High Penetration of Renewable Energy in the Transportation Sector: Scenarios, Barriers, and Enablers

Preprint

L. Vimmerstedt, A. Brown, G. Heath, T. Mai, M. Ruth, M. Melaina, T. Simpkins, D. Steward, and E. Warner
National Renewable Energy Laboratory

K. Bertram, S. Plotkin, D. Patel, T. Stephens, and A. Vyas
Argonne National Laboratory

Presented at the 2012 World Renewable Energy Forum
Denver, Colorado
May 13-17, 2012

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Conference Paper
NREL/CP-6A20-54442
June 2012

Contract No. DE-AC36-08GO28308

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/help/ordermethods.aspx

Cover Photos: (left to right) PIX 16416, PIX 17423, PIX 16560, PIX 17613, PIX 17436, PIX 17721

Printed on paper containing at least 50% wastepaper, including 10% post consumer waste.

WREF 2012: HIGH PENETRATION OF RENEWABLE ENERGY IN THE TRANSPORTATION SECTOR: SCENARIOS, BARRIERS, AND ENABLERS

Laura Vimmerstedt, Austin Brown, Garvin Heath,
Trieu Mai, Mark Ruth, Marc Melaina,
Travis Simpkins, Darlene Steward, Ethan Warner
National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, CO 80401

Kenneth Bertram, Steven Plotkin, Deena Patel,
Thomas Stephens, Anant Vyas
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

ABSTRACT

Transportation accounts for 71% of U.S. petroleum use and 33% of its greenhouse gases emissions. Pathways toward reduced greenhouse gas emissions and petroleum dependence in the transportation sector have been analyzed in considerable detail, but with some limitations. To add to this knowledge, the U.S. Department of Energy has launched a study focused on underexplored greenhouse-gas-abatement and oil-savings opportunities related to transportation. This Transportation Energy Futures study analyzes specific issues and associated key questions to strengthen the existing knowledge base and help cultivate partnerships among federal agencies, state and local governments, and industry.

1. INTRODUCTION

The transportation sector is an engine of economic strength, contributing directly to gross domestic product and also supporting every sector of the economy indirectly.[1] Automakers, drivers, fleet operators, legislators, and regulators of the future will face challenges in enabling growth while reducing impacts on climate change and lowering dependence on petroleum. Transportation currently accounts for 71% of U.S. petroleum consumption and 33% of its greenhouse gas (GHG) emissions. If the nation seeks to address the associated economic, environmental, and security effects, transportation stakeholders will need to follow a pathway toward reduced GHG emissions and petroleum dependence. Current transportation energy use is shown in Fig. 1. Renewable energy accounts for only 4% of transportation energy use.

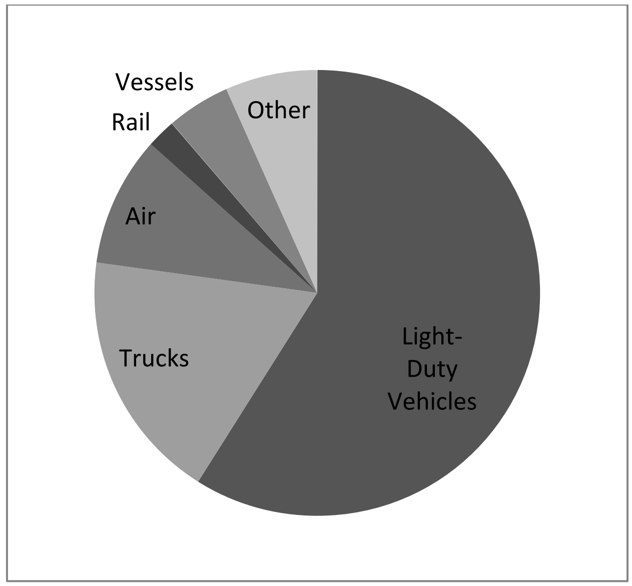

Fig. 1 Current transportation energy use by mode.[2] Total energy use is 27.5 quadrillion BTUs.

