SPECIAL REPORT 299:
REDUCING TRANSPORTATION GREENHOUSE GAS EMISSIONS AND ENERGY COMSUMPTION:
A RESEARCH AGENDA

Greenhouse Gas (GHG) and Energy Mitigation for the Transportation Sector

Recommended Research and Evaluation Program

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Paper prepared for the Transportation Research Board

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EXECUTIVE SUMMARY

This paper was prepared at the request of the Transportation Research Board, to recommend a program of research and evaluation on reducing greenhouse gas (GHG) emissions and energy consumption for surface transportation and aviation.

Climate change scientists are recommending 60-80% reductions in GHG by 2050, compared to 1990 levels, with significant near-term reductions as well. Achieving this level of reduction will require major changes in many aspects of transportation in the United States and throughout the world. The paper concentrates on research to assist in reducing GHG reductions, as opposed to research focused on reducing energy consumption, because GHG reductions are "the long pole in the tent," – i.e., achieving the recommended targets for GHG reductions is highly likely to reduce U.S. petroleum consumption and dependence on foreign oil to desired levels.

While there is a large and growing amount of research on GHG reduction strategies for transportation, it does not address many issues (especially for operational strategies and strategies to reduce GHG associated with construction, maintenance, and agency operations), it is hampered by lack of empirical information, it reflects dramatically different views and judgments, and the quality is uneven.

To overcome the current research limitations, and to help attain major GHG reductions, this paper recommends a major research program, of 31 research elements, organized in five categories:

Foundational Research

1. GHG Targets for Transportation
2. Lessons Learned from the Past
3. Cap and Trade or Carbon Pricing Implications for Transportation
4. Other Countries
5. Common Ground
6. U.S. Economic/Demographic Scenarios
7. Transportation GHG Strategy Bundles
8. Institutional, Management, and Organization Issues
9. GHG Educational Program for Policy Makers and Others

Policy Research on GHG Strategies

1. GHG Analysis Guidelines

2. Near-Term Low-Hanging Fruit Strategies
3. Vehicle and Fuel Strategies
4. Pricing Strategies
5. VMT Reduction Strategies
6. Land Use Case Studies
7. Comparative Overview Analysis of Individual GHG Strategies

Practitioner-Oriented Research

1. Practitioner Toolkit for Near-Term Low-Hanging Fruit Strategies
2. Practitioner Toolkits for Additional Strategies
3. Development and Deployment of Promising New Technologies, Processes and Tools

Data, Models, and Other Tools

1. Surface Transportation Travel Modeling
2. Scenario Planning Tools for Surface Transportation
3. Data on Surface Transportation Personal Travel behavior and Land Use and Transportation Networks
4. Intercity Passenger Data (Aviation, Intercity Bus, and Intercity Passenger Rail)
5. Freight Data for All Modes
6. Vehicle Data
7. VMT Data
8. Privacy Issues
9. Transportation Project Data
10. Multi-Year Monitoring and Evaluation for Major Policy Initiatives
11. Public Education Tools

Advanced Research Program for Universities and Others

1. Advanced Research Program

A substantial investment in this research is recommended:

- $ 36.55 million for one-time research
- $ 11.3 million for iterating major elements of the research on a four-year cycle, to update and refresh it
- $ 430 million for ongoing, annual research (of which $386 million is for data collection programs on travel behavior, freight, and vehicles, which would support a wide range of transportation planning and policy purposes, in addition to GHG reductions)

Virtually all of the research is recommended to be carried out through the use of panels that represent the major government transportation organizations and non-governmental stakeholders, across the different transportation modes. Use of such panels raises costs significantly, due to the extra time and analysis needed to resolve differences and strive for consensus.

Finally, in chapter X, the paper identifies many current research programs on transportation GHG reduction strategies, and emphasizes the importance of maintaining ongoing linkages with these programs.

I. INTRODUCTION – GHG, ENERGY, AND TRANSPORTATION

> Reducing greenhouse gas emissions and energy consumption are important goals for the nation and the transportation sector. Both goals are increasingly compelling and urgent. The challenge they present may be the greatest faced by the United States and the world since World War II. When comparing the two goals, experts on GHG and energy issues consider GHG to be "the long pole in the tent" – that is, if the United States achieves a 60-80% reduction in GHG emissions (the target recommended by some climate scientists), it is highly likely to reduce U.S. petroleum consumption and U.S. dependence on foreign oil to desired levels. Therefore, this paper focuses primarily on research needs to achieve GHG reduction targets.

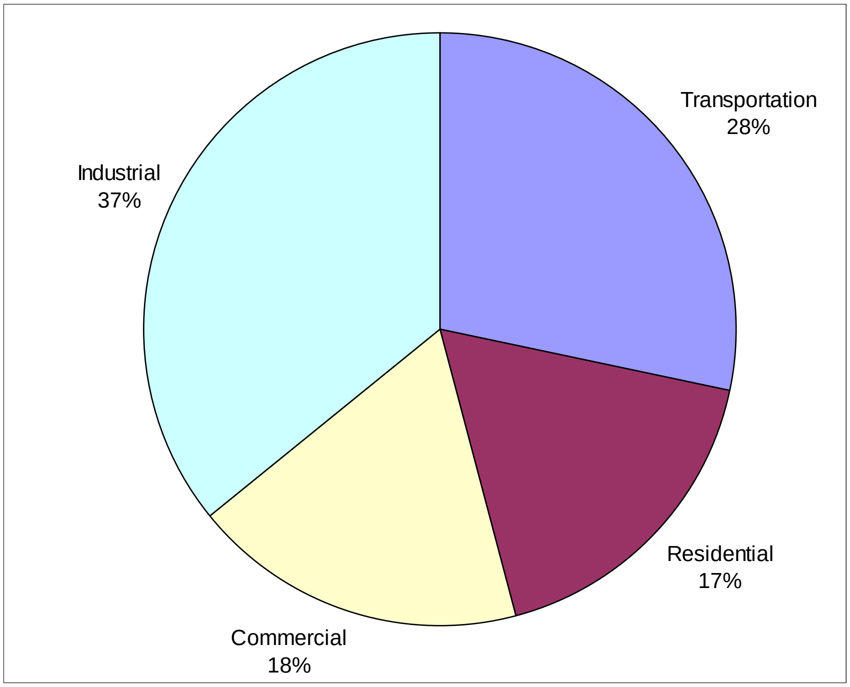
Climate change science has advanced rapidly in recent years. According to the United Nations Intergovernmental Panel on Climate Change (IPCC) now unequivocal that climate change is happening and poses significant risks to the planet. There is strong (albeit not unanimous) scientific agreement that increasing anthropogenic GHG emissions are primarily responsible for the observed climate change. In 2008, the Global Carbon Project emphasized:

> "Recent studies by a global team of carbon cycle scientists concluded that anthropogenic CO2 emissions have been growing four times faster since 2000 than in the 1990s and are now above the worst-case scenario projected by the IPCC."

Some climate scientists are calling for 60-80% reductions in anthropogenic GHG below 1990 levels by 2050, and many countries and states have adopted targets in this range, as well as targets for 2020 and other intermediate years.

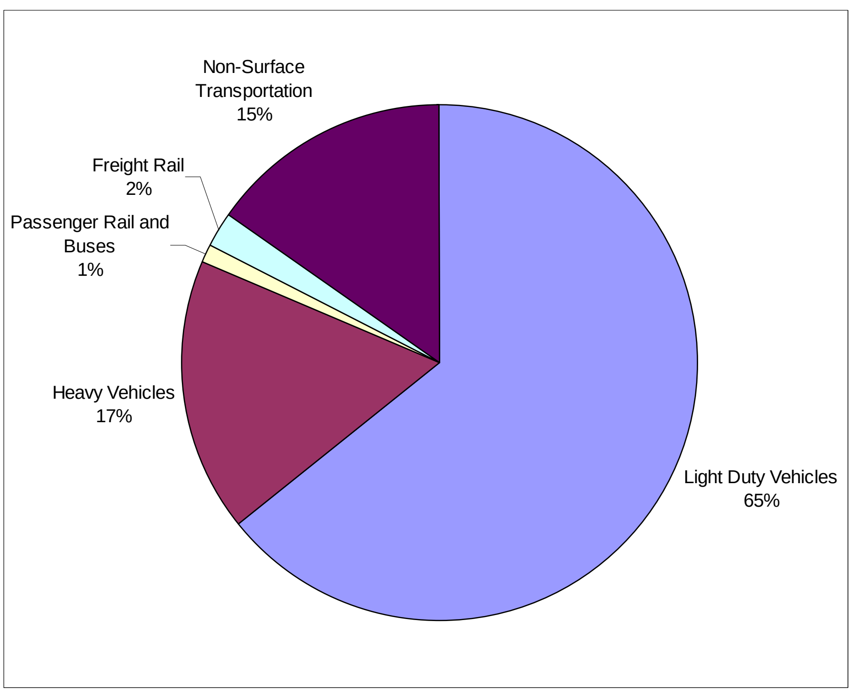
The United States is responsible for a substantial share of the GHG accumulating in the atmosphere. On a per capita basis, the United States generates 4 times as many GHG as the worldwide average per capita emissions. Within the U.S., transportation generates 28% of U.S. GHG, with 82% of the transportation GHG emitted from highway vehicles – light duty vehicles and medium and heavy duty trucks and buses.

A growing percent of the American public and elected officials expect the transportation sector to achieve major reductions in transportation GHG – potentially in the 60-80% range, consistent with overall GHG reduction goals. ***Achieving a 60-80% reduction in transportation GHG is an extraordinary challenge. It will require transformative changes in transportation, to the point that climate change is likely to have more impact on the future of surface transportation than any other issue.***



SOURCE: EIA, Emissions of Greenhouse Gases in the United States 2006, November 2007.

FIGURE 1 U.S. GHG emissions by sector, 2006.



SOURCE: EIA, Emissions of Greenhouse Gases in the United States 2006, November 2007.
Estimated Mode Level for 2006 based on 2005 Shares.

FIGURE 2 U.S. transportation sector GHG emissions by mode, estimated.

CURRENT UNDERSTANDING OF STRATEGIES TO REDUCE TRANSPORTATION GHG/ENERGY CONSUMPTION

To identify research needs for reducing transportation GHG, it is useful first to consider the range of potential strategies for reducing transportation GHG/energy consumption in five major categories. These five categories are applicable to all motorized transportation modes:

1. Improve vehicle technology
2. Use low carbon fuels
3. Moderate or reduce VMT (including VMT reductions through land use changes)
4. Improve operations of vehicles and systems
5. Reduce energy/carbon associated with construction, maintenance, operation, and administration of transportation infrastructure and systems

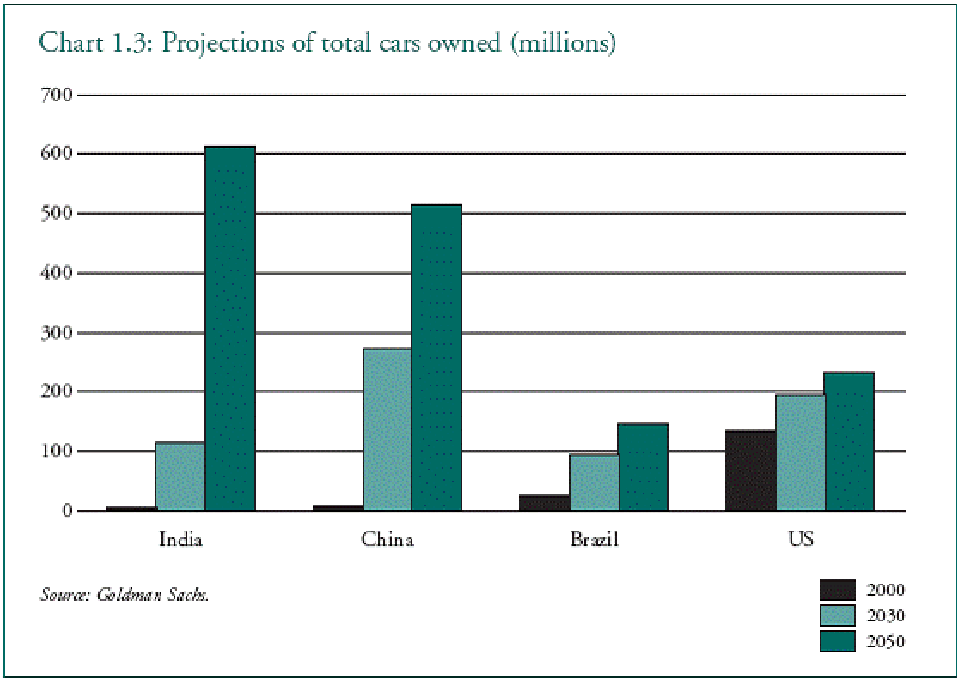
The first two strategies above, vehicle technology and fuels, are the largest potential contributors to reducing transportation GHG/energy in the United States and around the world. Not only is there high potential for major vehicle/fuel improvements, but low-carbon vehicles and fuels are of transcending importance because of explosive increase in vehicle ownership and use expected worldwide through 2050, especially in China, India, other Asian nations, and South America.

As Figure 3 shows, in 2000 the ratio of cars in the U.S. to cars in China, India, and Brazil combined was 2.5 to 1. By 2050, that ratio is projected to reverse, to a 1 to 5 ratio. As several major European studies have emphasized, it will not be possible to achieve GHG reduction targets without virtually decarbonizing vehicle technology and fuels.

Many U.S. and European analysts of vehicle technology and fuels have concluded that:

- By 2030, improvements in conventional light duty vehicle (LDV) technology and fuels can reduce CO_2/mile up to 50% (in fact, the California car standard, if approved by EPA, would achieve an estimated 42 MPG for new vehicles by 2020);
- By 2050, advanced vehicle/fuel technologies may achieve near-zero CO_2/mile for LDVs – but only with a concerted effort to overcome economic and technological hurdles, including potential consumer resistance in the United States;
- To maximize the potential GHG reductions from electric vehicles, significant advances will be needed in decarbonizing electric power sources; and
- For medium and heavy duty trucks, aircraft, buses, locomotives, and ships, there are also significant opportunities to reduce GHG/energy through vehicle and fuel improvements, although probably less dramatically than for LDVs.

While low- and near-zero-carbon vehicles and fuels can go a long way to achieving GHG/energy reduction goals, other strategies will also be needed, especially in the near to mid-term, before major technological improvements can be made. Growth in vehicle miles travelled (VMT) in the U.S. has been declining every decade since the 1950s, as shown by Figure 4, but even the recent 1.5% growth rate will, when compounded over decades, undermine efforts to reduce U.S. GHG by 60-80% by 2050.



SOURCE: The King Review, Table 1.1 and Goldman Sachs, "The BRICs and Global Markets: Crude, Cars and Capital." Goldman Sachs Global Economics Paper No 118, 2004.

FIGURE 3 Car ownership projections for India, China, Brazil, and U.S.

