CHAPTER ONE

DEMAND

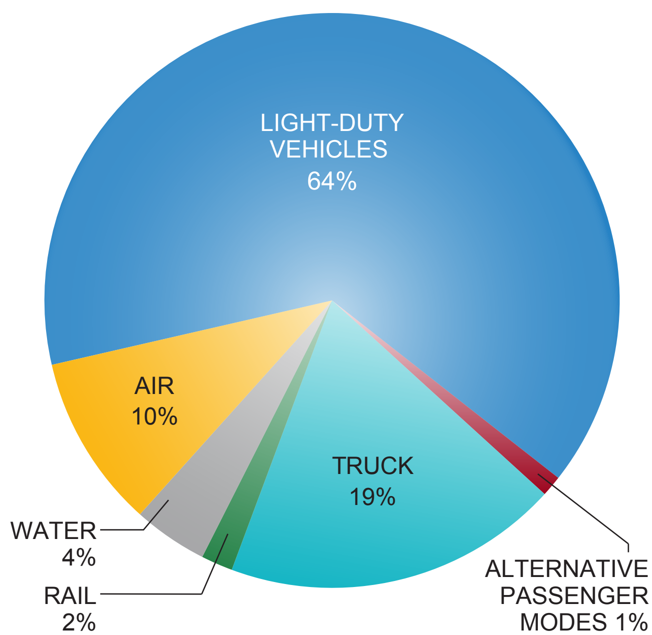
INTRODUCTION

Understanding the demand for transportation services is a foundational element for a meaningful analysis of the impact of energy prices, new technologies, and regulatory frameworks on energy consumption. This chapter discusses the fundamental drivers underlying the demand for transportation services in the United States. In addition, it discusses the relationship between demand for services and energy consumption through an analysis of the 2010 Annual Energy Outlook (AEO2010) Reference Case relative to the alternative energy price cases.[1] The chapter also points to areas of uncertainty in the demand for transportation services stemming from uncertain economic growth, structural shifts in economic output, and shifts in transportation infrastructure and regulations.

The primary modes of transportation include on-road light-duty (LD) vehicles, on-road trucks—which is disaggregated into medium-duty (MD) vehicles, Class 3-6, and heavy-duty (HD) vehicles, Class 7&8—plus rail, water, and air.

The modal distribution for 2010 transportation energy consumption is presented in Figure 1-1. The LD vehicle sector was the largest transportation energy consumer, comprising 64%, followed by truck accounting for 19%. This study focuses more heavily on these on-road sectors, which are qualitatively and quantitatively discussed, whereas air, rail, and water are discussed only qualitatively or in topic papers, which can be found on the NPC website.

This study posits Reference, Low, and High Oil Price Cases from which to examine the impact of different fuel-vehicle system portfolios on energy consumption, fuel diversity, and greenhouse gas (GHG) emissions. For each of these cases, demands for transportation services are taken from the AEO2010 through the year 2035. From 2036 to 2050, transportation demands are taken from



Note: Pie chart includes commercial light-duty trucks under "Truck," and excludes transportation sectors of recreational boats, lubricants, pipeline, and military use.

Source: Energy Information Administration, AEO2010.

Figure 1-1. *Transportation Energy Consumption, Modal Distribution for 2010*

1 *Annual Energy Outlook* is published by the U.S. Department of Energy, Energy Information Administration. Most recent and prior editions are accessible at www.eia.gov. The 2010 edition is at http://www.eia.gov/oiaf/archive/aeo10/index.html.

VISION,[2] where available, or extrapolated to 2050 using the AEO2010 growth rate between 2030 and 2035. The study's quantitative analysis was structured around the AEO2010 because its demand projections were developed from a comprehensive energy model that was transparent and well documented.[3]

BACKGROUND

Key Demand Drivers in the Transportation Sector

Macroeconomic indicators such as gross domestic product (GDP), population, and industrial activity largely determine the demand for transportation services. Services include everything from the movement of freight across roads, railways, and waterways to movements of people by driving or flying.

