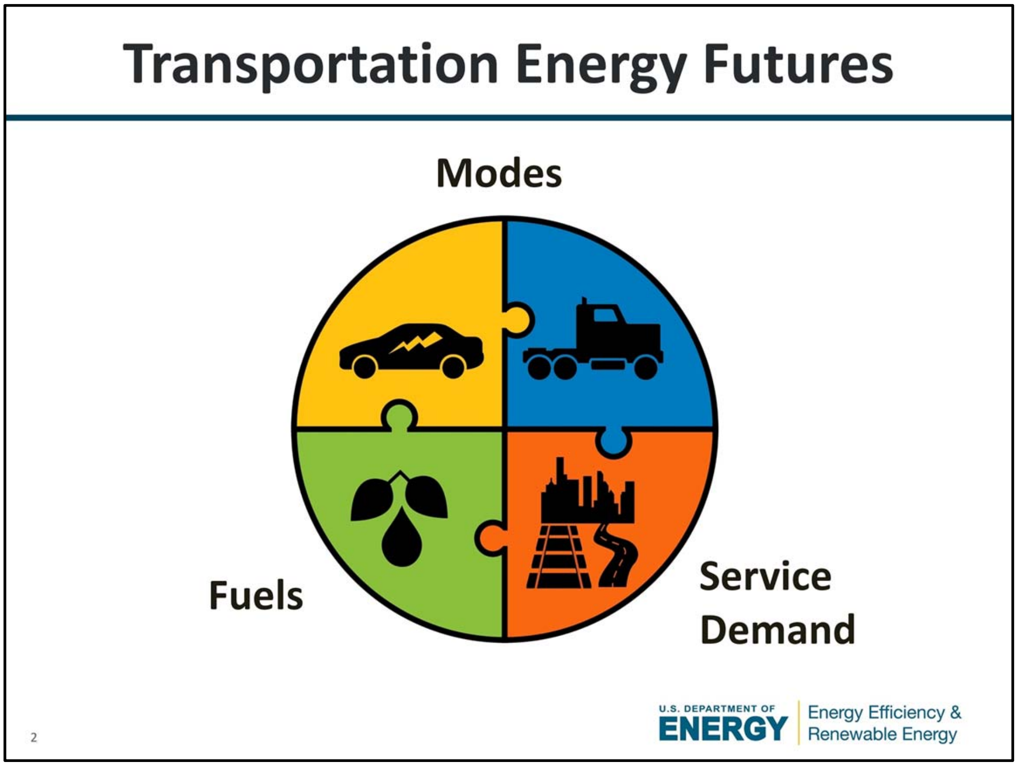
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Transportation Energy Futures

Project Overview and Findings

NREL/PR-6A20-56270



Transportation currently accounts for 71% of total U.S. petroleum use and 33% of the nation's total carbon emissions. Energy-efficient transportation strategies and renewable fuels have the potential to simultaneously reduce petroleum consumption and greenhouse gas (GHG) emissions. The U.S. Department of Energy's (DOE) Transportation Energy Futures (TEF) project examines how a combination of multiple strategies could achieve deep reductions in petroleum use and GHG emissions. The project's primary objective is to help inform domestic decisions about transportation energy strategies, priorities, and investments, with an emphasis on underexplored opportunities related to energy efficiency and renewable energy. The central finding of TEF is that combinations of strategies exist that can produce reductions in petroleum use and GHG emissions of 80% or more, but they would require concerted and successful action across a wide variety of topics and organizations.

Outline

- Approach and motivation for the study
- Key findings from primary topic areas
- Study conclusions regarding transportation energy consumption and emissions reduction potential.

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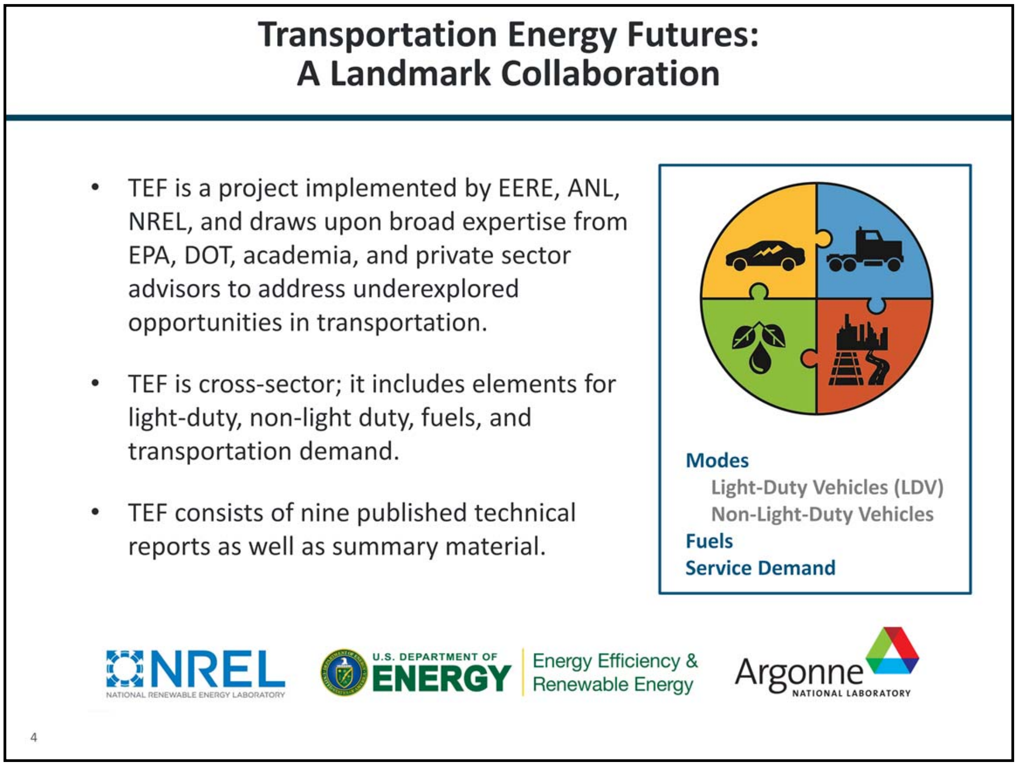

This work was conducted as part of the Transportation Energy Futures (TEF) project sponsored by DOE. In addition to the DOE and its Office of Energy Efficiency and Renewable Energy, TEF benefitted from the collaboration of experts from the National Renewable Energy Laboratory and Argonne National Laboratory, along with steering committee members from the Environmental Protection Agency (EPA), the Department of Transportation (DOT), academic institutions, and industry associations.