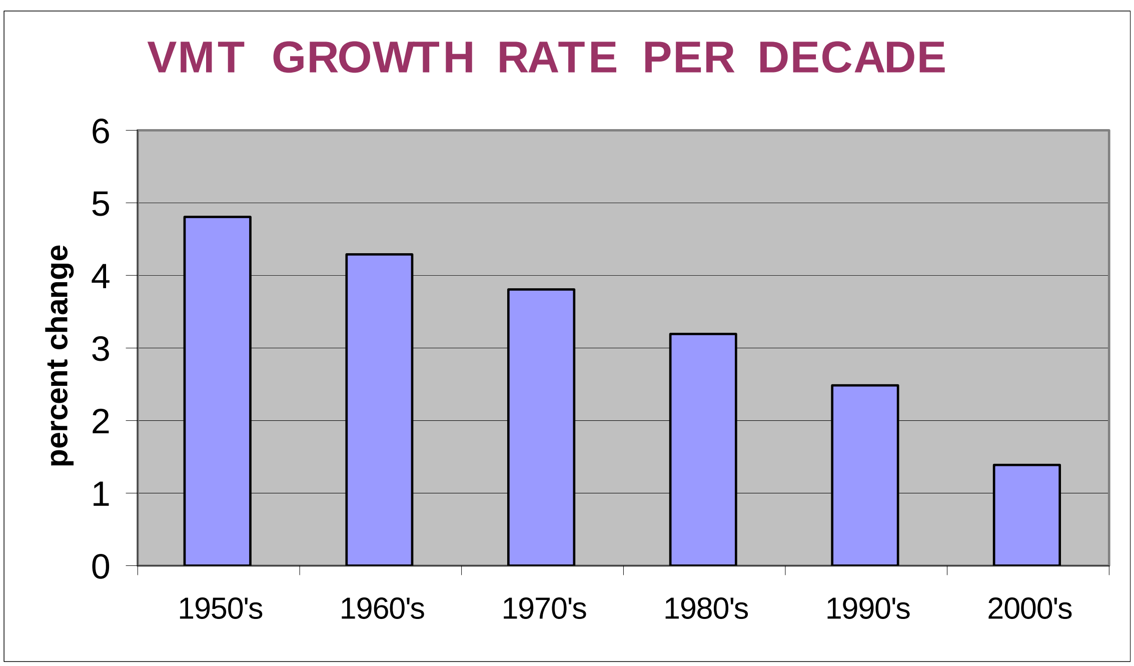


FIGURE 4 VMT growth rate per decade. (Source: Alan Pisarski and Cambridge Systematics)

Strategies to moderate or reduce VMT by all motorized modes need to be considered, along with (a) strategies to improve the efficiency of system and vehicle operations and (b) strategies to reduce "embodied" or life-cycle GHG associated with constructing and maintaining transportation systems. These three strategy areas are discussed more fully in Chapter II. In addition, Appendix A provides a tabular presentation of the wide range of potential GHG reduction strategies for transportation, organized in the five categories of transportation GHG reduction.

II. EXISTING RESEARCH AND THE NEED FOR FURTHER RESEARCH

The literature on transportation strategies to reduce GHG emissions is quite large, and it is growing rapidly. The Bibliography at the end of this paper identifies many key reports, but probably only about 10% of the relevant literature.

Despite the large and growing amount of research literature, it does not address many issues, it is hampered by lack of empirical information, it reflects dramatically different views and judgments, and its quality is uneven. For policy makers, the literature is difficult to use because so much of it is contradictory or inconsistent. For transportation practitioners, the same problem applies and also very little of the research has been synthesized and packaged for use at the practitioner level.

To achieve 60-80% GHG reductions in the transportation sector, a major research effort will be needed to overcome these limitations and to provide sound information that will help reduce transportation GHG. Research is needed to inform multiple audiences, at multiple levels, and for a wide range of GHG reduction strategies.

A. Target Audiences for Research

There are several target audiences for the research:

- Transportation policy makers (elected officials as well as appointed officials at all levels of government – Governors, Members of Congress, Federal executive branch officials, state legislators, state DOT CEOs, MPO executives and boards, local government officials, transit system CEOs and boards, airport executives, etc.)
- Transportation practitioners in all modes (engineers, planners, system operators, etc.)
- Stakeholders (all those who have a stake in the transportation system, including the transportation industry as well as nongovernmental organizations)
- Citizens (in their role as transportation users who generate GHG and as voters who influence public policy)

B. Research Levels/Categories

To serve these audiences, research is needed at four levels:

- Foundational Research
- Policy Research for GHG Strategies
- Practitioner-Oriented Research for GHG Strategies

- Improvements in Data, Models and Tools

C. GHG Strategies to be Researched

Research needs to address the five types of strategies for GHG reduction cited in the previous chapter: vehicles, fuels, VMT, vehicle/system operations, and construction/maintenance/agency operations. Existing research and knowledge is very different for each of these strategy areas:

- For vehicles and fuels there is a large and growing array of research, both in the U.S. and other countries. The research on vehicles and fuels is constantly evolving, as promising innovations are emerging from many different sources. Some of the technological innovations are moving into the marketplace or are highly promising in the near-mid term, while others have major technological hurdles to overcome. Equally as important as the technology is the need for understanding the economics and marketability of new vehicles and fuels. In addition, transportation policy makers need research on vehicle technologies and fuels to be synthesized periodically, to inform policy analysis and decisions on other transportation GHG strategies.
- Research on VMT strategies (including land use change) is substantial, wide-ranging and divergent, with drastically different results from different authors. There is a need to evaluate the VMT and land use research, illuminate the differences, obtain more empirical information, more fully explore many issues, and reach well-documented conclusions on key questions.
- For vehicle/system operations and for construction/management/agency operations, there is relatively little research. These strategy areas offer significant potential for GHG reduction and would benefit from a substantial expansion in research, for both policy makers and practitioners.

Below is a fuller discussion of each strategy area and the research needs.

Vehicles and Fuels Research

For the United States and the world, vehicles and fuels research is highest priority, because it has the greatest potential for reducing GHG from all modes of transportation. Moreover, on a worldwide basis, the expected explosion in auto ownership and usage in other countries means that the near decarbonization of vehicles and fuels is essential if the world is to achieve the 60-80% reductions in GHG called for by climate scientists.

Substantial research is underway in the U.S. and around the world to improve current vehicle technology, as well as to develop new vehicle technology and fuels (this is especially true for cars and light trucks, with a lesser amount of research underway for other types of vehicles). It is vitally important that the U.S. expand and accelerate this research, for all types of vehicles, to have any hope of meeting worldwide GHG reduction targets. Moreover, the U.S. has a strong interest in being a world leader in developing new vehicle technology and fuels for many reasons in addition to GHG reductions: to reduce U.S. energy dependence on foreign oil, to revitalize the U.S. vehicle manufacturing industry, to generate jobs, to improve the U.S. economy and trade balance, to help meet transportation GHG reduction needs in developing countries, and to improve U.S. credibility in the world arena.

Most of the research on vehicles and fuels is occurring in the private sector or under the auspices of the Department of Energy (DOE) or Environmental Protection Agency (EPA). As such, research on vehicles and fuels is largely outside the scope of this paper. However, the organizations that provide transportation infrastructure and manage transportation operations on that infrastructure need to understand the prognosis for vehicle/fuel decarbonization for each mode in order to (a) gauge how large the GHG reductions must be from other transportation strategies, (b) evaluate the potential effectiveness of other GHG reduction strategies, and (c) prepare for needed collateral changes in transportation infrastructure, operations, and financing to accommodate new vehicle technology and fuels. In addition, for cars and light trucks there is a need to gauge the "rebound effect" to measure how much driving may increase in response to reduced operating costs that result from increased fuel efficiency – or, conversely, if new vehicles are more expensive to own and operate, to gauge potential reductions in driving.

VMT Research

Reducing VMT for cars and light trucks is an extremely complex and value-laden area for research and policy. On the one hand, there is growing recognition in the transportation sector that reducing or reversing VMT growth is necessary to meet GHG reduction goals, and that there are important potential co-benefits in the form of reducing congestion and unwanted environmental impacts. On the other hand, there are deep-seated differences in views about the adverse impacts of VMT reduction, the willingness of the American public to reduce VMT, and the effectiveness of strategies to achieve VMT growth reductions or reversals.

While there has been and continues to be substantial research on VMT issues, the results are not dispositive on many key questions, due to lack of empirical data, modeling limitations, the difficulty in predicting consumer response, and the complexity of the interactions. In addition, much of the research is not trusted by both transportation professionals and environmental stakeholders, because it is associated with advocates of one perspective or another and is considered to be incomplete or biased.

While some advocates estimate significant GHG reductions from land use and other strategies to reduce VMT, others find relatively modest potential, which would take decades to be achieved. For example, the 2007 "Growing Cooler" analysis by Reid Ewing and others estimated that with aggressive land use policies the cumulative 43-year reduction in transportation GHG would be in the range of 3.5 to 5% of transportation GHG, compared to the 2050 base case without these policies. In two studies sponsored by the American Public Transportation Association, the GHG reductions associated with current transit use nationwide represent 1/3 of 1% of transportation GHG in one study, and five times as much, or 1.67% of national transportation GHG, in the other study. Most studies find that transportation pricing strategies could achieve much higher effects on both VMT and GHG, if aggressive pricing is adopted.

There is a deep schism – "colliding world views" – between advocates of reducing VMT and changing land use and those who are skeptical. Major questions arise from this debate: How much do we need to lower VMT in order to meet GHG reduction targets? Even if percentage impacts on GHG are small, are these reductions necessary to meet GHG targets? Are they worthwhile because they help achieve other public policy objectives? Or are there countervailing impacts on consumer preferences and public policy objectives? How effective are different VMT reduction strategies? How cost-effective are they, considering the full range of social and individual costs? What are the positive and negative side effects of lowering VMT on other goals, such as economic growth, environmental quality, accessibility and mobility, and quality of life? How much can land use changes contribute to reducing VMT and GHG? What are the side effects (both positive and negative) associated with land use change?

Research can provide some of the answers to these questions, but ultimately many of the answers will depend on values and public preferences as much as on objective information. Among the American public, there are many who hold "New Urbanist" values – and many who do not. Where the former predominate, communities may choose to concentrate on reforming land use and transportation to meet their goals, including GHG reductions. Where the latter predominate, communities may choose to achieve GHG reductions through vehicle technology, low-carbon fuels, and operational changes, without overhauling land use and travel behavior. Research should provide good information to both to make their policy choices, and should provide the tools for both types of communities to pursue their policy choices.

A major review is currently underway by NAS on the GHG reduction potential associated with land use changes to reduce VMT (Policy Study B0103: Committee for the Study on the Relationships Among Development Patterns, Vehicle Miles Traveled, and Energy, chaired by Professor Gomez-Ibanez of Harvard). However, the study will not be available until summer of 2009, and interim information is not available. Once the study is released, it should be helpful in clarifying what we know and don't know about this area, as well as identifying further research needed on the relationship of land use, transportation, and GHG/energy.

Research on Operations of Transportation Vehicles and Systems

Current research in this area is limited, but suggests 10-20% reductions in highway transportation GHG may be achieved through improving the operations of individual drivers and from more efficient management of the highway system. This magnitude of reductions is supported by a 2009 ecodriving pilot program in Denver which involved 400 drivers and found ecodriving reduced CO2/month/vehicle by 15% and improved fuel economy by 10% (see Bibliography, #86); by "The EcoDriver's Manual: A Guide to Increasing Your Mileage and Reducing Your Carbon Footprint" which provides CO2 estimates and references for a wide range of ecodriving practices (see Bibliography, #83); and "Real-World CO2 Impacts of Traffic Congestion," which found that CO2 emissions on specific facilities could be reduced by up to almost 20% through three different congestion mitigation strategies (see Bibliogaphy, #84). These reductions are also supported by experience in European countries that have implemented ecodriving programs (see Bibliography#88).

Based on the significant, near-term potential for reducing GHG through ecodriving and traffic operational improvements, this area warrants at least a comparable level of research and deployment effort as for VMT reduction. Research on this area is needed for both policy makers and for transportation practitioners.

Potential strategies on which research would be valuable include speed management, speed enforcement, Intelligent Speed Adaptation (ISA) devices on vehicles, advanced traveler information systems (ATIS), multi-modal integrated corridor management (ICM), in-vehicle navigation aids, incident management, active traffic flow management, optimizing traffic signals for GHG reductions (including re-timing of signals, synchronized signalization, and real-time adaptive traffic signalization), roundabouts, removal of bottlenecks, and ecodriving by individual LDV and HDV drivers (less acceleration, reduced idling, properly inflated tires, avoiding congestion, avoiding high speeds, engine tune-ups, lower weight carried in the trunk, prudent use of air conditioning, etc.) Several European countries are placing high emphasis on ecodriving policies.

Operational strategies offer important co-benefits, as well as some tradeoffs, such as (a) improved safety from lowering speeds, offset by increased travel time from lower speeds, and (b) reduced congestion and reduced vehicle operating costs, offset by "induced" demand from free-flowing traffic. More research is needed to evaluate the GHG reduction potential of operational strategies, how to maximize the potential in different settings, how to achieve lasting changes in driver operating practices, what the tradeoffs are, and how to offset the tradeoffs. In addition, research is needed to improve travel and air quality models to reflect operational characteristics (see Chapter VII on Data, Models, and Other Tools). A significant research effort is warranted operational strategies to reduce GHG, not only for GHG reductions but also to achieve other potential benefits.

For other modes – transit, aviation, and intercity passenger and freight rail, there is even less understanding of potential operational strategies to reduce GHG. Research could identify opportunities for reducing fuel consumption and GHG emissions through operational strategies. For example, can air traffic control routes and procedures be more efficient, without compromising safety? Should military airspace be delineated differently to allow for more efficient commercial air traffic routing? On the other hand, potential GHG and energy reductions are less for these modes than for highway passenger vehicles. This is largely because of the significant differences in mode shares, but in addition, ror freight rail and commercial aviation, there is already a powerful incentive to minimize fuel consumption to lower costs and stay competitive. That undoubtedly has some influence on air traffic control procedures as well as on the operations of commercial airliners. For transit and intercity passenger rail, there are also significant economic incentives to minimize fuel consumption because of budgetary constraints.

Research on Transportation Construction, Maintenance, and Operations of Transportation Vehicles and Systems

This is an important but neglected area. Much of the transportation GHG research and analysis has not taken account of the substantial GHG and energy associated with constructing transportation vehicles and facilities and maintaining them, or the wide range of agency operating practices (such as roadside mowing, snowplowing, transportation administrative buildings, airport lighting, etc.).

The University of California at Berkeley recently published a life-cycle analysis for transportation modes which found that when life-cycle GHG is accounted for, the total GHG for various transportation modes increases significantly. At the high end, life cycle GHG for light rail is 2.6 times the operational GHG of light rail, while at the low end life cycle GHG for transit buses is 1.4 times their operational GHG and life-cycle GHG for automobiles is 1.6 times operational GHG. Additional research is needed to expand the understanding of this area of GHG, to factor life-cycle GHG into policy analysis, and to identify strategies and practices to reduce GHG associated with these activities.

