2445
Short Penalty	0	0	0	-0.3241
ConstHSR	0.0072	0	1.8633	-0.3083
	Non-Business			
	Air	Rail	Bus	Auto
Cost	-0.0423	-0.0716	-0.0511	-0.0193
LH Time	-1.1544	-0.7124	-0.2667	-0.3315
A/E Time	-1.3451	-1.8865	-0.8001	-0.4973
Wait Time	-0.7696	-0.8549	-0.5334	-0.2210
Short Penalty	0	0	0	-0.6707
ConstHSR	0	0	1.0668	-0.5118

Trips diversion is calculated as follows:

Diverted Trips = Source Mode Forecast Trips * Maximum (0, (New Diversion Percentage - Base Diversion Percentage)/(1 - Base Diversion Percentage)

Where

Base Diversion Percentage = $\text{Utility}_{\text{EXISTING RAIL}}$ / ($\text{Utility}_{\text{EXISTING RAIL}}$ + $\text{Utility}_{\text{SOURCE MODE}}$).

And

New Diversion Percentage = $\text{Utility}_{\text{HSR}}$ / ($\text{Utility}_{\text{HSR}}$ + $\text{Utility}_{\text{SOURCE MODE}}$)

Following this model, three different high-speed rail options were analyzed: a system with an average speed of 125 mph (HSR 125); a system with an average speed of 150 mph (HSR 150); and a system with an average speed of 200 mph (HSR 200). Note that these are average speeds, meaning that the top speeds will have to be higher. For each of these options the model utility coefficients were adjusted to reflect higher value of times (VOT) with increasing speed. In Volpe's model the coefficients for high-speed rail were assumed to be the same as existing rail, and as can be calculated from Table 4.12, the VOT for high-speed rail in the Volpe model is $15.5 for business and $9.9 for non-business trips. With an increasing level of service of the trip, and with increasing speed, the VOT for (high-speed) rail is likely to increase though and the VOT for high-speed rail travelers could be more similar to air travel than to existing rail (Levinson et. al., 1996). The coefficients for the three HSR options in this study were adjusted to reflect these changes, as can be seen in Table 4.13. The coefficients for Access and Egress time and cost remained unchanged in this study.

Table 4.13: Utility Coefficients Adjustments for HSR

HSR Coefficients and Value of Time		
HSR Option	**Coefficients for Line Haul Cost and Time**	**Value of Time**
HSR 125	Same as Existing Rail	Business: $15.5 Non-Business: $9.9
HSR 150	Average between Rail and Air	Business: $23.5 Non-Business: $13.62
HSR 200	Same as Air	Business: $50.77 Non-Business: $27.29

For each of the HSR options, the Volpe Model estimates the number of diverted trips for each mode and the total number of HSR trips and based on these estimates, the HSR capacity needed to support the HSR trips was determined as well as potential cancellation of existing air, rail and bus service. To determine the number of high speed trains needed in each corridor for the different HSR options, trains with a capacity of 300 seats (similar to European high speed trains) were used in the analysis. In 2008, Amtrak's average load factor was about 50%,[46] which is assumed to be the same for the HSR options. For each rail segment in the corridor the HSR trips per day were calculated based on Volpe's estimates and the result was increased by 30% to account for other travelers on the route that connect through one of the corridor cities. This 30% was determined using the air

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[46] http://www.bts.gov/publications/key_transportation_indicators/february_2010/html/amtrak_load_factor.html

characteristics in the corridors.[47] The total number of trips for each HSR segment determines the number of trains needed (assuming the 50% load factor).

For Air, Rail and Bus, the number of diverted trips will only have an effect on service, VMT, and CO_2 emissions if the number of diverted trips per day is high enough to result in cancellation of flights, trains, and buses from the regular schedule. Although no information regarding air, rail and bus scheduling and supply strategies was available, rough estimates were made regarding the cancellation of service. For Air the potential number of planes that could be removed from the schedule was estimated by looking at the number of diverted trips per day, percentage of diverted trips, average load factor and frequency. For Rail, the cancellation was assumed to be a direct function of the average load factor of trains (50%). Amtrak's trains generally have a capacity of 322 passengers per vehicle (CNT, 2006), so for each 160 diverted trips per day, one train would be cancelled from the schedule. The diverted trips from the Bus mode were very low for each corridor (around 0-10 diverted trips per day) and this was assumed to not meet the threshold of service cancellation.

For Auto the diverted trips have an immediate effect on vehicle trips, VMT and CO_2 emissions. Change in Access and Egress trips also are a direct result from diverted trips and since CO_2 emissions for A/E bus and rail modes were calculated on a PMT basis, diverted trips will directly affect A/E CO_2 emissions as well.

The change in service for Air, Rail, and HSR changed the utilities for each mode, since frequency of service is incorporated in Volpe's Model. The initial change in service

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[47] The typical load factor for air is 70% (CNT, 2006). The trips for the city pairs in the corridors averaged to account for only 50% of the capacity. Therefore, on average, another 20% of the travelers come from connecting flights. This results in a ration of 70:30 for city pair trips and connecting trips.

was therefore looped back to the model, which in most cases resulted in additional diverted trips and in some cases in service changes. The final number of diverted trips by mode (as well as the percentage shift) for each corridor are shown in Figure 4.18 and Tables C.5 – C.10. The values for the percentage shift for Automobile are not shown in the graphs. They range from less than 0.1% (HSR 125 Keystone) to 1% (HSR200 California). The total number of diverted trips from Auto, Air, Rail and Bus by corridor are presented in Table 4.14.

Table 4.14: Total number of diverted trips from Auto, Air, Rail and Bus by corridor

Total Number of Diverted Trips By Corridor			
	HSR125	**HSR150**	**HSR200**
Pacific Northwest	126,536	1,038,820	1,237,799
Keystone	31,907	132,012	224,714
California	207,793	833,806	1,389,067

The effects of the cancellation of Air and Rail service, the decrease in Auto trips and the addition of HSR service on CO_2 emissions are shown in Figure 4.19 and Table C.11.