The project addresses underexplored opportunities in understanding of pathways to deep reductions in petroleum use and GHG emissions. Transportation energy use and emissions are dependent on a combination of three factors: vehicle efficiency (modes), fuel carbon intensity (fuel), and vehicle use (service demand). Due to the multiplicative relationship between these three factors, it is necessary to reduce all three to decrease total transportation energy use and emissions. The Transportation Energy Futures study (TEF) divided the areas of inquiry among these three key aspects of transportation energy use: Light-duty vehicle (LDV) and Non-light-duty vehicle (NLDV) Modes, Fuels, and Demand. Considering the interaction of all of these pieces, provides a more complete picture of energy use and potential savings for the transportation sector as a whole.

Fundamental motivations for the study include: (1) Examine of the entire transportation sector; (2) Focus on areas and aspects not currently addressed in detail by EERE or the available literature; (3) Investigate the technical potential for deep reductions (>80%) in petroleum and energy use and GHG emissions; and (4) Help inform the DOE transportation portfolio, including R&D priorities and potential partnerships.

Scoping and Review

- Built on a foundation of previous and ongoing DOE, DOT, and EPA analysis
- Selected a 19-member steering committee of experts from industry, academia, government, and non-profits
- Refined the topic list into a set of highest-priority issues to cover in partnership between the steering committee and project team
- Engaged experts for extensive peer review throughout the project.

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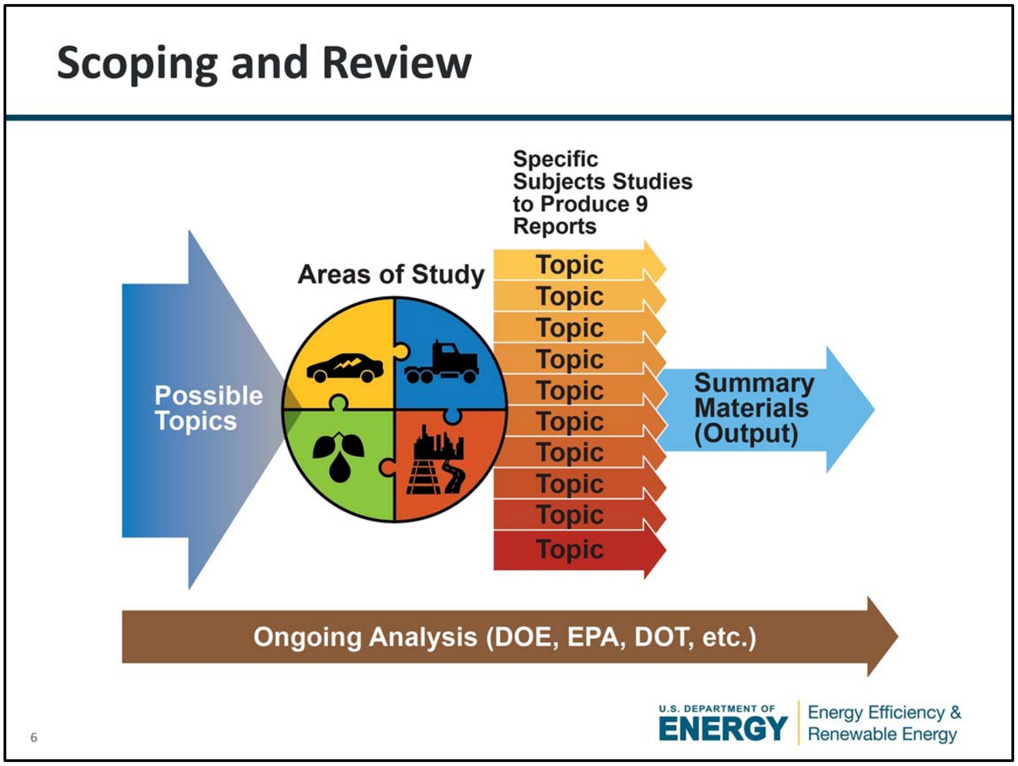
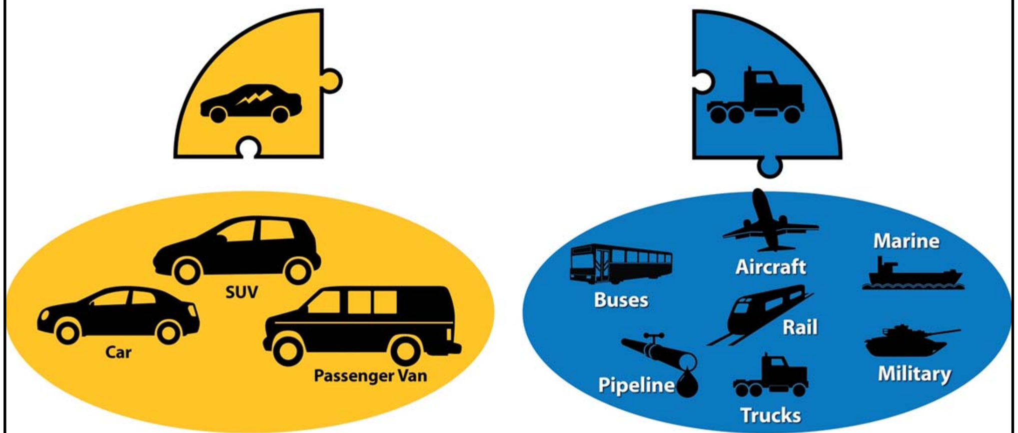
The steering committee included individuals from the following organizations: DOE, EPA, DOT, UC Berkeley, California Energy Commission, University of Utah, United States Council for Automotive Research, University of Michigan, International Council on Clean Transportation, Institute for the Future, Alliance of Automobile Manufacturers, Organisation for Economic Co-operation and Development, UC Davis, Center for Strategic and International Studies, Lawrence Berkeley National Laboratory, Rochester Institute of Technology, and UC Riverside. While steering committee members provided valuable input in scoping and throughout the study, their mention here does not constitute approval of the findings of the study.