The latest reference case from the Energy Information Administration (EIA) Annual Energy Outlook 2012[3] does not forecast a significant change from this status quo. Overall transportation energy use and liquid fuel sources are projected to remain similar to current use over the next 25 years. Fig. 1 presents current energy use by mode; Fig. 2 presents energy use by energy source, over time. A modest increase in biofuel use and the efficiency improvements from the Corporate Average Fuel Economy standards (CAFE) are not projected to significantly change these markets (although the latest proposed standards, between 2017 and 2025, are not yet included in this baseline).

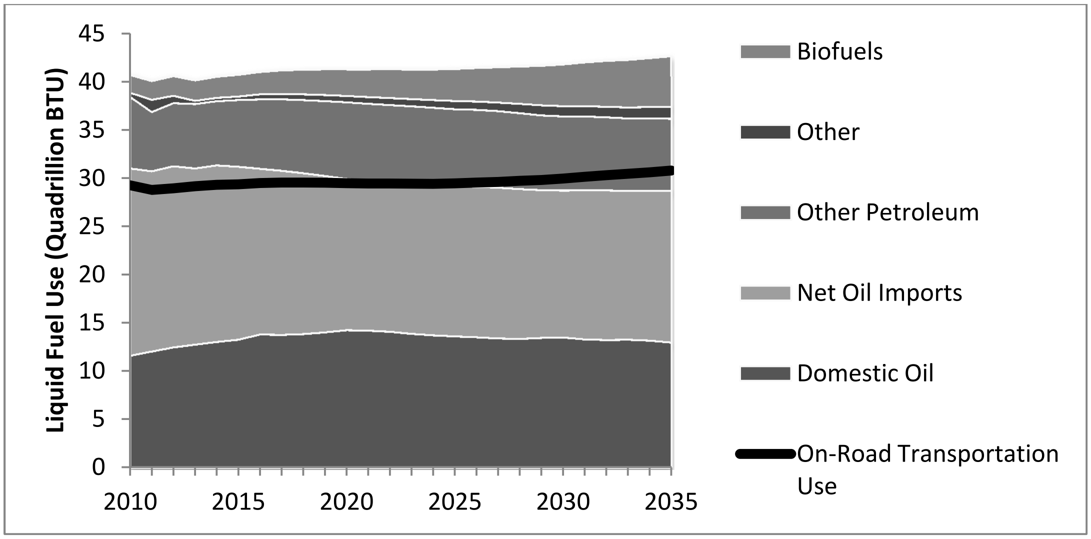

Fig. 2 AEO2012 (early release) forecast of liquid fuel use by fuel (colored area plot) and on-road transportation liquid fuel use (black line).

The U.S. Department of Energy (DOE) is exploring how energy sector petroleum use and GHG emissions might be reduced through application of technologies supported by the Office of Energy Efficiency and Renewable Energy (EERE). Scenarios that support these explorations, while not predictions or goals, are helpful in identifying possible gaps in the DOE's research and development (R&D) portfolio. They also highlight actions that might be necessary, in addition to R&D, to create the market and policy context receptive to the advanced technologies and systems that may be needed to meet national goals.

Although considerable analysis has been conducted on these issues in recent years,[4, 5, 6, 7, 8] significant gaps remain. To help understand these gaps, DOE has launched the Transportation Energy Futures (TEF) study to identify underexplored GHG-abatement and oil-savings opportunities related to the role of advanced transportation energy technologies and systems in the development of possible new technological, strategic, and policy pathways. The intent of the TEF study is to consolidate current transportation energy knowledge, advance analytic capacity-building, and explore additional opportunities for sound strategic action. Analyzing these specific issues and associated key questions can strengthen the existing knowledge base and help cultivate partnerships among federal agencies, state and local governments, and industry.

The study's primary goal is to help address high-priority questions and inform domestic decisions about transportation energy strategies, priorities, and investments, including investments in energy research. Results are being documented in written reports, analytic tools, and data sets, which will be disseminated and discussed with stakeholders. The study involves gathering a compendium of existing analyses and findings, and conducting original research and analysis in previously-less-examined areas identified as having the greatest potential impact on GHG emissions and oil use.