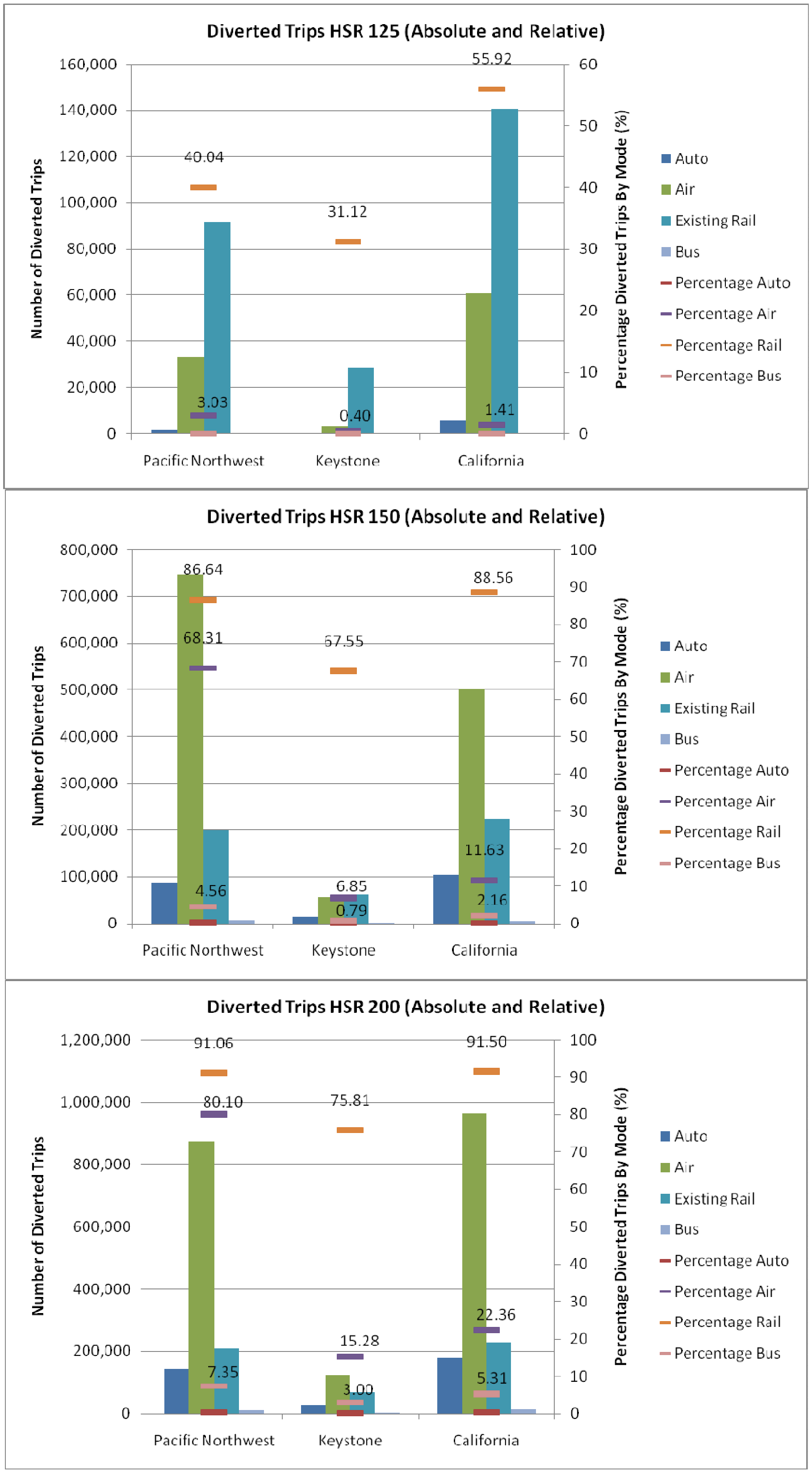

Figure 4.18: Diverted Trips by Mode for HSR 125, HSR 150, and HSR200

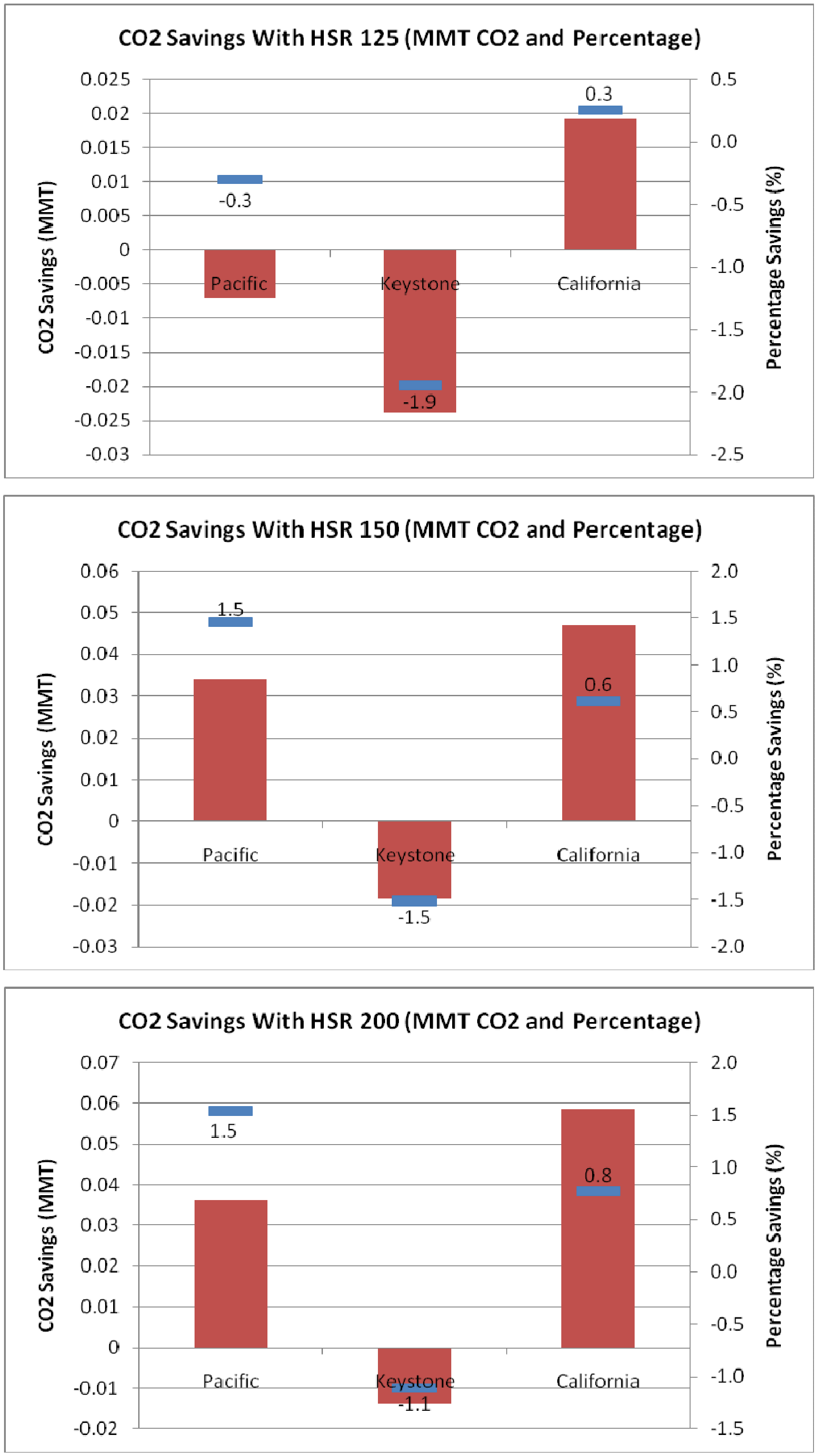

Figure 4.19: CO$_2$ Savings for HSR 125, HSR150, and HSR200

As can be seen from Figure 4.18 the largest relative shift to HSR came from existing rail. This is an expected result since rather than shifting modes, existing rail travelers just shift to a faster version of the same mode. For HSR150 and HSR200 shifts from Air to HSR are relatively large as well, especially for the Pacific Northwest. This higher share for the Pacific Northwest compared to the other corridors can be explained by the smaller distances for each city pair which results in HSR travel times comparable to those for Air. In addition, the flight connections and frequencies for Eugene have a negative effect on the Air utility compared to other city pairs. For Bus and especially Auto shifts are very low. This was expected especially since the utility of the HSR mode (like Air, Rail, and Bus) is much lower mainly due to Access and Egress transportation, frequency and the need of a car at the destination.

One of the problems HSR is facing is the frequency of trains to compete with other modes. The number of diverted trips is directly related to the frequency and the frequency is impacted by the number of diverted trips. Therefore, when the number of diverted trips is relatively low, changes to the frequency will be low, resulting in even less diverted trips. This effect can be clearly seen when the Keystone corridor and the California corridor are compared. Since travel activity in the California corridor is over four times the size of travel activity in the Keystone corridor, the initial number of diverted trips based on a default frequency is much higher, resulting in a higher frequency, which positively effects number of diverted trips again. The opposite can be said for Keystone. Due to the relatively low travel activity, the initial number of diverted trips for HSR is low, resulting in a lower frequency, which negatively affects the number of diverted trips.

It is therefore crucial for HSR to have a high enough frequency to be able to compete with the other modes.

From Figure 4.19 it becomes clear the HSR125 does not have a positive impact on CO_2 emissions at all, especially for the Keystone corridor. Even for higher speeds, the Keystone corridor does not see any CO_2 savings. This is a result of the unfavorable coal-based electricity mix used to power the electric trains (see Table 4.9). For the same reason the Pacific Northwest shows the greatest beneficial impact, since hydroelectric power is the main electricity source for this region.

Although the HSR200 results in more diverted trips than HSR150, the impact of this average speed increase on CO_2 savings is very small. The higher number of diverted trips requires more HSR trains and even though it does result in cancellation of more flights, it does not affect the cancellation of existing rail much. The reason for this is that the majority of the ridership for existing rail travel is to or from cities/stations in between the major cities. A HSR is unlikely to stop there, so the existing rail is still needed.

Potential CO_2 savings would increase significantly if the load factor for HSR is assumed to be higher. This is a challenge that existing rail is facing as well. The assumed load factor for HSR in the analysis was 50%, thus at full capacity you could serve twice as many travelers without seeing a doubling of your CO_2 emissions. To evaluate the impact of a higher load factor, as well as having higher HSR frequencies, a scenario was developed to analyze the requirements of an HSR system that has significant CO_2 savings. In this scenario the HSR150 option was taken and the frequencies were assumed to be similar to Air service. In addition, the load factor was assumed to be 70% (30% of this is assumed to be connecting trips), comparable to air service, instead of Amtrak's average 50%. Finally, the extra ridership that would be needed to support this frequency at a 70% load factor was taken from the Auto mode. The number of diverted trips by mode (as well as the percentage shift) for each corridor is shown in Figure 4.20 and Table C.12 and C.13. The impact on CO_2 emissions are shown in Figure 4.21 and Table C.14.