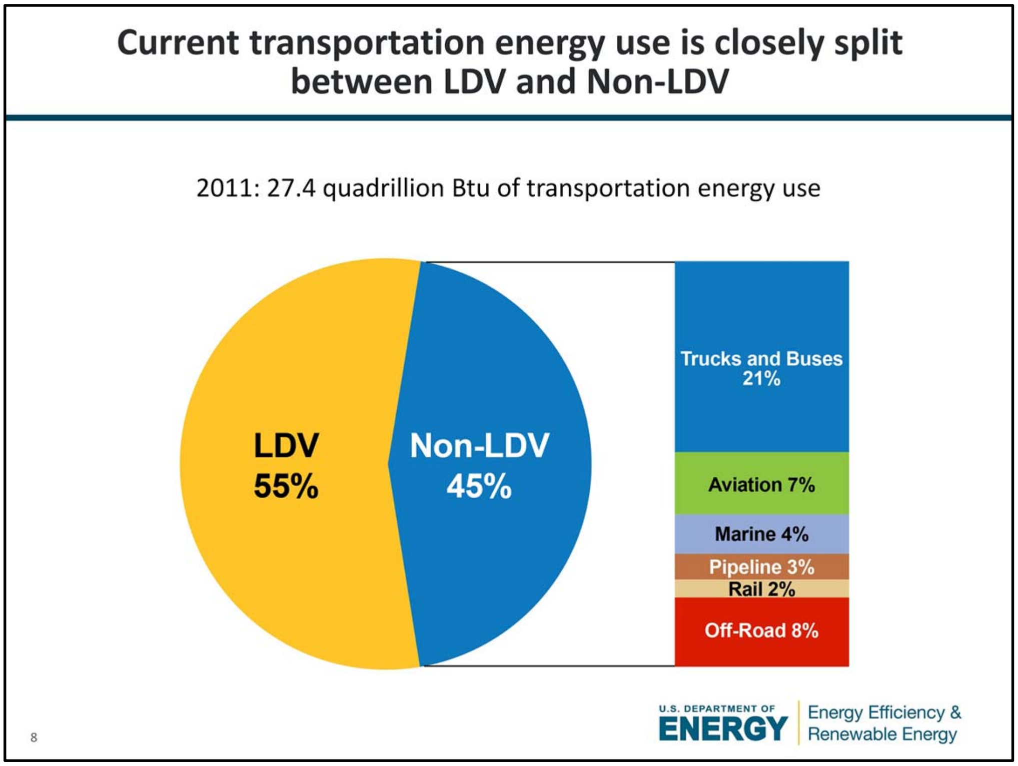
This graphic illustrates the topic selection and research process. The steering committee provided input for down-selecting the list of study topics to focus on the highest-priority issues. Individual teams conducted research on these nine topics, tapping experts for review throughout the project.

Key Findings/Modes



LDVs

Non-LDVs



Light-duty vehicles such as cars and SUVs currently account for 55% of U.S. transportation delivered energy consumption (EIA, 2011). Their miles of travel are expected to increase by up to 75% by 2050. However, during the same time, LDV efficiency has the potential to decrease per-mile energy use by 61%, enough to completely offset the growth in service demand and even decrease net energy use compared to a 2005 baseline. These reductions would require significant, rapid advances in both vehicle and fuel technology that, while ambitious, are technically feasible.

The remaining 45% of U.S. transportation delivered energy consumption is from trucks and busses 21%); aviation (7%); marine (4%); pipeline (3%); rail (2%); off-road (8%) (EIA, 2011), which are often less studied. However, their service demand is expected to increase by up to 217% (aviation) by 2050 to satisfy 27.5 billion tons of freight demand in 2040 and 30.2 billion tons in 2050. Trucking's share—when measured in tons and ton-miles—is projected to continue to grow at the expense of rail and waterborne freight. Again, increasing vehicle efficiency is essential to simply keep NLDV energy consumption level through 2050.

Vehicle efficiency improvements are essential to balance increases in travel and freight demand

Effects of vehicle efficiency improvements and use increases on net energy consumption by 2050

	LDVs	Trucks	Aviation	Inland Marine	Ocean Marine	Rail	Pipeline	Off-road
Vehicle energy efficiency improvements	61%	50%	65%	30%	75%	35%	20%	18%
Vehicle use increases	75%[a]	87%[a]	217%[b]	32%[a]	450%[c]	47%[a]	16%[a]	20%[d]
Net changes in total energy consumption	-32%	-17%	+11%	-8%	+38%	-4%	+1%	-6%

[a] EIA projections extrapolated.
[b] FAA projections extrapolated.
[c] Growth in dollar value of trade (EIA).
[d] Projected at half the population growth.

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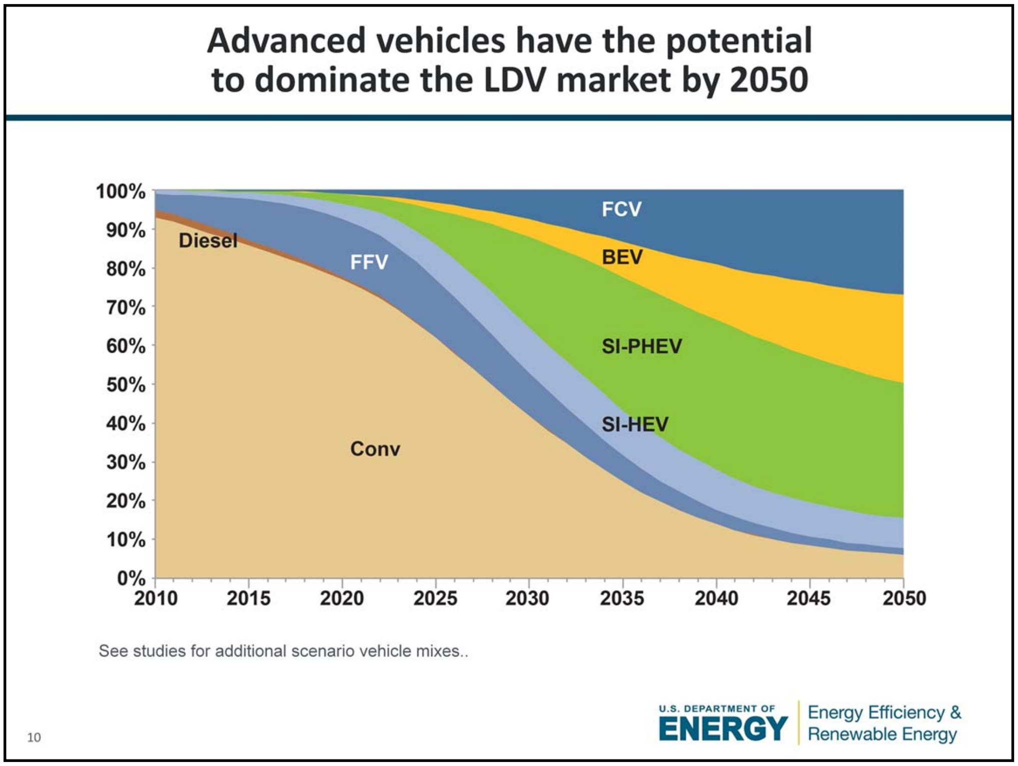
This table illustrates that with highly feasible energy intensity (efficiency) improvements, NLDV net energy consumption can stay approximately level and LDV consumption can fall significantly. Conversely, however, without energy efficiency measures energy consumption may increase by 50% or more by 2050. These estimates do not include potential impact from demand-side measures such as VMT reduction and mode shifting. These opportunities are discussed in the 'demand' section of this presentation and the related TEF reports.

