Literature Review:
Transportation Adaptation in Response to Climate Change

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1. INTRODUCTION

Scientific evidence on climate change and the potential for serious global impact is now stronger than ever (Stern, 2006). The Intergovernmental Panel on Climate Change (IPCC) released a statement in the Fourth Assessment Report that there is a ninety-percent probability (very high confidence) that greenhouse gas emissions produced by human activities have caused most of the observed global warming since the mid-twentieth century (IPCC, 2007). Over recent years, global warming has occurred at a rate of 0.2°C per decade, leading to observable changes such as varying rainfall patterns, sea level rise, ice and snow melt, and increase in intensity and frequency of extreme weather events (IPCC, 2007). As global warming continues, time is running out to stabilize and reduce greenhouse gas emissions in order to avoid the “devastating impacts on our planet” (Environment, Heritage, and Local Government, 2007).

A growing concern facing the transportation sector in the United States is the potential impact of climate change on land transportation. As scientific evidence on climate change continues to support the relationship between anthropogenic activities and global warming, greenhouse gas concentrations continue to rise at a rate of more than 2 parts per million each year (Stern, 2006). Currently the United States is the largest emitter worldwide, with transportation accounting for one third of carbon dioxide emissions (Ewing et al., 2008). Therefore, much of the discussion and efforts related to transportation and climate change is focused on mitigation and reducing transportation’s contribution to climate change (Valsson and Ulfarsson, 2009).

As the risk of climate change becomes imminent, pressure for adaptation within transportation agencies to promote sustainable practices and alter behavior, continues to rise. While mitigation efforts are essential to slowing the threat of climate change, adaptation practices to build resilience and protection from impacts should be accelerated (Stern, 2006).
Bridging the connection between climate change-induced design factors and reducing their impact through transportation adaptation practice is fundamental. As mitigation techniques such as alternative fuels, congestion pricing, and transportation demand management techniques are implemented, adaptation practices must support changes in infrastructure, land use, and development patterns. Therefore, exploring the integration between mitigation and adaptation from climate change can provide a foundation for developing a decision tool for adapting to climate change through sustainable transportation planning.

Since climate change impacts are based on geographical context, the Mid-Atlantic coastal region is used as an example throughout this literature review. It is evaluated in detail in order to allow for further research related to this specific region. It was selected based on its accessibility and unique characteristics associated with sea level rise.

The following literature review is divided into two sections: (1) Background on Climate Change and (2) Land Transportation and Climate Change. The first section discusses the science of climate change and the elements of adaptation. The second section defines climate change in the context of land transportation in terms of the potential impacts and existing initiatives toward adaptation. These sections are then tied together in the conclusions where general reflections are made regarding transportation adaptation in response to climate change impacts.
2. BACKGROUND ON CLIMATE CHANGE

This section defines the science of climate change based on a literature review. Details regarding climate trends within the Mid-Atlantic coastal region of the United States are discussed as well as the concept of climate change adaptation in response to potential impacts.

What is Climate Change?

Scientific evidence on climate change and the potential for serious global impact is now stronger than ever (Stern, 2006). The Intergovernmental Panel on Climate Change (IPCC) states that there is a ninety-percent probability (very high confidence) that greenhouse gas emissions produced by human activities have caused most of the observed global warming since the mid-twentieth century (IPCC, 2007).

The phrase “climate change” is used to signify alterations in the Earth’s “pattern of weather, meaning the averages, the extremes, the timing, the spatial distribution not only of hot and cold, but of cloudy and clear, humid and dry, drizzles and downpours, snowfall, snowpack, snowmelt, blizzards, tornados, and typhoons” (Holdren, 2008). These changes are in addition to rising temperatures (referred to as global warming), which has already and will continue to occur in response to atmospheric amplified warming. Amplified warming is the result of high concentrations of carbon dioxide emissions and other greenhouse gas emissions (methane, nitrous oxide, halocarbons, and ozone) trapping additional infrared energy beyond what occurs naturally (National Academies, 2008). The process of natural warming can be seen in Figure 2.1 which is based on the greenhouse effect where the majority of sunlight emitted onto the Earth’s surface is absorbed by the oceans and land. The remaining infrared energy radiates outwards from the Earth and is either absorbed by the greenhouse gases, emitted into space, or reflected back toward the Earth’s surface (National Academies, 2008).
Since the 1750’s human activities have been influencing the global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide leading to a disruption in the natural warming process (Ewing et al., 2008). The increased release of greenhouse gas emissions is responsible for the amplification of this process where additional infrared energy is trapped, further warming the atmosphere and the Earth’s surface. As a result, long term climatic changes have been observed and are projected to continue, including increased temperatures, heavy precipitation, droughts, rising sea level, heat waves, tropical cyclone intensity, and extreme weather events (Ewing et al., 2008). Therefore, rising temperatures along with additional indicators (increased ocean temperatures, shrinking mountain glaciers, and decreasing polar ice cover) suggest that the threat of climate change is undeniable requiring an urgent global response (Stern, 2006).

Figure 2.1-The Greenhouse Effect (U.S. Global Change Research Information Office, 1996)
Global Warming

Recently, scientific evidence has proven that global warming has occurred at a rate of 0.2°C per decade, leading to observable changes such as varying rainfall patterns, sea level rise, ice and snow melt, and increase in intensity and frequency of extreme weather events (IPCC, 2007). Over the past thirty years there has been a more pronounced warming trend and even more recently, nine out of ten of the warmest years occurred over the last decade (National Academies, 2008). Figure 2.2 displays the global temperature increase for both the annual and five-year mean.

Although these upward trends are indisputable, there are questions regarding whether the warming trend is unusual compared to trends prior to the 20th century. Based on scientific analysis on tree rings, ice cores, ocean sediments, and other “proxies,” it has been identified that there is a “high level of confidence that the global mean surface temperature was higher during the last few decades of the 20th century than during any comparable period since at least 1600 A.D.” (National Academies, 2008). This warming process has been extremely rapid, placing undue stress on both social and environmental systems, leading to additional disruptions in long term weather patterns. As a result, researchers believe that the term “global warming” does not serve justice to the problem and rather it should be called a “global climatic disruption” (Holdren, 2008).
There is a strong link between global average surface temperature and global climate. The surface temperature serves as an index for the state of climatic patterns and a small alteration in the index results in large changes in the patterns (Holdren, 2008). These small changes in temperature (0.2°C per decade) are leading to extreme changes in sea level rise, and widespread melting of ice and snow. Figure 2.3 displays the relationship between increasing global temperature, rising sea level, and melting of snow cover.
In 2007, the Intergovernmental Panel on Climate Change reported that there is a “very high confidence” behind the relationship of anthropogenic activities and global warming (IPCC, 2007). Through fossil fuel burning as well as land use changes, humans are pushing the climate toward the heating direction and further away from natural cooling (Holdren, 2008). Scientific evidence supports this claim by modeling natural patterns against direct observations which take into account human activity. Figure 2.4 displays the temperature differences in model results (grey) versus observation results (red) from 1850 to 2000.
The first graph shows that after 1950, the observations were higher than the model results of natural patterns, suggesting that human activity has influenced the global average surface temperature. The second graph depicts an influence beyond human activity since the model results including human activity are still below the observation results between the 1900’s and 1975. Therefore, the third graph suggests a trendline which takes into account both human and natural activity results to show a more accurate depiction of global warming.
Figure 2.4- Comparison of Natural vs. Man Made Causes (National Academies, 2005)
**Greenhouse Gases**

The main cause of global warming has been attributed to the release of greenhouse gas emissions including carbon dioxide, methane, nitrous oxide, halocarbons, and ozone (National Academies, 2008). As of 2006, the current level of carbon dioxide is 430ppm and is rising at more than 2ppm each year (Stern, 2006). In order to stabilize carbon dioxide emissions, annual costs of 1% of global GDP/year are required to maintain a level between 500ppm and 550ppm, assuming immediate action is taken (Stern, 2006). Releasing carbon dioxide is just one of the multiple contributors of anthropogenic warming. The following is a list of the greenhouse gases that are imposing external warming on the Earth’s surface (National Academies, 2008):

- Carbon dioxide- associated with the release of fossil fuels, deforestation, and other land use changes.
- Methane- released primarily through raising livestock, growing rice, filling landfills, and using natural gas.
- Nitrous oxide- resulting from agricultural activities and land use changes.
- Ozone- associated with a warming effect when produced near the Earth’s surface via reactions involving carbon monoxide, hydrocarbons, and nitrogen oxide.
- Halocarbons- attributed to the use of chlorofluorocarbons (CFC’s) including refrigerants and fire retardants which is also responsible for damaging the ozone layer.

In addition to these aforementioned greenhouse gases, other human activities are forcing temperature changes. The most prominent activities are discussed in detail (National Academies, 2008):

- Aerosols- industrial processes are associated with the release of aerosols which cool the planet by reflecting sunlight back into space.
- Black carbon particles (soot)-produced by the burning of fossil fuels or vegetation and responsible for a warming effect since they absorb incoming solar radiation.
Deforestation - removal of trees leads to a modification in the amount of sunlight that is reflected back to space.

Land use changes - alteration in the use of land such as increased impervious cover which influences the amount of sunlight reflected back into space.

Climate Trends

Climate change is a phenomenon that will affect all countries throughout the world at a national, state, and local level (Stern, 2006). Although everyone is at risk for impact, the costs and degree of impact will vary based on regional context. Influences such as latitude and longitude, coastal regions, islands, sea level, and terrain will lead to unique circumstances at the local level. For example, coastal regions are more at risk for flooding, a symptom of sea level rise, while countries in the upper Northern hemisphere are more at risk for widespread snow and ice melt.

Global Trends

In order to understand a more local region such as the Mid-Atlantic coastal region, the confidence levels behind global changes should be explored. The IPCC released their confidence levels (supported by scientific research) suggesting the likelihood of historical and future trends, as well as human influences on various climate trends. Table 2.1 displays the IPCC’s confidence on individual phenomenon as they relate to climate change.
In terms of the IPCC’s (2007) degree of confidence they are “virtually certain” that most land areas will experience fewer cold days and nights as well as more frequent hot days and nights. Increased frequency of heat waves and warm spells are “very likely” along with increased frequency and intensity of heavy precipitation events (IPCC, 2007). The increased temperatures will lead to significant changes throughout the Arctic including ice, snow, and permafrost thaw and intense precipitation will result in extreme flooding particularly for coastal regions. Extreme weather events including drought, cyclones, and hurricanes are “likely” causing significant harm to the natural and built environment. Extreme precipitation events combined with global warming has caused high sea level rise to be “likely.”

Globally, sea level rise will continue to be an issue for many coastal regions as long as the global average surface and sea temperatures continue to rise. Contributing sources
include thermal expansion of heated seawater, melting of glaciers, ice caps, and ice sheets. Table 2.2 displays the contributions of each source toward sea level rise as well as compares the rate of sea level rise in 1961-2003 and 1993-2003. The most contributing factor over both time periods is the melting of glaciers and ice caps. This rate of melting has been about twice the average for the 20th century (Holdren, 2008). Figure 2.5 displays the disappearance of summer sea ice in the Arctic region from 2005 to 2007. The pink line represents the median ice edge and the white area indicates the existing ice area. In 2005, the sea ice extent was 5.6 million square feet and reduced to 4.3 million square feet by 2007. This indicates a rapid change in the melting of Arctic ice as well as the associated sea level rise throughout the world.

**Table 2.2-Contributions of Sea Level Rise over Time (IPCC, 2007)**

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Thermal expansion</td>
<td>0.42 ± 0.12</td>
<td>1.6 ± 0.5</td>
<td></td>
</tr>
<tr>
<td>Glaciers and ice caps</td>
<td>0.50 ± 0.18</td>
<td>0.77 ± 0.22</td>
<td></td>
</tr>
<tr>
<td>Greenland Ice Sheet</td>
<td>0.05 ± 0.12</td>
<td>0.21 ± 0.07</td>
<td></td>
</tr>
<tr>
<td>Antarctic Ice Sheet</td>
<td>0.14 ± 0.41</td>
<td>0.21 ± 0.35</td>
<td></td>
</tr>
<tr>
<td>Sum of individual climate contributions to sea level rise</td>
<td>1.1 ± 0.5</td>
<td>2.8 ± 0.7</td>
<td></td>
</tr>
<tr>
<td>Observed total sea level rise</td>
<td>1.6 ± 0.5*</td>
<td>3.1 ± 0.7*</td>
<td></td>
</tr>
<tr>
<td>Difference (Observed minus sum of estimated climate contributions)</td>
<td>0.7 ± 0.7</td>
<td>0.3 ± 1.0</td>
<td></td>
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</tbody>
</table>
Although climate change is a global phenomenon, issues in addressing the problem will vary across individual regions throughout the world. Since climate change impacts depend on regional context and geographic location, planning for each region throughout the world will be unique. This distinctive quality of the various potential impacts of climate change on different locations requires an assessment at a more regional, localized scale.

Throughout the United States, a great diversity exists for a range of potential climate change impacts. These impacts are far from uniform throughout the country. Each area will experience their own share of changes in temperature, precipitation, sea level rise, and hurricane intensity. Therefore, evaluating each region’s potential impacts allows for planning strategies and action against climate change to be tailored to its specific needs (McNeil, 2009).