Research and analysis are being conducted with an eye toward identifying short-term actions that support long-term solutions. TEF encompasses more than technology and examines each key question in the context of the marketplace, consumer behavior, industry capabilities, and the energy and transportation infrastructure.

Across the study's analytic topics, team members are:

- Reviewing the state of knowledge and available tools
- Generating new tools for novel transportation analysis
- Analyzing the cost of possible low-carbon scenarios
- Analyzing potential actions by DOE and other federal agencies
- Pairing analytic outputs with research, deployment, and policy recommendations
- Summarizing findings in issue papers

TEF's suite of technical reports is slated for release later this year. Individual results within each topic could contribute to strategy formulation. In addition, impacts in all study areas will be applied to refine the overall transportation-sector petroleum use or GHG reduction opportunity assessment. A format for a summary of reduction opportunities is shown in Fig. 3.

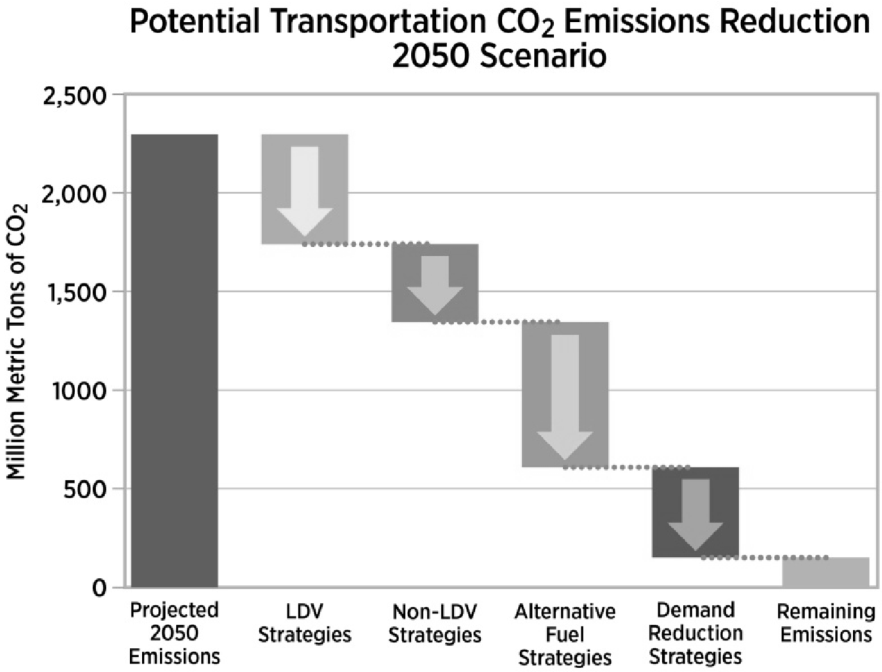

Fig. 3 Bars represent possible carbon dioxide (CO_2) reduction from each type of strategy. This is for illustration only, and quantities from this chart should not be used.

The approach to the TEF study is collaborative and intended to foster partnerships among a broad constituency of organizations in the transportation energy sector. The DOE is the primary project sponsor. The project team responsible for TEF implementation includes representatives from the National Renewable Energy Laboratory and Argonne National Laboratory. The TEF steering committee consists of some of the nation's foremost experts on transportation energy from the DOE, the Environmental Protection Agency, the Department of Transportation, academic researchers, and industry associations.

The four primary areas under exploration are light-duty vehicles (LDVs), non-light-duty vehicles (NLDVs), fuels, and transportation demand. The remaining sections of this paper discuss the TEF papers and tools being developed in each of these areas. The results from the individual topic areas will be combined to estimate total technical potential for impact, to be presented in a format similar to Fig. 3.