TEF does not focus on LDV efficiency technologies, which have been analyzed in great detail, but does discuss specific NLDV efficiency opportunities. Given the current state of technology and projected growth, the greatest efficiency potential lies with trucks and aviation. TEF also identified efficiency opportunities in less-studied modes such as marine, pipeline, and off-road vehicle energy use. Although these modes are relatively minor users of energy, TEF explored known opportunities for efficiency since these modes provide critical transportation services, and deep cuts in petroleum use and GHG emissions may require a comprehensive approach.



Conv: conventional internal-combustion engine vehicles; Diesel: diesel internal combustion engine vehicles; FFV: flex fuel (gas or biofuel) internal combustion engine vehicles; SI-HEV: hybrid gasoline-electric vehicles; SI-PHEV: plug-in hybrid gasoline-electric vehicles; BEV: battery electric vehicles; FCV: fuel cell vehicles

For the LDV fleet mix, Oak Ridge National Laboratory's MA^{3}T model and Argonne National Laboratory's VISION tool were used to generate two LDV scenarios, one reference and one with advanced technology assumptions based on achieving optimistic technology goals and widespread availability of hydrogen for fueling fuel-cell vehicles and electricity for charging plug-in vehicles. The resulting potential advanced technology fleet mix in 2050 includes the following stock shares of vehicle by power train: conventional gasoline and diesel internal combustion engine (8%), hybrid electric vehicles (8%), gasoline spark ignition plug-in hybrid electric vehicles (35%), battery electric vehicles (22%), and fuel cell vehicles and hydrogen internal combustion engine vehicles (27%). The carbon intensity of hydrogen and electricity is assumed to be reduced by 80% to 90% relative to today, reflecting a national shift to cleaner production sources under this scenario.

Non-cost barriers to adoption of advanced vehicles must be overcome to reach such scenarios

Non-Cost Barrier	Relevant Factors	Possible Policy Responses
• Limited driving range and fueling/charging stations	• Vehicle range • Driver mobility needs • Local conditions • Driver's value of time	• Subsidization of charging/fueling stations • Information
• Unfamiliarity • Lack of awareness	• Prevalence of new technology • Preferences of early adopters	• Labeling • Information • Outreach programs
• Bias or perceived negative differences • Uncertainty of benefits	• Social and behavioral factors	• Information • Outreach programs
• Lack of adequate standards	• Maturity of new technologies • Potential for incompatibilities or safety issues	• Testing and standards development
• Limited availability in models/makes	• Consumer preferences • Modularization of design and manufacturing	• R&D on modularization

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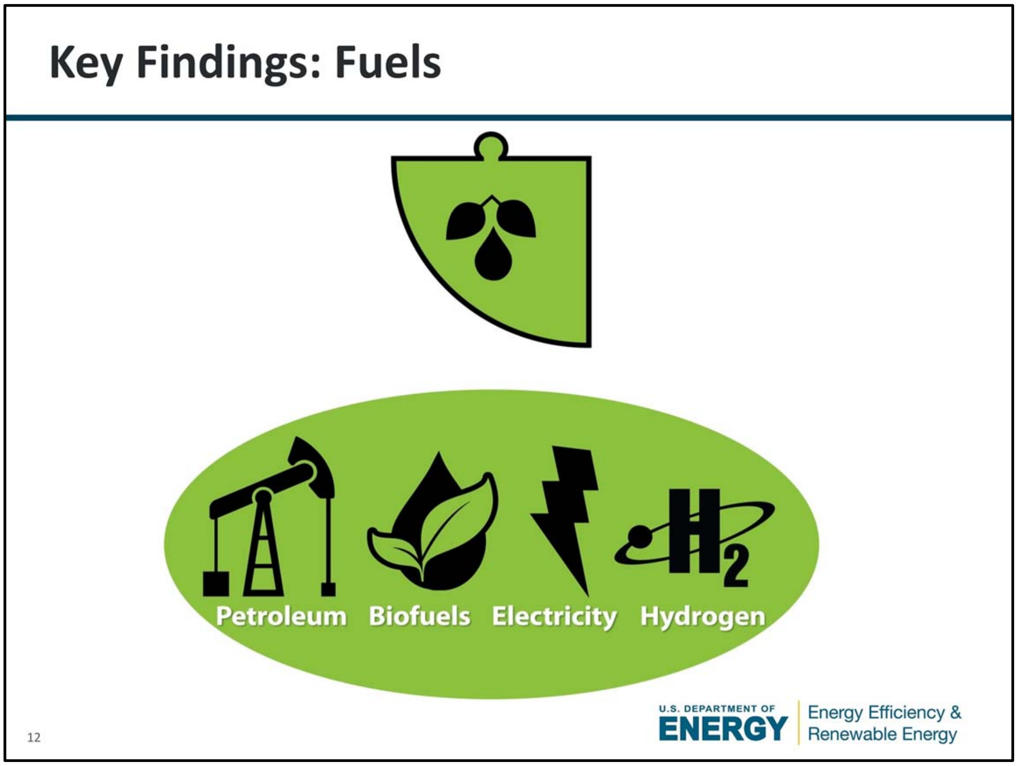
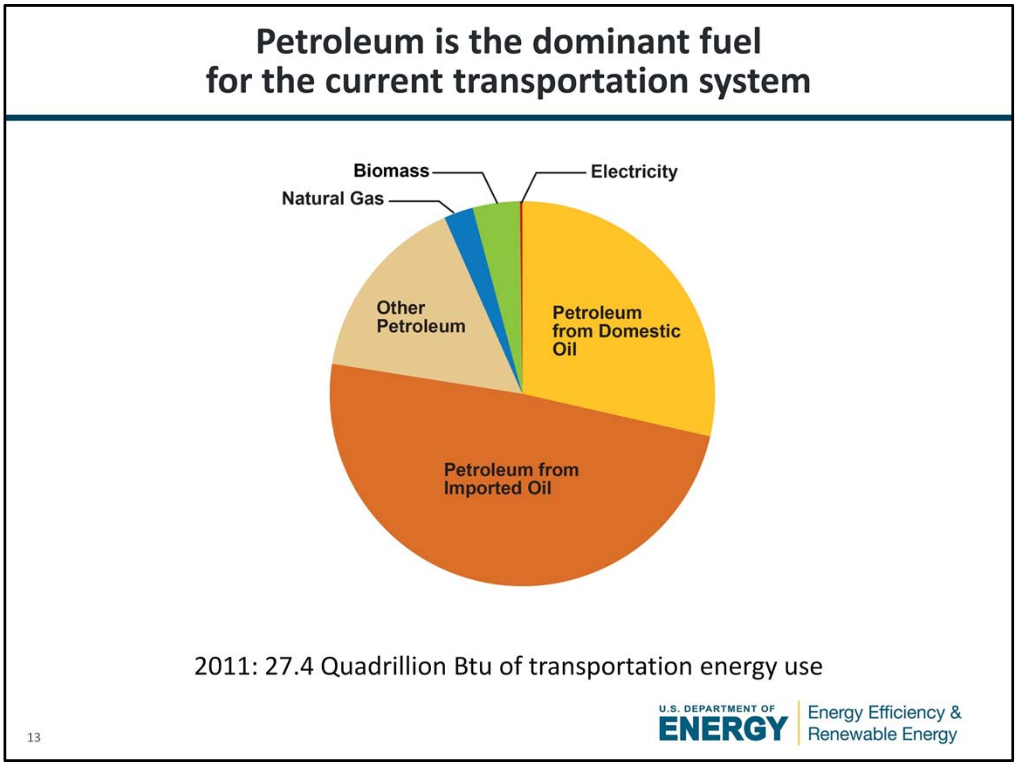
Because the costs and characteristics of advanced LDVs are very well studied by DOE and others, TEF focused on non-cost barriers for consumers' and investors' decisions and timing, which is also essential to such rapid technology deployment. This table lists potential non-cost barriers, along with possible policy responses, in order of decreasing severity from top to bottom (according to report conclusions). Some non-cost barriers are significant enough to deter consumers from considering certain types of advanced vehicles.