The demand for transportation services is typically expressed in terms of vehicle miles traveled (VMT), ton-miles, or passenger seat miles depending on the mode of transit. Figure 1-2 shows the annual growth rate in transportation services by mode from 2010 to 2035 according to AEO2010. The blocks indicate the compounded annual growth rate in the Reference Case. The maximum and minimum points of the vertical line are the growth rates in the AEO2010 High and Low Economic Growth Cases, respectively. The first three variables are the growth rates of the key macro indicators—GDP, population, and the value of industrial shipments.

Two key points from the figure are that all modes are projected to grow over the 25 years, and the range of uncertainty in economic activity translates into a comparable range of uncertainty in the demand for services. Note also that the growth rates of the different modes align more closely

2 VISION is a spreadsheet tool developed and maintained by Argonne National Laboratory to calculate the impact of varying assumptions on light-duty vehicles and Class 3-8 trucks. The version used in the study was calibrated to the AEO2010 through 2035 and extended data to 2050.

3 The National Energy Modeling System (NEMS) is used to estimate AEO data.

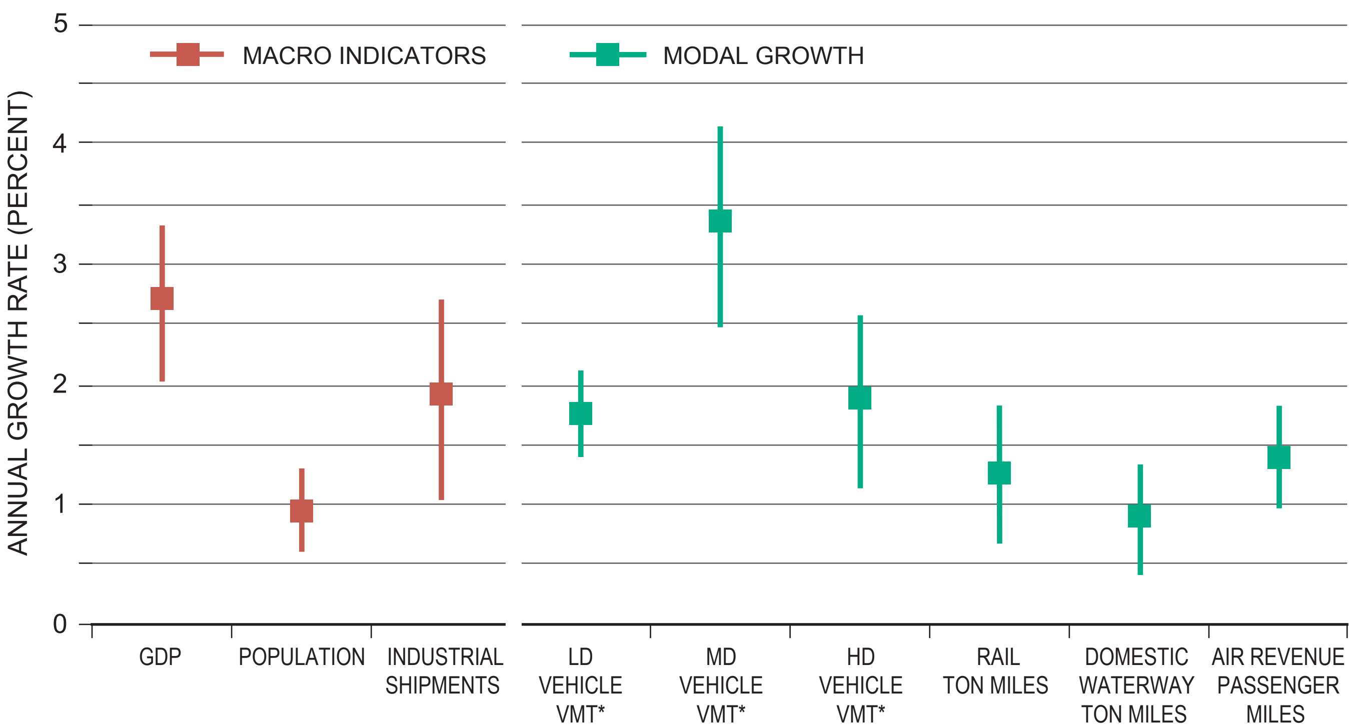


Figure 1-2. *AEO2010 Transportation Services Demand in the Reference, High, and Low Economic Growth Cases (Compound Annual Growth Rates 2010–2035)*