2. TOPICS AND TOOLS

2.1 Light-Duty Vehicles

In aggregate, light-duty vehicles (LDVs) use the most energy of any mode in the transportation sector today. While LDV energy-savings opportunities have been scrutinized, two gaps in knowledge were identified for examination in TEF:

- Timing and investment along the deployment pathway of advanced vehicles
- Non-cost barriers to consumer adoption of advanced vehicle technologies.

2.1.1 Deployment Pathways

Analysts may develop scenarios for the deployment of new vehicle technologies for a variety of reasons, including examination of the feasibility of goals, such as GHG and/or oil use reduction goals. EERE uses scenario analysis to estimate the possible impacts of LDV technologies developed through supported R&D. A "reality check" can add robustness to these scenarios' representation of technology development and deployment in the marketplace.

The TEF study's deployment pathway analysis is examining two aspects of "reality checking" – whether the timing of the vehicle deployment envisioned by the scenarios corresponds to recognized technology development and deployment limits, and whether the investments that must be made for the scenario to unfold seem likely to meet criteria that the investment community applies.

2.1.2 Non-Cost Barriers

The rate of new vehicle technology adoption and the associated rate of petroleum-use and GHG reductions depends on how rapidly vehicles with these technologies enter the fleet through new vehicle purchases. How quickly this happens depends on consumer preferences. New technologies often increase the prices of vehicles. In addition, there are barriers to adoption that are not related to increased purchase prices.

TEF is examining and classifying findings from the literature on non-cost factors that influence consumer decisions, including range anxiety, refueling availability, technology reliability, and lack of consumer familiarity. Non-cost barriers are ranked according to the assessed magnitude of severity and potential effectiveness of available policies. This ranking could help assess the potential to diminish barriers through DOE programs or actions. TEF quantifies the severity of non-cost barriers by assigning an "effective cost" to each one.

2.2 Non-Light-Duty Vehicles

In 2009, 45% of U.S. transportation energy use consisted of transportation of freight and passengers by medium and heavy trucks (over 10,000 lbs. gross vehicle weight), aircrafts, ships, trains, pipelines, and off-road equipment—the non-light-duty vehicle NLDV transportation modes. Previously, these NLDV modes had not been studied as extensively as the LDV sector for opportunities to reduce energy consumption and GHG emissions.

2.2.1 Non-Light Duty Efficiency

TEF is examining and summarizing opportunities to improve the efficiency of all NLDV transportation modes. This covers heavy highway vehicles (medium and heavy trucks), and off-road and non-road vehicles (aircraft, vessels, railroads, mobile equipment, and pipelines). The study quantifies the energy efficiency improvement possible based on review of the available literature on each NLDV mode of transportation. TEF emphasizes technological improvements, but also considers operational improvements. Cost information (when available), anticipated demand growth, and historical changes in energy efficiency are all considered.

2.2.2 Freight Mode Switching

Mode-switching opportunities, such as moving freight from trucks to rail and ships, or passengers from air to rail travel, are being evaluated. TEF is developing and reviewing underlying quantitative estimation methods that can assess mode-switching opportunities.

The primary objective in this activity is to gain a better understanding of the role that mode-shifting can play in achieving future reductions in freight transportation energy demand and GHG emissions. As trucking is responsible for the largest share of freight transportation energy consumption, and rail and water modes are more energy efficient on a per-ton-mile basis, the primary focus of this analysis is to identify approaches that can foster more energy efficient freight mode shifts, such as changes in infrastructure (e.g., Panama Canal deepening, upgraded intermodal facilities), regulation and policy mechanisms.

Freight transportation modes in the United States have evolved to take advantage of their unique market characteristics. Certain modes tend to dominate particular markets. These modes often complement each other because each mode captures transport of goods that best matches its relative strengths. The key to identifying strategies that can affect mode shifts is defining those places where there is potential for competition.

A freight transportation analysis tool is being used to assess mode-switching opportunities (see 2.4).

2.3 Fuels

2.3.1 Fuels Infrastructure Expansion

Infrastructure expansion requirements for deployment of non-petroleum, low-GHG-intensity fuels (especially electricity, biofuels, and hydrogen) are being compared through a consistent framework.