The United States can be broken down into eight separate regions, each holding their own potential risks as a result of climate change. The regions include: Northeast and Mid-
Atlantic, Midwest, West, Great Plains, Southeast, Pacific Northwest, Alaska, Hawaii and U.S. Affiliated Islands. Table 2.3 displays each region and its associated impacts.

Table 2.3-Relationships among Regions and Climate Change Phenomena (McNeil, 2009)

<table>
<thead>
<tr>
<th>Climate Change Phenomena/ Region</th>
<th>Northeast and Mid-Atlantic</th>
<th>Midwest</th>
<th>West</th>
<th>Great Plains</th>
<th>Southeast</th>
<th>Pacific Northwest</th>
<th>Alaska</th>
<th>Hawaii and US Affiliated Islands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in very hot days and heat waves</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increases in Arctic temperatures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Rising sea levels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Increases in intense precipitation events</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increases in hurricane intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

For the purposes of this research, the Mid-Atlantic region was selected, specifically the coastal region in order to capture those areas most at risk for sea level rise. Therefore, the climate change phenomena specific to this region includes an increase in very hot days and heat waves, rising sea levels, and increases in intense precipitation events. These three potential impacts serve as the focus for adaptation action and strategies suggested throughout this research.

**Climate Change Adaptation**

Science shows that the climate is changing and will continue to accelerate over future years, having a significant impact on the built and natural environment (Pew Center on Global Climate Change, 2009). With this knowledge, mitigation efforts such as setting limits on emissions will not be sufficient, or timely enough to avoid all potential impacts of climate change (Pew Center on Global Climate Change, 2009). Therefore, in order to prepare and protect societies, economies, and the environment, adaptation efforts are required. These efforts require steps to improve planning, develop more climate-resilient infrastructure, and overall provide better information to individuals on how they can respond (Stern, 2006).
Climate change adaptation is defined by the IPCC (2007) “as the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects which moderates harm or exploits beneficial opportunities” (EPA, 2009). The Pew Center on Global Climate Change (2009) further supports this definition with their own, stating adaption involves “actions by individuals or systems to avoid, withstand, or take advantage of current and projected climate changes and impacts…in order to decrease a system’s vulnerability, or increase its resilience to impacts.” Both definitions stress the ability to moderate or avoid harm as a result of climate change impact. The adaptation process requires significant preparation in regards to the following areas (Pew Center on Global Climate Change, 2008):

- Risk assessment
- Prioritization of projects
- Funding and allocation of both financial and human resources
- Solution development and implementation
- Information sharing
- Decision-support tools
- Collaboration across agencies, sectors, and geographic boundaries
- Creativity in design

Based on each geographic location, these adaptation aspects should be tailored to their needs.

An example of an adaptation strategy in response to rising sea level is shore protection. Construction of dikes, bulkheads, and beach nourishment can prevent the impacts of sea level rise such as flooding, eroding beaches, and inundation of low-lying coastal properties (EPA, 2009). The adaptation strategy should be selected based on its associated costs and benefits and alternative strategies should be considered as necessary, such as inland retreat (relocating structures inland).
Adaptive Capacity

The potential for adaptation, similar to climate change phenomena, will not be consistent throughout various societies and systems. The geography, economy, social and political structures, as well as many other factors will inevitably influence the ability for regions to adapt. The inherent ability for a system to adapt to climate change impacts is termed adaptive capacity. More specifically, it involves an evaluation of “What is feasible in terms of repair, relocation, or restoration of the system?” and “Can the system be made less vulnerable or more resilient?” (Pew Center on Global Climate Change, 2009).

Since adaptive capacity is uneven across and within societies, the potential for individuals and groups to have insufficient capacity is present (EPA, 2009). Additionally, those that have high adaptive capacity do not always translate into a direct reduction in vulnerability (EPA, 2009). An example of this can be depicted through residents living in urban areas adapting to heat stress. Although there is a high capacity for residents to adapt to heat stress through low-cost methods, residents in some locations throughout the world still experience high levels of mortality (EPA, 2009). Therefore, high adaptive capacity does not directly correlate to increased resilience or decreased vulnerability.

There are many key factors that drive adaptive capacity and lead to inconsistency across and within regions. These key factors include economic resources, technology, information and awareness, skills and human resources, infrastructure, and institutional support and governance (Pew Center on Global Climate Change, 2009). Table 2.4 displays key factors for adaptive capacity along with examples of how they pertain to a region’s ability to adapt. These key factors limit the participation of developing countries as well as some areas in developed countries to implement adaptation practices, specifically due to a lack of economic and technologic resources.
Regardless of location, in general, the ability for natural systems to adapt is more limited than built systems (Pew Center for Global Climate Change, 2009). Therefore, an effort to reduce the effects of urbanization, decrease barriers to migration paths, and avoid habitat fragmentation, is necessary to encourage ecosystem adaptation (EPA, 2009).

Similarly, efforts to allow the built environment to adapt are essential and begin with encouraging a supportive governance, supportive social structures, and creating information through continued research and data collecting. Once a society has gone through the effort of building their adaptive capacity, then adaptation actions (or activities) can be implemented.

**Adaptation Activities**

A system’s adaptive capacity serves as a foundation for which adaptation activities can be delivered. The United Nations Framework on Climate Change (UNFCC) describes adaptation activities as being technological, managerial, behavioral, or policy-based (McNeil, 2009). Based on individual sectors, the activities will be tailored to their needs. For example, transportation focuses on monitoring and infrastructure construction activities, which fall under the technological activities (McNeil, 2009).

<table>
<thead>
<tr>
<th>Factors</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic resources</td>
<td>Wealth of individuals and localities.</td>
</tr>
<tr>
<td>Technology</td>
<td>Localized climate and impact modeling to predict climate change and variability; efficient irrigation systems to reduce water demand.</td>
</tr>
<tr>
<td>Information/awareness</td>
<td>Species, sector, and geographic-based climate research; population education and awareness programs.</td>
</tr>
<tr>
<td>Skills/human resources</td>
<td>Training and skill development in sectors and populations; knowledge-sharing tools and support.</td>
</tr>
<tr>
<td>Natural resources</td>
<td>Abundant levels of varied and resilient natural resources that can recover from climate change impacts; healthy and inter-connected ecosystems that support migration patterns, species development and sustainability.</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Systems that provide sufficient protection and enable efficient response (e.g., wireless communication, health systems, air-conditioned shelter).</td>
</tr>
<tr>
<td>Institutional support/governance</td>
<td>Governmental and non-governmental policies and resources to support climate change adaptation measures locally and nationally.</td>
</tr>
</tbody>
</table>
Along with the type of activity, the timeline for adaption to occur is influential. Activity response can be defined through reactive and proactive action (Burton et al., 2006). Reactive adaptation response is typically after the fact, meaning that once a problem has occurred, then adaptation takes place. In contrast, proactive response suggests adaptation prior to the problem acting as a more preventative approach.

Activities are also distinguished based on their potential impact if implemented. The following categories describe an activity’s impact (University of Washington and King County, 2007):

- No regret- benefits occur even if climate change does not occur
- Low regret- provide benefits at relatively little cost or risk
- Win-win- reduce impact of climate change while providing other social or economic benefits

Therefore, adaptation activities are selected based on their type, response, and impact on individual systems. Figure 2.6 displays the cycle of building adaptive capacity in order to deliver adaptation actions based on its potential impact. Each measure to build capacity or take action may address a risk related to climate as well as indirectly address a non-climate related risk.
Adaptive Management

Effective implementation of adaptation activities should be applied under the approach of adaptive management. Adaptive management is managing systems under the threat of abrupt change where policies are treated as experiments which are tested against the experience of implementation (Dewar and Wachs, 2006). This entails that adaptation is an
iterative process, following a cycle of six general steps: assessment, design, implementation, monitoring, evaluation, and adjustment (Dewar and Wachs, 2006). Similarly, the United Nations Development Programme further defines the process as an adaptation policy framework (APF) that includes five steps (Burton et al., 2004):

1. Scoping and designing the adaptation project- ensuring that the project is well-integrated into the national policy planning and development process
2. Assessing current vulnerability- responding to issues on what factors, efforts and issues determine the society’s vulnerability including exposure, sensitivity, and capacity to adapt
3. Assessing future climate risks-development of future scenarios of what trends may occur
4. Formulating an adaptation strategy-identifying and selecting a set of policy options and measures to create a strategy
5. Continuing the adaptation process- implementing, monitoring, evaluating, improving and sustaining the initiatives

Both processes emphasize the importance of scoping/assessment and suggest that it is the “most vital stage throughout the APF process” (Burton et al., 2004). The first step, assessing the potential impacts through defining the scope, is fundamental to the cycle and requires defining clear objectives, identifying actions that balance risk and learning opportunities, identifying metrics to assess achievement of objectives, identifying uncertainties, and hypothesizing potential effects of alternatives (Dewar and Wachs, 2006). Defining the objectives of the adaptation process sets the scope for future steps and creates the ability for integration into existing policy.

Another key step in the process is identifying and assessing current vulnerabilities. Determining vulnerabilities can help in prioritizing and implementing action effectively and
efficiently. The IPCC defined a list of criteria to aid in this step (Pew Center on Global Climate Change, 2009):

- Magnitude of Impact - large, medium, or small scale
- Timing of Impact - short or long term
- Persistence/Reversibility - permanent, near-permanent, or irreversible damage
- Likelihood/Certainty - high or low confidence and associated urgency
- Importance - value to society
- Equity - vulnerability associated with adaptive capacity

Throughout the process, key stakeholders should be included in order to broaden participant perspectives in identifying problems and solutions related to adaptation (Pew Center on Global Climate Change, 2009). Adaptation planning requires collaboration between and within local, state and federal governments as well as across academic, professional, and scientific communities. In addition, integration between jurisdictional and geographic boundaries is required in order to share results of completed assessments with similar sectors (Pew Center on Global Climate Change, 2009).

**Barriers to Adaptation**

In addition to the key factors of adaptive capacity and limitations within adaptation management, the ability for a system to adapt can also be affected by real or perceived barriers/constraints. Questions behind the need, as well as immediacy for adaptation, may be brought into question as a result of some of the following barriers (Adaptation: Barriers to Adaptation, 2009):

- Limited understanding of climate risks and vulnerabilities
- Lack of supportive policies, standards, regulations, and design guidance
- Existing legal or regulatory restrictions
- Lack of availability or restricted access to appropriate technologies
• Costs of identified adaptation options when budgets are limited
• Lack of availability of resources (in-house expertise)
• Cultural rigidity and conflict
• Short term nature of planning horizons

In addition to “real” barriers, there are perceived barriers related to the uncertainty associated with climate change:

• Mismatch between planning horizons and climate change projections
• Perspective that climate change is not a “big problem yet” so a proactive approach is not necessary
• Belief that uncertainty is too great to take action now
• Lack of useful precedents or evidence of adaptation actions (what are others doing?)
• Lack of acceptance/understanding of risks associated with implementation (what if the decision is wrong?)

Overcoming these barriers is a challenge, however, building a strong adaptive capacity through improving the understanding of climate change, evaluating associated risks and vulnerabilities, and updating legal and institutional frameworks is essential to successful adaptation.

**Adaptation versus Mitigation**

Recently, climate change action has focused on the need to reduce the occurrence of climate change phenomena, also referred to as mitigation. Mitigation is defined as action to minimize greenhouse gas emissions throughout various aspects of society (Pew Center on Global Climate Change, 2009). Efforts such as energy efficiency techniques throughout the home, office, or industry is one low-cost method, as well as land use changes associated with smart growth/compact development plans. A more costly mitigation technique includes investing in
renewable energy such as wind, solar, geothermal, or hydropower. From policy standpoint governments, both nationally and internationally, are setting emission targets and engaging in both traditional regulatory policies as well as market-based incentives to reduce carbon dioxide emissions. Regardless of whether these mitigation efforts have, and will continue to be successful, reducing greenhouse gas emission alone will not solve the problem of climate change.

Despite the emphasis on mitigation efforts, the potential risk for climate change is still present. Recent scientific research suggests that model projections are conservative and have underestimated the actual rate of climatic change and its associated impacts (Pew Center on Global Climate Change, 2009). In addition, the emissions released today will remain in the atmosphere for decades or centuries after they have been produced, suggesting that there is a time lag from today’s emissions to future impacts. This time lag means that the “Earth is committed to some additional warming no matter what happens now to reduce emissions” through mitigation efforts (Pew Center on Climate Change, 2009). Therefore, a proactive approach in adapting to these changes will avoid the compounding effects of long term impacts. The next 10-20 years are the most influential and “will have a profound effect on the climate in the second half the century and in the next” (Stern, 2006). Generally, over time this process will become a challenge, and therefore, delaying adaptation leads to more “dangerous and much more costly” situations in the future (Stern, 2006).

From an intuitive standpoint, adaptation affects the costs and benefits of mitigation; however, this point is often neglected in actual policy making (Kane and Shogren, 2000). This results from fragmented policy where adaptation policy focuses on natural hazards and mitigation policy focuses climate (Kane and Shogren, 2000). An example of this is in the Kyoto Protocol which is an international agreement consisting of mitigation efforts with limited adaptation. As a result, most policies use targets and timetables without acknowledging the ability of adaptation to aid in reduction efforts (Kane and Shogren, 2000). Kane and Shogren
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(2000) suggest that “effective climate protection needs to use an integrated portfolio of mitigation and adaptation strategies.”