D. Other Research "Slices"

In addition to researching the five GHG strategy areas identified above, other research "slices" are needed to inform policy makers and practitioner groups:

- Freight Transportation: Freight transportation accounts for 20-25% of transportation GHG (17% for highway HDVs, 2% for intercity freight rail, and the remainder for marine freight, pipelines, and air cargo). Reducing GHG in freight transportation may be more difficult than for passenger transportation, because (a) unlike passenger transportation, there is little or no discretionary freight movement; (b) impacts on freight transportation have substantial implications for the economy and global competitiveness; (c) vehicle turnover occurs more slowly for freight vehicles, slowing down the potential from new technology and new fuels; (d) because of economic competition, freight carriers already have significant incentive to minimize energy costs (and thereby GHG emissions), and (e) freight transportation is expected to grow faster than passenger VMT.
- Rural Areas: Most discussion of reducing transportation GHG focuses on metropolitan areas. GHG reduction potential is likely to be smaller in rural areas, but (a) achieving 60-80% GHG reductions will require reductions to come from all geographic areas; (b) some rural strategies may be more effective than some urban strategies; and (c) rural areas are less wealthy and less able to adapt to higher fuel and vehicle costs associated with GHG reduction policies, and have fewer options for meeting GHG reduction targets.
- Near-Term GHG Reductions: Climate change scientists emphasize the importance of early actions to reduce GHG, in part because GHGs accumulate in the atmosphere and many persist for 100 years or more. Research is needed to identify and support implementation of near-term GHG reductions. Particularly valuable would be strategies that entail relatively little cost to implement, incur little or no public resistance, and have no or few drawbacks – i.e., "low-hanging fruit" and "no regrets" strategies. Examples of such strategies might include: ecodriving promotion and training for LDV drivers; ecodriving training for drivers of medium duty vehicles (MDV) and heavy duty vehicles (HDV); traffic flow improvements; incident management; LED traffic lights; carpool/vanpool programs; low-carbon pavements; reduced mowing of highway ROW; and increased use of existing transit; telecommuting; trip-chaining; and idle-reduction programs.
- Transportation Pricing: Available research suggests that transportation pricing strategies can be an effective way to reduce GHG, through pricing that rewards the purchase and use of low-carbon vehicles and fuels, efficient driving habits (ecodriving, trip-chaining, carpooling, vanpooling, etc.), and lower VMT. Pricing strategies to reduce surface transportation GHG include a national carbon tax, vehicle feebates, pay-as-you-drive-insurance, carbon-based vehicle registration and usage fees, congestion pricing, cordon pricing, high-occupancy toll lanes, mileage-based fees, parking pricing, and increased fuel taxes. Fewer pricing strategies have been identified for aviation, but could include pricing relating to airport access for all types of vehicles (including rental cars), ground support equipment, terminal operations, general aviation operations, and commercial aviation.

See Appendix B for more details on these areas and important research questions for them.

III. CRITERIA AND CONSIDERATIONS FOR DEVELOPING RESEARCH RECOMMENDATIONS

In 2009, The National Academies issued a report, "Informing Decisions in a Changing Climate." Although this report was concerned primarily with decision support for climate adaptation across all sectors, many of its recommendations and findings are highly pertinent to research on reducing transportation GHG:

> "Recommendation 1: Government agencies at all levels and other organizations, including the scientific community, should organize their decision support efforts around six principles …: (1) begin with users' needs; (2) give priority to process over products; (3) link information producers and users; (4) build connections across disciplines and organizations; (5) seek institutional stability; and (6) design processes for learning."
>
> "The Federal government should selectively support state and local governments and nongovernmental organizations to expand their efforts to provide effective decision support to their climate-affected constituencies."
>
> "Learning poses difficult challenges for climate related decision making, especially by public agencies, because frequently there are multiple participants with varied and changing objectives interacting with uncertain and evolving knowledge."
>
> "We found that the most appropriate model for learning under such conditions combines participatory deliberations with expert analysis in an iterative manner. The model is quite demanding in its need for leadership and other resources."

The research program in this paper was developed to be responsive to these recommendations and findings. It is designed to serve multiple audiences, it recognizes the varied interests of governmental and nongovernmental organizations, it recognizes that knowledge about climate and GHG reduction strategies is highly uncertain and evolving, it is multidisciplinary, it draws on collaborative research efforts, it combines expert analysis with participatory deliberations, and it is iterative.

The following eleven objectives were of highest importance in designing the research program that follows:

1. Focus on Two Primary Audiences -- Policy Makers and Practitioners: Research is needed to support good transportation policy decisions to achieve GHG reductions, and also to support transportation practitioners in implementing GHG reduction strategies. Their needs are different, both in the research questions and in the packaging and dissemination of research results.
2. Recognize Colliding World Views: For several decades, transportation policy has been buffeted by colliding world views, especially between the traditional transportation sector and environmentalists. This has produced warring "research" to advance each view. For the public, policymakers, and even transportation professionals, it can be time-consuming and difficult to evaluate the merits of the warring research and understand key underlying

assumptions for the analysis. There is a risk that the "research" results that are repeated most often, or accompanied by the best sound bites, or playing to popular perception, will form the basis for public policy decisions, without adequate factual or analytic support. There is a need for more collaborative research by representatives of the different world views, more peer review or scrutiny of research results, guidelines for GHG analysis, and credible nonbiased research teams. Research should be designed to bridge the policy gap (or at least illuminate the differences) among advocates of fundamentally different approaches to reducing transportation GHG.

3. Be Responsive to Evolving Knowledge and Issues: GHG and energy research, knowledge, and issues are evolving rapidly, with new information and insights emerging almost weekly. Moreover, legislative activity and executive branch policies are beginning to accelerate, at both state and federal level, which influences research needs, especially relating to implementation of new government directives. This is likely to continue for years to come. As such, research programs need to be dynamic, phased, and updated periodically. They should be designed to evaluate and incorporate new information and issues as they emerge.

4. Emphasize Cost-Effectiveness: Most research on GHG reductions concentrates on effectiveness – i.e., how much of a GHG reduction can be achieved from particular strategies? Equally important, but not as emphasized, is cost-effectiveness – i.e., what is the cost per ton of GHG reduced? Cost-effectiveness should always be an important criterion for individual, business, and public policy decisions, and it is even more compelling in light of the potentially long-term recession affecting the United States and the world. Accurately estimating cost-effectiveness, is challenging, especially because the calculation should include co-benefits and dis-benefits of various strategies that are often difficult to place a value on, including effects on personal utility (such as travel time) and the environment (such as air and water quality). Good information on cost-effectiveness is important not only to aid in selecting from among different transportation GHG strategies, but also for comparing the cost-effectiveness of transportation GHG strategies to strategies in other sectors, and for determining how much of the overall GHG reduction responsibility should be assigned to transportation. Several European climate analysts have suggested that, at the margin, it may be significantly more expensive to rely on transportation GHG strategies, and that strategies in other sectors would be more cost-effective. McKinsey and Company's analysis of cost-effectiveness of across all sectors identifies far more non-transportation technology opportunities costing less than $50/ton than transportation technology opportunities. Significantly more research is needed to determine whether this pattern holds up when co-benefits and dis-benefits are part of the calculation, and when behavioral strategies are added. If the pattern does hold up, it may be preferable from a broad societal view to establish a lower GHG percentage reduction for transportation than for other sectors.

5. Evaluate Other Impacts of Transportation GHG Strategies: Most transportation GHG reduction strategies will have other impacts – on the economy, environment, safety, travel time, consumer utility, etc. It is important for research to illuminate these other impacts along with the GHG reduction potential and cost-effectiveness of GHG strategies.

6. Increase the Soundness and Credibility of Research: Research should be sound in its analytical methodology, with findings that match the research scope and methodology. It must also be credible to multiple audiences, transparent, even-handed, and, whenever possible, peer-reviewed. The quality of current research on transportation GHG reduction strategies is

extremely uneven, in part because of the growth in research that is designed to support one or another of the "colliding world views" described above.

7. Draw on International Research: U.S. research on GHG reductions can benefit from information and insights from other countries – and other countries can benefit from information and insights gained through U.S. research and experiences. GHG research should draw on international research on GHG/energy reduction strategies, and foster continuous sharing of research information between the United States and other countries, many of which are farther advanced in their emphasis on climate change and their development of strategies to reduce GHG emissions.

8. Stimulate and Support University Research: Academic research should play an important role in transportation GHG research, for several reasons. Universities are the repositories of a tremendous amount of intellectual capital, universities can bring a valuable and different perspective compared to other researchers, many universities are already playing a significant role in transportation GHG research, and student involvement in university research generates a pipeline of more knowledgeable future employees for the transportation sector.

9. Support Near-Term GHG Reductions: Because GHG are cumulative and long-lived, research is needed to identify and support implementation of transportation GHG strategies that can be implemented as soon as possible, based on cost-effectiveness, implementability, public acceptability, and reliability of expected GHG reductions. There are many GHG reduction actions that meet these criteria and a research program should clearly document them and get them into the hands of transportation policy makers and implementing agencies.

10. Evaluate GHG Reduction Strategies in Bundles: Individual GHG reduction strategies can be synergistic – or counterproductive to each other. It is important for research to look for sets of strategies that reinforce each other (this is especially true for TDM and behavioral change). Also, strategies can be packaged to deter unintended consequences of single strategies.

11. Disseminate Research Results to Influence Policies and Actions: Dissemination of research results is as important as the research itself. Research results must be disseminated promptly, clearly, and effectively, in order to not only reach but also influence the decisions and actions of target audiences. Research results need to reach not only transportation professionals, but also elected officials who shape legislation and fund programs, and also the general public, whose views and lack of knowledge often constrain the willingness of elected officials to make needed policy changes. Also, research needs to reach the public to influence their travel and land use behavior that significantly affects transportation GHG and energy consumption.

The research recommendations that follow are organized into five major research blocks:

- Foundational Research
- Policy Research for GHG Strategies
- Practitioner-Oriented Research
- Data, Models, and Other Tools
- Advanced Research Program for Universities and Others

For each recommended research activity that follows, a cost estimate is provided. It is important to note that estimated costs are heavily influenced by the reliance on advisory groups of multiple perspectives. The larger and more diverse the advisory groups, the greater the time and analytical requirements will be, causing costs to be much higher than the basic analysis alone would be. This effect is even greater for research on issues with deeply held and often passionate differences among stakeholders.

IV. RECOMMENDATIONS FOR FOUNDATIONAL RESEARCH

1. GHG Targets for Transportation

Setting the appropriate target for transportation GHG reductions is extremely important, as it will drive the depth and breadth of transportation GHG strategies, as well as the selection of the strategies. How high should the targets be for transportation GHG reductions? Should all sectors, including transportation, bear equal percentage reduction responsibilities? Or should sectoral GHG reductions be based on maximizing cost-effectiveness of the strategies across all sectors? How might a cost-effectiveness target be implemented, in a world of imperfect and changing information? Would it be feasible and appropriate to follow a cost-effectiveness strategy, based on phasing – e.g., first implement all strategies with costs of less than $50/ton of GHG reductions? Later, if needed, raise the cost ceiling to $100/ton of GHG reductions? Or is there another basis for establishing GHG targets for transportation? This analysis should draw on information and perspectives on this issue in international climate reports, including the IPCC report, the Stern Review, and OECD papers. It would recommend one or more approaches to establishing GHG reduction targets for transportation. It would consider the implications of different GHG targets for different transportation modes. The analysis and recommendations would be vetted by an expert panel drawn from inside and outside the transportation sector. Recommendations should be presented and discussed in multiple forums – international conferences on climate change, multi-sector climate change conferences in the U.S., and U.S. transportation conferences. Estimated cost: $1 million, including the expert panel.

2. Lessons Learned from the Past

What lessons can the U.S. learn from past experiences in reducing emissions from transportation? In the 1970’s to early 1980’s, the United States debated and adopted a variety of transportation strategies to reduce energy consumption (e.g., CAFÉ standards, speed limits, right-turn-on-red, and TDM). Again, in the 1990’s, the United States promoted or adopted a variety of transportation strategies to reduce criteria pollutants and comply with the Clean Air Act Amendments of 1990 (e.g., vehicle and fuels standards, employer trip reduction programs, transit programs, more compact land use, etc.). Based on those experiences, this research element would evaluate the experience under the 1990 Clean Air Act Amendments and the energy embargo and conservation efforts of the 1970’s-1980’s. What strategies were most effective in reducing transportation emissions and energy consumption? What strategies were most cost-effective? What factors limited the effectiveness of various strategies, and why? How strong are those limitations today? How was public support achieved for state and national policy changes? Where did lack of public support hamper or prevent strategies from being adopted or being effective? What side-effects or unintended impacts occurred? The analysis would be vetted by an expert panel drawn from multiple stakeholders. Results should be presented and discussed in multiple forums in the United States, including conferences for elected officials (e.g., National Conference of State Legislators, U.S. Conference of Mayors, National Governors' Association, National League of Cities, National Association of Counties, etc.) as well as transportation events. Estimated cost: $2 million, including expert panel and presentation at multiple forums.

3. Cap and Trade or Carbon Pricing Implications for Transportation

What are the implications of carbon-cap-and-trade programs or carbon pricing for transportation? Cap and Trade programs are being developed and implemented by multistate coalitions. A Cap and Trade program, or possibly a carbon tax, is likely to be enacted at the national level. This research element would consider how carbon cap and trade or carbon pricing would affect transportation, including:

- Effect on Transportation GHG: How much of a GHG reduction effect would carbon cap and trade programs or carbon pricing have on transportation? The Congressional Budget Office has analyzed one Federal carbon cap and trade legislative proposal and concluded that it will reduce transportation GHG, largely through raising fuel prices, but the effect will not as great as for GHG reductions in other sectors of the economy. Further analysis would be helpful to verify the CBO estimates and extend the analysis to a variety of cap and trade or carbon pricing legislative proposals or parameters – or, if Congress enacts a national cap and trade program soon, the analysis could focus on the enacted program.
- Reasons for Lower GHG Effects: Why is the impact on transportation GHG expected to be proportionately less than the impact on other sectors? Lack of alternatives to driving? Current underpricing of transportation? Costliness of alternatives? High value attached to motorized mobility by individuals and business? Depending on the reasons for the differential, is it appropriate to adopt other policies to increase GHG reductions from transportation?
- Other Impacts on Transportation: In addition to GHG reductions, what other transportation impacts might be associated with a cap and trade program or carbon pricing? For example, how might it affect fuel prices? Would cap and trade programs and carbon pricing have the effect of reducing VMT and if so by how much? How much would it reduce transportation user fee revenues? What are other implications and impacts for different transportation modes?
- Transportation Features: What features could be built into a national cap and trade program or carbon pricing to maximize its effectiveness in reducing transportation GHG and energy reduction? What features could minimize or offset adverse implications for the transportation sector?
- Multi-State Cap and Trade: Considering regional (multi-state) cap and trade programs, what are their transportation GHG impacts and other implications for transportation?
- Use of Carbon Offsets by Transportation: How could carbon offsets be utilized by the transportation sector? By transportation organizations selling carbon offsets for transportation initiatives that reduce GHG? By transportation organizations purchasing carbon offsets to meet GHG targets more efficiently? What guidelines for carbon offset trading would be appropriate for the transportation sector?

This research would be carried out either by an NAS panel or by contracted research overseen by a steering committee composed of experts in cap and trade and carbon pricing, as well as representatives of the academic, transportation and environmental communities. Results should be presented and discussed in multiple forums in the United States, including forums of elected officials as well as transportation and environmental forums. Estimated cost: $1 million, including panel and presentation of results in multiple forums.