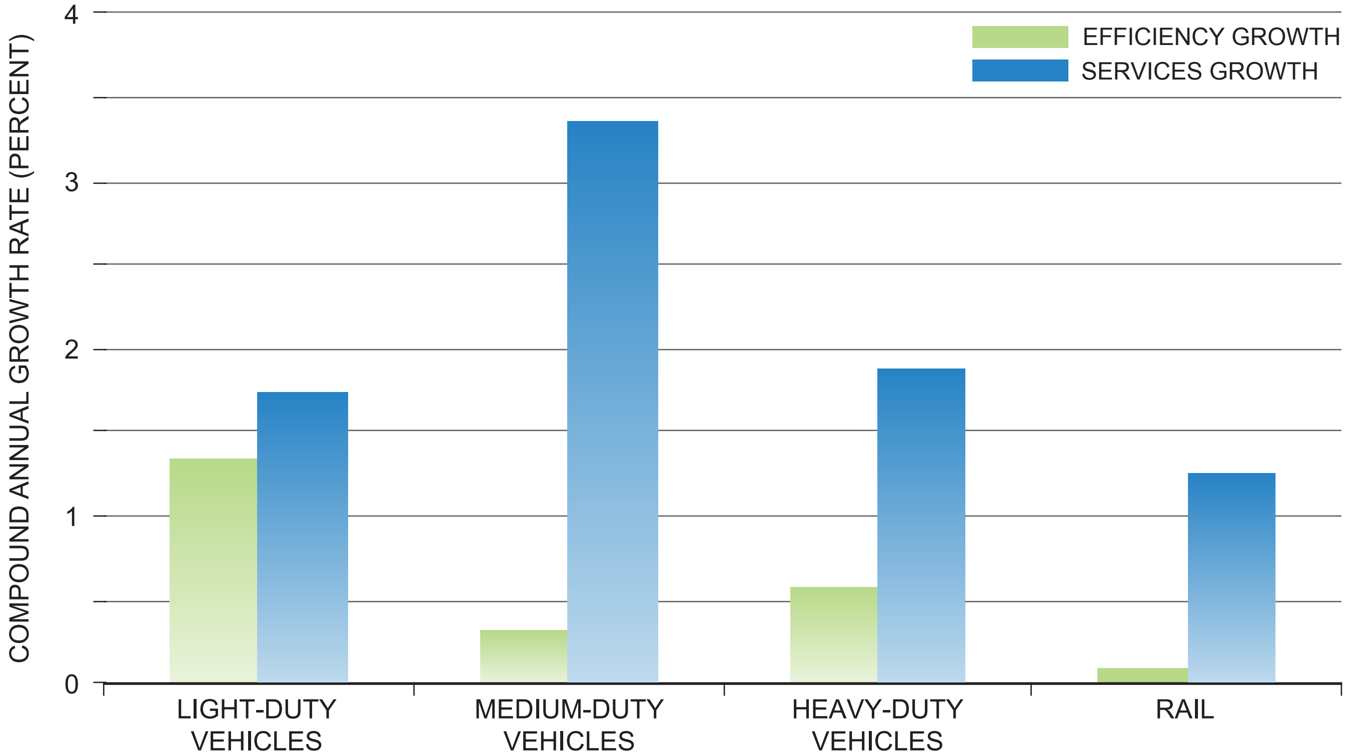


Figure 1-3. *AEO2010 Reference Case Transportation Services Demand and Fuel Efficiency Growth (Compound Annual Growth Rates 2010–2035)*

with particular indicators. The growth ranges in the passenger modes, LD vehicles, and air passenger miles compare more closely with that of the population growth, while the freight modes align with GDP and industrial shipments. The reference growth rate of HD vehicle VMT is similar to that of industrial shipments, whereas the MD vehicle VMT is closer to GDP. This is because GDP incorporates the service sector of the economy and MD vehicles (Class 3-6 trucks) are dominated by delivery and service vehicles.