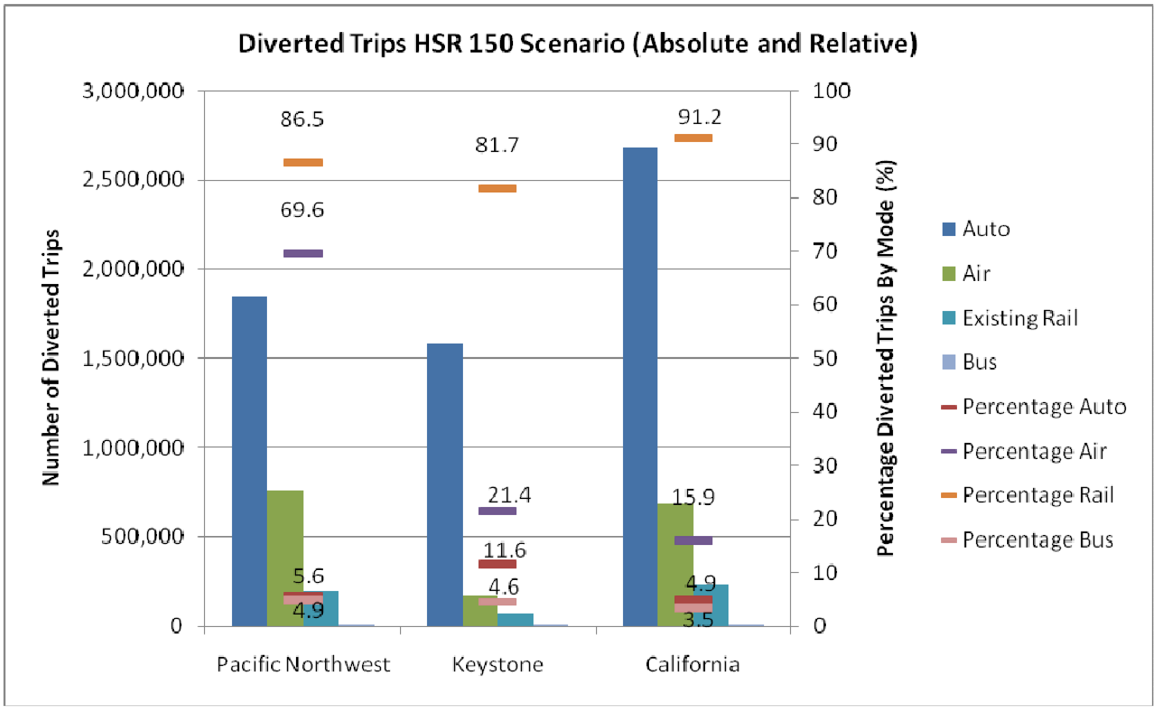

Figure 4.20: Diverted Trips For HSR150 Scenario

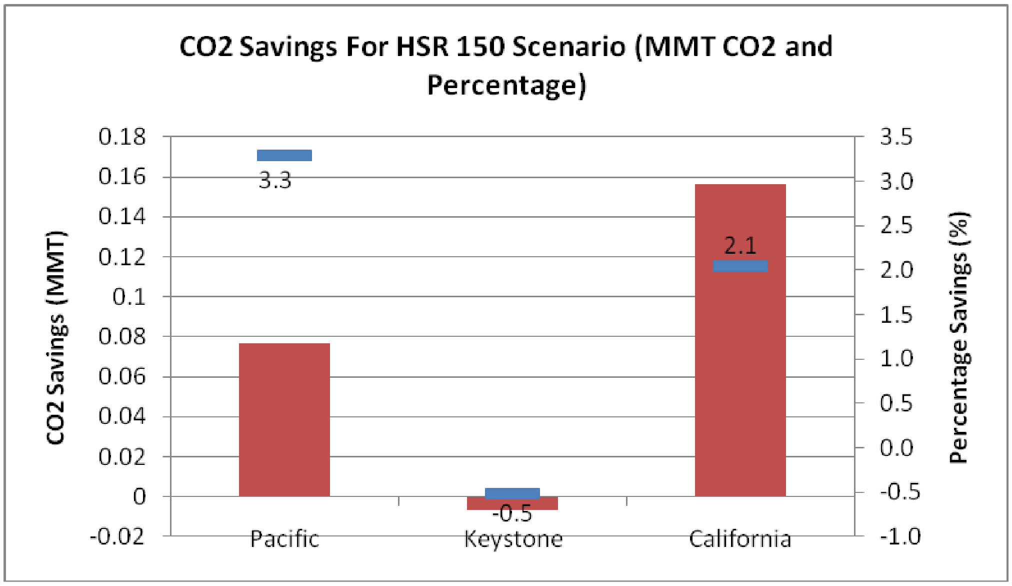

Figure 4.21: CO_2 Savings For HSR150 Scenario

The higher HSR frequency results in slightly higher diversion percentages for Air, Rail and Bus. If the extra ridership to support this frequency and the 70% load factor were to come from Auto, a huge increase in diverted Auto trips would be the result. The new diversion percentages of Auto trips (different from the Volpe Model estimate) that would have to divert to HSR to support it would have to be almost 6% for the Pacific Northwest, 5% for California, and over 11% for Keystone. This scenario shows that the impact on CO_2 savings increases significantly as well, up to 3.3% for the Pacific Northwest. As has been discussed before, the impact for this corridor is the largest mainly due to the electricity mix. For the Keystone corridor the impact would still be negative. The required shift in Auto mode share would mainly be a result of pricing strategies, which will be analyzed in the next section.

4.3.4.6 What impact will a carbon tax have on carbon emissions?

As has been discussed in Chapter 2, market-based instruments (MBIs), such as emission trading (cap-and-trade programs), and pollution charges (carbon tax), are gaining momentum as important policy mechanisms for greenhouse gas emissions reductions. The implementation of MBIs targeting the transportation sector is likely to affect some modes more than others, depending on the emissions for each mode. The impact of a carbon tax on passenger transportation and CO_2 emissions was analyzed within the study corridors. It was assumed that such a tax would be levied on a (centralized) industry level, rather than at the end-use level. The industries are assumed to incorporate the extra cost in their pricing strategies towards the end-user. Especially for public modes like air, rail and bus, the extra cost for each trip heavily depends on the occupancy rate of each vehicle.

For this analysis the above mentioned scenario (HSR150 with competitive frequencies and 70% load factor) was used. For each corridor the average carbon emissions per passenger mile were estimated and based on a carbon tax of \$43/tC[48] and the trip length the carbon cost per trip were estimated. This cost can be added to the demand model for each mode separately. Table 4.15 presents the carbon cost per passenger mile for each mode based on the \$43/tC carbon tax.

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[48] This value reflects the estimated social cost of carbon from IPCC (2007) mentioned earlier in this study. This estimated cost has a large spread and the true damage cost of carbon is topic of debate in the literature

Table 4.15: Carbon Cost By Mode For $43/tC Carbon Tax

Carbon Cost By Mode For $43/tC Carbon Tax (Cents/PMT)			
	Pacific	Keystone	California
Auto	0.45	0.45	0.45
Air	0.69	0.62	0.43
Rail	0.41	1.04	0.39
Bus	0.06	0.11	0.06
HSR	0.16	0.53	0.28

As can be seen in Table 4.15, HSR has a lower carbon cost per passenger mile than Auto, Air and Rail, except for the Keystone corridor. A carbon tax could therefore have a positive impact on HSR compared to the other modes (except for Bus), since the additional trip cost is lower (assuming that the distances are roughly the same). The differences between HSR and Air are the largest (except for Keystone) so especially compared to Air, HSR would could benefit from a carbon tax. However, a carbon tax of $43/tC only results in a very small carbon cost per trip. A 100-mile car trip, for example, would only cost an extra 45 cents, an increase of less than 1%. The relative increase in Air cost is even lower than that. A carbon tax of this magnitude does not have a significant impact on mode shifts and CO_2 emissions. A much higher carbon tax would be needed in order to get the 5-6% Auto trips diverted to HSR in order to support the HSR system.

The impact of a carbon tax of $400/tC was analyzed to see if that would result in significant trip diversions. The carbon cost per passenger mile for each mode based on a $400/tC carbon tax are presented in Table 4.16.

Table 4.16: Carbon Cost By Mode For $400/tC Carbon Tax

Carbon Cost By Mode For $400/tC Carbon Tax (Cents/PMT)			
	Pacific	Keystone	California
Auto	4.2	4.2	4.2
Air	6.4	5.7	4.0
Rail	3.8	9.7	3.6
Bus	0.6	1.1	0.5
HSR	1.5	4.9	2.6

The Auto diversion percentage for this scenario estimated by the model is still very low: less than 0.5%. The effect on the other modes is very small as well (see Table C.15-16). The impact on CO_2 emissions are shown in Figure 4.22 and Table C.17.[49]

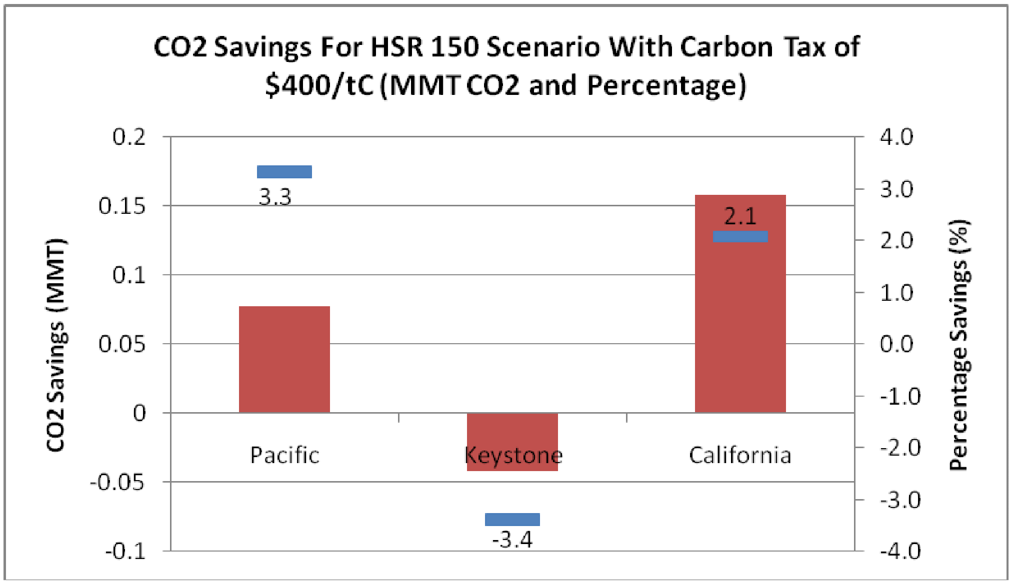

Figure 4.22: CO_2 Savings For HSR150 Scenario With $400/tC Carbon Tax

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[49] Note that these results are specific to the HSR150 scenario developed and include the Auto diversion needed to support the HSR system, even though the model does not reflect such diversions.

As can be seen from Figure 4.22 and Figure 4.21, even a carbon tax of $400/tC does not have an extra noticeable positive effect on CO_2 emissions in the corridors. The Keystone corridor has an even more negative outcome, but this is due to the fact that the model was forced to divert Auto trips in order to reach the 70% load factor in this scenario and the per passenger mile carbon emissions are higher for HSR than for Auto for this corridor (see Table 4.16). In the unrestricted model, this diversion would not have occurred. Given these results it is very unlikely that a carbon tax will result in the auto diversions needed to support an HSR system that has a positive impact on CO_2 emissions in a corridor.