4. Other Countries

What can the U.S. learn from other countries' approaches to reducing transportation GHG? How can the U.S. contribute to transportation GHG reductions in other countries, especially in developing countries? (The latter is especially important, as participants in the March 30-31, 2009 Summit on America's Climate Choices emphasized the necessity of U.S. leadership in helping developing countries, especially China, India, Russia, and Brazil, find low-carbon ways to grow.) Two initial overview papers would be prepared, one to summarize transportation GHG approaches in other countries, and the other to describe the needs of developing countries for low-GHG transportation options. The papers would be circulated to key international organizations (PIARC, OECD, ECMT, etc.) to elicit their comments and additions. The papers would be presented to multiple forums in the United States. They would be updated every four years. In addition, this research activity would fund international scans and international travel to participate in conferences (both to bring international experts to the United States as well as to send U.S. governmental and stakeholder representatives to other countries) on an ongoing basis. The latter would include presentation of U.S. research and GHG reduction activities to international communities. Estimated cost: $500 K for the initial papers, plus $1 million per year for international scans and participation in international conferences and for periodic updates of the papers.

5. Common Ground

Where do stakeholders share common ground on GHG reduction policies and strategies for transportation? How can that common ground be increased? Where and why do views diverge? This research could be carried out through a series of facilitated workshops, over an 18-month period, engaging representatives of major governmental transportation organizations and nongovernmental stakeholders from industry, environmental groups, and others. A skilled facilitator, trusted by all parties, would be needed. The facilitator could guide the group through a series of questions to establish areas of agreement and areas of divergence, and to illuminate the areas of disagreement. For areas of disagreement, the group would be asked what research and information might enable convergence. The process would be repeated every four years. Estimated cost: $500 K for an 18-month facilitated process and report, repeated every four years.

6. U.S. Economic/Demographic Scenarios

What are the high-level economic and demographic scenarios for the U.S. through 2050 that could affect the achievement of transportation GHG reductions? How should these scenarios be considered in GHG policy making for transportation? This would be an overview "white paper" developed by economic and demographic experts outside the transportation sector. The paper would be used in the other elements of this research program, and would be made available to states and MPOs which undertake scenario analysis. Estimated cost: $300 K for an overview paper, largely drawn from existing analyses, and to be refreshed/updated every four years at a similar cost.

7. Transportation GHG Strategy Bundles

What are some possible bundles of transportation strategies to achieve 25% GHG reductions by 2025 and 80% GHG reductions by 2050, compared to 2005 levels? (Different targets could be substituted or added, if appropriate.) There are, of course, an infinite number of possible combinations, so this effort would need to rely on good judgment and the results would be illustrative rather than definitive. As a point of departure, consider the approach taken by Dr. David Greene and Andreas Schaefer in "Reducing Greenhouse Gas Emissions from U.S. Transportation" (a March 2003 publication of the Pew Center on Global Climate Change). Consider life-cycle GHG as well as operational GHG. Are there bundles that could achieve GHG reduction targets at $50 or less per ton of GHG reduced? What would be the order-of-magnitude costs, tradeoffs, obstacles, and co-benefits of these bundles – for government, households, and businesses? What policies would be needed to implement these bundles? The "Moving Cooler" analysis currently underway by Cambridge Systematics will provide an initial foundation, which can be evaluated and refined with the addition of key elements that may not be present in "Moving Cooler" (e.g., life cycle GHG and value of travel delays associated with different scenarios). This research effort would be guided by an NAS panel of multiple governmental and nongovernmental representatives which would specify the parameters of the research, to be carried out by a research team. Results would be presented in a two-day workshop, with panels of commenters and opportunity for audience discussion. Results would also be synthesized and summarized for elected officials and policy makers, as well as in a more detailed, technical format, for other audiences. Results would be presented in multiple transportation and non-transportation forums. The process would be repeated every four years, to take advantage of new information and developments. Estimated cost: $1 million for each iteration.

8. Institutional, Management, and Organizational Issues

What kinds of institutional, management, and organizational changes would aid in reducing transportation GHG? This research element would analyze current institutional, management, and organizational arrangements to identify factors that inhibit the ability to reduce transportation GHG, as well as potential changes that could contribute to GHG reductions. It would consider factors internal to state DOTs, transit agencies, MPOs, US DOT, and local transportation agencies. It would also consider the need for new or improved mechanisms for coordination and collaboration with other organizations – such as local land use officials and environmental agencies -- and with the private sector. It would document institutional, management, and organizational changes made by transportation organizations to focus on GHG and energy reductions (such as New York State DOT's cross-agency task force). It would scan other countries for potentially helpful experience. The analysis could be undertaken by a research team, vetted by an advisory committee comprised of representatives of academia, multiple transportation organizations and stakeholders, plus non-transportation management experts. Estimated cost: $500 K for an initial review, plus $300 K for updates every four years.

9. GHG Educational Program for Policy Makers and Others

Based on the above research results, and supplemented by the results of the 2008-2010 National Academies initiative, "America's Climate Choices," develop a high-level educational program on transportation GHG for policy makers and others. The program should be packaged in multiple formats (workshop, video, manual, powerpoint, etc.) and at three levels of intensity (comparable to a one-hour overview, a three-hour workshop, and a full-day review). It would address such questions as: What is the scientific evidence of climate change? What is transportation's role in climate change? How can transportation GHG be reduced? What are some different bundles of strategies to achieve GHG reduction targets for transportation? What are the costs and implications of these bundles for other public policy goals and consumer welfare? The program would be developed through an expert research team, including adult education experts as well as climate change and transportation experts, with an advisory panel of representatives from academia, government agencies and nongovernmental stakeholders. The program would include a detailed road map for deploying the educational program to policy makers through such forums as National Governors' Association, National Conference of State Legislators, U.S. Conference of Mayors, National League of Cities, National Association of Counties, etc., as well as through Congressional staff, AASHTO, state air quality agencies, National Association of Development Organizations, nongovernmental environmental organizations, Federal agency staff of US DOT, EPA, DOE, and others. The educational program would be updated and refreshed annually, based on new information and developments. Estimated cost: $1 million to develop the program and dissemination roadmap, plus $300 K per year for deployment and updating.

V. RECOMMENDATIONS FOR POLICY RESEARCH ON GHG STRATEGIES

1. GHG Analysis Guidelines

There is a bewildering plethora of GHG analysis in the current literature, many with major deficiencies. Much of the literature is advocacy-based. Little peer review is occurring, and most transportation policy makers and practitioners do not have the time or expertise to distinguish sound GHG analysis from unsound analysis, or to understand the limitations of different analyses. To address these concerns, this research activity would develop guidelines for analyzing transportation GHG strategies, with the goal of increasing transparency, completeness, accuracy, and comparability of GHG analyses. This research activity would also consider what steps could be taken to maximize use of these guidelines by all researchers and policy advocates. An NAS panel would be formed to develop the guidelines. The panel would draw on governmental and nongovernmental representatives, drawn from both the transportation community and from others knowledgeable about GHG analysis generally. The panel would review and evaluate the primary methodologies currently being used for transportation GHG analysis, including those provided by the Climate Registry, Center for Clean Air Policy, U.S. EPA, and the International Council for Local Environmental Initiatives (ICLEI). The guidelines would consider life-cycle GHG as well as operational GHG. The guidelines would address methodologies for carbon footprint analysis, carbon inventories, and GHG scenario planning, as well as GHG estimation for individual strategies and bundles of strategies. The panel would recommend ways to promote the maximum use of the guidelines in future GHG analyses by both governmental organizations as well as nongovernmental advocacy groups and individuals. The guidelines would be widely disseminated and highlighted at relevant conferences. Estimated cost: $1 million (one-time cost).

2. Near-Term Low-Hanging Fruit Strategies

Climate change scientists emphasize the importance of early actions to reduce GHG, in part because GHGs accumulate in the atmosphere and many persist for 100 years or more. The purpose of this research element is to provide policy support for near-term transportation GHG strategies, by identifying "low-hanging fruit" and "no regrets" strategies. Specifically, this research would identify GHG reduction strategies that could be implemented to achieve near-term GHG reductions, based on the following criteria: likely to cost less than $50/ton of GHG reduction over 5-10 years, generally acceptable to the public, quickly implementable, require relatively small government investment, and do not require new legislation or regulations. (A parallel research activity is described in the section on "Practitioner-Oriented Research," to support implementation activities.) This policy-oriented research would consider:

- Strategies to be Analyzed: For starters, consider and analyze the following, based on the criteria listed above: ecodriving promotion and training for LDV drivers; ecodriving training for MDV and HDV truck drivers; LED traffic lights; carpool/vanpool programs; low-carbon pavements; reduced mowing of highway ROW; increased use of existing transit; telecommuting; trip-chaining; traffic signal synchronization, traffic incident management, speed enforcement; truck stop electrification; and idle-reduction programs. Beyond this starter list, identify other strategies that meet the above criteria.
- Scope: Consider strategies relevant to highway LDVs, HDVs, transit, aviation, bike/ped, freight rail, intercity bus, and passenger rail. Include strategies identified and/or implemented in other countries, as long as they meet the above criteria for implementation in the United States. Consider near-term strategies for all phases of transportation functions (maintenance, construction, operations, design, planning, etc.). Include strategies for a variety of situations – statewide, metropolitan regions, urban centers, suburbs, and rural areas. Beyond geographic applicability, indicate other circumstances where each strategy is most applicable and effective.
- Policy Support: What policies could be adopted to maximize the implementation of these GHG reduction strategies? At the Federal level? State and local level? Private sector?

This research activity would be carried out by a research team, advised by a multi-modal, multi-stakeholder panel. Research results would be documented in a format targeted to policy makers and decision makers, both in hard copy and on the web. The research would include a dissemination road-map to ensure the information reaches key policy makers and decision makers. Estimated cost: $1 million, including advisory panel and dissemination of results to policy makers and decision makers.

3. Vehicle and Fuel Strategies

How much can and should the United States rely on vehicle and fuel improvements to reduce transportation GHG, for all modes? And by when? For estimating potential future GHG reductions from other strategies, what assumptions are appropriate for future carbon-intensity of transportation vehicles? Consider both incremental improvements to current vehicles and fuels, as well as transformative changes. Consider international research on vehicles and fuels, as well as U.S. research. Consider both technological challenges as well as consumer response, market economics affecting the penetration of more efficient vehicles and fuels, and potential for government interventions (e.g., higher CAFÉ standards, increased R&D, vehicle feebates, etc.). Consider effects of different vehicle technologies/fuels on National Ambient Air Quality Standards. For electric vehicles, consider the carbon intensity of existing electricity sources and the potential for decarbonizing the electric grid. Provide estimates of the carbon intensity of vehicles in 2020, 2035, and 2050, based on three levels of optimism – low, medium, and high. To address these issues, commission three papers by different experts on potential vehicle/fuel improvements. Present the papers at a two-day workshop of experts and stakeholders. Also present the papers at forums of transportation and environmental organizations, as well as elected officials (e.g., National Conference of State Legislatures, National Governors' Association, U.S. Conference of Mayors, National League of Cities, National Association of Counties, etc.) Repeat the process every four years, to take advantage of new information, changes in government policies, and R&D results. Estimated cost: $1 million for three overview papers, by three different experts, plus workshop and other forums. An additional $1 million for each subsequent iteration.

4. Pricing Strategies

How can transportation pricing policies be designed and implemented to reduce GHG and advance other goals -- reduce congestion, finance transportation, promote technological improvement, support environmental goals, and improve overall economic efficiency in the United States? Could a new approach to transportation pricing be "married" in some way with carbon cap-and-trade or a carbon tax? This research would focus on win-win-win-win-win-win strategies through varied approaches (including combinations of pricing approaches) to transportation, across all modes, but particularly for pricing of LDV, MDV, and HDV highway modes. What other impacts (such as safety) might ensue from pricing strategies? How could equity and distributional concerns be mitigated? How would rural areas be affected? Given the magnitude and potential of this approach, Congress would authorize this study, to be carried out by NAS, using a distinguished panel, drawing on multiple stakeholders, to conduct the study. Estimated cost: $2 million (one-time cost).

5. VMT Reduction and Land Use Strategies

How much can and should the United States rely on VMT reductions or lower VMT growth rates to reduce transportation GHG? Consider LDV VMT, MDV VMT, and HDV VMT. By when? What are the most effective strategies for reducing VMT or reducing VMT growth? What are the likely costs, obstacles, tradeoffs, and co-benefits? Who should make policy decisions on VMT reduction – Local governments? MPO? State DOT? State Governor and Legislature?

Federal Government? Consider land use changes along with pricing, mode shift, and other strategies to reduce VMT. To answer these questions, form a broad-based advisory group, first to seek consensus on the right list of research questions relating to VMT reduction. Then, based on consensus, the advisory panel would commission a series of research and policy papers on the questions – including potentially multiple papers on some of the individual questions, to represent varying perspectives. Convene a workshop to present the papers and engage in discussion of the major points. Conduct at least two webinars to present the papers and seek feedback and questions. Repeat the process every four years, based on new information and possible changes in perspectives. Estimated cost: $2 million for the first iteration, and $500 K for each iteration of the process, every four years.

6. Land Use Case Studies

Conduct seven comprehensive, in-depth case studies of major initiatives to achieve compact land use and reduce VMT. Case studies would include Portland, Oregon; Arlington, Virginia; the Atlantic Steel in-town development in Atlanta, Georgia; and the prospective implementation of SB 375 in California, plus three other case studies to be determined. The case studies would document each policy initiative, and would generate before-and-after data on VMT, density, emissions, housing cost, housing unit living space, governmental costs, household and business cost impacts, and the demographics of the affected populations (especially income and household size). Measures would be calculated per capita (as opposed to per household, which can be misleading). GHG estimates would be provided on a life-cycle basis, rather than solely for operational GHG. The case studies would analyze this information to discern policy implications and opportunities for other areas. The studies could be done under the auspices of a TRB panel, or via a contract effort with an advisory committee drawn from key stakeholders. Estimated cost: $500K per case study, for a total of $3.5 million (one-time cost).

7. Comparative Overview Analysis of Individual GHG Strategies

This research entails comparative overview analysis on the nine GHG strategy areas listed below. For each of the strategy areas, what is their effectiveness on a life-cycle basis – the range of potential life cycle GHG reductions in 10 years? 25 years? By 2050? What are their costs, cost-effectiveness, tradeoffs, obstacles, and co-benefits? For costs and cost-effectiveness, include not only direct dollar costs, but cost estimates for travel time, environmental impacts, etc., as well as the value of savings associated with co-benefits. What Federal, state, and local policy changes would support these strategy areas? (Each of these strategy areas would also be the focus of practitioner-oriented research, which is described in a separate section below.)

- Transportation pricing (vehicle feebates, GHG-based vehicle registration fees, congestion pricing, cordon pricing, parking pricing, pay-as-you-drive auto insurance, VMT-based user fees, carbon-weighted VMT-based user fees, etc.)
- Land use, transit, and bike/ped combined (a combination of strategies to achieve GHG reductions through more compact land use)
- Carpooling, vanpooling, car-sharing, working at home, tele-shopping, tele-education, tele-medicine, trip-chaining, and ecodriving (strategies that focus primarily on changing travel behavior for passenger trips)

- Intercity passenger bus, rail, and high speed rail (strategies that would aim to reduce GHG by shifting auto and aviation travel to these modes)
- Rural transportation (strategies that would enable GHG reductions in rural settings)
- Airports and air traffic control (strategies to reduce GHG associated with airports and air traffic operations, for both commercial and general aviation, including airport ground support equipment, low-carbon aviation fuels, air traffic routing, airport operations, aviation pricing policies, airport access, etc.)
- Freight (strategies that would reduce GHG associated with freight travel in the United States, including all freight modes, mode shift strategies, technology strategies, operational strategies such as anti-idling, truck stop electrification, and logistics improvements, etc.)
- Transportation system management and operations (strategies to reduce highway GHG through speed management, congestion relief, incident management, bottleneck removal, traffic smoothing, roundabouts, traveler information services, etc.)
- Transportation construction, maintenance, and agency operating practices (strategies to reduce GHG associated with construction, maintenance, and agency operations, including construction equipment, pavement mixes, pavement practices, work-zone management, LED lights, solar panels, LEED-certified transportation buildings, mowing practices, roadside vegetation, agency vehicle fleet choices and management of vehicle fleets, employee travel choices, etc.)