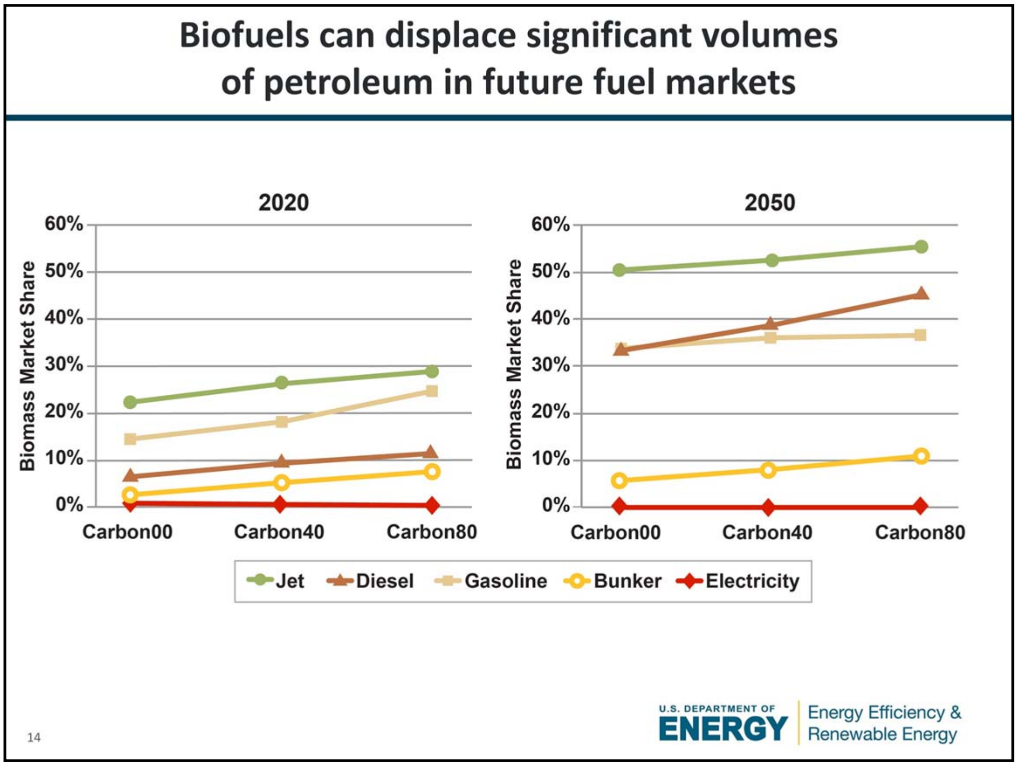
Even if sufficient consumer demand exists for advanced light-duty vehicles, it is uncertain how long it will take for new technologies to proliferate in the market and whether manufacturers will choose to invest in such technologies. Based on the deployment timelines of previous vehicle technologies, it could take from 16 to more than 22 years for market introduction to full saturation of the fleet by new vehicle technologies. Cash flow analysis and decision tree analysis can help shed insight on potential manufacturer and investor decision pathways.



TEF also explored substitution of biofuels, electricity, and hydrogen for petroleum across the entire transportation sector. The study does include some aspects of natural gas, but does not comprehensively analyze the role of natural gas in the transportation sector.



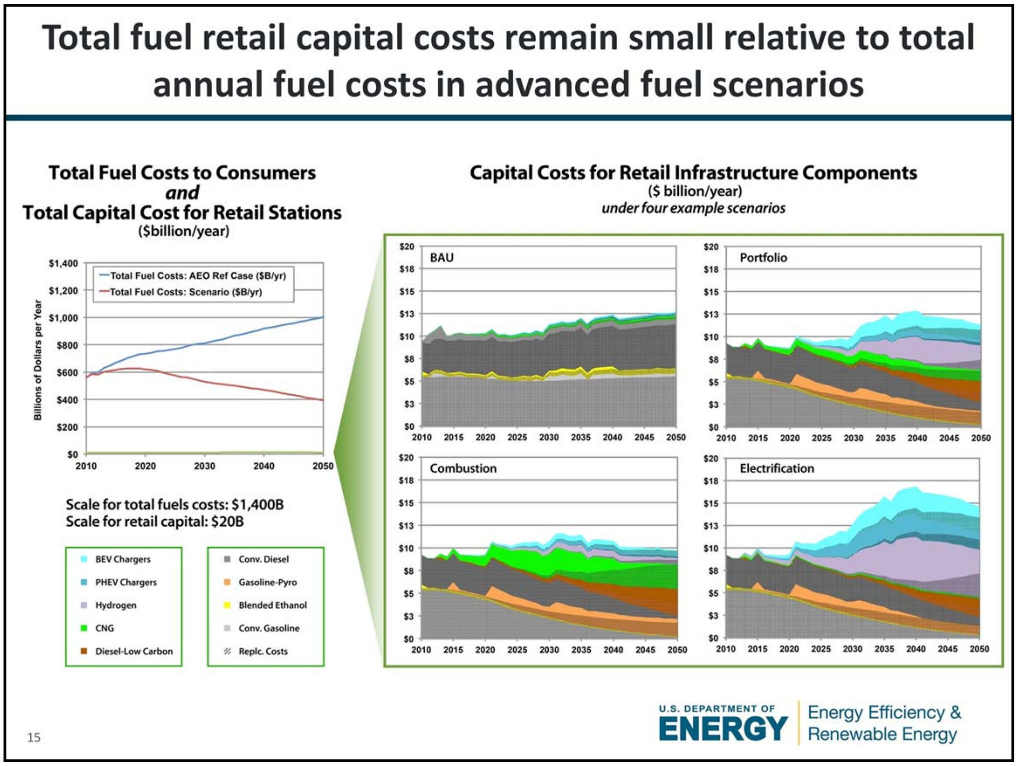
Petroleum has dominated the transportation fuel sector due to its extremely high energy density (gasoline: 47,000BTU/kg vs. TNT: 4,000BTU/kg) and relative ease of transport and storage due to its liquid state at room temperature. The types of petroleum not used for transportation are also valuable, such as in the production of plastics. Petroleum is the liquid fossil fuel which is produced from the raw material of oil. “Other petroleum” is the additional products of the refining process. Other petroleum is a mix of natural gas plant liquids, refinery gains, and blending components.