4.3.4.7 What type of policy has the largest potential impact and where?

Figure 4.23 summarizes the impacts of the analyzed policies and strategies on CO_2 emissions for each study corridor. The Figure shows that the largest potential impacts on CO_2 emissions come from automobile related strategies. This is a result of the large auto share as main mode and access/egress mode to and from airports and bus and train stations. The largest absolute impacts can be realized in the California corridor due to its current CO_2 footprint. All corridors show similar percentage savings, with a slightly higher impact of electric vehicles for the Pacific Northwest corridor and a lower impact for the Keystone corridor due to the different electricity mixes.

The non-auto strategies all have an impact on CO_2 emissions of less than 5%. Of the non-auto strategies, the HSR150 Scenario (high frequency and load factor) has the largest impact for the Pacific Northwest corridor, again due to the favorable electricity mix. This

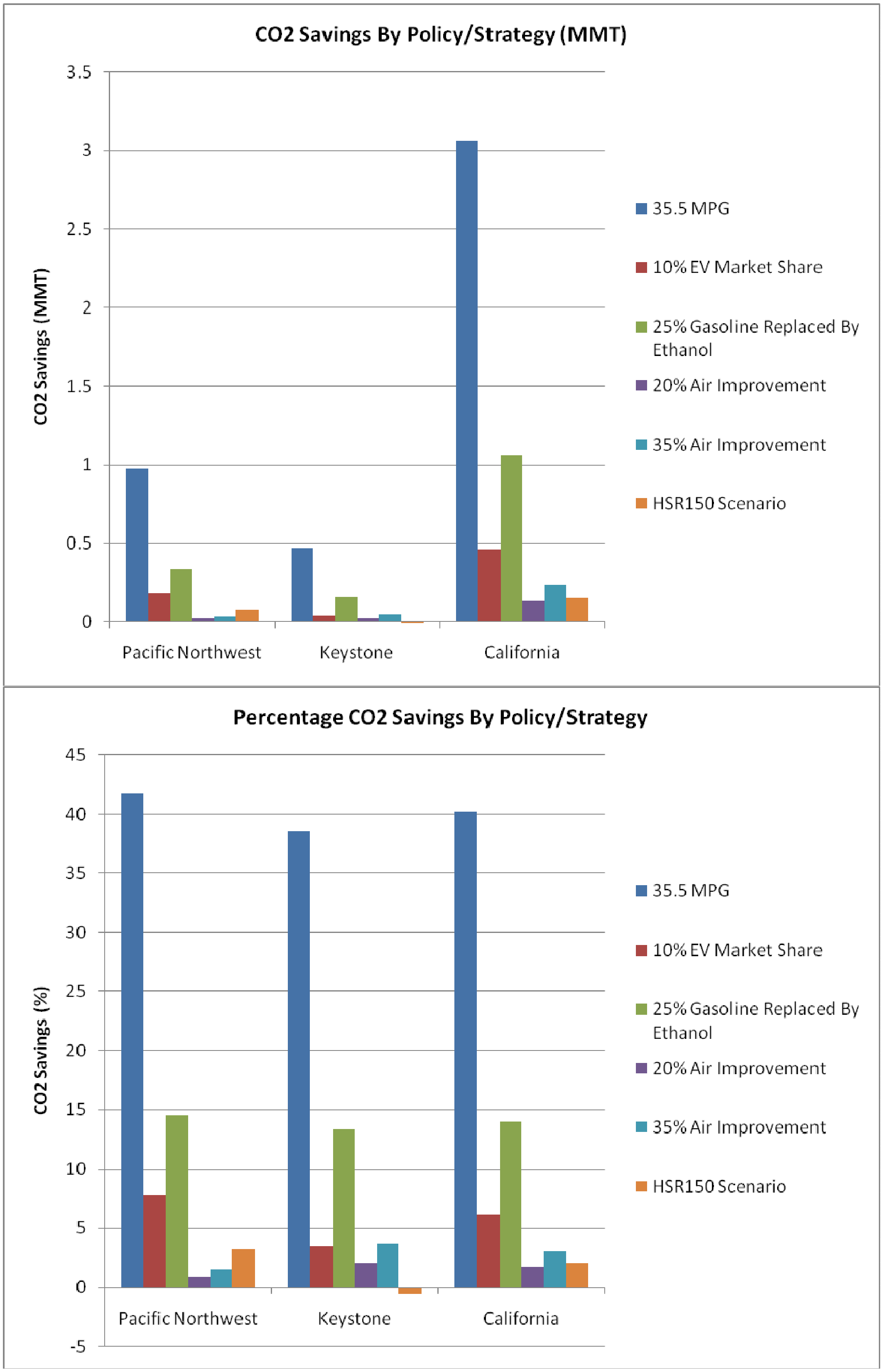

Figure 4.23: CO_2 Savings By Policy/Strategy

impact is much higher than the strategies targeting air emissions. For California the HSR 150 Scenario has a similar impact as a 20% improvement in aircraft emissions. A 35% improvement in aircraft emissions has the highest impact. The Keystone corridor shows a negative CO2 savings for the HSR150 Scenario. This is a result of the coal-based electricity generation. Air improvement strategies have a similar impact as for the California corridor.

4.3.4.8 Summary of Assumptions and Caveats

The impact of certain the policies and strategies on CO_2 emissions must be treated as approximate and descriptive in nature. The accuracy of the final carbon estimates depends heavily on the following factors and assumptions:

- for all policies/technologies it is assumed that implementation is indeed possible and that the technologies will be competitive
- the cost of automobile travel was not adjusted for the different auto strategies. The loss in tax revenue due to fuel efficient vehicles and electric vehicles will be offset by other transportation pricing strategies like VMT-based pricing
- the upstream emissions factor for electric vehicles was assumed to be the same as gas-powered cars. This may not be the case and it very well could be a higher factor since the actual direct emissions are much lower for electric vehicles
- the upstream factor is assumed to be the same for ethanol (vehicles) as for gasoline (vehicles) due to lack of better numbers. Like electric vehicles, this factor could be much higher since the direct emissions are lower for ethanol powered vehicles.

- the lack of sophisticated long-distance demand models
- the assumption that VOLPE’s CFR model and its coefficients represent the corridors in this study
- no information regarding air, rail and bus scheduling and supply strategies was available and rough estimates were made regarding the cancellation of service
- the price for the HSR mode was calculated following Volpe’s method using the average Amtrak yield per mile. Changes in this price could affect the ridership and emissions significantly. Prices will have to be competitive to draw the ridership
- no intermodal trips were included in the analyses. Intermodal trips where a traveler takes one leg by air for example and another by HSR could have emissions benefits

4.3.4.9 Sources of Uncertainty

The estimation of the impacts of certain policies on GHG emissions is expected to be subject to many uncertainties. The limited understanding of several key aspects and the limitations to the predictability of such aspects result in potential large uncertainties in GHG projections. Key aspects in the greenhouse inventory analyses and the policy analyses are population growth, socio-economics, travel activity, technological change and future improvements, land use change, (modeling) human behavior, responses to a new mode, and surprises (e.g. failure of a large transportation network/mode or unforeseen technological breakthroughs/discoveries). Although it is not in the scope of this research to fully analyze the extend of each of these uncertainties, it is important to address that many of these uncertainties cannot be analyzed by merely using statistical and quantitative methods of assessment. According to Dessai and Sluijs (2007), who discuss uncertainty as it relates to climate change adaptation, a focus on statistical methods tend to “ignore policy relevant uncertainty information about the deeper dimensions of uncertainty that in principle cannot be quantified.” Dessai and Sluijs (2007) state that lack of attention for unquantifiable uncertainties “makes the perceived scientific foundation basis of climate policies prone to controversies, can undermine public support for climate policies, and increases the risk that society is surprised by unanticipated climate changes“. The same applies to GHG reduction policies and strategies and their impacts.

Dessai and Sluijs (2007) classify uncertainty on a scale running from ‘knowing for certain’ to ‘not know’. They indicate three classes (Dessai and Sluijs, 2007):

- “‘Statistical uncertainty’: this concerns the uncertainties which can adequately be expressed in statistical terms, e.g., as a range with associated probability (examples are statistical expressions for measurement inaccuracies, uncertainties due to sampling effects, uncertainties in model-parameter estimates, etc.). […]
- ‘Scenario uncertainty’: this concerns uncertainties which cannot be adequately depicted in terms of chances or probabilities, but which can only be specified in terms of (a range of) possible outcomes. For these uncertainties it is impossible to specify a degree of probability or belief, since the mechanisms which lead to the outcomes are not sufficiently known. Scenario uncertainties are often construed in terms of ‘what-if’ statements.
- ‘Recognized ignorance’: this concerns those uncertainties of which we realize – some way or another – that they are present, but of which we cannot establish any useful estimate, e.g., due to limits to predictability and knowability (‘chaos’) or due to unknown processes. A way to make this class of uncertainties operational in climate risk assessment studies is by means of surprise scenarios. Usually there is no scientific consensus about the plausibility of such scenario's while there is some scientific evidence to support them.”

As mentioned before, the objective of this study was to develop a methodology for quantifying GHG emission inventories and for analyzing the impacts of certain policies and strategies on GHG emissions and conducting uncertainty analyses is not within in the scope of this study. For future work, such analyses should be included and an in-depth discussion of this topic can be found in Dessai and Sluijs (2007). They identified a number of tools for uncertainty analysis relevant to climate change adaptation decision making processes, which are useful for the uncertainty analysis of GHG emissions inventories as well. They mapped how well each of the methods can cope with three levels of uncertainty: statistical uncertainty, scenario uncertainty and recognized ignorance Dessai and Sluijs (2007).