This research would be carried out by a research team, which would utilize the GHG Analysis Guidelines described above. The research team would draw on nine advisory panels to provide input and feedback on each strategy area. Advisory panels would include governmental and nongovernmental representative of major stakeholders. Results would be documented in an abbreviated form targeted to elected officials and high-level executives in government, as well as in a detailed series of reports, one for each strategy area. Results would be presented at major transportation forums, and summary results would be presented to forums of elected officials (e.g., National Conference of State Legislators, National Governors' Association, U.S. Conference of Mayors, National League of Cities, National Association of Counties, etc.). Results would be updated every four years. Estimated cost: $4.5 million for the initial research, based on an average cost of $500K for each research area, with some areas being more costly than others. For subsequent updates every four years, cost would be substantially lower, at an estimated $1.8 million (based on an estimated update cost of $200K per strategy area, on average).

VI. RECOMMENDATIONS FOR PRACTITIONER-ORIENTED RESEARCH

1. Practitioner Toolkit for Near-Term Low-Hanging Fruit Strategies

Prepare practitioner handbooks to aid in implementing strategies with near-term GHG potential, based on the corresponding policy research in Chapter V. Separate handbooks would be designed for logical groupings of strategies, based on different practitioner audiences. For each strategy in the handbooks, the following would be provided: information on costs, effectiveness, successes, barriers, and side-effects; best practices; case studies; a summary of resources, web-links, and practitioner contacts for more information. Handbooks would be posted on the web, as well as provided in hard copy.

In addition to the handbooks, this research effort would:

- Conduct a series of workshops for transportation practitioners (at least 10 per year, over a period of three years), to convey the key information and foster continuous exchange of new information and experiences;
- Develop an interactive website for transportation practitioners to support exchange of information and insights on a continuous basis; and
- Present summary information at key meetings of practitioners (e.g., AASHTO Subcommittee on Maintenance, AASHTO Subcommittee on Systems Operations and Management, TRB conferences on practitioner issues, National Association of County Engineers, etc.)

The research would be carried out by a research team and completed within 12-18 months. It would be aided by an advisory panel of practitioners and, if desired, stakeholder representatives, to provide input and feedback. It would be revisited and updated every four years, to take advantage of experience in implementing the strategies, both in the U.S. and other countries. The update would include evaluative information and case studies for strategies implemented since the initial release of the research results. Estimated cost: $2 million for the initial research effort, including an advisory panel, workshops and interactive website. For subsequent updates, $400 K every four years.

2. Practitioner Toolkits for Additional Strategies

For each of the nine strategy areas identified earlier for individual policy analysis, prepare a practitioner handbook for implementing the strategies. Each of the nine handbooks would include information, tools, best practices, available funding resources, contacts, and case studies to aid practitioners in implementing GHG reduction strategies. The research would draw on international experience and information, as well as U.S. information and experience. The nine strategy areas are repeated here for easy reference:

- Transportation pricing (vehicle feebates, GHG-based vehicle registration fees, congestion pricing, cordon pricing, parking pricing, pay-as-you-drive auto insurance, VMT-based user fees, carbon-weighted VMT-based user fees, etc.)
- Land use, transit, and bike/ped combined (a combination of strategies to achieve GHG reductions through more compact land use)
- Carpooling, vanpooling, car-sharing, working at home, tele-shopping, tele-education, tele-medicine, trip-chaining, and ecodriving (strategies that focus primarily on changing travel behavior for passenger trips)
- Intercity passenger bus, rail, and high speed rail (strategies that would aim to reduce GHG by shifting auto and aviation travel to these modes)
- Rural transportation (strategies that would enable GHG reductions in rural settings)
- Airports and air traffic control (strategies to reduce GHG associated with airports and air traffic operations, for both commercial and general aviation, including airport ground support

equipment, low-carbon aviation fuels, air traffic routing, airport operations, aviation pricing policies, airport access, etc.)

- Freight (strategies that would reduce GHG associated with freight travel in the United States, including all freight modes, mode shift strategies, technology strategies, operational strategies such as anti-idling, truck stop electrification, and logistics improvements, etc.)
- Transportation system management and operations (strategies to reduce highway GHG through speed management, congestion relief, incident management, bottleneck removal, traffic smoothing, roundabouts, traveler information services, etc.)
- Transportation construction, maintenance, and agency operating practices (strategies to reduce GHG associated with construction, maintenance, and agency operations, including construction equipment, pavement mixes, pavement practices, work-zone management, LED lights, solar panels, LEED-certified transportation buildings, mowing practices, roadside vegetation, agency vehicle fleet choices and management of vehicle fleets, employee travel choices, etc.)

In addition to the handbooks, this research effort would develop a road map for disseminating the information through workshops, presentations at key meetings of practitioners, and an interactive website for transportation practitioners to support exchange of information and insights on a continuous basis.

The research would be carried out by a research team and completed within 18 months of the corresponding policy research on individual GHG reduction strategies. It would be aided by an advisory panel of practitioners and, if desired, stakeholder representatives, to provide input and feedback. It would be revisited and updated every four years, to take advantage of new information and experience in implementing the strategies, both in the U.S. and other countries. The update would include evaluative information and case studies for strategies implemented since the initial release of the research results. Estimated cost: $5 million for the initial research effort, including advisory panel, workshops, and interactive website. For subsequent updates, $1 million every four years, including workshops.

3. Development and Deployment of Promising New Technologies, Processes and Tools

As a result of the policy and practitioner research described in preceding sections, it is likely that promising new technologies, processes, and tools will be identified. This research area would provide funds to develop them fully and stimulate deployment through pilot projects. Examples include (a) carbon negative concrete (now in development in the United Kingdom); (b) "Intelligent Speed Adaptation" technology (also being developed in the United Kingdom); (c) zoning policies to support compact development in different geographic settings; and (d) VMT-based pricing (as piloted in Oregon). Estimated cost: $50 million per year, for both development and pilot projects.

VII. RECOMMENDATIONS FOR DATA, MODELS, AND OTHER TOOLS

There are major deficiencies in the data, models, and other tools currently used for transportation decision making of all kinds, and it is necessary to address these larger issues in order to have the data and models needed to inform transportation GHG decisions. These deficiencies have been increasing over time, due to a variety of limitations: funding limitations at all levels of government, limited staff capabilities at all levels of government, and privacy concerns for transportation data. In addition, there are growing concerns in the transportation community about the organizational ability of U.S. DOT and the Bureau of Transportation Statistics to meet overall transportation data needs, including those relating to GHG reduction policies. To support sound GHG reduction policies, a broad and deep program to improve transportation data, models, and other tools is needed – a program that addresses existing foundational weaknesses in transportation data and models, as well as the additional refinements needed for GHG policy.

To support GHG policy as well as overall transportation policy needs, these improvements are needed:

- More robust data on personal travel behavior at lower levels of geography, including longitudinal data on the linkage between travel behavior and land use;
- Better data on freight transportation, to support freight policies, investments, and logistics changes that reduce GHG;
- Better data on transportation networks and the in-use vehicle fleet;
- Travel model improvements to account for the effects of pricing, operations strategies, land use, life-style factors, time of day, nonmotorized transportation, and other factors;
- Improved modeling capabilities within MPOs and other transportation organizations, to deal with complex GHG policy issues; and
- Multi-year monitoring of travel behavior changes that occur in response to new GHG policies, land use changes, and transportation investments.

Data collection and modeling are expensive. The costs to completely meet the needs for improved data, models, modeling capabilities, simulation, and other tools could easily exceed $300 million/year nationally. While seemingly large, this $300 million/year cost amounts to 0.15% of the $199 billion in Federal, state and local public expenditures on transportation in the United States in 2006 (and only 0.02% of the $1.45 trillion in U.S. transportation-related goods and services in 2007.

A large share of the $300 million estimated cost for data is for data needed to support sound metropolitan transportation planning. For example, one recent estimate is that an expenditure of $0.70-0.75 per capita per year is needed for data to support metropolitan area transportation planning, which translates to $180 million/year for data to support all types of metropolitan transportation planning. The $0.70-0.75 per capita cost was confirmed by experienced data experts on the staff of two major MPOs, the North Central Texas Council of Governments (NCTCOG) and the Atlanta Regional Commission (ARC), in a telcon on May 12, 2009. Supporting data provided by these experts include the following costs for data collection (does not include costs for management and analysis of the data, which would be an additional 18%):

- For household surveys, large MPO costs are $180-200 per household, needed every 5 or 10 years for 1% of all metropolitan households (this compares to a cost of $185/household cost for obtaining data through the National Household Travel Survey, which is the generally preferred option for small MPOs);

- For transit on-board surveys, ARC is spending $2 million to survey 10% of riders every 5 years, to meet requirements for FTA's New Starts program and other purposes;
- For commercial vehicle surveys, NCTCOG's costs are $570,000 every 10 years (for metro areas with seaports, costs would run significantly higher);
- For traffic count and speed data, NCTCOG costs are $570,000 every 5 years;
- For workplace surveys, NCTCOG costs are $388,000 every 10 years;
- For airport ground access information, NCTCOG costs are $388,000 every 10 years;
- For parking data, NCTCOG costs are $270,000 every 10 years; and
- For tracking land use NCTCOG spends $500,000/year to convert county parcel data into land use models (does not include county costs of accumulating and updating parcel information); and
- To purchase a freight data set for the state of Georgia, ARC spent close to $1 million.

Additional expenditures would be needed for nonmetropolitan data collection; for national, state, and local activities to improve travel models; for improving staff capability to use travel models; and for other tools, such as scenario planning tools.

The following improvements are recommended:

1. Surface Transportation Travel Modeling: Conduct research and deployment associated with implementing the recommendations in TRB Special Report 288, "Metropolitan Travel Forecasting – Current Practice and Future Direction," in order to improve (a) travel models and (b) modeling capabilities at MPOs, state DOTs and transit agencies. Steps to improve modeling capabilities would include increased training, workshops, best practices, peer exchanges, evaluation programs, case studies, etc. These improvements will support improved planning and decision making generally, including planning and policies to reduce GHG. Estimated cost: TRB Special Report 288 recommended Federal funding for these improvements at the level of $20 million/year for six years.
2. Scenario Planning Tools for Surface Transportation: Evaluate the scenario planning tools currently available and used by MPOs and others; document their strengths and limitations for GHG estimation purposes; ensure they are robust for all five categories of GHG reduction strategies, provide examples and training on how to use them for GHG estimation; identify improvements that are needed; and develop enhancements or new scenario planning tools for GHG purposes. In addition, establish an ongoing program of technical assistance and funding for scenario planning pilots. Estimated Cost: $5 million (one-time cost) and $20 million/year for scenario planning technical assistance and pilots.
3. Data on Surface Transportation Personal Travel Behavior and Land Use and Transportation Networks: Under the auspices of TRB, form a panel to develop recommendations for improving data on travel behavior and transportation networks, to support GHG reduction planning and policies. This panel should be representative of Federal, state, and local government as well as industry and nongovernmental stakeholders, across all surface transportation modes (including bike/ped), and would include academic and private sector experts on transportation data collection and surveys. (One possibility is to piggyback or extend the National Travel Forecasting Steering Committee now being formed by TRB at the request of US DOT in response to recommendations in TRB Special Report 288 on metropolitan travel modeling.) The panel would:
   - Develop recommendations for data needed for national GHG policy purposes.

– Develop recommendations for data needed at the state and local level to plan and implement GHG reduction policies.

– Sponsor an international scan of national travel surveys across the world for insights relevant to the U.S. context (The United Kingdom has a continuous cross-sectional design and Germany uses cross-sectional surveys with large samples carried out every 5 to 10 years, supplemented by two ongoing longitudinal panel surveys, one of which focuses on everyday travel and one which is a survey of long-distance travel. The United Kingdom and France are testing and implementing national GPS as part of their data collection.)

– Consider opportunities to augment major existing U.S. travel surveys, such as the National Household Travel Survey (NHTS) and American Community Survey (ACS), with an ongoing longitudinal panel to obtain new data needed for GHG analysis (longitudinal surveys could take the form of either "true" panel surveys or repeated cross-sectional surveys).

– Take into account the growing concern about the onerous disclosure constraints of the ACS, which will sharply reduce ACS's utility, particularly for modes with limited levels of utilization – transit, biking, walking, and working at home.

– Identify data needed to understand Americans' land use choices over time and the effect of land use choices on VMT, PMT, and travel behavior, with sensitivity to life-cycle influences and different socio-economic characteristics associated with travel and land use choices.

– Identify opportunities to use person-based GPS and other advanced technologies to collect fine-grained, reliable data on location and length of trips in different settings, by individuals of differing socio-economic characteristics, in a way that allows measurement of changes in behavior over decades and yields information on route choice, travel time, mode choice, travel time, hot and cold starts, trip chaining, and facility type.

– Consider and recommend how to minimize "social desirability bias" in travel surveys. (Psychologists use the term "*social desirability bias*" to describe the tendency of people to respond to socially-charged questions with answers that fit the prevailing social norm).

– Evaluate the Federal Highway Performance Monitoring System (HPMS), identify improvements needed to support effective GHG decisions (including potentially direct measures of recurring and nonrecurring congestion, possibly through measures from probe vehicles), and implement improvements in HPMS.

– Examine new sources of improved network data at the state and local level, including signal location and timing; travel times and speeds; traffic counts; and transit routes, stops and schedules, for both bus and rail transit; this would include determining the cost / benefit of relying on passive or digital data sources for more timely, accurate, and accessible network data.

– Identify opportunities for national data integration and/or integrated data products and programs, so the strength in one data set complements the weakness in another data set.

Given the broad scope of this panel, it may be appropriate to form subgroups and develop a phased schedule (over 3 or more years) for issuing findings and recommendations. As the findings and recommendations are issued, funding for actual data collection would be phased up, both for national data collection and state/local data collection.

Estimated costs: For the NAS Panel -- $2 million (one-time cost for evaluation). For Metropolitan Passenger Data Collection -- $180 million/year nationally (based on estimate of 70-75 cents/capita, to be phased in). For National Land Use and Behavioral Data (including NHTS) -- $35 million/year. For Surface Transportation Network Data -- $30 million/year. Note that these costs support data improvements needed for all types of surface transportation planning and policies in metropolitan areas, including GHG policies and planning.

4. Intercity Passenger Data (Aviation, Intercity Bus, and Intercity Passenger Rail): Evaluate existing data on these modes, identify gaps or needs with respect to GHG estimation, and implement improvements to support GHG reduction policies. This evaluation could be carried out by an NAS panel or through a research team, with an expert panel or steering committee to guide the effort. Estimated cost: For evaluation -- $850 K (one-time cost). For data collection – potentially $15 million/year.