**Adaptation in Support of Mitigation**

Mitigation measures, although important to addressing the potential impacts of climate change, many times require and depend on adaptation of existing infrastructure (McNeil, 2009). As mentioned, adaptation affects the costs and benefits of mitigation which is not always addressed in climate change policy (Kane and Shogren, 2000). Whether they are intended or unintended dependencies, reducing greenhouse gas emissions requires a system that supports these changes. For example, changes in land use or changes in fossil fuel distributions will alter the existing system as well as require behavior to adapt as well.

More specifically, the recent support of alternative fuels for transportation such as hydrogen, biofuel, and liquefied natural gas requires significant investment in the production and distribution of these fuels. Therefore, existing infrastructure that is petroleum-based will have to adapt and change to producing, storing, transporting, and distributing alternative fuels. This also leads to unintended consequences such as environmental impacts, additional costs, and influences on public safety (McNeil, 2009).

Similarly, modal changes such as promotion of public transit through rail or bus will require alterations with the existing transportation infrastructure. As commuters switch to these more sustainable forms, the system’s ability to sustain the increased capacity needs to be supported through additional rail lines, bus routes, passenger cars, bus fleets, drivers, etc. This requires adaptation in transportation management as well as transportation infrastructure.

Additionally, land use changes such as the location of housing and transportation facilities may require adaptation as commuters select residences closer to their workplace. Shifting away from urban sprawl and toward more compact developments may encourage changes in housing development. These mitigation measures of smart growth development
where high density, walkability, and transit oriented design are suggested will alter existing community and neighborhood infrastructure.

Regardless of the sector, there is a strong link between successful mitigation and supporting adaptation practices. In order to reduce a system’s impact on climate change, the system must be capable of changing to the extent necessary to support the reduction measure.

**Adaptation Initiatives**

The majority of climate change adaptation initiatives in the United States are in their earliest stages (Pew Center on Global Climate Change, 2009). In contrast, other countries have taken a leading role in proactive adaptation efforts to decrease system vulnerability and increase resilience to impacts (McNeil, 2009). Therefore, these countries serve as examples of how adaptation actions can be implemented as well as integrated into policy making.

**Global Efforts**

Global adaptation initiatives stem from the United Nations Framework on Climate Change (UNFCC) which is an international treaty that originally focused on mitigation strategies and more recently recognizes adaptation as a major component of climate change response (UNFCC, n/d). Building on the findings of another global organization (the IPCC) the UNFCC believes that an enhancement of adaptation efforts is required since “accumulated historical emissions have already “committed” the Earth to some level of warming and that the impacts of this warming are already being felt” (UNFCC, n/d). In response, in 2004 the UNFCC set up two tracks for adaptation efforts (UNFCC, n/d):

1. Development of a structured program of work on the scientific, technical, and socio-economic aspects of vulnerability and adaptation to climate change in the Subsidiary Body for Scientific and Technological Advice (SBSTA).
2. Adoption of concrete implementation measures for furthering information and methodologies, concrete adaptation activities, technology transfer and capacity-building under the Subsidiary Body for Implementation (SBI).

The UNFCC continues to channel funds to adaptation projects as well as focuses on research and development through the dissemination of knowledge at expert meetings, workshops and reports.

The Pew Center on Global Climate Change is a collaboration of scientists, business leaders, policy makers, and experts on climate change that are taking a leading role in addressing the issue of adaptation at all geographic scales. They focus on the need for funding, information dissemination, capacity building, and development of proactive and reactive approaches for vulnerable countries (McNeil, 2009). Reports on the role of climate change from a state, local, national, and global perspective serve as an exemplary direction for how to respond to the long-term costs of climate change impacts (Pew Center on Global Climate Change, 2009).

Another global organization that focuses on the local scale is the ICLEI (International Council on Local Environmental Initiatives)-Local Governments for Sustainability which specializes in both mitigation and adaptation support. Their mission is to work with local governments to build resiliency to climate impacts throughout the world (ICLEI-Local Governments for Sustainability, 2008). Currently over 250 localities in the United States as well as over 1,000 worldwide have made commitments to sustainable development and climate protection (University of Washington and King County, 2007).

**International Efforts**

Many countries are realizing the importance of climate change adaptation within the scope of protecting and reducing vulnerabilities, in addition to supporting mitigation. Therefore, initiatives, policies, decision support tools, and databases are being developed and serve as examples for future adaptation practice. The following is a list of countries and a brief description of their contributions to climate change adaptation.
**United Kingdom**

The United Kingdom Climate Impacts Programme was formed in 1997 to help coordinate research and assist organizations with adapting to climate change. They have primarily focused on assessing climate change impacts and identifying potential adaptation strategies (West and Gawith, 2005) which are represented in Figure 2.7.

![Figure 2.7-UKCIP's Role in Addressing Climate Change](image)

Through their research on impacts and adaptation, they have developed and assembled numerous tools, guides, databases, and reports listed below (McNeil, 2009):

- BRAIN- Base for Research, Adaptation, Impacts, and News online database
- Guide to introducing climate change into the decision making process
- Adaptation Wizard- a 5-step web-based tool to help organizations adapt to climate change
- Evaluation on stakeholder involvement
- Dissemination efforts like SKCC (Sustaining Knowledge for a Changing Climate)
• Research projects funded through the BKCC (Building Knowledge for a Changing Climate) including the BIONICS (BiOlogical and eNgineering Impacts of Climate Change on Slopes), AUDACIOUS (Adaptable Urban Drainage-Addressing Change in Intensity, Occurrence, and Uncertainty Of Stormwater, and BESEECH (Building Economic and Social Information for Examining the Effects of Climate eHange).

Future efforts include the completion of UKCP09 (United Kingdom Climate Projections for 2009) which will be a comprehensive package of climate change information based on updated scenarios for the UK through 2099 (About UKCP, 2009). The UKCP09 will include probabilistic climate, marine, weather generated and historical climate projections in order to better quantify some of the uncertainties related to climate modeling and potential impact in the 21st century (About UKCP, 2009). In addition, they are focusing heavily on the integration of adaptation into climate change action through costing impacts, supporting mitigation measures, and assessing options through the built and natural environment (McNeil, 2009).

Additional efforts in the United Kingdom include adaptation strategies in London based on previous reports titled “Climate Change and London’s Transport System” and “Adapting to Climate Change: Lessons for London” (The Heinz Center, 2007). The strategy will seek to “mainstream” climate issues such as flooding, drought, and temperature increases as well as air quality and winter storm severity through the Greater London Authority (The Heinz Center, 2007). Also, in support of adaptation practices is the Department of Transport who breaks down the impacts by mode as well as addresses road safety, economics, local versus regional issues, and public safety in relation to climate change in London (Department for Transport, 2008).
Australia

The Australian government has taken significant effort in climate change adaptation through the development of the “National Climate Change Adaptation Framework” which outlines a timeline for collaboration between governments to address key climate change issues related to the community and institutions. The goal of the framework is to aid decision-makers in integrating climate change into policy regardless of scale and sector (Council of Australian Governments, 2007). This framework falls under the Council of Australian Governments “Plan of Collaborative Action on Climate Change” which has been one the many efforts to meet Australia’s international obligations under the UNFCC (Council of Australian Governments, 2007). More recently, the Australian government committed over $10 million over a period of four years in order to establish research networks, focusing on the effects of climate change and adaptation efforts.

State governments have also become involved in climate change adaptation. The Victorian Government has focused on state efforts in response to the potential impacts on Victoria which include increased temperature, drier conditions, and more frequent extreme events (State of Victoria, 2009). Projects and activities are taking place across multiple sectors including agriculture, infrastructure, water, health, business and industry, and coasts. The infrastructure study examines the potential risks of climate change on Victoria’s infrastructure systems including power, water, transport, buildings, and telecommunication (State of Victoria, 2006).

On a local scale, the Australian government is encouraging local entities to get involved in climate change action through the “Climate Change Adaptation Action for Local Governments” guide (SMEC Australia, 2007). The guide provides adaptation actions and options for local policy-making with the notion that regardless of what changes occur, the actions provide a net benefit to the society (SMEC Australia, 2007). The Local Government
Association of Queensland as well as the Sydney Coastal Councils Group has begun to take action through exploring adaptation strategies in response to their local impacts (McNeil, 2009).

**South Africa**

South Africa’s city of Cape Town has undergone the process of developing a city adaptation plan of action. The framework addresses various adaptation initiatives in biodiversity, coastal zones, health, stormwater management, water supply and fire management (City of Cape Town, 2006). Within the framework they have established eight steps that guide the city’s plan (City of Cape Town, 2006):

1. Assessment of current climate trends and future projections
2. Undertaking a vulnerability assessment- identify current vulnerabilities (in each sector and for cross-cutting themes) based on current climate risks and trends and identify future vulnerabilities based on future climate scenarios and risks
3. Strategy formulation
4. Development of adaptation options
5. Evaluation of priority adaptation strategies
6. Program and project scoping and design – (CAPA)
7. Implementation
8. Monitoring and evaluation of interventions

These eight steps reflect the general method for adaptive management discussed previously.

Overall, the city’s adaptation plan serves as an example for cities throughout the world, both developing and developed, to prepare for climate change.

**Canada**

In 1998, the first assessment of climate change impacts in Canada (The Canada Country Study) was completed (Natural Resources Canada, 2004). From this the “Climate Change Impacts and Adaptation: A Canadian Perspective” was produced which is a summary of recent studies that serve the goal of raising awareness of the range and significance of climate
change impacts and adaptation issues (Natural Resources Canada, 2004). More recently, in 2006 Natural Resources Canada (2004) released “Canada’s Climate Change Impacts and Adaptation Program” with the goal of reducing the country’s vulnerability to change. The program also supports the Climate Impacts and Adaptation Research Network (C-CIARN) which “facilitates linkages between stakeholders and researchers, promotes new research techniques and methodologies, disseminates information, and provides a voice for an emerging impacts and adaptation research community” (Natural Resources Canada, 2004).

At the local level, districts such as Vancouver are identifying the need for adaptation based on their unique needs. Integrated Stormwater Management Plans are being developed to protect communities from localized flooding as well as to preserve environmental quality (The Heinz Center, 2007). The plans are watershed specific, flexible, and adaptable with a template that allows for all municipalities of the Greater Vancouver Regional District to implement their plans by 2014 (The Heinz Center, 2007).

**European Commission**

In 2000, the European Climate Change Programme was launched in response to the EU strategy to implement the Kyoto Protocol. In 2005, the European Climate Change Programme II was created to further explore climate change impacts related to adaptation, emissions, carbon capture, and aviation (European Union, 2006). The European Union’s (EU) 7th Framework Programme focuses on “putting adaptation and mitigation into perspective” through exploring potential challenges that the EU will face. In addition they take a global approach in discussing adaptation and raising measures in Europe that could also be applied to other locations throughout the world. They view the EU as an entity that can provide international leadership in adaptation for both developed and developing countries.

The Climate Change Impact Research Coordination for a Larger Europe (CIRCLE, 2009) is a team of researchers and partners that have come together to align national research programs within the 19 partner countries. Figure 2.8 displays the scope of CIRCLE
based on the triangle of climate change (climate impacts, mitigation, and adaptation) (CIRCLE, 2009).

As depicted in the diagram, their focus is on assessing vulnerabilities and potential impacts in order to develop adaptation measures.

**New Zealand**

New Zealand has focused on adaptation in the transportation sector with the paper “Climate Change Impacts on the State Highway Network: Transit New Zealand’s Position” (Kinsella and McGuire, 2005). Using a two-stage approach, they first assess whether action is necessary, and then they assess the feasibility of acting now to protect transportation infrastructure (Kinsella and McGuire, 2005). For stage one, they developed a flow diagram that helps to determine the likelihood of impact which evaluates whether action is needed (Figure 2.9).
This iterative process helps to define the need for action in order to increase the efficiency and effectiveness of climate change action. Based on the results, adaptation activities were then evaluated focusing on state highways.

**National Efforts**

Proactive and comprehensive adaptation planning within the United States is still in the early stages. Over the last five years, interest in mitigation and more recently adaptation have risen dramatically (McNeil, 2009). As of November 2008, over 75 bills addressing some
aspect of adaptation were introduced to Congress (Pew Center on Global Climate Change, 2009). The bills recognize the necessity for an approach to identify at-risk systems and to address the scope of funding and responsibility that will be required at all levels (Pew Center on Global Climate Change, 2009). With the absence of federal legislation supporting adaptation, efforts at the state and local level are vital to addressing the unavoidable impacts that will occur in the near future.

United States research programs are establishing themselves and are beginning to address some of the issues in response to national climate change concerns. The following is a discussion of some of the programs and their efforts toward adaptation.

The US Environmental Protection Agency (EPA) carried out a study “Climate Change Science Program Synthesis and Assessment Product: Preliminary Review of Adaptation Options for Climate Sensitive Ecosystems and Resources” to review management options for adapting to climate variability, to identify characteristics of successful adaptation implementation, and to meet resource management needs (EPA, 2009).