Many different fuel and vehicle technologies have been proposed and assessed as options for sustainable, low-carbon mobility. Past studies have focused on topics including vehicle design, fuel production and delivery processes, techno-economic policy modeling, and characterization of present and future consumer behavior patterns. Several studies have focused on one or more alternative fuels, as well as on the potential for deep GHG reductions by using a combination of low-carbon fuels and advanced or improved end-use. Other studies have examined low-carbon fuel scenarios for the entire transportation sector, but most have focused on the LDV market segment. Some studies have recommended a portfolio policy incorporating multiple low-carbon fuel and vehicle options, and other studies have concluded that the differences in costs and benefits associated with these options are too small.

Our literature survey suggests a need to explore other scenario attributes beyond cost comparisons of different advanced long-term transportation technology options, especially in scenarios that reach deep reductions in petroleum use and GHG emissions over the long term. The TEF analysis responds to this need by focusing on infrastructure expansion trends required for such scenarios, using tools being developed for the study (see 2.3.2).

Today's transportation sector is served by a very large, efficient and reliable petroleum liquid fuel infrastructure. If alternative low-carbon fuels are to displace petroleum fuels, they must provide similar levels of cost, convenience, and reliability. To reach significant GHG reductions across the entire transportation sector, the infrastructures delivering these fuels must expand to provide large volumes of fuel to a diverse set of end users who are dispersed across large geographic regions. Moreover, this expansion must occur quickly to meet GHG reduction goals by 2050. In some cases, such as compressed natural gas (CNG), electricity, and hydrogen, this infrastructure expansion must proceed in step with the introduction and widespread adoption of alternative fuel vehicles.

The TEF study is developing low-carbon scenarios to explore distinct means of achieving an aggregate 80% reduction in GHG emissions and similarly low petroleum use by 2050 across seven U.S. transportation modes and market segments: 1) Light duty, 2) medium- and heavy-duty, 3) air, 4) marine, 5) rail, 6) bus, and 7) military.

Low-carbon transportation fuels are critical components of any strategy to reach this level of reduction. TEF examines requirements for expanding low-carbon fuel infrastructure across the U.S. transportation sector, with an emphasis on fuel production facilities and retail components that interface with LDVs. We begin with estimates for aggressive demand reductions and highly efficient end-use technologies, such as on-road vehicles, vessels, locomotives, and aircraft. We then explore distinct fuel supply scenarios, involving possibilities such as successful deployment of a range of advanced vehicle and fuel technologies; market dominance by hybridized internal combustion engine vehicles fueled by advanced biofuels and natural gas; and market dominance by electric drive vehicles in the LDV sector (including battery electric, plug-in hybrid, and fuel cell vehicles, which are fueled by low-carbon electricity and hydrogen).

These scenarios represent a range of possible low-carbon fuel demand outcomes that are explored in terms of the scale and scope of fuel infrastructure expansion requirements. The scenarios are being evaluated on the basis of fuel costs, energy resource utilization, expansion of fuel production infrastructure, and expansion of retail infrastructure for LDVs.

2.3.2 Tool Development: Fuel Infrastructure

The TEF study is developing a fuel delivery infrastructure and cost tool to support consistent assessment of fuel infrastructure expansion pathways. This spreadsheet-based calculator accounts for most fuel delivery infrastructure needs associated with a given fuel supply scenario. The tool covers distributed residentially- and commercially-located vehicle chargers, retail fueling station charging equipment, natural gas fueling equipment, and hydrogen fueling equipment, and replacement costs for all infrastructure at the end of its useful life.

2.3.3 Biomass Utilization

Biomass resource supply and demand are being analyzed to explore the quantities that might be used in each sector (primarily transportation or electricity generation), and how biomass might be allocated among several different transportation sector fuel markets. Because biomass is a limited resource with many competing uses, its allocation for transportation fuel, electricity generation, or products depends upon the characteristics of each of these markets and the interactions and policies affecting each market. The TEF study analyzes competition for biomass among the electricity generation market, the gasoline market, and the diesel market, the jet fuel market, and the bunker fuel market.