5. Freight Data for All Modes: Evaluate existing data for freight modes, to identify data improvements needed to support GHG policies and planning. This would encompass intercity freight rail, intercity trucking, urban goods movements, air cargo, barges, and maritime freight. This evaluation could be carried out by an NAS panel or through a research contract, with an expert panel or steering committee to guide the effort. Estimated cost: For evaluation -- $850 K (one-time cost). For freight data collection -- $25 million/year.

6. Vehicle Data: Re-instate the Census Bureau's Vehicle Inventory and Use Survey, and expand it to encompass all types of vehicles, in order to provide reliable, timely data on fuel economy and other characteristics of vehicles in operation on the nation's roadways. This Survey, previously conducted every five years since the 1960s, was discontinued due to budget cuts after the 2002 results were tabulated, leaving a major gap in information, particularly for the medium and heavy duty truck fleet in use in the United States. Estimated cost: $4-6 million every five years if reinstated as a quinquennial survey, or $1.5 million per year if reinstated as a continuous survey with annual results. (These estimates assume that the survey would be conducted through contractors to US DOT rather than through re-establishing a branch at the Bureau of the Census.)

7. VMT Data: Evaluate potential for collecting improved data on VMT through various options, including leveraging vehicle probe data from passenger autos or commercial fleets, collecting odometer data during state or local vehicle inspections, use of infrastructure-based ITS technologies to measure VMT on specific facilities, and use of transponders and vehicle-based GPS devices to collect VMT data. This evaluation could be performed through an NAS panel or via research contract, with an expert panel or steering committee to guide the research effort. Estimated cost: $1 million (one-time cost for evaluation, including multi-stakeholder panel).

8. Privacy Issues: Analyze the privacy concerns associated with the American Community Survey (ACS), the Commodity Flow Survey (CFS), and other passenger travel or freight surveys, develop recommendations to reduce or eliminate those concerns, and implement the recommendations. Develop guidelines and institutional arrangements for addressing privacy issues for national, state, and local data collections. The purpose is to eliminate or minimize privacy-based limitations that are reducing the data available to the Federal government, states, MPOs, and others. Estimated cost: $850 K (one-time cost for evaluation and recommendations).

9. Transportation Project Data: For all major Federally-funded transportation improvements (e.g., projects over $1 billion) and for a sample of projects between $100 million to $1 billion, measure the GHG associated with construction of the improvements and establish a periodic system to estimate operational GHG based on operational and usage characteristics of the improvement over at least a 20-year life. This would apply to all modes – highways, transit, aviation, high speed rail, and marine. Estimated costs: Costs for project measurement and monitoring could be built into the project cost, and would likely be less than 0.5% of the project cost (e.g., less than $5 million for a $1 billion project).

10. Multi-Year Monitoring And Evaluation For Major Policy Initiatives: Provide funding for multi-year monitoring and evaluation of changes that result from major GHG policies. This would encompass both Federal policies and state/local policies. An initial priority area for such monitoring and evaluation would be California's groundbreaking SB 375 law linking transportation, housing, and land use in order to achieve metropolitan area GHG reduction targets for light duty vehicles. Estimated cost for a program to monitor/evaluate SB375 and at least 3 other future policy initiatives: $1 million/year.

11. Public Education Tools: Develop materials that MPOs, state DOTs, and other transportation organizations can use to educate the public about transportation GHG. Materials would be in multiple formats, including web material, print material, video, kiosks, powerpoint presentations, etc. Contents would focus on the public as both (a) transportation users/drivers; and (b) citizens who influence public policy choices (such as land use change, pricing policies, etc.). The contents should be correlated with the earlier recommended research, in Chapter IV, but it is expected that different packaging and approaches would be needed for the general public as opposed to policy makers. Update and refresh the materials annually, based on new information, shifting public perceptions, etc. Estimated cost: $1 million/year for development and refreshing of prototype materials (does not include costs for sufficient copies for national deployment).

The total cost for improving data, models, and other tools to support overall transportation planning and decision making as well as GHG policy and decisions adds up to less than $5 million in one-time evaluation costs, and $300 million per year in ongoing costs, which is 0.15 percent of the $200 billion spent per year on transportation by all levels of government in the United States.

VIII. RECOMMENDATION FOR ADVANCED RESEARCH PROGRAM FOR UNIVERSITIES AND OTHERS

The National Science Foundation (NSF) research model would be a valuable approach for transportation GHG research, to supplement the other kinds of research outlined above. An NSF-type program for transportation GHG research would be characterized by:

- A focus on creating and advancing knowledge (as opposed to focusing on policy and implementation)
- Use of expert panels to identify research topics and develop RFPs
- Receptivity to self-initiated research proposals
- A competitive selection process, using expert panels

One of the advantages of the NSF model is that it is conducive to (but not limited to) university research, because of its emphasis on creating and advancing knowledge. As noted in Chapter III, universities can play an important role in transportation GHG research, for several reasons. Universities are the repositories of a tremendous amount of intellectual capital, universities can bring a valuable and different perspective compared to other researchers, many universities are already playing a significant role in transportation GHG research, and student involvement in university research generates a pipeline of more knowledgeable future employees for the transportation sector as well as future university faculty who can capitalize on their GHG knowledge in their training and research activities.

An advanced research program of this type could be managed by US DOT, TRB, NSF, or The National Academies. To optimize both credibility and linkages to the transportation sector, to minimize risks of politicization, and to take advantage of a well-established organizational research capability, TRB management of the program is recommended. A separate section within TRB could be created, staffed by Ph.D level employees on par with academic researchers.

Estimated cost: $50 million/year is recommended (which compares to $4 billion/year in the current NSF program, across all areas of research).

IX. COST ESTIMATES AND TIMELINES

TABLE 1 Proposed Research Timeline (Shaded areas below represent time span of research. Asterisks indicate research areas that would be revisited and updated every four years.)

	Years:	1	2	3	4	5	6 -10	11-15	16-20
Foundational Research	GHG Targets								
	Lessons Learned								
	Cap and Trade/Carbon Pricing								
	Other Countries								
	Common Ground						*	*	*
	U.S. Economic/Demographic Scenarios						*	*	*
	Transportation GHG Strategy Bundles						*	*	*
	Institutional, Management, and Organizational Change						*	*	*
	GHG Educational Program for Policy Makers and Others						*	*	*
Policy Research for GHG Strategies	GHG Analysis Guidelines								
	Near-Term Low-Hanging Fruit Strategies						*	*	*
	Vehicles and Fuels.						*	*	*
	Pricing								
	VMT Reduction						*	*	*
	Land Use Case Studies								
	Comparative Overview Analysis of Individual GHG Strategies								
Practitioner-Oriented Research	Practitioner Toolkit for Near-Term Low-Hanging Fruit Strategies						*	*	*
	Practitioner Toolkit for Additional GHG Strategies						*	*	*
	Development and Deployment of Promising New Technologies, Processes, and Tools								
Data, Models, and other Tools	Surface Transportation Travel Modeling								
	Scenario Planning								
	Data on Surface Transportation Travel Behavior and Networks								
	Intercity Passenger Data								
	Freight Data								
	Vehicle Data								
	VMT Data								
	Privacy Issues								
	Project Data								
	Multi-Year Monitoring Data for Major Policy Initiatives								
	Public Education Tools								
Academic Research	Advanced Research Program for Universities and Others								

TABLE 2 Estimated Research Costs

Areas		One-Time Costs (millions)	Periodic Costs Every Four Years (millions)	Annual Costs (millions/ year)
Foundational Research	GHG Targets for Transportation	$1		
	Lessons Learned from the Past	$2		
	Cap and Trade or Carbon Pricing	$1		
	Other Countries	$0.5		$1
	Common Ground		$0.5	
	U.S. Economic/Demographic Scenarios		$0.3	
	Transportation GHG Strategy Bundles		$1	
	Institutional, Management, and Organizational Change	$0.5	$0.3	
	GHG Educational Program for Policy Makers and Others	$1		$0.3
Policy Research for GHG Strategies	GHG Analysis Guidelines	$1		
	Near-Term Low-Hanging Fruit Strategies	$1		
	Vehicles and Fuels		$1	
	Transportation Pricing	$2		
	VMT Reduction	$1	$0.5	
	Land Use Case Studies	$3.5		
	Comparative Overview Analysis of Individual GHG Strategies	$4.5	$1.8	
Practitioner-Oriented Research	Practitioner Toolkit for Near-Term Low-Hanging Fruit Strategies	$2	$0.4	
	Practitioner Toolkit for Additional GHG Strategies	$5	$1	
	Development and Deployment of Promising New Technologies, Processes, and Tools			$50
Data Models and Other Tools	Surface Transportation Travel Modeling*			$20
	Scenario Planning*	$5		$20
	Data on Surface Transportation Travel Behavior and Networks*	$2		$245
	Intercity Passenger Data*	$0.85		$15
	Freight Data*	$0.85		$25
	Vehicle Data*			$1.5
	VMT Data*	$1		
	Privacy Issues*	$0.85		
	Project Data			% of project cost
	Multi-Year Monitoring and Evaluation for Major Policy Initiatives			$1
	Public Education Tools			$1
	Advanced Research Program for Universities and Others			$50
Total		$36.55	$11.3	$430

NOTE: The above costs are heavily influenced by the use of advisory groups with multiple perspectives and interests, especially for research on issues characterized by deeply held and often passionate differences. The larger and more diverse the advisory groups for these research activities, the greater are the time and analytical requirements, causing costs to be much higher than the basic analysis alone would be.

* These activities and corresponding costs would support a full-range of transportation decision making, not just GHG policies.

X. LINKS TO OTHER RESEARCH PROGRAMS

Maintaining strong links to other research programs will be extremely important throughout the deployment of a transportation GHG research program. The purposes of such linkages are to avoid duplication, take advantage of other research, and promote cross-disciplinary and international collaboration.

Linkages can be achieved in multiple ways, including periodic meetings with those who manage the relevant programs, inclusion of participants from relevant programs on the advisory committees recommended for the research in this paper, and periodic conferences and workshops designed to showcase recent, ongoing, or planned research by different organizations.

Below are some of the current research programs which have been or will be generating research relating to GHG mitigation generally or transportation GHG in particular:

- "America's Climate Challenges," the ongoing 2008-2010 high-level overview of climate change challenges by The National Academies, with a series of reports expected in 2009-2010.
- "America's Energy Future," an ongoing initiative of The National Academies that focuses on energy issues.
- US DOT's research programs, including those of FAA, FHWA, FTA, FRA, and RITA.
- US EPA's research programs, including those relating to fuels, autos, VMT, land use, GHG inventorying, and air quality modeling.
- University research programs, including University Transportation Centers and university environmental research programs.
- The Strategic Highway Research Program (SHRP-2), especially (a) Project CO9, "Incorporating Greenhouse Gas Emissions into the Collaborative Decision-Making Process," 18-month study initiated spring 2009; and (b) Project C10, "Partnership to Develop an Integrated Advanced Travel Demand Model and a Fine Grained, Time-Sensitive Network," estimated contract date September 2009 with duration of 30 months.
- TRB Policy Study B0103, by the Committee for the Study on the Relationships Among Development Patterns, Vehicle Miles Traveled, and Energy, chaired by Professor Gomez-Ibanez of Harvard, final report expected summer of 2009.
- TRB Policy Study B0106, by the Committee for a Study of Potential Energy Savings and Greenhouse Gas Reductions from Transportation, chaired by Emil Frankel, underway.
- TRB Special Task Force on Climate Change and Energy, chaired by Marcy Schwartz.
- National Cooperative Highway Research Program, including these studies: (a) Transportation Program Responses to Greenhouse Gas Reduction Initiatives and Energy Reduction Programs, scheduled for completion February 2009; (b) Methods to Address Greenhouse Gas Emissions from Transportation Construction/Maintenance/Operations Activities, to commence in 2009, with a 12-month duration; (c) Evaluate the Interactions between Transportation-Related Particulate Matter, Ozone, Air Toxics, Climate Change, and Other Air Pollutant Control Strategies, to commence in 2009, with a 12- month duration; and (d) Implications of Performance Standards, Conformity-Style Approaches, and other Mechanisms for Assessing Greenhouse Gas Reduction Strategies and Integrating GHG Objectives into Transportation Decision Making, scheduled to begin in January 2009.

- Transit Cooperative Research Program, including this ongoing study: "Greenhouse Gas Emissions Savings from Transit – Synthesis of Information Related to Transit," with a start date of June 2008
- Aviation Cooperative Research Program, including these recent and ongoing studies: (a) Guidebook on Preparing Airport Greenhouse Gas Emissions Inventories (completed early 2009); (b) Low-Cost, High Return Practices to Reduce Airport carbon Footprints, initiated August 2008; and (c) Environmental Optimization of Aircraft Departures: An Investigation of Fuel Burn, Emissions, and Noise Interdependencies," with a start date of August 2008.
- National Cooperative Freight Research Program, including this ongoing study: "Representing Freight in Air Quality and Greenhouse Gas Models," with a start date of October 2008.
- AASHTO's Center for Environmental Excellence Technical Assistance Program on Climate Change, launched in January 2009.
- "Moving Cooler," a study of the cost-effectiveness of travel behavior strategies for surface transportation, by Cambridge Systematics, with final report expected summer of 2009.

In addition to the above U.S. research programs, there are many international organizations that sponsor research or showcase research results, including OECD, PIARC, ECMT, and IRF, plus individual countries, especially European countries, Japan, and Australia. One of the recommendations in this paper (in the "Foundational Research" section) is to fund an ongoing program to monitor international research, exchange information between the United States and other countries, and support international scans (in both directions) and participation in international conferences.

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BIBLIOGRAPHY

NOTE: Some reports are listed below under two different headings, when they are directly relevant to both headings.

Climate Science

1. Hansen, J., et al., “Target Atmospheric CO_2: Where Should Humanity Aim?” in *Atmospheric and Oceanic Physics*, 2008.
2. Hooss, G., et al., “A Nonlinear Impulse Response Model of the Coupled Carbon Cycle Climate System (NICCS),” *Climate Dynamics*, 2001.
3. Intergovernmental Panel on Climate Change (IPCC), Summary for Policymakers of the Synthesis Report of the IPCC Fourth Assessment Report”, in *Climate Change 2007*, Cambridge University Press, New York, 2007.
4. Pew Center on Global Climate Change, “Climate Change 101: Understanding and Responding to Global Climate Change, Overview,” 2009.

Climate Economics, Carbon Cap and Trade Programs, and Cost Effectiveness of Strategies

5. Lutsey, Nic, “Prioritizing Climate Change Mitigation Alternatives: Comparing Transportation Technologies to Options in Other Sectors,” Ph.D dissertation at University of California, Davis, 2008.
6. McKinsey and Company, “Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?” December 2007.
7. McKinsey and Company, “Pathways to a Low-Carbon Economy, Version 2 of the Global Greenhouse Gas Abatement Cost Curve,” 2009.
8. Stern, Sir Nicholas, “The Economics of Climate Change: The Stern Review,” Cambridge, UK: Cambridge University Press, 2007.
9. U.S. Climate Action Partnership, “A Blueprint for Legislative Action: Consensus Recommendations for U.S. Climate Protection Legislation,” January 2009.
10. U.S. Congressional Budget Office, “Policy Options for Reducing CO2 Emissions,” Feb. 2008.
11. U.S. Congressional Research Service, “The Role of Offsets in a Greenhouse Gas Emissions Cap-and-Trade Program: Potential Benefits and Concerns,” April 4, 2008.
12. U.S. Congressional Research Service, “Carbon Tax and Greenhouse Gas Control: Options and Considerations for Congress,” February 2009.
13. University of Maryland Center for Integrative Environmental Research, “The US Economic Impacts of Climate Change and the Costs of Inaction,” October 2007.