The Pew Center on Global Climate Change has done numerous reports related to adaptation in the United States. The “Climate Change 101: Understanding and Responding to Global Climate Change” report touches on the specific impacts the country may face, factors for adaptive capacity, and existing efforts throughout the country (Pew Center on Global Climate Change, 2009). They suggest that the federal government support state and local jurisdictions in the following areas (Pew Center on Global Climate Change, 2009):

- intellectual leadership
- research and development
- policy and regulation
- coordination
- funding
- models and planning tools
• education and awareness
• sharing of best practices
• consideration of federal lands

The USAID Global Climate Change Program focuses on assisting developing and developed countries in transition to address climate-related concerns. A guide manual was published called “Adapting to Climate Variability and Change” which serves to educate other countries in assessing vulnerabilities as well as design/adaptation projects that allow for more resilient systems (Pew Center for Global Climate Change, 2009).

The United States Climate Change Science Program is responsible for integrating federal research on climate from a diversity of sectors including Agriculture, Energy, Transportation, and the Interior. For example, “The Impacts of Climate Variability and Change on Transportation Systems and Infrastructure” study assesses roads, airports, rail, transit, pipelines, ports, and waterways in terms of climate change impact, specific to the Gulf Coast. A similar evaluation is necessary for the various other regional areas throughout the country.

The Heinz Center on Science, Economics, and the Environment in Washington D.C. has completed a “Survey of Adaptation Planning” which reviews adaptation planning guidebooks and frameworks as well as existing adaptation planning efforts (The Heinz Center, 2007). It is designed to be used as a “road map” to successful adaptation practice through sharing of best practices on adaptation (The Heinz Center, 2007). In addition, they have published “Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments” with the intentions of helping decision-makers at all jurisdictional levels to prepare for climate variability through a detailed, “easy-to-understand” process for preparedness (University of Washington and King County, 2007).
**State Efforts**

Comprehensive and proactive adaptation planning is still emerging in the United States; however, adaptation planning at the state and local level is gaining greater attention and additional resources as they begin to complete their mitigation plans (Pew Center on Global Climate Change, 2008). State efforts include adaptation within the scope of state Climate Action Plans addressing mitigation as well as separate commissions for comprehensive adaptation paralleling mitigation (Pew Center on Global Climate Change, 2008). In addition, many state governments are supporting local action through adaptation action plans. Regardless of scale, these efforts allow for collaboration and education where states can learn from each other.

State governments are starting to acknowledge the need for broad-scale adaptation planning through Climate Action Plans as well as comprehensive state adaptation plans. The following seven states have already taken steps toward this goal: Arizona, Arkansas, Colorado, North Carolina, South Carolina, Utah and Vermont (Pew Center on Global Climate Change, 2009). An additional eight states have started adaptation planning in parallel with mitigation activities: these include Alaska, California, Florida, Maryland, Massachusetts, New Hampshire, Oregon, and Washington. Figure 2.10 displays a map of the states either with state adaptation plans or with adaptation plans recommended in Climate Action Plans.
As shown by the states in white, most states have focused on GHG mitigation plans to reduce or avoid impacts of climate change rather than considering adaptation efforts (Pew Center on Global Climate Change, 2008). Thirty-four states have created, or are in the process of developing Climate Action Plans focusing mostly on state GHG emission inventory data and recommendations to avoid or reduce impacts by sector (Pew Center on Global Climate Change, 2008). Figure 2.11 displays these states that are addressing climate change mitigation through Climate Action Plans.
One common trend is that the action plans emphasize the economic and environmental value of GHG emission reductions rather than the need for proactive adaptation planning. As stated, only seven out of these thirty-four states are addressing adaptation in these plans. Perhaps this is due to the regional context where specific states are less vulnerable than others to impending climate change impacts.

Coastal regions both east and west are more proactive in the adaptation efforts specifically in response to their unique threat of sea level rise. The states that are taking action, such as Maryland and California, are setting up strategies that help to define federal and state roles in responding to climate impact as well as coordinating planning and funding initiatives to reduce human, economic, and ecosystem impacts (Pew Center on Global Climate Change, 2008).

California is an exemplary state that is setting an agenda for climate change, focused around adaptation. In 2005, California’s governor, Arnold Schwarzenegger, signed an executive order which called for biannual updates from the California Environmental Protection Agency (EPA) on adaptation plans, mitigation strategies, and global warming impacts (Pew Center on
Global Climate Change, 2008). In 2006, a report from the California Climate Change Center set up a research agenda around the following questions to guide the state’s goals for adaptation action (Luers and Moser, 2006):

- What level of climate change (or risk of change) is society willing to accept (thus also raising questions about the extent of greenhouse gas mitigation)?
- What goals should adaptation achieve, e.g., preserving the status quo, actively managing change toward new conditions, promoting deeper societal changes required for sustainability?
- What is an acceptable level of individual vs. public risk and how should the responsibility in case of impact be shared?
- What are the social justice, environmental, economic, and other issues associated with allocation of scarce resources as more systems come under growing pressure from climate and other stresses?

More recently in 2008, the governor released an executive order to revise the agenda for climate change adaptation (McNeil, 2009). The order called on the state Climate Action Team and other agencies to create a Sea Level Rise Assessment Report and a Climate Adaptation Strategy (Pew Center on Global Climate Change, 2009). California has led the way in policy and research where they are focusing on effective adaptation methods for public health, biodiversity and habitat, water, forestry, agriculture, oceans and coastal resources, and infrastructure (Pew Center on Global Climate Change, 2009). These efforts are exemplary and should serve as a guide for other states to encourage adaptation planning throughout the United States.

Another state that is leading the way in the Mid-Atlantic region is Maryland. The Maryland Commission on Climate Change supported the formation of the state’s Adaptation and Response Working Group (ARWG) which recommends strategies for reducing the vulnerability of the states’ coastal, natural, and cultural resources as well as preventing impact to communities throughout the state (Maryland Commission on Climate Change, 2009). In their Climate Action
Plan they have a chapter titled “Comprehensive Strategy for Reducing Maryland’s Climate Change Vulnerability” where they focus on sea level rise and coastal storm impacts (Maryland Commission on Climate Change, 2008). This dedication to adaptation within their action plan allows for proactive recommendations regarding reducing impacts as well as developing a regional vision for the future. The following key recommendations for adaptation practice in Maryland are made (Maryland Commission on Climate Change, 2008):

- Take action now to protect human habitat and infrastructure from future risks
- Minimize risks and shift to sustainable economies and investments
- Guarantee the safety and well-being of Maryland’s citizens in times of foreseen and unforeseen risk
- Retain and expand forests, wetlands, and beaches, to protect us from coastal flooding
- Give state and local governments the right tools to anticipate and plan for sea level rise and climate change
- State and local governments must commit resources and time to assure progress

These goals can serve as a template for objectives and recommendations for developing adaptation plans throughout coastal regions.

**Local Efforts**

Local communities and cities throughout the country are witnessing the impacts of climate change and with support from federal and state governments are capable of implementing adaptive responses (Pew Center on Global Climate Change, 2008). Similar to state efforts, most municipal action is focused on mitigation techniques to reduce greenhouse gas emissions. However, some cities are including adaptive responses in their plan through efforts such as desalinating groundwater, flood protection, erosion prevention, and preparing for water
shortages (Pew Center on Global Climate Change, 2008). Typically the efforts are privately funded or managed, or are the responsibility of a municipal agency.

In addition to federal and state support, there is a global organization, ICLEI- Local Governments for Sustainability, which has formed a national program called Climate Resilient Communities, serving as a resource for local adaptation planning within the United States (ICLEI USA, 2008). The goals of the program include the following (ICLEI USA, 2008):

- Increase the ability of local governments to assess their vulnerability to future changes in the climate by linking them directly to the most current climate science on future regional impacts.
- Facilitate informed decision making based on climate science.
- Develop tools to assist communities to prioritize and implement adaptation actions.
- Increase the integration of climate change mitigation and adaptation planning.
- Train local government staff and leaders on effective planning implementation of adaptation strategies.
- Enable peer-to-peer learning among a national network of communities.
- Foster citizen support for and engagement in advancing their community’s resiliency.

Currently a handful of cities are involved in the program including Homer, AK, Ft. Collins, CO, Miami-Dade County, FL, and Keene, NH. These four cities will be the first to complete the program from which ICLEI hopes to compile adaptation protocols and share the information with other cities throughout the nation (Pew Center on Global Climate Change, 2008).

Although individual cities are taking action, currently there is no formal process for collaboration or cross-jurisdictional sharing of information about adaptation activities (Pew Center on Global Climate Change, 2009). Therefore, at this point each local action is independent and separate from other cities.
One city that is leading the way in local climate change adaptation is King County, Washington. In 2006, an adaptation team was formed to build scientific expertise behind policy, planning, and capital investment decisions (Pew Center on Global Climate Change, 2008). By 2007 they created a comprehensive adaptation plan containing detailed strategies for each sector (biodiversity and ecosystem, climate science, economic, land use, buildings, transportation, public health, safety, and emergency preparedness) that explicitly defines the roles of each department and its responsibilities in implementing climate change strategies (The Heinz Center, 2007). Table 2.5 displays the adaptation measures addressed under each impact area in the 2007 King County Climate Plan. Throughout this process King County has been working closely with ICLEI’s Climate Resilient Communities program and is serving as a model for impact-specific adaptation recommendations for other localities (Pew Center on Global Climate Change, 2008).
Table 2.5- King County’s Adaptation Strategic Focus Areas (King County, 2007)

<table>
<thead>
<tr>
<th>Focus Area</th>
<th>Sample Adaptation Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Science</td>
<td>Expand Water and Land Resources Division’s climate change impact analysis and impacts research areas (e.g., groundwater resources, precipitation patterns, etc.). Build awareness of climate change impacts and adaptation measures (e.g., create a climate change outreach database; invest in education/outreach, etc.).</td>
</tr>
<tr>
<td>Public Health, Safety &amp; Emergency Preparedness</td>
<td>Collaborate in research and share information with the public health community, in areas such as thermal stress, infectious disease, food quality and supply, and social justice issues. Update emergency and hazard mitigation plans and activities to address projected changes.</td>
</tr>
<tr>
<td>Surface Water Mgmt, Freshwater Quality &amp; Water Supply</td>
<td>Conduct technical analysis of projected impacts to stream flows to large rivers and tributaries. Produce and promote the use of reclaimed water for industrial and irrigation purposes, as well as consideration for other future uses. Incorporate climate change impacts into water supply planning processes and wastewater treatment investment plans.</td>
</tr>
<tr>
<td>Land Use, Buildings and Transportation</td>
<td>Review all county plans, policies and investments for consideration or inclusion of climate change impacts (e.g., Regional Hazard Mitigation Plan, Shoreline Master Plan, River and Floodplain Management Program, transportation infrastructure plans, etc.). Numerous actions are included to address flooding and sea-level rise projections.</td>
</tr>
<tr>
<td>Financial &amp;Economic Impacts (now Economic, Agriculture &amp; Forestry)</td>
<td>Examine climate change impacts on key industries for the state including government, forestry, and agriculture (the county has already identified a number of actions to protect the health of these industries).</td>
</tr>
<tr>
<td>Biodiversity &amp; Ecosystems</td>
<td>Collaborate with climate impact organizations and fishery agencies to support the resilience of salmon, wildlife, and biodiversity against climate change impacts. Evaluate the need for additional biodiversity monitoring. Incorporate climate change projections into salmon recovery planning efforts.</td>
</tr>
</tbody>
</table>

Another city that is addressing community adaptation planning is New York City, NY. In 2007, Mayor Bloomberg released PlaNYC where he addressed adaptation in recognition that climate model results indicate that the city will face significant economic and health risks from flooding, hurricanes, and storm surges (Pew Center on Global Climate Change, 2008). Three initiatives were established as guidelines for how the city would conduct the adaptation planning process, focusing specifically on high risk communities. The adaptation initiatives are as follows (The City of New York, 2009):

- Create an intergovernmental Task Force to protect our infrastructure
- Work with vulnerable neighborhoods to develop site-specific strategies
• Launch a citywide strategic planning process for climate change adaptation

Using global and regional climate models to aid in adaptation planning and investment, the New York Climate Change Task Force focuses heavily on the potential for flooding. The report is explicit about the need to update the city’s 100-year floodplain maps, amend the building codes, document floodplain management strategies to secure discounted flood insurance for residents (The Heinz Center, 2007). Figure 2.12 displays the predicted flood level after a storm surge at the Holland Tunnel. These figures suggest immediacy behind implementing local adaptation action.

Since the release of PlaNYC, a 2009 Progress Report was published stating the efforts the city has taken to meet the above-mentioned adaptation initiatives. In 2008, the New York City Climate Change Adaptation Task Force was established as the first of its kind, bringing together stakeholders from the private and public agencies to leverage resources and develop adaptation strategies (The City of New York, 2009). The development of the Task Force has led to addressing the following two goals through the development of an outreach program to assist in
developing neighborhood-specific adaptation strategies as well as launching a city-wide strategic plan in 2009.