5 CONCLUSIONS AND RECOMMENDATIONS

Quantifying the change in GHG emissions due to strategies aimed at reducing transportation GHG emissions is one of the most challenging aspects of integrating GHG emissions and climate change into transportation planning and policy analysis. The inventory techniques and methods for estimating the impact of different strategies and policies are still relatively unsophisticated. The methodology for developing intercity passenger transportation CO_2 emissions inventories that was developed in this research provides a defensible approach to estimating the CO_2 emissions in U.S. corridors and proved to be very valuable for the analysis and comparison of the impacts of policies and strategies on CO_2 emissions. The methodology consists of estimating the number of trips by mode, estimating the direct CO_2 emissions, and estimating indirect CO_2 emissions and was applied to three corridors in the U.S. -- San Francisco/Los Angeles/San Diego; Seattle/Portland/Eugene, and Philadelphia/Harrisburg/Pittsburg.

As the analyses of policy and strategy impacts on CO_2 emissions show, the largest gain in CO_2 savings can be achieved by strategies aiming at automobile emissions due to its sizeable share as main mode and access/egress mode to and from airports and bus and train stations. An average fuel economy of 35.5 mpg would result in a 38-42% savings of total CO_2 emissions; replacing 25% of gasoline use with cellulosic ethanol can have a positive impact on CO_2 emissions of about 13.4-14.5%; and a 10% market share for electric vehicles would result in potential CO_2 savings of 3.4-7.8%. The impact of a 20% or 35% improvement in aircraft efficiency on CO_2 savings is much lower (0.88-3.65%)

than the potential impacts of the policies targeting automobile emissions. Three HSR options were analyzed using Volpe's long-distance demand model: HSR125, HSR150, and HSR200. Only the HSR150 and HSR200 would result in noticeable CO_2 savings, and then just for two of the three corridors: the Pacific Northwest (1.5%) and California (0.6-0.9%). With increased (competitive) frequency and load factors, a HSR150 system could result in CO_2 savings of 3.3% and 2.1% for the Pacific Northwest and California, respectively. This would require a mode shift from auto of 5-6%. This shift in auto mode share would mainly be a result of pricing strategies. One such pricing strategy, a carbon tax, could have a positive impact on auto diversion towards HSR. However, even a carbon tax of $400/tC, a multiple of 10 compared to today's tax, would not result in a diversion higher than 0.5%. There are no visible CO_2 savings due to this tax. From these results, HSR may not be such an obvious choice, however, with increased ridership and diversions from other modes, CO_2 savings increase significantly due to the lower emissions per passenger mile for HSR. Higher diversion may occur once a HSR rail system is built, as was seen in several other countries. The framework developed in this study has the ability to determine the GHG emissions for such HSR options and increased diversions.

Recommendations and areas for further research to better understand or estimate the CO_2 emission inventories and potential strategy impacts include the following:

Improving Long-Distance Demand Modeling and Data. As was discussed in Chapter 3, the state-of-practice of long-distance modeling in the U.S. is inadequate for detailed analysis and reliable data is scarce. Developing sound American long distance personal travel data and models is crucial to estimating CO_2 emissions and policy impacts more accurately, especially when new modes like HSR are being analyzed. When better models and data become available, these should be used in the methodological framework developed in this study.

Improving Energy and Emissions Data. Especially for the rail modes, but also for air, reliable energy consumption and emissions data was difficult to find in most cases. To improve our understanding of the emissions and impacts of intercity travel, further research is needed on energy and emissions data .

Improving life-cycle emissions data. The state-of-the-art in calculating life-cycle emissions is in its early stages as far as most transportation modes are concerned, and no two major studies have adopted the same set of steps to measure these emissions, or made the same assumptions regarding energy consumption rates from the individual activities they include in their “cradle-to-grave” LCA methodologies. In addition, downstream emissions from the disposal of vehicles and infrastructure are not even included in today’s most comprehensive LCA analysis. For a full analysis and understanding of transportation life-cycle CO_2 emissions, refinement of life-cycle emissions data is crucial, and the end-of-life phase should be included.

Cost-Effectiveness of Policies. The analysis of impacts of various policies and strategies on emissions did not look at cost-effectiveness although such analyses are very important to decision making. The vulnerability of the U.S. economy will have a significant impact on the transportation financial situation, increasing the need for cost-effective measurements. Further research on the cost-effectiveness of the different policies and strategies is clearly needed.

Transportation GHG emission reduction policies and strategies vary significantly in terms of the strategy type. One of the main challenges in comparing such different policies is fairly quantifying the cost and the monetary value of the benefits for a comparison. In the report Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions (Cambridge Systematics, 2009; see Section 2.4.2.3) such an attempt was made for strategies that focus on reducing VMT and improving the efficiency of the transportation network. The report categorizes the strategies and estimates cost as detailed as possible, The estimates are characterized by many uncertainties and assumptions, however. The challenge of estimating cost may even be greater in regards to the cost of technological developments like increasing fuel efficiency or alternative fuels.

Future Scenarios. This study analyzed the potential impact of certain policies and strategies compared to its base year (2008). Most of the strategies would take at least 20 years to be fully implemented and it is therefore important to analyze future potential impacts compared to a business-as-usual scenario, taking into account growth in long-distance transportation and potentially land-use changes.

Analyzing network effects. The corridors analyzed in this study were analyzed in isolation and the network effects were not included. Future research should include this network effect from trips connecting through a given corridor, and also account for the effect of linked corridors. The potential savings from intermodal trips should be analyzed as well.

Increasing Auto Diversion to HSR. The success of a HSR system and the potential CO_2 savings are directly related to the ridership. As the HSR150 scenario in this study showed, a diversion of 5-6% from auto would be needed to realize a 70% load factor. Even though European high speed rail systems have shown that it is possible to realize such load factors and diversions, the likelihood of such a result in the United States is less clear and needs further analysis, with targeted pricing strategies most likely needed.

Including A/E emissions. For each passenger transportation mode included in an analysis, CO_2-related access and egress emissions should be included to get a true picture of the emissions inventory. As this study has shown, the A/E emissions account for as much as 10-20% of total air and rail mode emissions and up to almost 50% for bus mode. This cannot be ignored. The mode that passengers use to travel to and from airports and rail stations will significantly affect overall CO_2 emissions and larger savings can be achieved by integrating A/E transportation in transportation planning and in, for example, HSR station design.

Analyzing other GHGs. This research only analyzed CO_2 emissions and did not include other GHG like water vapor, ozone, methane (CH_4), and nitrous oxide (N_2O), and criteria air pollutants. To get a full GHG emission inventory these gases should be included in GHG emissions inventories and in a future methodological framework.

Aircraft Emissions at Altitude. Aircraft emit GHGs directly into the upper troposphere and lower stratosphere and have an impact on the atmospheric composition (IPCC, 2001). The impact of these emissions at altitude and the inclusion of such differences in GHG emissions inventories require further study.

Bus Mode. Even though bus was included in the methodology and in the analysis, most attention was focused on other modes. Bus does show the lowest emissions per PMT though and it could be useful to further analyze the potential of bus travel and how to increase the utility/mode share for this mode of travel.

APPENDICES

APPENDIX A. LONG-DISTANCE TRAVEL DEMAND STUDIES

Table A.1: Recent Examples of Long Distance Travel Demand Studies

Model/Study	Geographic Detail	Modes	Trip Purposes	Demand Component	Model Objectives	Method	Explanatory Variables
UNITED STATES							
TSAM (Ashiabor, Baik et al (2007-2008))	County level	Car, Air, SATS, (Bus, Rail)	Business / Non-Business	TG (trip generation), TD (trip distribution), MC (mode choice), TA (traffic assignment)	Nested and mixed logit models were developed to study national-level intercity transportation in the United States. The Transportation Systems Analysis Model (TSAM) estimates nationwide intercity travel demand in the United States.	Nested Logit/Mixed Logit	Travel time, Travel Cost, Household Income, Region Type
Koppelman (1990)	City/Metro Pairs (using data from NTS 1977)	Car, Air, Bus, Rail	Business / Non-Business	TG, TD, MC, Service Class Choice	Develop a behavioral framework and model system for intercity travel	Disaggregate Nested Logit Model	Travel time, cost, departure frequency, distance between city pairs, household income, structure, and size, employment, museum index, recreation index.
Koppelman and Sethi (2005)	Only mode choice/service class choice from surveys	Car, Air, Rail Sleeper, Rail Premium Coach, Rail Economy Sleeper	NA	MC, Service Class Choice	This research integrates the considerable progress that has been made in relaxing the assumption of independence across alternatives and the homogeneity of error variance/covariance across observations within the context of closed form extensions of the MNL/NL models.	MNL Model, nested logit, and generalized nested logit	Cost, schedule convenience, overnight dummy, quality of service, group size, income, distance
Coldren et al (2003)	City pairs in the U.S.	Air	NA	Itinerary Share Models	This study reports the results of aggregate air-travel itinerary share models estimated at the city-pair level for all city-pairs in the US. These models determine the factors that influence airline ridership at the itinerary level and support carrier decision-making.	Aggregate multinomial logit	Level-of-service, connection quality, carrier, carrier market presence, fares, aircraft size and type, and time of day.