Data Sources and GHG Accounting

14. Center for Clean Air Policy, "CCAP Transportation Emissions Guidebook," 2005, http://www.ccap.org/safe/guidebook/guide_complete.html.
15. Center for Clean Air Policy, “CCAP Travel Data and Modeling Recommendations to Support Climate Policy and Performance-Based Transportation Policy,” January 30, 2009.
16. Center for Clean Air Policy, “Examples of Specific Travel Data and Modeling Improvements that Could be Incorporated in Federal Policy and Upcoming Legislation,” January 30, 2009.
17. Climate Registry, “General Reporting Protocol,” May 2008.
18. Parsons Brinckerhoff, "Highways Agency Carbon Accounting Tool – Justification Report," for the United Kingdom Highways Agency, March, 2008.
19. U.S. Energy Information Administration, *Annual Energy Outlook 2008*, March 2008.

20. U.S. Environmental Protection Agency Office of Transportation and Air Quality, Greenhouse Gas Emissions from the U.S. Transportation Sector 1990-2003, March 2006.
21. World Resources Institute and World Business Council for Sustainable Development, “The GHG Protocol for Project Accounting,” December 2005.

Energy and Climate Policies and Information - General

22. Becker, William, “Climate and Energy Policies for the 44th President and 111th Congress, Presidential Climate Action Project, power point presentation, November 13, 2008.
23. Greene, David L., “Modeling the Oil Transition: A Summary of the Proceedings of the DOE/EPA Workshop on the Economic and Environmental Implications of Global Energy Transitions,” February 2007.
24. International Energy Agency/OECD, *Saving Oil in a Hurry*, 2005.
25. National Petroleum Council, “Facing the Hard Truths about Energy – A Comprehensive View to 2030 of Global Oil and Natural Gas,” 2007.
26. The National Academies, “Informing Decisions in a Changing Climate,” 2009.
27. The National Academies, “What You Need to Know about Energy,” May 2008.

Transportation GHG– General

28. American Association of State Highway and Transportation Officials, "Primer on Transportation and Global Climate Change," April, 2008.
29. American Association of State Highway and Transportation Officials, “Transportation – Are We There Yet?: Climate Change and Sustainability,” January 2009.
30. Batac, Tiffany, and Lem, Lewison, "Transportation Strategies to Mitigate Climate Change," in *ASCE Leadership and Management in Engineering*, July 2008.
31. Burbank, Cynthia, “Strategies for Reducing the Impacts of Surface Transportation on Global Climate Change: A Synthesis of Policy Research and State and Local Mitigation Strategies,” for NCHRP 20-24 (Task 59), February 2009.
32. Gallagher, Kelly, et al., “Policy Options for Reducing Oil Consumption and Greenhouse Gas Emissions from the U.S. Transportation Sector,” John F. Kennedy School of Government, Harvard University, July 2007.
33. Greene, David, and Schaefer, Andreas, “Reducing Greenhouse Gas Emissions from U.S. Transportation,” Pew Center on Global Climate Change, May 2003.
34. Hagler Bailly Inc, “Transportation and Global Climate Change: A Review and Analysis of the Literature,” for US DOT, (June 1998).
35. Leotta, Kathy, and Burbank, Cynthia, “One Percent VMT Growth or Less to Meet Greenhouse Gas Emissions Reduction Goals,” for 2009 Transportation Research Board Annual Meeting, January 2009.
36. Pisarski, Alan, “The Nexus of Energy, Environment and the Economy: A Win, Win, Win Opportunity,” in *ITE Journal*, January 2009.
37. University of Washington and King County, “Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments,” University of California –Davis, September 2007
38. Yang, Christopher, et al, “Meeting an 80% Reduction in Greenhouse Gas Emissions from Transportation by 2050: A Case Study in California,” Transport. Res. Part D (2009).

Transportation – Surveys, Data, and Modelling

39. Bonsall, Peter, “What is so Special about Surveys Designed to Investigate the Sustainability of Travel Behavior,” University of Leeds, UK, at the 8th International Conference on Survey Methods in Transport, Annecy, France, May 25-31, 2008.

40. Committee for Determination of the State of the Practice in Metropolitan Area Travel Forecasting, “Metropolitan Travel Forecasting – Current Practice and Future Direction,” *TRB Special Report 288*, 2007.
41. Karash, Karla, et al., “Understanding How Individuals Make Travel and Location Decisions: Implications for Public Transportation,” *Transit Cooperative Research Program (TCRP) Report 123*, 2008.
42. Rodier, Caroline, “A Review of the International Modeling Literature: Transit, Land Use, and Auto Pricing Strategies to Reduce vehicle Miles Traveled and Greenhouse Gas Emissions,” submitted to the 2009 TRB Annual Meeting, November 2009.

Transportation – International Studies and Perspectives

43. Bonsall, Peter, “What is so Special about Surveys Designed to Investigate the Sustainability of Travel Behavior,” University of Leeds, UK, at the 8th International Conference on Survey Methods in Transport, Annecy, France, May 25-31, 2008.
44. Carsten, Oliver, et al., “Speed Limit Adherence and its Effect on Road Safety and Climate Change,” University of Leeds, project funded by Commission for Integrated Transport and the Motorists Forum, October 2008.
45. European Conference of Ministers of Transport, “Transport and Environment: Review of CO2 Abatement Policies for the Transport Sector,” 2006.
46. European Environment Agency (EEA), “Climate for a Transport Change – TERM 2007: Indicators Tracking Transport and Environment in the European Union,” *EEA Report No 1/2008*.
47. International Energy Agency/OECD, “Saving Oil in a Hurry,” 2005.
48. International Transportation Forum, “Transport and Energy: The Challenge of Climate Change,” summary of a forum, 2008.
49. King, Julia, “The King Review of Low-Carbon Cars, Part I: The Potential for CO2 Reduction,” October 2007, and “Part II: Recommendations for Action,” March 2008.
50. Norman, Jonathan, et al, "Comparing High and Low Residential Density: Life Cycle Analysis of energy Use and Greenhouse Gas Emissions," in ASCE *Journal of Urban Planning and Development*, March 2006.
51. OECD Observer, “Ecodriving: More than a drop in the ocean?” accessed 3-20-09 at http://www.oecdobserver.org/news/fullstory.php/aid/2596/Ecodriving:_More_than_a_drop_in_the_ocean.html
52. Parsons Brinckerhoff, "Highways Agency Carbon Accounting Tool – Justification Report," for the United Kingdom Highways Agency, March, 2008.
53. Proost, Stef, Catholic University of Leuven, Belgium, “A Full Account of the Costs and Benefits of Reducing CO2 Emissions in Transport,” 2008.
54. Stern, Sir Nicholas, *The Economics of Climate Change: The Stern Review*, Cambridge, UK: Cambridge University Press., 2007.
55. World Resources Institute and World Business Council for Sustainable Development, “The GHG Protocol for Project Accounting,” December 2005

Transportation GHG Strategies - Autos and Fuels

56. Farrell, A. and D. Sperling, *A Low-Carbon Fuel Standard for California-Part 1 Technical Analysis*, University of California: Berkeley California, 2007.
57. German, John, *Weight Reduction and Safety Implications*, Presentation to Passenger Vehicle GHG Symposium, 2008, http://www.arb.ca.gov/cc/ccms/meetings/042108/4_21_current_techn_4_german.pdf

58. Greene, David L., et al., *Feebates, Rebates and Gas-guzzler Taxes:A Study of Incentives for Increased Fuel Economy*. Energy Policy, 2005.
59. Heywood, John, et al., "On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions," MIT Laboratory for Energy and the Environment, July 2008.
60. King, Julia, "The King Review of Low Carbon Cars," for the U.K. Government, March 2008.
61. Kromer, Matthew, and Heywood, John, "Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet," May 2007.
62. Plotkin, Steve, "Examining Fuel Economy and Carbon Standards for Light Vehicles," in "The Cost and Effectiveness of Policies to Reduce Vehicle Emissions," Organization for Economic Cooperation and Development and International Transport Forum, 2008.
63. Samaras, C. and K. Meisterling, *Life Cycle Assessment of Greenhouse Gas Emissions from Plug-in Hybrid Vehicles: Implications for Policy*, Environ. Sci. Technol., 2008.
64. Schipper, Lee, "2008 Fuel Economy trends in Industrialized Countries, When the Rubber Hits the Road," special presentation for the World Resources Institute, 2008, http://embarq.wri.org/documentupload/fuel%20economy_wri.pdf
65. Schipper, Lee, "Automobile Fuel; Economy and CO2 Emissions in Industrialized Countries: Troubling Trends through 2005/6," the World Resources Institute Center for Sustainable Transport, 2007.
66. Searchinger, Tim, "The Impacts of Biofuels on Greenhouse Gases: How Land Use Change Alters the Equation," (2008)
67. U.S. Environmental Protection Agency, "Emission Facts: Greenhouse Gas Emissions from a Typical Passenger Vehicle," (February 2005).
68. U.S. National Renewable Energy Laboratory, *Research Advances: Cellulosic Ethanol*, DOE, Editor, U.S. Department of Energy Office: Golden, CO, 2007.

Transportation GHG Strategies – Planning, Travel Behavior, and Land Use

69. Brown, Marilyn A., Southworth, Frank, and Sarzynski, Andrea, Brookings Institution, "Shrinking the Carbon Footprint of Metropolitan America," May, 2008.
70. Cortright, Joe, "Portland's Green Dividend," a white paper from CEOs for Cities, July 2007.
71. Ewing, Reid, et al., "Growing Cooler: The Evidence on Urban Development and Climate Change," Urban Land Institute, 2008.
72. Handy, Susan, "Smart Growth and the Transportation-Land Use Connection: What Does the Research Tell Us?" in International Regional Science Review, Volume 28, No. 2, 2005.
73. Hughes, Knittel, and Sperling, "Evidence of a Shift in the Short-Run Elasticity of Gasoline Demand," NBER, September 2006.
74. ICF International, "Integrating Climate Change Considerations into the Transportation Planning Process," July 2008.
75. Leotta, Kathy, "Implementing the Most Effective Transportation Demand Management (TDM) Strategies to Quickly Reduce Oil Consumption," Parsons Brinckerhoff, January, 2007.
76. McGuckin, Nancy, Zmud, Johanna, and Nakamoto, Yukiko, "Trip Chaining Trends in the U.S., Understanding Travel Behavior for Policy Making," Presentation for the Transportation Research Board, 2005.
77. Norman, Jonathan, et al, "Comparing High and Low Residential Density: Life Cycle Analysis of Energy Use and Greenhouse Gas Emissions," in ASCE *Journal of Urban Planning and Development*, March 2006.
78. Porter, Chris, "The Role of State DOTs in Support of Transit-Oriented Development," NCHRP Report 20-20 (Task 20), 2006.
79. Science Applications International Corporation, "Public Transportation's Contribution to U.S. Greenhouse Gas Reduction," September 2007.

80. Stone, Brian, et al., "Mobile Source CO2 Mitigation Through Smart Growth Development and Vehicle Fleet Hybridization," in *Environmental Science & Technology,* March 15, 2009
81. U.S. Federal Highway Administration, "Summary Report – MPO Peer Workshop on Planning for Climate Change," 2008.
82. Wassmer, Robert, "Causes of Urban Sprawl in the United States: Auto Reliance as Compared to Natural Evolution, Flight From Blight, and Local Revenue Choices," in the *Journal of Policy Analysis and Management,* Spring 2008.

Transportation GHG Strategies – Vehicle and System Operations

83. Auto Alliance, "The EcoDriver's Manual: A Guide to Increasing your Mileage and Reducing Your Carbon Footprint," at www.fs.fed.us/sustainableoperations/documents/The**EcoDrive**rs**Manual**.pdf. 2008.
84. Barth, Matthew and Boriboonsomsin, Kanok, "Real-World CO2 Impacts of Traffic Congestion," University of California at Riverside, November 2007.
85. Carsten, Oliver, et al., "Speed Limit Adherence and its Effect on Road Safety and Climate Change," University of Leeds, project funded by Commission for Integrated Transport and the Motorists Forum, October 2008.
86. Correll, DeeDee, "Drivers in Denver Cut Back on Speeding, Tailgating, and Hard Braking When They Realize How Much Gas is Burned, a City Experiment Discovers," in *Los Angeles Times,* February 2, 2009.
87. Eddy, Martha Morecock, *The Role of ITS in Global Climate Change,* Presentation to the ITS World Congress November 2008. At https://1bosweb3.experient-inc.com/Events/ITSA/WorldCongress2008/Proceedings/agenda_by_topic.cfm?topic=PSEM&no=90244
88. Organization for Economic Cooperation and Development (OECD), "Ecodriving: More than a drop in the ocean?" accessed 3-20-09 at http://www.oecdobserver.org/news/fullstory.php/aid/2596/Ecodriving:_More_than_a_drop_in_the_ocean_.html

Transportation GHG Strategies – Freight

89. North Carolina State University Center for Transportation and Environment, "Best Practices Guidebook for Greenhouse Gas Reductions in Freight Transportation," October 2007.
90. U.S. Environmental Protection Agency, "Freight Carrier Innovative Strategies," Smartway Transport Program, http://www.epa.gov/smartway/, 2008.

Transportation – Life-Cycle GHG

91. Chester, Mikhail, and Horvath, Arpad, University of California, Berkeley, "Environmental Life-Cycle Assessment of Passenger Transportation: A Detailed Methodology for Energy, Greenhouse Gas and Criteria Pollutant Inventories of Automobiles, Buses, Light Rail, Heavy Rail, and Air," Volume 2, 2008.

Transportation – Specific States or Locales in the United States

92. Arizona Climate Change Advisory Group, "Climate Change Action Plan," August 2006.
93. California Department of Transportation, "Climate Action Program at Caltrans," December 2006.
94. Center for Climate Strategies, "Brief Descriptions of State Climate Actions: Transportation and Land Use," http://www.climatestrategies.us/ewebeditpro/items/O25F17651.PDF

95. Center for Transportation Studies, University of Minnesota, "Reducing Greenhouse Gas Emissions From Transportation Sources in Minnesota," June 2008.
96. Climate Change Steering committee for the Metropolitan Washington Council of Governments Board of Directors, "National Capital Region Climate Change Report," Final Draft, November 12, 2008.
97. Heminger, Steve, Metropolitan Transportation Commission, "Regional Policies for TOD: the San Francisco Bay Area Experience," at Rail-Volution, November 2007.
98. Montana Climate Change Advisory Committee, "Montana Climate Change Action Plan: Final Report of the Governor's Climate Change Advisory Committee," November 2007.
99. New Mexico Climate Change Advisory Group, "Final Report," December 2006.
100. New York State Department of Transportation, "Climate and Energy Report," August 1, 2008.
101. Parsons Brinckerhoff and Victoria Transport Policy Institute, "Sound Transit 2 Planning Sustainability Assessment of Sound Transit 2 Plan," final, August 5, 2008.
102. Poor, Aaron, "Climate Change Initiatives of State Departments of Transportation: Synthesis," prepared for Washington DOT, January 10, 2008.
103. University of Minnesota, "Reducing Greenhouse Gas Emissions from Transportation Sources in Minnesota," for the Minnesota state legislature, June 2008.
104. Vermont Agency of Transportation, "VTrans Climate Change Action Plan," June 2008.
105. Vermont Governor's Commission on Climate Change, "Final Report and Recommendations of the Governor's Commission on Climate Change," presented to Governor James H. Douglas, October 2007.