In addition to King County and New York City, other cities throughout the United States have been proactive in adapting to climate change. The following list describes each city with their associated efforts (The Heinz Center, 2009):

- **Boston, Massachusetts- CLIMB (Climate’s Long-Term Impacts on Metro Boston)** was released in 2004 with the goal of preparing an integrated adaptation plan to reduce existing risks and require all new construction to evaluate the risks posed by climate change in 2050.

- **Chicago, Illinois- Comprehensive climate action plan including both mitigation and adaptation based on a risk assessment of action vs. non-action.**

- **Fort Collins, Colorado-Climate Task Force production of adaptation plan focused on the challenge of managing water resources (ICLEI pilot program)**

- **Homer, Alaska- Founded a Global Warming Task Force to create a resilient local economy, protect existing infrastructure, and adopt wise policies for future development (ICLEI pilot program)**

- **Keene, New Hampshire- Focus on vulnerabilities to climate change and prioritized them in order to identify the top five vulnerabilities within each three sectors: built, social, and natural environment (ICLEI pilot program)**

- **Los Angeles, California- Million Trees L.A. is an initiative to reduce the urban heat island effect.**

- **Miami-Dade County, Florida- Climate Change Advisory Task Force formed six subcommittees, one of which focuses on adaptation of infrastructure and property (ICLEI pilot program)**

- **San Francisco Bay Area- San Francisco Bay Conservation and Development Commission have approved a preliminary action plan focusing on sea level rise.**
Adaptation Tools

Across the various scales of adaptation efforts, tools have been assembled with the goal of encouraging organizations, institutions, communities, and individuals to adapt to climate change. In 2007, a workshop was held in Geneva to discuss and share adaptation tools that were developed throughout the world. The following is a list of databases, tools, and processes presented at the workshop along with a general description of their purpose (The World Bank et al., 2007):

Information generation, databases and platforms

- PRECIS- Providing Regional Climates for Impact Studies (UK Met Office Hadley Centre)- climate impact assessments in developing countries using GCM (global climate model) to provide spatio-temporal hydro-climatic state variables, soil hydrology, thermodynamics, and vegetation dynamic variables

- Vulnerability Mapping and Impact Assessment-uses GCM outputs, agriculture systems and land use data, GIS and vulnerability data to provide information on vulnerable populations and options for agricultural sector

- SERVIR Climate Change Mapping Tool- assist users of the USAID Climate Adaptation Guidance Manual to access climate information

- SDSM- Statistical DownScaling Model (UK)- computer-based information to provide daily, transient, risk information for impact assessment over the 1961-2100 time horizon primarily for water resource management

- Climate Analysis Indicators Tool (CAIT) -World Resources Institute-database including information on historical impacts, specifically from disaster events and the vulnerability and impacts component is part of a wider tool-kit of country level data on greenhouse gas emissions.

- National Adaptation Programme of Action -UNITAR-international support to NAPA country teams through technical assistance in synthesizing existing
vulnerability and adaptation information and formulation of relevant projects and profiles.

- CIEAR (Climate envelopes/adaptation risk screening platform)- SEI-collection of software tools, databases, guidance, examples/prototypes and communications to provide immediate links between climate episodes, trends, and impacts affecting the environment, economics, and social welfare.

**Computer-based Decision Tools**

- CRISTAL- project-based tool piloted for Nicaragua, Mali, Tanzania, and Sri Lanka in agriculture, water resource, infrastructure, and natural resource management sectors. Delivers vulnerability and livelihood profiles and integration of adaptation concerns into project portfolios

- ADAPT- World Bank- tested in South Asia and undertakes a sensitivity analysis for projects and identifies those that are sensitive to climate change and provides adaptation advice based on GCM data.

- Adaptation Wizard- UK Climate Impacts Programme- web-based tool to integrate climate risks into decision making at the organizational level and walks users through an economic analysis of adaptation options and scenarios

- Country Database –UNDP-GEF- help UNDP offices to develop adaptation proposals and improve awareness on climate risks for project designs through compiling a common set of information from National Communications and other scientific studies

**Adaptation/Risk Management Processes**

- Climate Quick Scans- DGIS- quick and dirty process that draws on expert advice to screen programs/projects in order to establish adaptation priorities and increase awareness on climate risks with partner countries.
• Preparedness for Climate Change- Red Cross- assessments key climate change related risks facing vulnerable citizens by drawing on Red Cross project details and Red Cross vulnerability data.

• Climate Change Adaptation Guidance Manual-USAID-manual that assists in mainstreaming of climate change adaptation in projects throughout multiple sectors such as agriculture, coastal development, water infrastructure, etc.

• ORCHID (Opportunities and Risks of Climate Change and Disasters)-IDS-process-based tool that utilizes qualitative inputs on climate science and applies them to risk assessment in terms of vulnerability and disaster risk.

In order to compare each tool, database, and process, Table 2.6 displays the audience, screening level, spatial scale, training time, application time, main data type (qualitative or quantitative), and whether economic analysis is included for each application.

As shown in the table, there are tools for multiple audience types, scales, purposes, and resolutions. Out of all of the tools listed, the Adaptation Wizard is broadly focused in terms of audience, scale, training requirements, diverse in terms of qualitative and quantitative data, and the only tool that includes economic analysis applicable to all audiences. Therefore this tool serves as a guide for this research and is evaluated further in detail.
Table 2.6—Comparison of Adaptation Tools, Databases, and Processes (The World Bank et al., 2007)

<table>
<thead>
<tr>
<th>Tool</th>
<th>Audience</th>
<th>Screening level</th>
<th>Spatial scale</th>
<th>Training time</th>
<th>Application time</th>
<th>Main data type</th>
<th>Economic analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.a) PRECIS (UK Met Office)</td>
<td>all</td>
<td>Input tool</td>
<td>multi-scale</td>
<td>varying</td>
<td>varying</td>
<td>Quantitative</td>
<td>No</td>
</tr>
<tr>
<td>1.b) Vulnerability assessment (ILRI et al)</td>
<td>donors</td>
<td>policy</td>
<td>national</td>
<td>unknown</td>
<td>2-6 months</td>
<td>Quant.</td>
<td>not at present</td>
</tr>
<tr>
<td>1.c) SERVIR (USAID, NASA)</td>
<td>all</td>
<td>various</td>
<td>local, regional</td>
<td>none</td>
<td>&lt;1 month</td>
<td>Quant</td>
<td>No</td>
</tr>
<tr>
<td>1.d) SDSM (Environment Agency)</td>
<td>gov’t, donors, other</td>
<td>project</td>
<td>multi-scale</td>
<td>half-day</td>
<td>&lt;1 month</td>
<td>Quant</td>
<td>No</td>
</tr>
<tr>
<td>1.e) CAIT (WRI)</td>
<td>all</td>
<td>programme</td>
<td>national</td>
<td>none</td>
<td>&lt;1 month</td>
<td>Quant</td>
<td>No</td>
</tr>
<tr>
<td>1.f) NAPA Platform (UNITAR)</td>
<td>gov’t, donors, NGOs</td>
<td>project, programme</td>
<td>multi-scale</td>
<td>none</td>
<td>NA</td>
<td>NA</td>
<td>No</td>
</tr>
<tr>
<td>1.g) CIEAR (SEI)</td>
<td>all</td>
<td>various</td>
<td>multi-scale</td>
<td>varying</td>
<td>varying</td>
<td>Quant</td>
<td>Yes in future</td>
</tr>
<tr>
<td>2.a) CRISTAL (IISD/ IUCN/SEI/Intercooperation)</td>
<td>all</td>
<td>project</td>
<td>local, regional</td>
<td>1 hour</td>
<td>&lt;1 month</td>
<td>Qualitative</td>
<td>not at present</td>
</tr>
<tr>
<td>2.b) ADAPT (World Bank)</td>
<td>all</td>
<td>project</td>
<td>local, regional</td>
<td>none</td>
<td>&lt;1 month</td>
<td>Qual</td>
<td>No</td>
</tr>
<tr>
<td>2.c) Adaptation Wizard (UKCIP)</td>
<td>all</td>
<td>various</td>
<td>multi-scale</td>
<td>none</td>
<td>&lt;1 month</td>
<td>Quant and qual</td>
<td>Yes</td>
</tr>
<tr>
<td>2.d) UNDP Country database</td>
<td>Country offices</td>
<td>Project</td>
<td>National</td>
<td>20 minutes</td>
<td>&lt;1 month</td>
<td>Quant and qual</td>
<td>No</td>
</tr>
<tr>
<td>3.a) Climate quick scans (DGIS)</td>
<td>donors</td>
<td>project, programme</td>
<td>multi-scale</td>
<td>none</td>
<td>&lt;1 month</td>
<td>Qual</td>
<td>No</td>
</tr>
<tr>
<td>3.b) Preparedness for Climate Change (Red Cross/Crescent)</td>
<td>NGOs</td>
<td>programme, policy</td>
<td>National</td>
<td>none</td>
<td>&gt; 6 months</td>
<td>Qual</td>
<td>No</td>
</tr>
<tr>
<td>3.c) Climate Change Adaptation Guidance Manual (USAID)</td>
<td>donors</td>
<td>policy, project</td>
<td>local, regional</td>
<td>2-6 months</td>
<td>Quant and qual</td>
<td>not at present</td>
<td></td>
</tr>
<tr>
<td>3.d) ORCHID (IDS/DFID)</td>
<td>donors, NGOs</td>
<td>programme</td>
<td>regional, national</td>
<td>none</td>
<td>2-6 months</td>
<td>Qual</td>
<td>Yes</td>
</tr>
<tr>
<td>3.e) CCA/UNDAF Guidance (UNDP)</td>
<td>Country offices</td>
<td>programme</td>
<td>National</td>
<td>none</td>
<td>&gt;6 months</td>
<td>Qual</td>
<td>No</td>
</tr>
</tbody>
</table>
The Adaptation Wizard is a web-based tool developed by the United Kingdom Climate Impacts Programme that was launched in 2004 to aid decision makers through the process of understanding climate change and integrating adaptation into decision-making (West and Gawith, 2005). The tool is based on a five-step process shown in Figure 2.13.

For each step, the Wizard assists the user with three aspects (West and Gawith, 2005):

- Explains if a decision-maker is ready to do the next step and what it will help to achieve
- Provide some key questions, and indicates which principles of good climate adaptation and resources should be drawn upon
- Provides a checklist of the principles and resources and explains the next steps
The Wizard provides a notepad which includes all the questions that the web-based form asks as well as tables that serve as templates for the adaptation strategy document. Table 2.7 displays a sample table that addresses the potential impacts of climate variables versus the risks that the organization may face.

**Table 2.7-Sample Table from Adaptation Wizard (UKCIP, 2009)**

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Specific event</th>
<th>Impact</th>
<th>Consequence</th>
<th>Threats that arose</th>
<th>Opportunities that arose</th>
<th>Actions taken to address impact</th>
<th>Identify critical thresholds (see Step 2.4)</th>
<th>Source &amp; credibility of information</th>
</tr>
</thead>
<tbody>
<tr>
<td>High summer temperatures</td>
<td>30°C for two days</td>
<td>Offices overheated</td>
<td>Staff uncomfortable and less productive</td>
<td>Loss of staff productivity</td>
<td>Hot weather generated more business</td>
<td>Relax dress code; flexible working hours; use fans</td>
<td>30°C for two days and warm nights</td>
<td>Past experience</td>
</tr>
<tr>
<td>Mild winter temperatures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry summers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet winters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rising sea levels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Etc.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The user is encouraged to complete each question under each step in order to successfully develop an adaptation strategy. The Wizard encourages that once the strategy is developed, an iterative process of reviewing and updating the strategy is necessary.

The Adaptation Wizard is an approach that encourages adaptation throughout a vast array of audiences. Therefore, the process and questions asked are general so that they are applicable to a variety of users. However, from a discipline-specific standpoint, sometimes the generality is too broad, causing a lack of direction and detail. For instance, within the transportation sector there are specific needs and impacts that may differ from the agricultural sector. Therefore, users are forced to identify these differences and unique characteristics on their own. Having an Adaptation Wizard that is more narrowly focused for individual sectors can improve detail and applicability in terms of discipline-specific management.
3. **Land Transportation and Climate Change**

This section applies the concept of climate change adaptation to the transportation sector. First, the influences of transportation on global climate change are explored to establish the existing emphasis on mitigation. Then, the impacts of climate change on the transportation sector from an adaptation perspective are described as well as existing efforts. The two perspectives are then tied together in the discussion of adaptation practices to support mitigation.

**Transportation Influence on Climate Change**

A growing concern facing the transportation sector in the United States is the relationship between transportation and climate change. As scientific evidence on climate change continues to support the relationship between anthropogenic activities and global warming, greenhouse gas concentrations continue to rise at a rate of more than 2 parts per million each year (Stern, 2006). Currently, the United States is the largest emitter worldwide, with transportation accounting for one third of carbon dioxide emissions (Ewing et al., 2008). Therefore, transportation agencies throughout the country have focused on integrating mitigation strategies into their planning process. Many of these mitigation strategies require significant infrastructural and behavioral adaptation.