Table A.1 (continued)

Model/Study	Geographic Detail	Modes	Trip Purposes	Demand Component	Model Objectives	Method	Explanatory Variables
INDIVIDUAL STATE STUDIES							
Michigan	2307 instate TAZs, 85 outstate TAZs	Car	HB work/biz, HB soc/rec/vac, HBO, NHB work/biz, NHB other	TG, TD, TA	Development, maintenance and application of a Statewide Travel Demand Model.	Used TransPla	Household size, income, travel cost, area type
Oregon	2950 zones (instate and within a 50 mile radius). Each zone fits within about 14.5 million grid cells ranging from 30x30 meters to 300x300 meters	Car drive, car shared, urban transit, air, AMTRAK, intercity bus, walk, bicycle	home-based, work-based	TG, TD, MC, TA	Develop a tranportation land use model to understand daily traffic patterns by using microsimulation techniques	Microsimulation (Monte Carlo) and logit models	regional economics and demographics, production allocations and interactions, houshold allocations, land development, commercial movements, houshold travel, and transport supply
Maryland	1607 zones (Maryland, Delaware and Washington DC as a whole, and parts of New Jersey, Pennsylvania, Virginia, and West Virginia. A regional model for 189 zones.	Car, air, rail, bus	Home Based Work, Journey to Work, Journey at Work, School, Home Based Shop, Home Based Other	TG, TD, MC, TA	Development of a Statewide Travel Demand Model.	Gravity model and nested logit model. A microsimulation technique is introduced for long-distance travel using the NHTS.	Socioeconomics and demographics (population, income, occupation status, household size, number of workers), travel time, travel cost

Table A.1 (continued)

Model/Study	Geographic Detail	Modes	Trip Purposes	Demand Component	Model Objectives	Method	Explanatory Variables
CORRIDOR STUDIES (N. Amer.)							
Cambridge Systematics (2006)	TAZs	Main mode: car, air, conventional rail, and HSR. For Access/Egress: Drive/Park, Drop off, Rental, Taxi, Transit, Walk/Bike	Business, Commute, Recreation, Other	TG, TD, MC, Access/Egress MC	To develop a new ridership forecasting model that would serve a variety of planning and operational purposes: To evaluate high-speed rail ridership and revenue on a statewide basis; To evaluate potential alternative alignments for high-speed rail into and out of the San Francisco Bay Area; and To provide a foundation for other statewide planning purposes and for regional agencies to better understand interregional travel.	Trip frequency. Multinomial Logit Models	Employment & Household Characteristics • Trip Purpose/Distance Class • Level of Service • Accessibility • Region • Traveling Party Size
Volpe Center (2008)	County and MSA level	Car, air, existing and high speed rail, bus	Business / Non-Business	Direct demand modeling	Evaluation of High-Speed Rail Options in the Macon-Atlanta-Greenville-Charlotte Rail Corridor	Logit model	travel time, travel cost, frequency, income
Bhat (1995)	Corridor: Toronto-Montreal. Only mode choice (from surveys)	car, air, train	Paid Business	Mode choice	The model is estimated to examine the impact of improved rail service on business travel in the Toronto-Montreal corridor.Travel demand models used to forecast future intercity travel and estimate shifts in mode split in response to a variety of potential rail service improvements (including high-speed rail) in the Toronto-Montreal corridor.	Heteroscedastic extreme value model using a maximum likelihood technique	travel time, travel cost, income, frequency, city type
Bhat 1997	Canadian interciy dataset: Toronto Montreal Corridor	car, air, train	Paid Business	Mode choice	This article uses an endogenous segmentation approach to model mode choice. This approach jointly determines the number of market segments in the travel population, assigns individuals probabilistically to each segment, and develops a distinct mode choice model for each segment group.	Endogenous Segmentation Mode Choice Model	income, sex (female or male), travel group size (traveling alone or traveling in a group), day of travel (weekend travel or weekday travel), (one-way) trip distance, frequency of service, total cost, in-vehicle travel time and out-of-vehicle travel time, large city indicator

Table A.1 (continued)

Model/Study	Geographic Detail	Modes	Trip Purposes	Demand Component	Model Objectives	Method	Explanatory Variables
EUROPEAN							
LMS (Netherlands)	National. 1308 Zones plus 55 external zones	Car driver, car passenger, train, bus/tram/metro, slow traffic	1. home-work 2. business (home-based) 3. business (non-home based) 4. Shopping 5. education (<12) 6. other, children 7. education (12+) 8. social-recreative	TG, TD, MC, TA	To predict the long-term impact of (policy) measures with respect to reducing traffic congestion, traffic unsafety, and air pollution in the future. The outcomes of the model may contribute to new or adapted policy measures. Three types of policy decisions are supported by LMS: 1. calculate situations without new policies; 2. estimate effects of a package of policy measures; 3. estimate effects of one policy measure.	Disaggregate tour frequency model	TG: Most important are: structure of household, licence holding and car availability in household, sex, age, educational level, income, licence holding and activity of person. TD/MC: Attraction variables of destination (employees, education places, number of residents, density of employees or population, business district) Accessibility variables (travel time, costs) Socio-economic attributes (licence holding, car availability, part/full time, age band, income band).
SISD (Italy)	Italy. 270 national zones, 62 external	Car, Bus, air, interregional train, intercity train, sleeping train	1. workplace commuting 2. work and professional business 3. university education 4. leisure and tourism 5. other purpose	TG, TD, MC, TA	1. to simulate the behavior of transportation systems 2. formulate management and planning policies 3. check the effectiveness of proposed interventions 4. official data source	Disaggregate tour frequency model	TG: Attraction variables (number of residents, employees, location, accessibility logsum) Socio-economic attributes of individual/ household (income category, age band, sex, employment status, education level, license holding dummies, car availability). TD/MC: Employees, hotel beds, same region dummy, travel time and cost per mode, frequency, income group, cars available, license holding dummies.
STREAMS (EU)	Member Countries of the EU. 201 Internal zones, 27 external outside EU, 4 external zones for the rest of the world	Car, air, coach, rail, air	1. commuting and business (<40 km) 2. shopping, personal business, education, visits (<40 km) 3. charter holdiday (>40 km) 4. business and commuting (>40 km) 5. international independent holiday (>40 km) 6. domestic holiday (>40 km)	TG, TD, MC, TA	1. to develop a multi-modal network based transport model of the EU covering passengers and freight 2. to produce an initial reference forecast of transport in the EU 3. to develop new modeling software	Aggregate trip frequency model	TG: Age, employment, car availability, household structure (aggregate average per distinguished population group). TD/MC: Full time employed persons, total population, tourism arrivals (bed spaces), gross value added.

Table A.1 (continued)

NTM 4 (Norway)	454 domestic zones	1. car driver 2. car passenger 3. public transport 4. slow traffic 5. air (long-distance model) 6. sea (long-distance model)	Short distance: 1. home based commuting 2. home based business 3. Education 4. work based business 5. shopping/personalbusiness 6. social visit 7. recreation, other Long distance (>100km): 1. work/education 2. Business 3. social visit 4. Recreation 5. services and other	TG, TD, MC, TA	Original objective: To make predictions of the impact of policy measures to reduce the environmental effects of private travel. Added: capability of forecasting traffic on specific infrastructure links	Disaggregate tour frequency model	Comparable and based on LMS (Netherlands)
SAMPERS (Sweden)	700 domestic zones, which are disaggregated into 9000 subzones. 180 zones in foreign countries.	1. car 2. train (several types) 3. coach / regional bus 4. air (for long distances) 5. car+ferry (for long distances) 6. walk-on ferry (for long distances) 7. Walk 8. bicycle	Short distance: 1. Work 2. Business 3. School 4. Social 5. Recreation 6. Other Long distance (domestic plus international): 1.private 2. Business	TG, TD, MC, TA	To predict demand effects of new infrastructure and services, changing incomes, different population structure, changes in trade and industry. To serve as a basis for calculation of traffic safety effects, environmental effects, energy consumption, accessibility effects, effects of policy measures.	Disaggregate tour frequency model	Comparable and based on LMS (Netherlands)
NTM (Denmark)	1300 zones	1. car 2. train (several types) 3. coach / regional bus 4. air	Short distance: 1. Work 2. Business 3. Shopping 4. Recreation 5. Other Long distance (domestic): 1.private 2. Business	TG, TD, MC, TA	To predict effects of long-distance high-speed train services and other infrastructure investments	Disaggregate tour frequency model	Comparable and based on LMS (Netherlands)
NTM (Switzerland)	755 domestic zones, 67 foreign zones	car, train	work, vacation, other	TG, TD, MC, TA	To make predictions of the impact of policy and infrastructure measures.	Aggregate trip frequency model, logit mode choice. Agent-based simulation	
BVWP (Austria)	676 domestic zones, 205 foreign zones	car, train, coach/regional bus	1. work 2. Business 3. School 4. Shopping 5. Leisure 6. other	TG, TD, MC, TA	To predict demand effects of new infrastructure and services, changing incomes, different population structure, changes in trade and industry. Optimize of National Transport Conception, environmental effects	Aggregate trip frequency model	

Table A.1 (continued)