Biomass can be used in diverse ways, each having pros and cons. In the transportation sector, biomass is the primary renewable resource that can be used to generate liquid fuels for today's vehicles and infrastructure. In the electricity sector, biomass can be co-fired with coal, possibly reducing the carbon intensity of coal-fired power plants with relatively little additional capital cost, and the hour-by-hour timing of electricity generation from biomass can be controlled. Biomass can also be an input for higher-value industrial products.

Exploration of biomass resource allocation between biopower and biofuels, as well as across different fuel markets, can improve the understanding how this energy resource might contribute to the national goals of reduced petroleum use and GHG emissions. While some existing literature explores this topic, and a few modeling tools have been developed to analyze it, a detailed economic analysis for the U.S. based on market equilibrium assumptions had yet to be performed.

2.3.4 Tool Development: Biomass Allocation

The research team is developing a simple market equilibrium modeling tool specifically for the TEF study. The Biomass Allocation and Supply Equilibrium (BASE) model includes supply curves for the following four categories of lignocellullosic biomass: forest residues, short-rotation woody crops (SRWC), agricultural residues, and switchgrass (the general name referring to all grassy energy crops). The model also includes corn for ethanol and butanol production, soybeans for biodiesel, and algae for diesel.

In addition, the model includes the five markets for biomass-based energy: electricity, gasoline, diesel, jet fuel, and bunker fuel. Multiple fuel and feedstock options are supplied for each fuel market. Well-to-wheel GHG emissions and petroleum use are calculated to determine carbon costs and report the effects of petroleum use.

2.4 Transportation Demand

TEF is assessing changes in transportation demand to understand underlying transportation service needs, their relationships to transportation technologies and systems, and the methods for quantifying these needs. These transportation demand options include the built environment, trip reduction and efficient driving, and freight demand scenarios.

2.4.1 Built Environment

The TEF study is summarizing and reviewing the relationships between the built environment and travel, energy, GHG emissions, and other factors. It addresses the following topics:

- A review of the literature, focusing on key sources that summarize research findings
- An introduction to how the built environment and urban form has been characterized in travel behavior research
- A summary of how the built environment affects travel, energy, and GHG emissions, as well as other factors, including economic growth, infrastructure and housing costs, the environment, social welfare, and equity
- An overview of tools and methods for analyzing the impacts of changes in the built environment on travel, energy, and GHG emissions
- A discussion of factors that influence urban form, including demographic, social, economic, technological, and policy drivers; decision-making processes; and historical examples of policy initiatives related to urban form
- A review of existing and potential future federal actions that might influence urban form
- Additional analysis needed for understanding the effects of changes in urban form on travel and energy, as well as the effects of federal actions
- A new tool (see 2.4.2) to develop national estimates of the impacts of urban development scenarios on transportation energy and GHG emissions

2.4.2 Tool Development: Built Environment

TEF is developing a built environment strategies national impact tool to make simplified estimates of possible levels of national transportation demand under different built environment strategies and conditions. The tool offers rough estimates of effects of variables identified in the literature and data review as being influential. The tool development process considers input data on built environment characteristics, including trips by mode, geographic characteristics, workplace location, density, diversity, design, destination accessibility, and distance to transit. Urban areas are grouped according to key characteristics that most closely relate to travel activity and expected future growth patterns. Within each group of urban areas, different scenarios are developed for change in urban form and associated growth in transportation energy use and GHG emissions between 2010 and 2050. This tool will be used to evaluate relationships between the dependent and independent variables to support the analysis of built environment impacts.