The following discussion of land transportation as an influence on climate change from a mitigation perspective is centered on the need for adaptation practice to support mitigation. Therefore, mitigation practice is discussed in preparation for exploring the feasibility and necessity for implementing adaptation techniques that encourage carbon dioxide emissions reduction within the land transportation sector.

**Traffic Growth**

Transportation is one of the largest emitters of greenhouse gases in the United States contributing to 28% of all emissions, which converts to roughly 6% of all global carbon
dioxide emissions (Schmidt and Meyer, 2008). Based on projections, this contribution will increase to 36% by the year 2020 (Greene and Schafer, 2003). The transportation contribution can be attributed to the rising passenger travel demand of 4.8 trillion person-miles traveled by Americans per year (Greene and Schafer, 2003). With this demand, along with the growing oil dependence, the increase in carbon dioxide emissions from transportation will continue to grow. Figure 3.1 displays the 2030 forecast by the Department of Energy (DOE) or carbon dioxide emissions from all transportation sources as a result of the projected growth in mobility. The largest sources contributing to the emissions increase are from passenger car and truck (both light and heavy) travel. Figure 3.2 breaks down the contributions of each mode to the United States greenhouse gas emissions from the transportation sector. As shown, the passenger car and truck modes contributes 71% GHG’s released by the transportation sector. Therefore, land transportation focusing on road travel requires special attention and additional efforts to not only mitigate but adapt to climate change.
Passenger car travel is the major contributor to transportation greenhouse gas emissions at 36%, followed by light trucks at 19%. Perhaps this is due to there being a high level of ownership which is currently at 229 million registered vehicles in the United States, one of the highest in the world (TRB Special Task Force on Climate Change and Energy, 2009).

This high level of ownership has led to an increase in travel activity which can be seen in Figure 3.3 showing the relationship between the growth of vehicle miles traveled (VMT) and the increase in vehicle registrations. This growth in VMT has led to a significant increase in annual delay and traffic congestion throughout the United States, specifically within urbanized areas. Based on 83 metropolitan areas studied by the Texas Transportation Institute, 34% of the roadway system was congested in 1982 which rose to 52% in 2003 (Sperling and Cannon, 2007).

In terms of economic losses, this increase in U.S. transportation congestion cost $63 million in 2003 (Sperling and Cannon, 2007). It has been proven that the never-ending cycle of “build it and they will come,” also defined as “triple convergence” (spatial, temporal, and modal factors leading to congestion) will continue to impact the transportation sector (Downs, 2004). This means that highway development induces more traffic, encourages urban sprawl, and increases
carbon dioxide emissions, further escalating the risk of global climate change (Ewing et al., 2008).

\[\text{Figure 3.3-Growth in VMT, Vehicle Registration, and Population based on 1980 Values (Bartholomew and Ewing, 2008)}\]

**Four-Legged Stool**

The transportation sector’s influence on climate change can be viewed as a four-legged stool, shown in Figure 3.4. Each leg represents a contribution of carbon dioxide emissions which transportation agencies are trying to mitigate through reduction strategies (Ritter, 2008). The first leg is “vehicles” which represents the miles per gallon efficiency of cars and trucks. Therefore methods to promoting hybrid vehicles would be one way to address this leg. The second leg, “fuels” suggests the corresponding emissions released as a result of burning petroleum and other fossil fuels for transportation. Alternative fuels, such as biodiesel, are starting to become popular as an option to petroleum gasoline. The third leg is “VMT” which
stands for vehicle miles traveled and is related to reducing the number of vehicle miles traveled by addressing land use management. Lastly, the fourth leg “Vehicle/System Operations” relates to modal efficiency and the ability to increase system capacity. A combination of these four aspects of how transportation influences climate change serves as the basis for mitigation strategies.

Figure 3.4- Four Legged Stool Approach to Transportation GHG Reductions (Ritter, 2008)

**Mitigation Strategies**

With the transportation sector contributing to a third of the United States carbon dioxide emissions, agencies throughout the country are focusing on reduction (mitigation) strategies (Ewing et al., 2008). Mitigation is defined as “actions to reduce greenhouse gas emissions” (Pew Center on Global Climate Change, 2009). This requires the transportation sector to not only improve vehicle fuel economy and reduce carbon content in energy sources but also to develop new planning frameworks (Replogle and Fung, 2009). The majority of these improvements require some sort of infrastructural or behavioral adaptation in order to ensure its effectiveness in reducing GHG’s. Therefore, this section is not meant to be exhaustive but rather
in preparation for the discussion on the potential for adaptation strategies to support mitigation techniques.

Existing mitigation initiatives can be classified into four major categories (each representing a leg of the four-legged stool approach): fuel efficient vehicles, alternative fuels, mobility demand management, and modal alternatives. Although these initiatives address different aspects of land transportation, implementing one of these concepts cannot guarantee an absolute reduction in greenhouse gas emissions. Rather, an effective mitigation strategy should address all aspects of greenhouse gas emissions through simultaneously implementing a variety of climate change initiatives (TRB Special Task Force on Climate Change and Energy, 2009). Equation 3.1 displays the relationship between the initiatives in reducing carbon emissions (TRB Special Task Force on Climate Change and Energy, 2009).

\[ \text{Carbon Emissions} = \text{Vehicle fuel intensity} \times \text{Fuel carbon intensity} \times \text{Vehicle travel activity} \]  

\textbf{Equation 3.1}

where:

- \textit{Vehicle Fuel Intensity}- fuel consumption per passenger-mile or ton-mile of travel (addressed through the fuel efficient vehicles initiatives).
- \textit{Fuel Carbon Intensity}- ratio of carbon dioxide generated per unit of fuel (addressed through alternative fuels initiatives).
- \textit{Vehicle travel activity}- number of trips per vehicle and average length of trips (addressed through mobility demand management and modal alternatives initiatives).

Each aspect of the carbon emissions calculation is discussed in terms of how the initiatives can lead to an overall reduction in carbon dioxide emissions.

\textit{Fuel Efficient Vehicles}

In 2006, Americans traveled almost five trillion miles, of which 87\% of the miles traveled were by roadway (TRB Special Task Force on Climate Change and Energy, 2009). Perhaps this is why in the same year the United States fuel consumption for personal vehicles
was 135.6 million gallons of gasoline, diesel, or gasohol (TRB Special Task Force on Climate Change and Energy, 2009). Since there are numerous external costs associated with fuel consumption including carbon emissions, economic impacts of importing petroleum, and environmental impacts of petroleum distribution, transportation professionals are looking to fuel efficient vehicles to increase fuel economies (Litman, 2005). Currently, car and light truck fleets in the United States have fuel economies of 22.4 mpg and 18 mpg, however, the current fleet entering the market rates at 30 mpg (TRB Special Task Force on Climate Change and Energy, 2009). Comparatively, the most fuel efficient compact diesel vehicle is rated at 41 mpg (TRB Special Task Force on Climate Change and Energy, 2009). Since combustion of petroleum fuels is directly proportional to carbon dioxide emissions (the most dominant greenhouse gas emission in the road sector), reducing the vehicle fuel intensity value from Equation 1 can lead to a reduction in overall carbon emissions (TRB Special Task Force on Climate Change and Energy, 2009). One major federal regulation that has supported fuel efficiency is the Corporate Average Fuel Economy (CAFÉ) standard which was originally enacted in 1970 during the oil crisis (Sperling and Cannon, 2007). The policy mandated that United States manufacturers must meet fuel economy standards (cars- 27.5 mpg and light trucks- 22.2) and was later expanded under the Energy Independence and Security Act of 2007 (EISA) to a combined fleet standard of 35 mpg by 2020 (TRB Special Task Force on Climate Change and Energy, 2009). The EISA also allows for trading fuel economy credits between manufacturers throughout the United States. In addition to regulations, incentive-based policies such as feebates, which provide a rebate on the purchase of fuel-efficient vehicles, and accelerated scrapping of old fuel inefficient vehicles are being utilized to promote the use of higher fuel efficient vehicles (TRB Special Task Force on Climate Change and Energy, 2009). Funding for these incentive-based policies is typically drawn from surcharges on the purchase of fuel-inefficient vehicles, which further discourages consumers from purchasing these vehicles (Litman, 2005).
**Alternative Fuels**

Similar to increasing fuel efficiency, alternative fuels such as electric, biofuels, hydrogen/fuel cells, and natural gas, are promoted with the goal of reducing vehicle fuel intensity, and in turn, reducing carbon dioxide emissions. In 1988, the Alternative Motor Fuel Act (AMFA) established incentives for U.S. manufacturers to sell dual-fuel vehicles (such as E85 which consists of 85% ethanol and 15% gasoline) by earning credits applicable to meeting standards under the CAFÉ regulation (Sperling and Cannon, 2007). Recent research has expanded beyond dual-fuel/flexible fuel vehicles to include other alternative fuels such as electric, additional biofuels from energy crops, hydrogen, and natural gas.

Electric vehicles are powered by electric motors and have a high-energy efficiency. However, since they are battery-run, electric vehicles have a short driving range of about 185 miles and typically are known for having a short battery life (Kahn Ribeiro et al., 2007). Another concern with electric vehicles is that over the lifetime of a vehicle, the lead-acid batteries emit 60 times more lead/km than a comparable car with leaded gasoline (Greene and Schafer, 2003).

Another alternative is biofuel which is a fuel produced from biomass such as vegetable oils, fermentation of sugars to alcohol, gasification of chemical synthetic diesel, and biodiesel (Kahn Ribeiro et al., 2007). In 2007, a Union of Concerned Scientists reported that emissions from ethanol are estimated at 88% below those from gasoline; however, there are economic and social concerns with the conversion of land from agricultural production to fuel feedstock (Ewing, 2008). Replacing only 10% of U.S. transportation petroleum with biofuel is estimated to require converting 30% of the nation’s farmland to fuel crop (Ewing et al., 2008).

Hydrogen-powered fuel cells are another alternative “fuel” (energy carrier) that uses hydrogen to produce electricity which powers the vehicle (Ewing et al., 2008). Since water is emitted, the combustion is carbon-free providing an alternative that reduces not only carbon emissions but also reduces oil dependence (TRB Special Task Force on Climate Change and...
Energy, 2009). One of the challenges with hydrogen is the need for implementation of fueling infrastructure to support the hydrogen fuel cell fleets.

Lastly, natural gas, which is mainly methane can be used directly as an alternative fuel or converted into a more compact fuel (Kahn Ribeiro et al., 2007). The natural gas can be stored in compressed or liquefied form on the vehicle allowing for a high octane rating and a higher compression ratio, which increases energy efficiency (Kahn and Ribeiro, 2007). Again, the need for separate refueling infrastructure is a concern along with increases in local pollutants and higher vehicle costs.

**Mobility Demand Management**

Another method to reduce carbon emissions from the transportation sector is through mobility demand management which reduces the overall amount of vehicular travel. Since the 1980’s, VMT has grown three times faster than the population, and is largely attributed to increasing trip length due to changing development patterns (Bartholomew and Ewing, 2008). As urban development has sprawled outwards into the suburbs, the geographic distribution of people and places has strongly influenced the relationship between land use and accessibility (Greene and Schafer, 2003). Therefore, in order to combat the costs of sprawl, concepts such as compact development and smart growth are being implemented to encourage high density, mixed use, interconnected streets, and pedestrian-transit friendly designs (Ewing et al., 2008).

By utilizing a combination of land use and transit policies in large-scale metropolitan planning, it is projected that in 30 years, VMT can be reduced by five to seven percent (Greene and Schafer, 2003). Additionally, if pricing policies such as parking charges and congestion pricing are implemented, this reduction could be increased to nine to ten percent over thirty years (Greene and Schafer, 2003).

Pricing transportation is an incentive-based method where changing the cost and structure can encourage travelers to either reduce the number of trips or use alternative modes (Greene and Schafer, 2003). Transportation pricing typically has been implemented in two main
ways, through internalizing the external costs such as GHG emissions and traffic congestion, and through converting fixed vehicle charges into mileage-based fees (pay-as-you-drive pricing) (Greene and Schafer, 2003). Incentive-based strategies can be in the form of parking pricing (users are charged for parking facility use), high occupancy vehicle/toll lanes (encourage carpooling through providing a reduction in cost or delay to drivers with more than one person in the vehicle), fuel taxes, congestion charges, or telecommuting incentives. Transportation Demand Management (TDM), a policy alternative that includes many of the incentive-based strategies listed above, is being implemented at the state and local level to reduce vehicular demand, and in turn, reduce fuel consumption (Sperling and Cannon, 2007). By reducing vehicular travel activity, Equation 1 suggests that as VMT decreases, carbon emissions decline, further reducing the potential impacts of climate change.

**Modal Alternatives**

In order to reduce vehicular activity, modal alternatives have to be addressed in order to satisfy travel demands. By providing modal alternatives to the personal automobile, such as public transit, walking, and biking, the number of vehicular trips can be redistributed to more environmentally-friendly modes, reducing carbon emissions. In 2006, public transit including buses, paratransit, heavy/light rail, and trolleybuses represented more than 4.8 billion VMT in 2006 which was only 3% of all VMT in the United States (TRB Special Task Force on Climate Change and Energy, 2009). Transportation planners are trying to increase this percentage specifically in dense regions, since public transit provides more capacity at a lower marginal cost and also diverts car users to a more carbon-efficient mode (Kahn Ribeiro et al., 2007). According to the American Public Transportation Association, one of the most powerful tools that may be needed to combat climate change is implementing a daily transit pass (TRB Special Task Force on Climate Change and Energy, 2009). The conversion of one commuter to switch from auto to transit is about 2.5 tons/year which is more dramatic than other energy reduction methods at the household level (TRB Special Task Force on Climate Change and
Energy, 2009). Therefore, providing incentives for transit ridership as well as supporting development of transit infrastructure is essential to promoting transit as a viable alternative mode to the automobile.