BVWP (Germany)	360 domestic zones, 83 foreign zones	1. car, 2. Train 3. bus (regional) 4. air 5. Bicycle 6. Walk	1. work 2. Business 3. Shopping 4. Education 5. Vacation 6.leisure and other	TG, TD, MC	To predict demand effects of new political situations in Europe and infrastructure and transport policy, socio-demography and economic, changes in trade and industry.	Aggregate trip frequency model	
MATISSE (France)	Links with OD distances varying from 50-2500km	Car, air, rail	Business, private	TG, TD, MC, TA	The model was developed to analyse long distance passenger traffic (trips >50 km), focusing on France.	Disaggregate trip frequency model	Travel time, cost, group size, time of day, car availability, fare reduction, quality of service
NTM (Great Britain)	2496 National Trip End Model (NTEM) Zones	Car Driver, Car Passenger, Bus, Rail, Metro, Taxi, Cycle, Walk	HB work, HB Employer's Business, HB Education, HB PB/Shopping, HB Recreation/Visiting Friend & Relatives, HB holidays and day trips, NHB Employer's Business, NHB Other	TG, TD, MC, Route Choice, TA	The Department for Transport’s National Transport Model (NTM) has been developed over a number of years, and has been used by the Department for forecasting travel trends for over 10 years, primarily for the purposes of producing the annual road traffic forecast report, policy formation, and strategic analysis of options, predominantly for England and Wales.	Nested Logit Model	Person type, Household income (indirectly through car ownership model), household type, gender, travel cost, travel time
STEMM	1269 zones	car, air, rail	Business, private, vacation	TG, TD, MC			
TRANS-TOOLS	NUTS3 based zonal system of 1269 zones within Europe	Road, rail, air	Business, private, tourism	TG, TD, MC, TA	TRANS-TOOLS had the objective to produce a European transport network model covering both passenger and freight, as well as intermodal transport, which overcomes the shortcomings of current European transport network models and provided the Commission with an in house updated instrument of simulation. The objective of the project was to build on the experience of existing transport models and implement a number of improvements that are the basis of the development of an integrated policy support tool for transport at EU level.	Non-linear logit function	Travel cost, travel time, frequency, number of transfers, population, GDP, employment, car ownership
Bel (1997) Spain	Spanish rail network by province	train, car	NA	NA	This paper specifies and empirically estimates, an explanatory model to evaluate the impact of travel time changes on inter-urban rail demand.	Double logarithmic form	Travel time, dummy variable for 'increase in air service frequency'

Table A.1 (continued)

Model/Study	Geographic Detail	Modes	Trip Purposes	Demand Component	Model Objectives	Method	Explanatory Variables
OTHER NON-U.S.							
Yao and Morikawa (2005) - Japan	6 zones from questionaires, 147 zones from the NTS	Car, air, Rail (conventional, HSR, Shinkansen), bus	business, non-business, home-based, non home based	trip generation, distribution, mode choice, route choice	to develop an integrated intercity travel demand modeling system suitable for substantial changes in service level.	Regression model and Nested Logit Models with route choice	TG: Accessibility, population, working population in service sector. TD: logsum MC, zonal GDP per capita, share of working population, business attractiveness, non-business attractiveness. MC: Travel cost, travel time, access time, frequency, value of travel time savings.
Aldian and Taylor (Australia - 2003) - Indonesia	Intercity Central Java. Number of zones unknown	Car only	NA	TG, TD, TA	A new approach to modelling inter-city travel that combines a behavioural travel demand model and a direct demand model. Fuzzy multicriteria analysis is applied to calculate aggregate utilities (trip production power and zone attractiveness).	Fuzzy multicriteria analysis. It adopts the structure of disaggregate models, but the deterministic part of utility function is developed at aggregate level. The multinomial logit model is applied to calculate trip distribution	TG: population density, gross domestic regional product. TD: road user cost (distance, road geometry, ride quality), number of hotel rooms

Notes: Demand Components: TG = trip generation, TD= trip distribution, MC= modal choice, TA = traffic (route) assignment

APPENDIX B. RESULTS FOR CORRIDOR ANALYSES

Note: MMT = Million Metric Tonnes

Table B.1: Auto and Bus Trips By Corridor

Business Trips Auto - Pacific Northwest

From\To	**Eugene**	**Portland**	**Seattle**
Eugene	0	182,392	20,076
Portland	191,700	0	1,455,367
Seattle	18,964	1,440,377	0

Total Trips Auto - Pacific Northwest

From\To	**Eugene**	**Portland**	**Seattle**
Eugene	0	1,782,641	521,689
Portland	1,873,616	0	14,224,315
Seattle	492,791	14,077,809	0

Business Trips Bus - Pacific Northwest

From\To	**Eugene**	**Portland**	**Seattle**
Eugene	0	388	60
Portland	408	0	3,097
Seattle	57	3,065	0

Total Trips Bus - Pacific Northwest

From\To	**Eugene**	**Portland**	**Seattle**
Eugene	0	8,723	2,847
Portland	9,168	0	69,601
Seattle	2,689	68,885	0

Business Trips Auto - Keystone

From\To	**Pittsburgh**	**Harrisburg**	**Philadelphia**
Pittsburgh	0	35,378	116,754
Harrisburg	35,267	0	264,270
Philadelphia	110,590	251,654	0

Total Trips Auto - Keystone

From\To	**Pittsburgh**	**Harrisburg**	**Philadelphia**
Pittsburgh	0	482,595	2,919,745
Harrisburg	481,071	0	3,604,896
Philadelphia	2,765,598	3,432,796	0

Business Trips Bus - Keystone

From\To	**Pittsburgh**	**Harrisburg**	**Philadelphia**
Pittsburgh	0	188	871
Harrisburg	188	0	1,406
Philadelphia	825	1,339	0

Total Trips Bus - Keystone

From\To	**Pittsburgh**	**Harrisburg**	**Philadelphia**
Pittsburgh	0	2,493	14,886
Harrisburg	2,486	0	18,625
Philadelphia	14,100	17,736	0

Table B.1 (continued)

Business Trips Auto - California

From\To	**San Francisco**	**Los Angeles**	**San Diego**
San Francisco	0	415,590	216,073
Los Angeles	415,451	0	1,036,651
San Diego	223,831	1,180,485	0

Total Trips Auto - California

From\To	**San Francisco**	**Los Angeles**	**San Diego**
San Francisco	0	11,783,695	6,126,554
Los Angeles	11,779,753	0	8,818,153
San Diego	6,346,533	10,041,660	0

Business Trips Bus - California

From\To	**San Francisco**	**Los Angeles**	**San Diego**
San Francisco	0	3,101	1,612
Los Angeles	3,100	0	5,514
San Diego	1,670	6,279	0

Total Trips Bus - California

From\To	**San Francisco**	**Los Angeles**	**San Diego**
San Francisco	0	66,258	34,448
Los Angeles	66,235	0	46,043
San Diego	35,685	20,265	0

Table B.2: Automobile CO_2 Emissions By Corridor

Auto CO2 Emissions (MMT CO2) - Pacific Northwest			
From\To	**Eugene**	**Portland**	**Seattle**
Eugene	0.000	0.048	0.036
Portland	0.050	0.000	0.597
Seattle	0.034	0.591	0.000

Auto CO2 Emissions (MMT CO2) - Keystone			
From\To	**Pittsburgh**	**Harrisburg**	**Philadelphia**
Pittsburgh	0.000	0.024	0.215
Harrisburg	0.024	0.000	0.093
Philadelphia	0.205	0.089	0.000

Auto CO2 Emissions (MMT CO2) - California			
From\To	**San Francisco**	**Los Angeles**	**San Diego**
San Francisco	0.000	1.089	0.746
Los Angeles	1.092	0.000	0.259
San Diego	0.773	0.295	0.000

Table B.3: Air CO_2 Emissions By Corridor

Air CO2 Emissions (MMT CO2) - Pacific Northwest			
From\To	**Eugene**	**Portland**	**Seattle**
Eugene	0.000	0.005	0.011
Portland	0.004	0.000	0.025
Seattle	0.010	0.024	0.000

Air CO2 Emissions (MMT CO2) - Keystone			
From\To	**Pittsburgh**	**Harrisburg**	**Philadelphia**
Pittsburgh	0.000	0.001	0.042
Harrisburg	0.001	0.000	0.005
Philadelphia	0.043	0.004	0.000

Air CO2 Emissions (MMT CO2) - California			
From\To	**San Francisco**	**Los Angeles**	**San Diego**
San Francisco	0.000	0.135	0.087
Los Angeles	0.142	0.000	0.035
San Diego	0.091	0.035	0.000

Table B.4: Rail CO_2 Emissions By Corridor

Rail CO2 Emissions (MMT CO2) - Pacific Northwest			
From\To	**Eugene**	**Portland**	**Seattle**
Eugene	0.000	0.003	0.001
Portland	0.003	0.000	0.004
Seattle	0.001	0.004	0.000

Rail CO2 Emissions (MMT CO2) - Keystone			
From\To	**Pittsburgh**	**Harrisburg**	**Philadelphia**
Pittsburgh	0.000	0.001	0.001
Harrisburg	0.001	0.000	0.006
Philadelphia	0.001	0.006	0.000

Rail CO2 Emissions (MMT CO2) - California			
From\To	**San Francisco**	**Los Angeles**	**San Diego**
San Francisco	0.000	0.001	0.001
Los Angeles	0.001	0.000	0.006
San Diego	0.001	0.006	0.000

Table B.5: Bus CO_2 Emissions By Corridor

Bus CO2 Emissions (MMT CO2) - Pacific Northwest			
From\To	**Eugene**	**Portland**	**Seattle**
Eugene	0.0000	0.0002	0.0001
Portland	0.0002	0.0000	0.0006
Seattle	0.0001	0.0005	0.0000

Bus CO2 Emissions (MMT CO2) - Keystone			
From\To	**Pittsburgh**	**Harrisburg**	**Philadelphia**
Pittsburgh	0.0000	0.0001	0.0008
Harrisburg	0.0001	0.0000	0.0002
Philadelphia	0.0008	0.0002	0.0000

Bus CO2 Emissions (MMT CO2) - California			
From\To	**San Francisco**	**Los Angeles**	**San Diego**
San Francisco	0.0000	0.0016	0.0014
Los Angeles	0.0016	0.0000	0.0007
San Diego	0.0017	0.0005	0.0000