While the demand for transportation services is largely determined by macro indicators, energy demand is determined by both the services demand and vehicle energy efficiency. Energy efficiency relates to how much energy is consumed per unit of service—such as miles traveled per gallon for on-road vehicles. Energy demand will increase through time if demand for services increases at a faster rate than efficiency improves. In Figure 1-3, compounded annual growth rates in fuel efficiency for on-road and rail modes are shown with the growth rates for transportation services. In the AEO2010, energy demand increases across all modes.

Energy prices relative to other consumer prices and producer costs also affect the level of transportation energy consumption, with higher prices discouraging demand. The price of energy relative to the cost of new vehicle technology through time determines the rate of fuel efficiency improvement. Generally, more vehicle technology is adopted to improve efficiency as the cost of energy increases. The fuel savings compensate for the increased cost of the vehicle fuel economy technology. This premise underlies the AEO2010 and the analysis of this study. In general, therefore, transportation energy consumption is more sensitive to energy prices than transportation services demand is sensitive to energy prices.

Take LD vehicle VMT as an example. In Table 1-1, VMT, vehicle fleet efficiency, and energy consumption for 2035 are shown for the AEO2010 Reference Case compared to the AEO High Oil Price and Low Oil Price Cases. Projected values are shown in

	Values			Values Indexed to Reference Case		
	High Oil Price Case	Reference Case	Low Oil Price Case	High Oil Price Case	Reference Case	Low Oil Price Case
Gasoline (2008$/gallon)	5.83	4.04	2.22	144	100	55
VMT (billions)	4,101	4,308	4,829	95	100	112
Stock Efficiency (mpg)	31.0	29.3	27.9	106	100	95
Energy Consumption (Quadrillion BTU)	16.60	18.44	21.73	90	100	118

Table 1-1. *AEO2010 Light-Duty Vehicle Services and Energy Consumption in 2035*

the first set of columns, while the second set shows relative values for high and low cases indexed to the Reference Case.

Under the AEO2010 High Oil Price Case, the gasoline price is 44% higher than in the Reference Case. Vehicle miles traveled are 5% lower while LD vehicle fleet efficiency is 6% higher, leading to 10% lower fuel consumption in 2035 than under the Reference Case. In the Low Oil Price Case, the gasoline price is 45% lower, VMT is 12% higher, and fuel efficiency is 5% lower, leading to an 18% increase in fuel consumption by 2035.

The following section discusses the key drivers behind the transportation services projections under the study Reference Case and the High and Low Oil Price Cases. These projections are used explicitly in the integrated analysis of the study. Energy efficiency projections in this chapter are, however, for illustrative purposes only. They are based on the AEO2010 and extrapolations. Chapters Two, "Light-Duty Vehicles," Three, "Heavy-Duty Vehicles," and Four, "Priorities for Technology Investment," discuss alternative projections for efficiency and the impact on fuel consumption assuming various technology and economic barriers are overcome. Possible structural changes in transportation service demands, not incorporated in the projections, are briefly discussed and references to other studies are provided. Demand side initiatives to reduce demand for services and energy, such as smart growth urban planning and real-time traffic flow management, are out of scope for this study but covered qualitatively in Chapter Six, "Greenhouse Gases and Other Environmental Considerations."

DISCUSSION BY MODE

Light-Duty Vehicle VMT

LD vehicles are composed of small cars through large SUVs and account for nearly 65% of transportation energy consumption. In the study Reference Case, LD vehicle VMT is projected to increase 78% from 2010—reaching nearly 5 trillion miles by 2050. This corresponds to a compound annual growth rate of 1.4%. This projection is based on the AEO2010 VMT through 2035 and VISION post-2035 and uses the Reference Oil Price Case, which increases from $70 per barrel to $167 per barrel (2008 dollars) over the same period.

Key concepts discussed in this section are:

- VMT is increasing but the rate of growth in VMT is slowing.
- VMT is relatively insensitive to oil prices.
- Growth in alternative passenger modes could alter LD vehicle VMT projections.