In addition to public transit, non-motorized forms of mobility such as walking and biking are essential to reducing vehicular travel, however, they are highly sensitive to the local built environment (Kahn Ribeiro, 2007). The average length of U.S. trips is 6.8 miles versus the average pedestrian trip which is 0.7 miles (Ewing et al., 2008). The majority of travel destinations are not within walking distance, and even if they are, the risk of walking/biking across major roadways typically does not permit non-motorized modes as a safe modal option. Therefore, adopting principles under the smart growth and compact development plans allows for more interconnectivity and accessibility not only for motorized travel but specifically for cycling and pedestrian activity.

Through the development of complete streets, which is a street that includes auto, pedestrian, cycling, and transit facilities, travel demand can be met while reducing vehicle miles traveled (Brown, 2008). Design standards such as sidewalk coverage, building setbacks, street widths, pedestrian crossing and signaling, landscaping, bike lanes, and bike racks are just some of the variables that can help shift an environment from being auto-dominated to pedestrian/cycling-oriented (Ewing et al., 2008). By promoting these alternatives through the design of complete streets, the number of vehicular trips can be easily reduced by about 10-20% (Brown, 2008).

Lastly, and perhaps most importantly, walking/biking promotes human health and welfare by reducing obesity, reducing lung-diseases, and promoting a sense of community (Brown, 2008). Rather than traveling in a vehicle that is isolated from the outside world, pedestrian/cycling facilities encourage travelers to interact with one another and promote physical activity. Therefore, the development of non-motorized facilities is essential to reducing
not only the environmental implications of climate change but also promoting human health and welfare.

Regardless of the strategy, mitigation is extremely necessary and vital to addressing the challenge of climate change. Therefore, this perspective of reducing GHG’s and preventing potential impacts is being emphasized in transportation agencies throughout the United States.

**Climate Change Impacts on Land Transportation**

Climate change has been proven that it is not simply a problem for the future. Despite mitigation efforts and drastic measures to stabilize or eliminate greenhouse gas emissions throughout the transportation sector, the effects of climate change will continue to be experienced (TRB Committee on Climate Change and U.S. Transportation, 2008). Therefore, this forces United States transportation practitioners to evaluate the potential impacts of climate change on transportation infrastructure. Identifying the potential impacts allows for the ability to implement adaptation practices in order to improve the resiliency and protect transportation systems from the risk of climate change.

In 2008, the Transportation Research Board published the *Special Report 290* which is a synthesis of information on climate change issues for designing, planning, operating and maintaining transportation facilities across a variety of transportation systems including rail, pipeline, highway, marine, and aviation. The following is a list of the potential impacts of climate change on transportation that were identified including examples of how land transportation operations and infrastructure will be impacted (TRB Committee on Climate Change and U.S. Transportation, 2008):

*Increases in very hot days* - Based on the IPCC (2007), heat extremes and heat waves will become more frequent, more intense, and longer lasting. These increases will cause transport problems such as thermal expansion of bridge joints and paved surfaces, rail-track deformities, and limits on periods of construction activity due to health and safety concerns.
Increases in Arctic temperatures- There is a 99% probability of occurrence that Arctic warming will occur causing significant changes to freeze-thaw cycles. Changes in these cycles will have a direct impact on road engineering specifically with the selection of pavement materials to withstand drastic temperature variations (Meyer, 2008). Also, thawing of permafrost will cause subsidence of roads, rail beds, and runway foundations.

Rising sea level- As the interaction between seawater expansion and ice melts in Greenland and Antarctica persist, sea levels will rise and coastal lines will continue to recede (Holdren, 2008). As a result, more severe storm surges for coastal regions will cause flooding and inundate low-lying road travel and rail lines. Additionally, sea level rise will cause erosion of road bases and bridge supports, as well as reduce the clearance under bridges.

Increase in intense precipitation event- The frequency and intensity of precipitation events, has and will continue to increase over a majority of land areas, which is consistent with increased warming and increased atmospheric water vapor (IPCC, 2007). These increased rainfall events will cause weather-related delays, increased flooding of evacuation routes, and increases in road washout. Flooding also causes potential landslides and mudslides which pose risk to travelers as well as damages roadways and rail tracks.

Increase in hurricane intensity- Due to increased sea surface temperatures as well as changes in other environmental factors, the risk of tropical storms increases (Emanuel, 2008). Hurricanes, specifically category 4-5 storms will lead to decreased stability of bridge decks, increased interruptions in road and rail travel due to debris blockage, and greater probability of road infrastructure failure. Additionally, increased frequency of hurricane events will lead to increased frequency of emergency evacuations on the designated routes.

The purpose for identifying these potential impacts is to allow United States transportation practitioners to acknowledge future changes and to incorporate plans that adapt from and mitigate climate change. Initiatives regarding planning, design, construction, operation, and maintenance of land transportation can provide guidance for decision-makers in
reducing the impacts of climate change not only to the sector, but to all aspects of the natural and built environment. Each impact will be discussed further in detail as it relates to land transportation.

**Vulnerability of Transportation Systems**

Currently there is no comprehensive inventory of the vulnerability of U.S. transportation infrastructure to climate change including the extent of exposure or damage costs (TRB Committee on Climate Change and U.S. Transportation, 2008). However, impact-specific data exists based on geographic context. Regardless of location, the vulnerability of a transportation system depends on its robustness and degree of protection from exposure to changes in temperature, precipitation, sea level, and extreme weather events (TRB Committee on Climate Change and U.S. Transportation, 2008). In addition, the redundancy of the system can improve resiliency and avoid disruption or failure as a result of change. For instance, if there are multiple routes connecting point A to point B, then if one route fails there is always a back up route to support the travel demand. This redundancy can increase mobility and ensure the adaptability of a system regardless of the potential impact.

**Temperature Changes**

As the number of hot days and frequency of heat waves increase, land transportation systems will experience changes in the operations/maintenance/design of roads and bridges. The following impacts are projected to result from increasing temperatures (TRB Committee on Climate Change and U.S. Transportation, 2008):

- More freeze-thaw conditions will create potholes and frost heaves on road surfaces which can results in load restrictions.
- Pavement surfaces will be compromised including softening asphalt, migration of liquid asphalt, and increased rutting from traffic
Excessive summer heat will encourage wildfires having a direct impact on the infrastructure system and decrease periods of construction activity.

Warmer winter temperatures will reduce snow and ice removal costs, reduce environmental impact of salt and chemicals on roads, extend construction season, and improve mobility through winter hazards.

The majority of these impacts are negative; however, the impacts resulting from warmer winter temperatures are less dramatic and sometimes beneficial, given the geographic context. For example, warming temperatures in Alaska can result in extreme negative consequences such as thawing of permafrost, subsidence of roads, and shorter season for ice roads. Comparatively, for northern states, the warming temperatures will lead to reduced costs for snow and ice removal and enhance safety and mobility during the winter seasons.

**Precipitation Changes**

Increases in intense precipitation events are directly correlated with the risk of increased flooding of coastal roadways. Currently probabilistic estimates of rainfall intensities for a variety of durations as well as recurrence intervals (20, 50, and 100 years) have been used in the design of road culverts, road beds, and stormwater management systems (TRB Committee on Climate Change and Transportation, 2008). With projected changes in precipitation, updates in design specifications will be required to increase capacity for longer durations. The projected impacts on land transportation as a result of these impacts are as follows (TRB Committee on Climate Change and Transportation, 2008):

- Increased flooding of coastal roads and low-lying bridge and tunnel entrances
- Increased frequency and severity of overflow of culverts
- Increased flooding of evacuation routes
- Increased weather-related delays and disruptions
- Increases in road washout
- Damages to road from landslides, mudslides, and erosion
- Increased erosion and scouring of bridge supports

Again, geographic context will play a role in the degree of impact, primarily targeting coastal regions. Increases in intense precipitation events and its direct correlation with rising sea level will significantly impact transportation infrastructure along the Gulf of Mexico and the Atlantic coast.

**Rising Sea Level Impacts**

Sea level rise, along with increased storm surge, is identified as one of the most serious effects of climate change by the IPCC (2007). Studies show that transportation infrastructure along some portions of the Gulf of Mexico and the Atlantic coast will be permanently inundated within the next century (TRB Committee on Climate Change and U.S. Transportation, 2008). It is estimated that currently 60,000 miles of coastal highway is exposed to periodic coastal storm flooding and wave action and in the near future existing evacuation routes could be compromised as well (TRB Committee on Climate Change and U.S. Transportation, 2008). Coastal highways represent only a small portion of the nearly 4 million miles of public roads in the United States, however, the vulnerability is increased due to its function (emergency evacuation routes) as well as its concentration in a few states (Titus, 2002). The projected impacts on transportation as a result of sea level rise include the following (TRB Committee on Climate Change and U.S. Transportation, 2008):

- More frequent interruptions to coastal and low-lying roadway travel
- Evacuation changes in development patterns resulting from increased storm surges
- Inundation of roads and severe flooding of underground tunnels
- Erosion of road base and bridge supports
Similar to responding to increased precipitation events, design specifications will need to be updated predominantly for coastal regions. However, as sea level rise increases and storm surges build on higher base, inland regions will have to account for the increased potential for flooding (Titus, 2002).

**Extreme Weather Events**

Extreme weather events include the increased frequency and severity of more intense tropical storms, hurricanes, typhoons, and other precipitation-related events. Characteristics of tropical storms that will impact the transportation system include longer periods of intense precipitation, wind damage resulting from increased wind speed, and wind-induced storm surge leading to significant wave action (TRB Committee on Climate Change and U.S. Transportation, 2008). These characteristics will impact the land transportation system in the following manner:

- Displaced highway bridge decks
- Loss of sign and signal supports leading to increased traffic congestion
- More frequent and potentially more extensive emergency evacuations
- More debris on roads interrupting travel
- Increased roadway flooding (and associated impacts previously mentioned) as a result of storm surge

Many of these impacts go hand in hand with previous impacts such as increased precipitation and sea level rise. Therefore, adaptation measures to address the risks associated with individual geographic regions can lead to significant improvements in infrastructure resiliency and preparation for extreme events.

**Transportation Adaptation Practices**

Transportation is typically viewed as one of the “causes” of climate change due to the sector contributing a full third of total carbon dioxide emissions released in the United States (Ewing et al., 2008). Therefore, emphasis on mitigation techniques has been the focus of not
only climate change policy but also transportation planning. Although mitigation techniques are important, adaptation practice and protecting existing and future transportation facilities from climate change consequences is also proving to be necessary. As mentioned, recent scientific research suggests that the model projections are conservative and have underestimated the actual rates of climatic changes and impacts (Pew Center on Global Climate Change, 2009). In addition, the emissions released today will remain in the atmosphere for decades or centuries after they have been produced suggesting that there is a time lag from today’s emissions to future impacts. Therefore, effects of climate change will impact transportation infrastructure requiring implementation of adaptation practices in addition to mitigation measures. Figure 3.5 displays the relationship between adaptation strategies and mitigation measures in addressing climate change impacts on the United States transportation sector.

Figure 3.5- Role of Mitigation Measures and Adaptation Strategies in Addressing Climate Change Impacts on Transportation (TRB Committee on Climate Change and U.S. Transportation, 2008)
This flow chart displays how mitigation measures are complemented by adaptation strategies to reduce the impacts on transportation. Despite mitigation efforts and mediating some of the environmental effects, the remaining changes in climate need to be addressed through adaptation policies and actions.

*Adaptation Strategies in Response to Potential Impacts*

In order to protect transportation infrastructure from the potential impact of climate change, adaptation practices are necessary to increase system resiliency and decrease the risk of failure. The TRB Committee on Climate Change and U.S. Transportation (2008) developed a framework that consists of three steps to developing possible adaptation strategies in response to climate change. The three steps are as follows (TRB Committee on Climate Change and U.S. Transportation, 2008):

1. Identify potential climate change effects-based on relevance to transportation, geographic scale, degree of certainty, and time frame
2. Determine potential impacts on transportation-based on mode, effect, geographic area, and type of impact
3. Develop possible adaptation strategies- by identifying critical infrastructure, monitoring changes, altering operations/maintenance/design, and relocating vulnerable infrastructure

Figure 3.6 displays the framework in detail and displays the relationship of how potential climate change effects will cause impact on U.S transportation while possible adaptation strategies can reduce the impacts.

Step 1 focuses on using the science of climate change to determine what effects pertain to transportation at the regional and local level as well as the certainty and time frame for which these changes can occur. Typically climate change projections are most accurate at the global scale; therefore the challenge is to narrow the scope down to the regional and local levels...
for which transportation is usually managed (TRB Committee on Climate Change and U.S.
Transportation, 2008). In addition, the differences in time scales for various infrastructure such
as short-term lifespan of 10-20 years (pavement) versus long term lifespan of 50-100 years
(bridges) can have a significant influence on how and when agencies need to respond (TRB
Committee on Climate Change and U.S. Transportation, 2008).