2.4.3 Trip Reduction and Efficient Driving

TEF researchers are reviewing strategies to reduce personal vehicle travel (through options, such as teleworking, teleshopping, and carpooling), and to encourage more efficient driving (by changing driver behavior and providing driver feedback)—all with the objectives of reducing energy use and GHG emissions. The work includes a review of the literature, an introduction to factors affecting travel behavior and how they are modeled, and an overview of the methods and tools for assessing the impacts of strategies on travel behavior, energy, and GHG emissions. For each strategy, energy and GHG benefits, costs, and other impacts are estimated, and key uncertainties, interactions, and barriers to implementation are identified. This effort addresses federal actions that could influence travel reduction and efficient driving.

2.4.4 Freight Demand

Proposals under discussion to abate U.S. GHG emissions would significantly change the demand for energy goods and other commodities. TEF is examining several potential low-carbon scenarios and estimates the implications for freight demand, including reduced coal transportation; increased transportation of biomass, biofuel intermediates, and finished biofuels; and reduced oil transportation.

2.4.5 Tool Development: Freight Transportation Analysis

This tool supports the mode-switching (see 2.2.2) and freight demand (see 2.4.4) efforts.

In order to estimate impacts of changes in the freight system, an accurate and credible representation of freight demand is needed. A tool is being developed to analyze data that includes the volume of freight movement by commodity and geographic markets served. By using such a tool to analyze a multimodal database, the TEF study is estimating the energy requirements and environmental impacts associated with the base case and alternative future transportation scenarios, which may involve changes in the commodities being transported among markets (including changes in energy commodities), the economic geography of the United States, the modes and routes used to transport freight, and the energy use and efficiency of those modes.

3. SUMMARY

The TEF study explores gaps in current knowledge about potential pathways to deep reductions in GHG emissions and petroleum use with a focus on four areas: LDVs, NLDVs, fuels, and transportation demand. The study highlights analysis, research, and other actions that would create market and policy context receptive to advanced technologies and the systems needed to meet national goals. Project results will inform decisions about transportation energy research investments, and will illuminate the role of advanced transportation energy technologies and systems in the development of possible new physical, strategic, and policy pathways.

4. REFERENCES

(1) The Transportation Challenge: Moving the U.S. Economy. Prepared for the National Chamber of Commerce by Cambridge Systematics, Inc. and Boston Logistics Group, Inc., 2008. Available: http://www.nssga.org/government/Reauthorization/12_Section_A.pdf, accessed March 16, 2012.

(2) Energy Information Administration, Annual Energy Review 2011. Available: http://www.eia.gov/totalenergy/data/annual/, accessed March 16, 2012.

(3) Energy Information Administration, Annual Energy Outlook 2012 (Early Release). Available: http://www.eia.gov/forecasts/aeo/er/, accessed March 16, 2012.

(4) Greene, D.L., Plotkin, S.E., Reducing Greenhouse Gas Emissions from U.S. Transportation. Prepared for the Pew Center on Global Climate Change, 2011. Available: http://www.c2es.org/docUploads/Reducing_GHG_from_transportation.pdf, accessed March 16, 2012.

(5) McCollum, D., Yang, C., Achieving Deep Reductions in U.S. Transport Greenhouse Gas Emissions: Scenario Analysis and Policy Implications. Energy Policy; Vol. 37, 2009.

(6) U.S. Department of Transportation, Transportation's Role in Reducing U.S. Greenhouse Gas Emissions, 2010. Available: http://ntl.bts.gov/lib/32000/32700/32779/DOT_Climate_Change_Report_-_April_2010_-_Volume_1_and_2.pdf, accessed March 16, 2012.

(7) National Academy of Sciences, Liquid Transportation Fuels from Coal and Biomass: Technological Status, Costs, and Environmental Impacts, 2009. Available: http://www.nap.edu/catalog.php?record_id=12620#toc, accessed March 16, 2012.

(8) National Academy of Sciences, Assessment of Fuel Economy Technologies for Light-Duty Vehicles, 2011. Available, http://www.nap.edu/catalog.php?record_id=12924, accessed March 16, 2012.

ACKNOWLEDGEMENTS

This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08-GO28308 with the National Renewable Energy Laboratory and under Contract No. DE-AC02-06CH11357 with Argonne National Laboratory.