TEF analysis indicates that biomass has the potential to provide a significant percentage of transportation liquid fuel needs, even at the baseline projected fuel demand level. In order to be able to model the market equilibrium for biomass supplies and consumption in a mature market, the research team developed a simple market equilibrium modeling tool specifically for the TEF project: Biomass Allocation and Supply Equilibrium (BASE). The model concludes that biofuels are competitive in transportation fuel markets, if R&D is successful and petroleum product prices are as high as the Energy Information Administration projects. Biomass is more viable for liquid fuels than power generation markets, except under scenarios where both carbon pricing and carbon capture and storage are available.

These charts show the market shares of energy from biomass used in gasoline, diesel, jet, bunker (fuel used onboard ships), and biopower markets, relative to the baseline energy demand. As shown, market share increases significantly from 2020 to 2050. Carbon pricing increases the amount of biofuel in many fuel markets by increasing the price of biomass feedstocks so that biopower is less competitive with other electricity generation alternatives, but does not prompt transformative change.

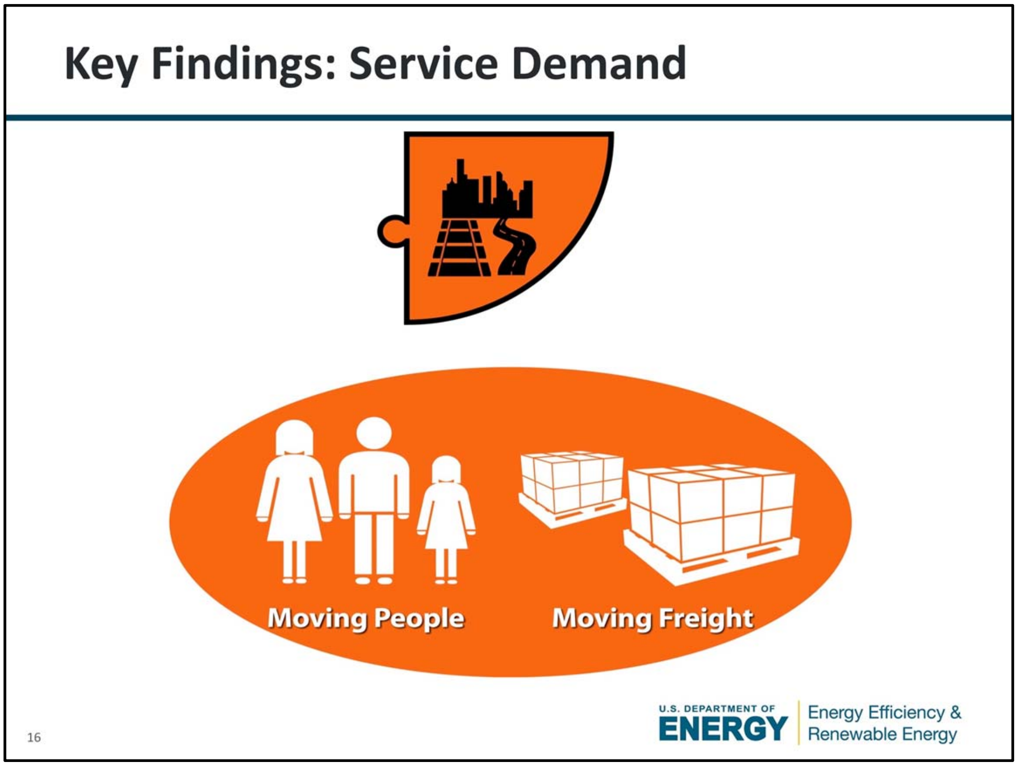
Fuel from biomass can constitute a substantial share of transportation fuel markets and displace significant volumes of petroleum. Biofuel production is constrained by the size of the potential biomass resource (here estimated with the DOE Billion Ton Study). However, vehicle efficiency and other strategies to decrease liquid fuel use such as vehicle electrification and service demand management could lower transportation fuel demand to the point that biomass could replace 100% of petroleum used for liquid fuels.



An additional important question about possible fuels scenarios is their retail infrastructure cost – for example gas stations, public and home charging, and hydrogen fueling stations. The chart at the top left of this slide shows the cost of this infrastructure as a share of overall fuel cost. The blue line shows the business-as-usual total cost of fuel; the red line shows total estimated technical costs in deep reduction scenarios, and the green line (near the bottom of the graph at this scale) shows the retail infrastructure share of that cost. These infrastructure costs represent a small share of overall fuel cost by 2050 (1-4%, or approximately $10-15 billion in retail costs of $350-$1,000 billion in total fuel costs).

Using four fuel development scenarios, we estimated future retail station capital cost for different fuel mixes: (1) Business as Usual (BAU): continued heavy reliance on petroleum-based fuels; (2) Portfolio: successful deployment of a range of advanced vehicle and fuel technologies; (3) Combustion: market dominance by hybridized internal combustion engine vehicles that are fueled by advanced biofuels and natural gas; and (4) Electrification: market dominance by electric drive vehicles in the LDV sector, including battery electric, plug-in hybrid, and fuel cell vehicles, that are fueled by low-carbon electricity and hydrogen. The Portfolio scenario is similar to the scenario shown in the 'modes' and conclusions sections of this presentation. Retail infrastructure costs for alternative scenarios involving electrification are significantly larger than BAU, but are still a small share of total fuel cost. Expanded use of biofuel can leverage existing infrastructure. BAU will require ongoing maintenance and expansion of petroleum fuel production as transportation demand continues to grow and outpaces efficiency improvements. In low-carbon scenarios, total fuel demand declines further due to accelerated efficiency improvements to such an extent that the amount of new production infrastructure is on a similar order of magnitude as expanded production capacity in BAU. Low-carbon scenarios could use far less fuel overall, due to greater vehicle efficiency, and therefore the total estimated cost of fuel would drop significantly in all alternative fuel scenarios explored (this does not account for investment risk that might be reflected in prices).