Table B.6: Access and Egress CO_2 Emissions by Main Mode

Air A/E CO2 Emissions (MMT CO2) - Pacific Northwest			
From\To	**Eugene**	**Portland**	**Seattle**
Eugene	0.000	0.001	0.001
Portland	0.001	0.000	0.006
Seattle	0.001	0.005	0.000

Air A/E CO2 Emissions (MMT CO2) - Keystone			
From\To	**Pittsburgh**	**Harrisburg**	**Philadelphia**
Pittsburgh	0.000	0.000	0.004
Harrisburg	0.000	0.000	0.001
Philadelphia	0.004	0.001	0.000

Air A/E CO2 Emissions (MMT CO2) - California			
From\To	**San Francisco**	**Los Angeles**	**San Diego**
San Francisco	0.000	0.016	0.006
Los Angeles	0.016	0.000	0.003
San Diego	0.007	0.004	0.000

Table B.6 (continued)

Rail A/E CO2 Emissions (MMT CO2) - Pacific Northwest			
From\To	**Eugene**	**Portland**	**Seattle**
Eugene	0.0000	0.0002	0.0000
Portland	0.0002	0.0000	0.0007
Seattle	0.0000	0.0007	0.0000

Rail A/E CO2 Emissions (MMT CO2) - Keystone			
From\To	**Pittsburgh**	**Harrisburg**	**Philadelphia**
Pittsburgh	0.0000	0.0000	0.0000
Harrisburg	0.0000	0.0000	0.0002
Philadelphia	0.0000	0.0002	0.0000

Rail A/E CO2 Emissions (MMT CO2) - California			
From\To	**San Francisco**	**Los Angeles**	**San Diego**
San Francisco	0.0000	0.0000	0.0000
Los Angeles	0.0000	0.0000	0.0012
San Diego	0.0000	0.0012	0.0000

Table B.6 (continued)

Bus A/E CO2 Emissions (MMT CO2) - Pacific Northwest			
From\To	**Eugene**	**Portland**	**Seattle**
Eugene	0.0000	0.0001	0.0000
Portland	0.0001	0.0000	0.0006
Seattle	0.0000	0.0006	0.0000

Bus A/E CO2 Emissions (MMT CO2) - Keystone			
From\To	**Pittsburgh**	**Harrisburg**	**Philadelphia**
Pittsburgh	0.0000	0.0000	0.0001
Harrisburg	0.0000	0.0000	0.0001
Philadelphia	0.0001	0.0001	0.0000

Bus A/E CO2 Emissions (MMT CO2) - California			
From\To	**San Francisco**	**Los Angeles**	**San Diego**
San Francisco	0.0000	0.0006	0.0002
Los Angeles	0.0006	0.0000	0.0005
San Diego	0.0003	0.0002	0.0000

Table B.7: Total CO_2 Emissions (Direct + Indirect) By Corridor

Total Direct + Indirect Emissions by Corridor (MMT CO2)					
	Auto	**Air**	**Rail**	**Bus**	**Total**
Pacific Northwest	2.169	0.124	0.040	0.004	2.338
Keystone	1.039	0.143	0.034	0.004	1.221
California	6.805	0.764	0.039	0.014	7.622

Table B.8: Share of Total CO_2 Emissions (Direct + Indirect) By Mode By Corridor

Total Direct + Indirect Emissions by Mode by Corridor (%)				
	Auto	**Air**	**Rail**	**Bus**
Pacific Northwest	92.8	5.3	1.7	0.2
Keystone	85.1	11.7	2.8	0.3
California	89.3	10.0	0.5	0.2

APPENDIX C. RESULTS FOR POLICY/STRATEGY APPLICATION

Table C.1: CO_2 Savings With Average Fuel Economy of 35.5 mpg

CO2 Savings With 35.5 MPG Fuel Economy		
	MMT CO2	**Percentage**
Pacific Northwest	0.976	41.8
Keystone	0.470	38.5
California	3.062	40.2

Table C.2: CO_2 Savings With 10% Electric Car Share

CO2 Savings With 10% Electric Car Share		
	MMT CO2	**Percentage**
Pacific Northwest	0.183	7.8
Keystone	0.042	3.4
California	0.464	6.1

Table C.3: CO_2 Savings With 25% Gasoline Replacement By Cellulosic Ethanol

CO2 Savings With 25% Gasoline Replacement By Cell. Ethanol		
	MMT CO2	**Percentage**
Pacific Northwest	0.339	14.5
Keystone	0.163	13.4
California	1.063	14.0

Table C.4: CO_2 Savings With 20-35% Improvement in Aircraft Efficiency

CO2 Savings With 20-35% Improvement in Aircraft Efficiency				
	20% Improvement		*35% Improvement*	
	MMT CO2	**Percentage**	**MMT CO2**	**Percentage**
Pacific Northwest	0.021	0.9	0.036	1.5
Keystone	0.025	2.1	0.045	3.6
California	0.136	1.8	0.238	3.1

Table C.5: Diverted Trips By Mode for HSR125

Number of Diverted Trips By Mode - HSR125					
	Auto	**Air**	**Rail**	**Bus**	**Total**
Pacific Northwest	1,641	33,027	91,780	87	126,536
Keystone	12	3,242	28,653	1	31,907
California	6,097	60,639	140,932	125	207,793

Table C.6: Percentage Diverted Trips By Mode for HSR125

Percentage Diverted Trips By Mode - HSR125 (%)				
	Auto	**Air**	**Rail**	**Bus**
Pacific Northwest	0.00	3.03	40.04	0.05
Keystone	0.00	0.40	31.12	0.00
California	0.01	1.41	55.92	0.05

Table C.7: Diverted Trips By Mode for HSR150

Number of Diverted Trips By Mode - HSR150					
	Auto	**Air**	**Rail**	**Bus**	**Total**
Pacific Northwest	87,385	745,455	198,595	7,385	0
Keystone	13,431	55,829	62,199	553	0
California	103,394	501,407	223,196	5,808	0

Table C.8: Percentage Diverted Trips By Mode for HSR150

Percentage Diverted Trips By Mode - HSR150 (%)				
	Auto	**Air**	**Rail**	**Bus**
Pacific Northwest	0.27	68.31	86.64	4.56
Keystone	0.10	6.85	67.55	0.79
California	0.19	11.63	88.56	2.16

Table C.9: Diverted Trips By Mode for HSR200

Number of Diverted Trips By Mode - HSR200					
	Auto	**Air**	**Rail**	**Bus**	**Total**
Pacific Northwest	143,086	874,092	208,726	11,894	0
Keystone	28,287	124,514	69,804	2,110	0
California	180,363	963,813	230,609	14,282	0

Table C.10: Percentage Diverted Trips By Mode for HSR200

Percentage Diverted Trips By Mode - HSR200 (%)				
	Auto	**Air**	**Rail**	**Bus**
Pacific Northwest	0.43	80.10	91.06	7.35
Keystone	0.21	15.28	75.81	3.00
California	0.33	22.36	91.50	5.31

Table C.11: CO_2 Savings With HSR125, HSR150, and HSR200

CO2 Savings With High Speed Rail						
	HSR125		*HSR150*		*HSR200*	
	MMT CO2	**Percentage**	**MMT CO2**	**Percentage**	**MMT CO2**	**Percentage**
Pacific Northwest	-0.007	-0.3	0.034	1.5	0.036	1.5
Keystone	-0.024	-1.9	-0.018	-1.5	-0.014	-1.1
California	0.019	0.3	0.047	0.6	0.059	0.8

Table C.12: Diverted Trips By Mode for HSR150 Scenario

Number of Diverted Trips By Mode - HSR150 Scenario					
	Auto	**Air**	**Rail**	**Bus**	**Total**
Pacific Northwest	1,848,710	759,672	198,346	7,886	0
Keystone	1,581,999	174,426	75,258	3,218	0
California	2,680,266	686,243	229,851	9,305	0

Table C.13: Percentage Diverted Trips By Mode for HSR150 Scenario

Percentage Diverted Trips By Mode - HSR150 Scenario (%)				
	Auto	**Air**	**Rail**	**Bus**
Pacific Northwest	5.61	69.62	86.53	4.87
Keystone	11.56	21.40	81.73	4.58
California	4.88	15.92	91.20	3.46

Table C.14: CO_2 Savings for HSR150 Scenario

CO2 Savings For HSR150 Scenario		
	HSR150 Scenario	
	MMT CO2	**Percentage**
Pacific Northwest	0.077	3.3
Keystone	-0.006	-0.5
California	0.156	2.1

Table C.15: Volpe's Diverted Trips By Mode for HSR150 Scenario With $400/tC Carbon Tax

Number of Diverted Trips By Mode - HSR150 Scenario With $400/tC Tax					
	Auto	**Air**	**Rail**	**Bus**	**Total**
Pacific Northwest	99,616	809,417	205,483	7,736	0
Keystone	51,493	167,528	80,418	2,805	0
California	140,093	675,530	232,907	7,524	0

Table C.16: Percentage Diverted Trips By Mode for HSR150 Scenario With $400/tC Carbon Tax

Percentage Diverted Trips By Mode - HSR150 Scenario With $400/tC Tax (%)				
	Auto	**Air**	**Rail**	**Bus**
Pacific Northwest	0.30	74.17	89.65	4.78
Keystone	0.38	20.55	87.34	3.99
California	0.26	15.96	92.42	2.80

Table C.17: CO_2 Savings for Carbon Tax of $400/tC For HSR150 Scenario

CO2 Savings For HSR150 Scenario With $400/tC Carbon Tax		
	HSR150 Scenario	
	MMT CO2	**Percentage**
Pacific Northwest	0.078	3.3
Keystone	-0.041	-3.4
California	0.158	2.1

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