Figure 3.6- Framework for Adaptation Strategies in Response to Potential Impacts (TRB Committee on
Climate Change and U.S. Transportation, 2008)

For Step 2 the potential impacts need to be determined in relation to the
transportation sector in terms of various modes, scale, and direct vs. indirect impact. Since
transportation is network-based, meaning that the infrastructure is interconnected and dependent
on other systems, a change to one location may also lead to changes in another. Therefore, the
potential impacts are not isolated by geographic region; rather they are interdependent on the
surrounding impacts to other transportation facilities. Similarly, changes in demographics,
social, and economic trends will also have an indirect impact on how transportation facilities are
impacted by climate change (TRB Committee on Climate Change and U.S. Transportation,
2008). This adds another complexity within managing transportation systems in response to
climate change.

Step 3 is focused on strategies that transportation decision-makers (planners, designers, engineers, and operations and maintenance personnel) can develop in response to the potential impacts. Assessing at-risk infrastructure is critical to prioritizing projects and determining changes over time. Changes in existing practices can take place throughout the asset management process including operations and maintenance as well as the initial design. This step requires significant collaboration between the decision-makers to identify opportunities and select best practices for adaptation.

**Adaptation to Support Mitigation in Transportation**

In addition to adaptation in response to the potential impacts of climate change, adaptation practices within the transportation sector are necessary in order for many mitigation measures to be effective. Mitigation measures alone cannot be implemented in time to prevent the impacts of climate on transportation infrastructure (McNeil, 2009). Therefore, adaptation practices related to infrastructure, travel behavior, development, investment policies, decision-making, and management are vital to protecting transportation in the United States. Intuitively, practitioners would agree with the notion that adaptation affects the costs and benefits of mitigation; however, up until now climate change policy has been fragmented (Kane and Shrogen, 2000). Most mitigation measures are implemented in the context of reducing climate impacts where adaptation is used in the context of protection from natural hazards (Kane and Shrogen, 2000). Therefore, adaptation of existing infrastructure and behavior is required to support successful mitigation measures within the transport sector.
Based on the mitigation measures discussed previously, adaptation within the transportation sector is necessary whether it is from a functional, behavioral, or managerial perspective. The following is a list of examples of mitigation measures with their supporting transportation adaptation practices:

- Alternative fuels (hydrogen, LPG, LNG, biofuels, electric)-development of a safe production and distribution network, refueling stations, storage facilities, structures and methods for transporting, charging stations
- Fuel efficient vehicles (diesel)-increase in quantity of refueling stations, storage facilities, behavioral changes
- Mobility Demand Management- increased toll facilities, increased high occupancy toll lanes/high occupancy vehicle lanes, use of electronic surveillance systems for monitoring high occupancy vehicle/high occupancy toll lanes, increased transit/pedestrian/cycling facilities, behavioral changes in mode choice, improved street interconnectivity for smart growth design, managerial changes to encourage TDM plans, reduced parking lot facilities
- Modal Alternatives-implementation of transit passes to encourage behavioral changes, increased transit/bike/pedestrian facilities, increased technology to support improvements in bus/rail service, improved bus routes, increased landscaping of roadways, increased building setbacks for pedestrian walkways

These are just a few examples of the adaptation needs that correlate to the four categories of mitigation measures. Depending on the transportation agency, their geographic context, their capacity demands, and their type of climate impact these adaptation practices will vary.

**Integration into Long Range Transportation Planning**

Due to the uncertainties behind climate change, transportation agencies including Metropolitan Planning Organizations (MPO’s) and state Department of Transportation agencies
(DOT’s) are largely not incorporating the concept of adaptation into transportation planning (ICF International, 2008). The lack of information regarding what impacts they can expect, where, and in what time frame creates a challenge in planning and managing transportation systems. However, efforts to begin incorporating these issues into Long Range Transportation Planning (LTRP) are encouraged by the Federal Highway Administration (ICF International, 2008).

Within transportation planning, there are many opportunities for practitioners to address the issues of climate change, both through mitigation and adaptation. The following are typical components within both statewide and metropolitan transportation plans that can include the issue of climate change (ICF International, 2008):

- **Vision and Goals:** GHG emissions reductions and increased resiliency of the system can be used to emphasize the linkages between existing goals and mitigation/adaptation measures
- **Trends and Challenges:** Rising GHG emissions and transportation’s role in increasing the risk of climate change can be addressed through VMT, congestion mitigation, changing development and land use patterns, address aging infrastructure, improve rapidly changing fuel and vehicle technologies
- **Strategies and Improvement Projects:** Inclusion of TDM (transportation demand management) plans and system management strategies to reduce GHG’s as well as adaptation to support mitigation efforts
- **Performance Measures:** Assess whether or not objectives related to climate change are met directly through GHG emissions or indirectly through congestion reduction, transit mode share, average vehicle occupancy, etc.

In conjunction with the components, transportation planning processes can incorporate climate change issues. The process of including stakeholders, evaluating all possible options, and coming to a final decision influences the final outcome of the plan and its effectiveness in
addressing climate change (ICF International, 2008). The following transportation planning processes can include climate change issues (ICF International, 2008):

- **Coordination:** Collaboration is necessary across multiple disciplines including environmental agencies, local air quality or natural resource agencies, freight carriers, operating agencies, local government authorities, emergency response teams, etc.

- **Integration of Land Use:** One of the most effective strategies to addressing climate change within the transportation sector is through the promotion of compact and transit-oriented development patterns. These strategies require the development of travel demand forecasts, population projections, a regional vision, and significant investment.

- **Link Funding:** Prioritization of projects within LTRP and transportation improvement programs (TIP) can be based on performance measures tied to climate change in order to determine an effective and efficient use of funds.

These components and processes can be incorporated into the typical metropolitan or state transportation planning process. Figure 3.7 displays an illustration of how the processes and components can be integrated into the basic steps of the transportation planning process (ICF International, 2008).

- **Step 1** is to incorporate as many stakeholders as possible and identify those that can address climate change issues.

- **Step 2** is to establish the vision, goals, and objectives which define the planning process and inclusion of mitigation/adaptation measures.

- **Step 3** is to define performance measures and identify data needs correlating with climate change impacts.

- **Step 4** is to evaluate existing deficiencies and vulnerabilities related to infrastructure, management, or operations.
• Step 5 is to develop alternative plan scenarios to include all possible options.
• Step 6 is to evaluate alternatives and select the preferred scenario.

The key suggestion made by this figure is that the process of including climate change into the transportation planning process should always be iterative. Although each step must be followed, feedback and revisions should be made throughout, creating a non-linear approach. In other words, improvements can always be made as projections or forecasts are improved, and uncertainties related to climate change impacts are resolved.

In terms of directly addressing the issue of adaptation in transportation planning, the inclusion of risk management is suggested by the U.S. Climate Change Science Program (Schmidt and Meyer, 2009). The purpose of a risk management framework in the context of transportation is to develop adaptive strategies related to transportation infrastructure in response to any and all climate-related risks (Schmidt and Meyer, 2009). Figure 3.8 displays the conceptual risk management framework.
Figure 3.7-Opportunities to Integrate Climate Change into LTRP (ICF International, 2008)
Risk can be defined by the characteristics of exposure and vulnerability. Exposure is the number and characteristics of the people, systems, regions that experience a hazard which in this case is some form of climate change impact. Vulnerability is how likely the exposed entities will be negatively impacted by the hazard. Therefore, adaptive strategies can target vulnerability by reducing the likelihood of the entity being negatively impacted. In addition, adaptation can improve resilience of a structure which is its ability to adapt and respond to internal or external changes in order to again, reduce the risk of climate change. More specific to transportation, resilience is a function of repair/replacement issues, socioeconomic resources, redundancy, and network connectivity (Schmidt and Meyer, 2009). Whether the adaptation strategies are based on protecting the system, further accommodating the system, or retreating vulnerable systems,
these practices can reduce climate change risk while simultaneously addressing other transportation planning concerns within the long range transportation planning process.

**Existing Transportation Adaptation Initiatives**

The uncertainties behind climate change and its potential impacts on transportation systems throughout the United States have caused many agencies to disregard the importance of integrating climate change adaptation into transportation planning. Little information, if any, regarding precisely what impacts agencies can expect, where, and when is causing many to not act or wait for further guidance on the topic (ICF International, 2008). However, some preliminary steps have been made in some agencies throughout the United States. These efforts are discussed based on DOT (Department of Transportation) agencies and MPO (Metropolitan Planning Organizations) jurisdictions as well as existing research center contributions.

**Department of Transportation Agencies**

Lack of information and detail regarding potential impacts of climate change to DOT agencies throughout the United States is causing challenges in addressing adaptation practices in transportation planning (ICF International, 2008). Currently, no DOT participating in a 2008 peer exchange has any specific programs and policies on climate change in place (McNeil, 2009). Based on a 2008 survey of all state DOT’s, as well as Puerto Rico and the District of Columbia, indicated that there were only eight jurisdictions that had general climate change policies in place (McNeil, 2009).

One Department of Transportation agency that has begun preliminary steps in addressing adaptation is the New York State DOT. They have created a working group for climate change issues where adaptation is being considered. They hope to conduct a study on regional sea level rise and climatic changes, reflective of the United States Climate Change Science Program studies (ICF International, 2008).
Similarly many DOT’s are discussing the topic of adaptation but very few are actually implementing practice into transportation plans. Therefore, as mitigation measures become more viable and emissions targets more feasible, adaptation practices should be integrated simultaneously to support these changes.

Metropolitan Planning Organizations

Many metropolitan planning organizations are currently not taking action to adapt the transportation system to changing climate (ICF International, 2008). The challenge of deciding how to incorporate adaptation into the LRTP is their focus even though the agency has no implementing authority (ICF International, 2008). In addition, it is not clear what level of involvement MPO’s should have in establishing protective measures against climate change (ICF International, 2008).

One MPO that is recognizing the need to consider adaptation within LRTP is the Puget Sound Regional Council. They are focusing on adaptation practice in response to the following impacts (ICF International, 2008):

- Accelerated pavement deterioration
- Flood roadways
- Bridge damage
- Increased maintenance
- Increased stormwater, drainage issues

The issues addressed by the MPO are raising awareness within Washington DOT and providing the opportunity for collaboration between agencies. Therefore, the MPO’s role in planning and coordinating efforts of local jurisdictions is extremely valuable in terms of identifying the potential climate impacts, defining objectives and goals, and suggesting the incorporation of adaptation action. This collaborative environment encourages a broader perspective for identifying alternatives and evaluating best adaptation practices across transportation jurisdictions.
Research Centers

Research centers have been progressive in defining an agenda for the inclusion of adaptation into transportation planning. Centers throughout the country have been focusing on the link between adaptive strategies and protection of transportation infrastructure from climate change impacts. The following are some research centers devoted to this topic:

- South West Region University Transportation Center (SWUTC)- focused on state and regional transportation decision making and the integration of adaptation practices based on climate change variability.
- Oregon Transportation Research and Education Consortium (OTREC)- researching the impacts of flooding on traffic patterns and transportation infrastructure
- Alaska University Transportation Center- evaluating the impacts of climate change through a flood frequency analysis for transportation design
- University of Delaware University Transportation Center (UDUTC)- researching the impact of sea level rise on the transportation infrastructure within Mid-Atlantic states

Research and development in the area of transportation adaptation practice can allow for significant improvements in how, where, and when agencies should be implementing these practices. Addressing areas where information is lacking will encourage agencies to take action and integrate adaptation along with mitigation measures into the long range transportation planning process.
4. CONCLUSIONS

Climate change is a global phenomenon that has been occurring in scientifically measured ways and will continue to be even more pronounced if not addressed (Schmidt and Meyer, 2009). Since the transportation sector is one of the major contributors to greenhouse gas emissions in the United States, most efforts have been toward mitigation strategies and measures to reduce carbon dioxide emissions. Regardless of emission limits and reduction strategies, these mitigation efforts will not be sufficient in decreasing the magnitude of global warming and its related impacts (Pew Center on Global Climate Change, 2009). Therefore, unavoidable impacts are already built into the climatic system, increasing the necessity for adaptation efforts (Pew Center on Global Climate Change, 2009).

Comprehensive and proactive adaptation planning throughout all sectors is still in its preliminary stages, particularly within transportation agencies. Based on a 2008 peer exchange, no DOT participating had any specific programs and policies on climate change in place and from a 2008 survey on all state DOT’s only eight jurisdictions had policies in place (McNeil, 2009). Therefore, the lack of information regarding where, how, and when climate change will occur, impacts transportation agency involvement is preventing many from taking any action at all.

Adaptation practices will become essential as potential impacts of climate change start to arise. In addition, adaptation to support mitigation should be recognized as a vital component of successful plans for emission reductions. Having the ability to adapt from a infrastructure standpoint as well as a functional, behavioral, and managerial perspective as a transportation agency, is necessary and will continue to gain significance as climate change threatens the viability of the United States transportation system.
5. REFERENCES