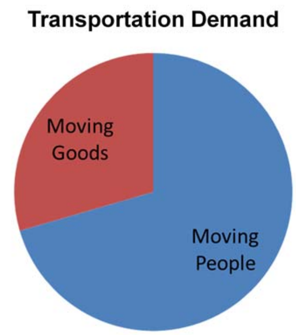
In diverse scenarios that include multiple alternative fuel types, providing adequate retail fueling with a comparable level of accessibility as existing petroleum fuels may be difficult to achieve while maintaining profitable sales volume at each retail location due to low fuel volumes. This suggests heterogeneous infrastructure expansion patterns are highly probable for CNG, hydrogen, and perhaps electricity.



Finally, TEF also examined demand for transportation services: movement of freight and people. Effective transportation is central to the economy, and demand for transportation of both goods and people is expected to increase significantly over the coming decades. Managing transportation demand is therefore a big opportunity for energy savings (up to ~20% combined impact). TEF examines how trip reduction, land use change, mode switching, and modifications in driver behavior can help mitigate the energy needs of increased demand. The opportunities and challenges of each of these are explored in detail in the topic reports.

Coordinated demand reduction strategies can lead to significant savings while maintaining service quality

Demand Reduction Strategy	Impact Type	Potential Magnitude of Impact
Built Environment Characteristics	LDV VMT reduction	12-18% (15% used for summary)
Trip Reduction	LDV VMT reduction	1-10% (5% used for summary)
Efficient Driving	MPG improvement	1-5% (5% used for summary)
Non-LDV Mode Switching	Ton-miles switched	<10% (10% used for summary)



2011: 27.4 quadrillion Btu of transportation energy use

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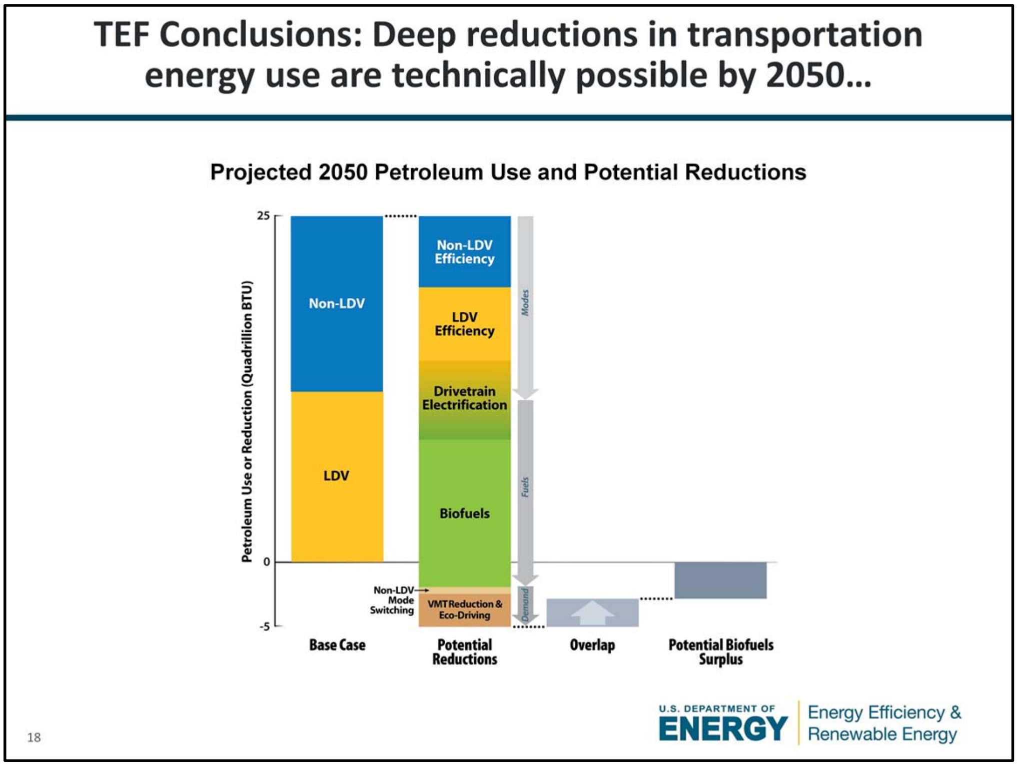
TEF breaks transportation demand management down into four topics across three reports:

Built Environment: Higher densities, a mix of uses, and walkable neighborhoods contribute to lower vehicle travel and energy use. Different government entities share roles influencing each of these factors, and the built environment has historically seen major local government roles. Changes to the built environment could result in a reduction in transportation energy and GHG emissions from less than 1% to as high as 10% by 2050. The high-end 10% reduction corresponds to a reduction of up to 16%–18% in urban light-duty vehicle travel. Although the potential energy benefits are significant, studies have identified the numerous other potential benefits associated with lower energy built environment scenarios. These potential benefits include lower municipal infrastructure costs, less traffic and improved safety, lower transportation costs, less noise, better health (both from lower pollution and additional exercise), higher land values, and improved equity. Each of these impacts are complex issues and depend on a variety of interacting factors at the local level.

Trip reduction and efficient driving: Numerous transportation strategies are directed at reducing energy use and greenhouse gas (GHG) emissions by changing the behavior of individual drivers or travelers. These behavioral changes may have the effect of reducing travel, shifting travel to more efficient modes, or improving the efficiency of existing travel. The estimated impact of individual strategies on surface transportation energy use and GHG emissions range from less than 1% to a few percent. We estimate the cumulative effect when travel behavior strategies are combined to result in a 7% to 15% reduction in energy use and emissions by 2030. Pricing strategies that are broadly applied have the greatest potential for substantial nearer-term effects. Trip reduction and efficient driving impacts are only projected to 2030 because they represent nearer-term options than the built environment (which has slower turnover). We assume this impact is the same in 2050 as the opportunity identified by 2030. Over the long term (2030 to 2050), there may be potential for significant collective impact of a set of strategies such as land use change, transit expansion, and nonmotorized improvements that are synergistic with road pricing strategies but not individually as significant in the shorter term.