Public Opinion Surveys

106. Clear Vision Survey, "Americans Consider Global Warming an Urgent Threat," September 27, 2007.
107. Gallup Survey, "Americans Assess What They Can Do to Reduce Global Warming," April 24, 2007.
108. Gallup Survey, "Increased Number Think Global Warming is Exaggerated," March 11, 2009. Accessible at http://www.gallup.com/poll/116590/Increased-Number-Think-Global-Warming-Exaggerated.aspx

Appendix A

Overview of GHG Reduction Strategies for Transportation

GHG Category	Today's Measures (2008-2015)	Tomorrow's Measures (2010-2030)	Supporting Measures and Policies
Vehicle Technology	• Incremental improvements in conventional gasoline LDVs and diesel HDVs • Low carbon auxiliary equipment on LDVs and HDVs • Increased use of conventional hybrid gas electric vehicles. • Improved efficiency for buses, aircraft, and locomotives	• Electric LDVs (hybrid gas electric, plug-in hybrid, battery electric) • Fuel cell vehicles • More advanced low carbon auxiliary equipment on LDVs and HDVs	• R&D for vehicles • Regulatory standards (fuel economy or GHG emission rate) • Feebates and other vehicle purchase incentives at the state, regional, or national level • Economy-wide pricing (carbon tax, carbon cap-and-trade) • Vehicle registration rates based on carbon emissions • Transportation pricing (carbon-based usage fees) • Vehicle buy-backs for older high-GHG vehicles • Govt and corporate fleet vehicle purchasing • Low-rolling resistance replacement tires • Tires with automatic pressure detection and inflation
Low Carbon Fuels	• 1st generation biofuels (corn and sugarcane, as long as they are truly low-carbon after considering well-to-wheel and land use GHG impacts) added to petroleum fuels • Lower-GHG fossil fuels (e.g., compressed natural gas)	• Electricity (plug-in hybrids and battery electrics) from lower-GHG power plants • Cellulosic and municipal waste biofuel • Algae-based biofuels • Hydrogen from renewable sources • Mobile air conditioning refrigerant replacement	• R&D for fuels • Biofuel blending mandates (based on lifecycle GHG) • Low-GHG fuel mandates (based on lifecycle GHG) • Carbon tax on fuels (or carbon cap-and-trade programs) • Limits on production and use of high GHG fuels (e.g., tar sands and liquefied coal) • Fuel infrastructure (e.g., .plug-in hybrid or electric vehicle recharging stations, hydrogen fuel stations, low-carbon power plants, fuel pipelines, etc.) • Government and corporate fleet usage of alternative fuels

VMT Moderation or Reduction	• Pricing • Carpool/vanpool incentives • Mode shift incentives – passenger • Mode shift incentives – freight • Telecommuting, tele-education, tele-medicine, and tele-shopping • SOV disincentives • Compact, mixed land use and transit-oriented development	• Intensified pricing policies • Intensified land use policies • Expanded infrastructure for HOV, transit, and bike/ped • Innovative and flexible forms of transit (e.g., jitneys) • Expanded freight rail and marine systems • Enhanced electronics/virtual reality to support telecommuting, tele-shopping, tele-education, tele-medicine, etc.	• Carbon taxes or cap- and-trade programs that raise fuel prices • Pay-as-you-drive insurance for LDVs • Congestion pricing for highways, aviation, and transit • Mileage-based highway user fees • LDV parking fees • Reduced LDV parking capacity • Dynamic carpool/vanpool programs • Telecommute programs • Car sharing programs • Zoning policies • Compact/mixed land use incentives • Transit-oriented development incentives • Constraints on low-density land use • Doublestack trains (including necessary infrastructure changes) • Improved freight logistics (e.g., intermodal transfers, maximizing loads, and reduced empty back hauls)
Operations of Vehicles and Systems	• Driver behavior changes (e.g., eco-driving for both LDV and HDV drivers) • Transportation systems management and operations (e.g., optimizing the performance of the existing highway system to reduce GHG through speed management, traffic smoothing, and congestion reduction) • More direct and efficient ATC routing and procedures	• Intensified driver behavior changes, aided by information technology and other technology as well as shifts in public outlook about lifestyle and environment • Intensified system management, aided by both technology and shifts in public opinion to support GHG-reduction strategies heretofore considered unacceptable • Speed control devices in vehicles, advisory or mandatory	• LDV and HDV driver education/"eco-driving" to reduce accel/decel, reduce high speeds, avoid congestion, reduce idling, optimally inflate tires, reduce extra weight, etc. • Real-time MPG readouts on dashboards • Electric plug-ins for truck auxiliary equipment at rest stops • Other programs to reduce HDV and LDV idling • ITS traffic management centers • ITS traveler information systems • Adaptive traffic signal control systems • Active traffic management • Traffic incident management

			and response to clear traffic incidents quickly • Emergency and special event traffic management to reduce congestion and idling • Managed lanes, such as HOV, HOT, and special use lanes • Lane and speed control • Elimination of highway bottlenecks • Highway roundabouts • Automated speed enforcement • Lowered speed limits • Design of highways to reduce high speeds and low speeds • Traffic management to suppress shock waves after traffic interruptions
Transportation Construction, Maintenance, Agency Operations, and Administration	• Energy efficient construction, maintenance, and operational practices • Low-GHG materials (cement, concrete, asphalt, etc.) • Alt fuels for vehicle fleets of transportation organizations • Energy efficient buildings for transportation agencies • Vegetation management in highway ROW or other land owned by transportation agencies	• Longer-life pavements • Carbon-negative cement which absorbs CO_2 as the cement hardens • Optimum asset management to reduce need for replacement/rehab • Alt fuels for transportation equipment • Significantly more energy-efficient transportation equipment • Incorporating renewable energy generation into transportation ROW (e.g., solar panels on ROW)	• R&D for construction practices and materials • Low-GHG pavements and paving practices, including smoother pavements, long-lasting pavements, in-place pavement recycling, and higher fly ash content in pavements • Carbon-negative pavements • LED traffic and street lighting • Reduced need for mowing highway ROW • Solar panel noise walls • Education/training of transportation employees • Construction traffic management • Incentives for employees to use carpools/vanpools and transit and to telecommute, where feasible • Guidelines and best practices for analyzing GHG in NEPA documents and incorporating GHG mitigation features in selected alternatives

NOTE: The above table expands on a table created by Dan Sperling and Nic Lutsey, in “Transportation and Greenhouse Gas Mitigation,” *Climate Action, United Nations Environmental Program*, 2007, pages 191-194.

Appendix B

Additional Detail on Selected Research Areas

FREIGHT TRANSPORTATION

Freight transportation accounts for 20-25% of transportation GHG (17% for highway HDVs, 2% for intercity freight rail, and the remainder for marine freight, pipelines, and air cargo). Reducing GHG in freight transportation may be more difficult than for passenger transportation, because (a) unlike passenger transportation, there is little or no discretionary freight movement; (b) impacts on freight transportation have substantial implications for the economy and global competitiveness; (c) vehicle turnover occurs more slowly for freight vehicles, slowing down the potential from new technology and new fuels; and (d) freight VMT is expected to grow faster than passenger VMT.

There is a wide array of potential strategies for reducing freight GHG, many of which have been described in "Best Practices Guidebook for Greenhouse Gas Reductions in Freight Transportation," by North Carolina State University's Center for Transportation and Environment. These strategies include: incremental as well as transformative changes in vehicle technology and fuels, anti-idling, longer-combination vehicles on highways, truck stop electrification, speed controls, logistics improvements, eco-driving training for vehicle operators, truck-only lanes, increased efficiency of auxiliary equipment, potential for reducing empty back-hauls or maximizing loads, and pricing strategies.

Below are some of the important questions that research could address:

- Within the context of global trade and economic trends, what are the most promising strategies to reduce GHG from freight transportation? In the near term? Mid-term? Long-term?
- How effective and cost effective are the different freight GHG strategies? In estimating cost-effectiveness consider the full range of costs and benefits of different strategies, including societal impacts as well as business costs and benefits.
- What is the potential for shifting freight movements to rail, barges, and pipelines, to reduce GHG – and at what cost?
- What are the potential GHG reduction and cost associated with maximizing use of double-stack trains?
- How would pricing and land use strategies to reduce transportation GHG affect freight transportation?
- What are the top 10-20 specific freight infrastructure projects with significant potential for reducing freight GHG? For these projects, estimate potential GHG reductions, project costs, cost-effectiveness, and other potential impacts on safety, congestion, other environmental impacts, impacts on freight transportation costs, etc.
- What strategies are the European Union, Japan, Australia, Canada, and other countries considering to reduce freight GHG? How applicable would these international strategies be in the United States?
- What are collateral benefits or dis-benefits for each strategy? Safety implications? Effects on global competitiveness? Freight labor force implications?
- What are the energy implications of each strategy?

- How could freight strategies be combined for maximum cost-effectiveness in reducing GHG?

RURAL TRANSPORTATION

Most discussions of reducing transportation GHG focuses on metropolitan areas. GHG reduction potential is likely to be smaller in rural areas, but (a) achieving 60-80% GHG reductions will require reductions to come from all geographic areas; (b) some rural strategies may be more effective than some urban strategies; and (c) rural areas may experience significant adverse effects from national GHG reduction policies (most notably, from the higher energy prices that are likely).

Some of the strategies that might be helpful in rural areas, for which research would be helpful, include: rural carpool/vanpool programs, rural eco-driving programs, rural ridesharing programs for non-work trips, vehicle technology and fuel incentives, speed management, telecommute programs, tele-medicine, highway construction and maintenance practices, expanded internet usage to replace rural travel, strategies aimed at rural tourism, potential for increased use of intercity bus, freight and passenger rail in rural areas, strategies to reduce GHG from rural transit, and rural land use strategies that could reduce VMT and GHG.

Key rural research questions include:

- What strategies are likely to be most effective and cost-effective in reducing rural transportation GHG?
- What state or federal policies relating to low-carbon vehicles and fuels could be most helpful to reduce rural transportation GHG? Vehicle feebates? Other incentives to purchase low-carbon vehicles and fuels? Adoption of California carbon standards for vehicles? Etc.
- What kinds of operational strategies could help reduce rural GHG – eco-driving programs, traveler information systems, roundabouts, speed management, etc.?
- How could travel substitution be maximized in rural areas – tele-shopping, tele-medicine, tele-learning, tele-working, etc? If these options are provided, how can rural communities be encouraged to make maximum use of them?
- What is the potential for improving short-line and other freight rail service in rural areas to reduce GHG and transportation costs? Are there rural areas where barge service or marine highways could be helpful in reducing GHG?
- What approaches and tools would be most useful to increase carpooling and vanpooling in rural areas in order to reduce GHG and transportation costs?
- How can use of existing transit, intercity bus service and intercity passenger rail service be maximized to help reduce GHG in rural areas? In what areas and under what circumstances would expansion of intercity bus, transit, or rail passenger service help reduce GHG?
- For rural tourism areas, what policies or services would help reduce GHG associated with rural tourism?
- What kinds of land use policies would achieve transportation GHG reductions in rural areas?
- What GHG reduction strategies are being implemented or considered for rural areas in the European Union, Australia, Canada, and other countries?

Research on rural strategies will be most useful if it is conducted with full-involvement of a range of rural transportation practitioners and stakeholders. Not only will their involvement inform the conduct of the research, but their involvement provides a jump start on the dissemination of information through early involvement of key members of the target audience.

NEAR-TERM GHG REDUCTIONS

Climate change scientists emphasize the importance of early actions to reduce GHG, in part because GHGs accumulate in the atmosphere and many persist for 100 years or more. Research is needed to identify and support implementation of near-term GHG reductions. Particularly valuable would be strategies that entail relatively little cost to implement, incur little or no public resistance, and have no or few drawbacks – i.e., "low-hanging fruit" and "no regrets" strategies. Examples of such strategies might include: eco-driving promotion and training for LDV drivers; eco-driving training for MDV and HDV truck drivers; LED traffic lights; carpool/vanpool programs; low-carbon pavements; reduced mowing of highway ROW; increased use of existing transit; telecommuting; trip-chaining; and idle-reduction programs.

Useful areas for research include:

- What GHG/energy reduction strategies should be implemented in the near term, based on evidence that they are likely to be cost-effective, generally acceptable to the public, quickly implementable, require minimal government investment, and do not require new legislation or regulations?
- What are some strategies that meet the above criteria for each mode – highway cars and light trucks, medium and heavy duty trucks, commercial aviation, general aviation, freight rail, intercity passenger rail, and transit?
- What kinds of strategies have other countries identified to achieve near-term GHG reductions?
- Consider strategies for all phases of transportation functions (maintenance, construction, operations, design, planning, etc.).
- What information and evidence can be assembled to equip transportation practitioners to implement promising near-term strategies? Case studies? References and practitioner contacts? Key tools?

TRANSPORTATION PRICING

Available research suggests that transportation pricing strategies can be an effective way to reduce GHG, through pricing that rewards the purchase and use of low-carbon vehicles and fuels, efficient driving habits (eco-driving, trip-chaining, carpooling, vanpooling, etc.), and lower VMT. Pricing strategies to reduce surface transportation GHG include a national carbon tax, vehicle feebates, pay-as-you-drive-insurance, carbon-based vehicle registration and usage fees, congestion pricing, cordon pricing, high-occupancy toll lanes, mileage-based fees, parking pricing, and increased fuel taxes. Fewer pricing strategies have been identified for aviation, but could include pricing relating to airport access for all types of vehicles (including rental cars), ground support equipment, terminal operations, general aviation operations, and commercial aviation.

Important research questions include:

- What pricing strategies have been adopted or are being considered in other countries? What can the United States learn from international pricing experience?
- What is the effectiveness and cost-effectiveness of each pricing strategy? In what situations are these strategies most promising, based on effectiveness, cost-effectiveness, and public acceptability?
- How will the pricing strategies affect VMT? For the VMT that is priced away, how much of it shows up on transit, carpooling/vanpooling, telecommuting, or simply eliminated trips?
- How are the VMT reductions distributed across different trip purposes – work trips, vs. recreational, vs. shopping, vs. vacation travel, etc.? (Some of the answers may be able to be generated or inferred from analysis of VMT reductions that occurred in 2007-2009.)
- How might adverse equity impacts be offset or minimized?
- What are the merits and public acceptability of a national carbon tax compared to the merits of transportation pricing strategies?
- How could a variety of pricing strategies be combined or phased so as to maximize GHG reductions, address equity concerns, lessen public resistance, and reduce congestion?
- What is the revenue potential of different pricing strategies, and how could the revenues from pricing strategies be used to (a) finance other GHG reduction strategies for transportation; (b) meet other transportation financing needs; and (c) address income equity issues associated with pricing?
- How could pilot programs be designed and funded to try out promising pricing strategies?