Mode switching: Mode shifting in passenger travel and in freight is challenging because the selection of mode is based on many factors distinct to the mode. TEF focuses on freight mode switching because several alternatives are available in freight, and the most promising type of passenger mode switching (high speed rail) is currently under heavy study by DOT and others. The types of policy measures that affect freight mode choice include pricing of fuel, roadway access, or emissions; regulations on trucker service hours, truck or railcar size and weight; and infrastructure and service improvement investments. Truck-to-rail modal shifts have the greatest overall potential for energy reduction, because trucks are the dominant mode in terms of freight tonnage and freight commodity value, while rail serves many of the same routes and uses substantially less energy. However, there are trade-offs between promoting efficiency improvements in less efficient but widely used modes (such as trucks) versus promoting mode shifts, and measures in these areas would be most effective if considered together.



This summary figure emphasizes that the potential transformation of the transportation system in deep reduction scenarios relies upon the three elements highlighted in this presentation: reducing energy intensity of transportation modes, reducing carbon intensity of transportation fuels, and reducing use intensity of transportation services (demand). [SEE BELOW FOR EXPLANATION OF FIGURE DETAILS]

Because transportation energy use and emissions are the product of all three of these elements, each must be reduced in conjunction to achieve deep reductions. Integration of these diverse strategies across different transportation modes has the technical potential to eliminate most transportation-related petroleum use and GHG emissions. However, major market barriers will need to be overcome to realize even a fraction of this potential:

1. Deep reductions require advanced technologies for light-duty vehicles. Deployment of these vehicles involves overcoming cost, range, and production issues, as well as consumer concerns.

2. Deep reductions also rely on non-light-duty vehicles becoming significantly more energy efficient through research, development, and policy.

3. Deep reductions require greater use of low-carbon, non-petroleum fuels, which rely on

adoption of different vehicle technologies and expansion of fuel production, fuel distribution, and retail fueling infrastructure.

4. Deep reductions rely upon shifts in transportation demand, which would involve steps to better meet transportation demand with improved system efficiency.

While deep reductions in transportation energy use and emissions are shown to be technically feasible, policy changes may be necessary to realize the changes outlined in each of the elements discussed in TEF. While TEF considers some of these policy levers, a coordinated policy approach remains beyond the scope of the study.

FIGURE DETAILS

Legend

Base Case: Projected 2050 transportation petroleum use, extrapolated from the U.S. Energy Information Administration's Annual Energy Outlook (2012) and categorized as LDV and non-LDV.

Potential Reductions: TEF-reported reduction potential in areas such as increasing vehicle efficiency of modes, fuel switching, and changing service to reduce use intensity. Reductions are relative to the base case.

Overlap: The reduction impacts of TEF strategies overlap; the additive effect of individually-implemented strategies is not equal to that delivered by simultaneous implementation of all strategies (e.g., fewer VMT combined with improved technology may produce fewer or less overall energy efficiency improvements than the sum of individual VMT and technology strategies). Subtracting this overlap from the reductions compensates for double counting.

Potential Biofuels Surplus: Biofuel production exceeding U.S. liquid fuel demand, with use of most or all projected available sustainable biomass feedstock and providing fuel for export.

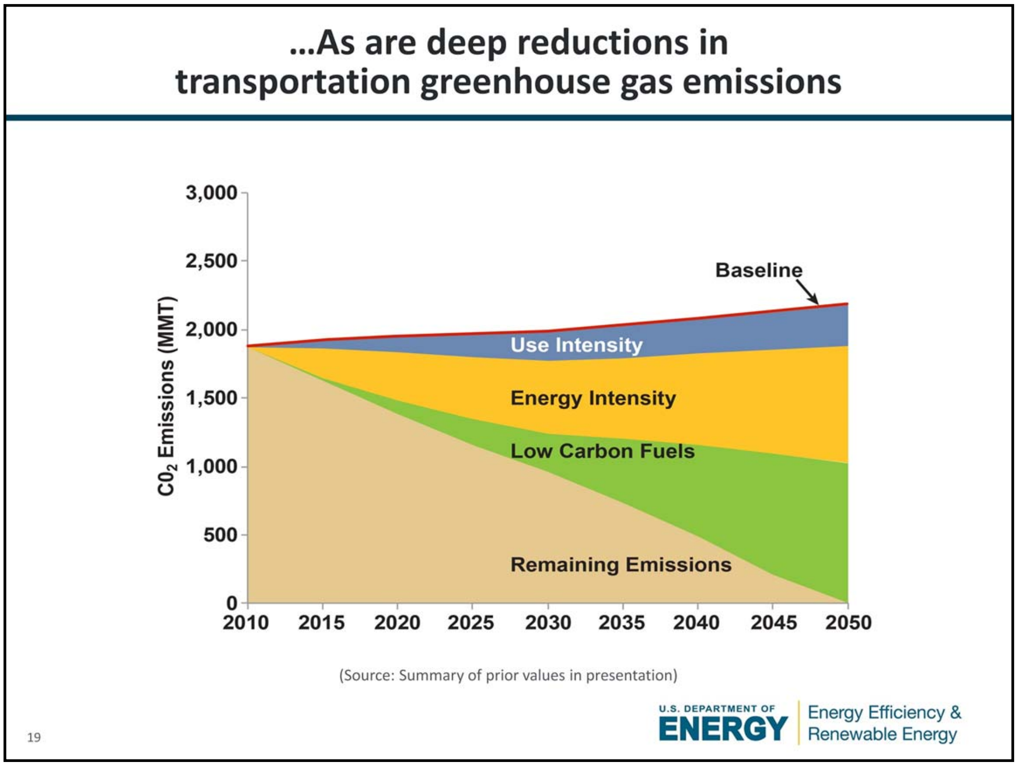
Notes

"LDV" = light-duty vehicle.

"VMT" = vehicle miles traveled.

"LDV efficiency" includes improvement of internal combustion and hybrid vehicles.

"Drivetrain Electrification" factors in reductions delivered by use of electric and fuel cell vehicles.



This wedge chart shows a corresponding illustrative scenario for GHG reductions to 2050. The top of the chart shows the baseline transportation emissions, and each wedge represents the amount that emissions could be reduced by that set of opportunities. The Use Intensity and Energy Intensity wedges correspond to service demand and vehicle mode efficiency, respectively. The green wedge corresponds to non-petroleum, low-carbon fuel use.

For More Information

- TEF Website with papers: http://www1.eere.energy.gov/analysis/transportationenergyfutures/
- TEF represented in an online scenario analysis tool: https://bites.nrel.gov/inputs.php?id=1146
- Many of the vehicle and fuel cost assumptions are also in the "Transparent Cost Database," available at: openei.org/tcdb/
- For questions, contact eere.analysis@EE.Doe.Gov.

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