The Slowing of VMT Growth

The rate of VMT growth is projected to vary over the study period, with slower growth occurring in the later years. Table 1-2 compares historical and projected VMT growth rates. The first three columns—GDP, GDP per capita, and population growth—indicate continued growth in macroeconomic indicators. These growth rates were all relatively steady, with just a tenth of a percent decline from 1996 to 2007. However, VMT, which grew at the rate of GDP growth from 1971 to 1995,

	GDP	GDP Per Capita	Population Growth	VMT Per Vehicle	VMT
1971–1995	3.1%	2.0%	1.1%	0.5%	3.1%
1996–2007	3.0%	1.9%	1.1%	0.3%	2.0%
2012–2035	2.5%	1.6%	0.8%	0.5%	1.5%
2036–2050	2.1%	1.3%	0.8%	0.2%	0.9%

Sources: Bureau of Economic Analysis, U.S. Census, Federal Highway Administration, Energy Information Administration AEO2010, and VISION 2010 Reference Cases.

Table 1-2. *Light-Duty Vehicle VMT and Indicators (Compound Annual Growth Rates)*

experienced a marked slowdown between 1996 and 2007, growing a full percentage point below GDP. This gap between economic growth and VMT is continued throughout the study period.

The study does not endorse or reject the GDP and population projections in the AEO2010, but accepts the assumption that VMT will grow at a slower rate over the evaluation timeframe. Recent studies have documented the slowing VMT growth rate in the last decade and agree that it is likely to persist due to changing demographics.[4,5,6] Polzin and Litman discuss many of the same trends. The following discussion is taken largely from Polzin. His analysis includes empirical data and postulates future VMT growth slows from 2.7% per year to 1.9% between 2001 and 2025. This compares reasonably well to 1.5% growth in the AEO2010; Polzin was writing before the 2007–2009 recession, so would not have anticipated the decline and slowdown in VMT between 2007 and 2011.

Polzin argues that the 1977–2001 growth in trip frequency per person is unlikely to repeat itself in the period from 2001 to 2025. The increase in female labor participation rates and the increase in female driver licensing rates have both stabilized after steadily increasing through the mid-1990s. The age distribution of the population is moving upward such that a greater proportion will be past the peak driving age. Though future older drivers are expected to drive more than earlier generations, their trip frequency relative to when they were younger is expected to offset VMT growth.

Greater vehicle availability contributes to VMT growth as people shift from being passengers in personal vehicles and mass transit to driving single occupancy vehicles. Vehicle availability also increases trip frequency per driver. Between 1970 and 2001, among the population 16 years and older, vehicles per capita grew from approximately 0.6 to nearly 1.0. As of 2001, 75% of the population lived in households with at least one vehicle per driver, another 20% were in households with the vehicles per driver ratio less than one, and only 5% were in households with no vehicle. Given the remaining small share of the population without access to a vehicle, this factor in historical VMT growth should moderate going forward.

Increases in real income traditionally have increased VMT because it increased vehicle affordability and increased activity away from home. It follows then that as the vehicles per driver ratio approaches saturation across households, increases in real income may not have as great of a future effect on VMT. Greater income will still increase activity away from home, though it is unclear whether that relationship will strengthen or weaken going forward. It will depend on households' preferences for activities away from home relative to other uses of personal income. Ultimately time, rather than real income per capita, will constrain VMT growth as activity increases away from home. Polzin, however, could not find evidence suggesting time spent traveling was dampening VMT growth.

4 Steven E. Polzin, *The Case for Moderate Growth in Vehicle Miles of Travel: A Critical Juncture in U.S. Travel Behavior Trends,* prepared for U.S. Department of Transportation, Center for Urban Transportation Research, University of South Florida, April 2006.

5 Todd Litman, "Changing Travel Demand: Implications for Transport Planning," *ITE Journal* 76, no. 9 (September 2006): pages 27-33.

6 Robert Puentes and Adie Tomer, *The Road...Less Traveled: An Analysis of Vehicle Miles Traveled Trends in the U.S.,* Brookings: Metropolitan Policy Program, December 2008.

In summary, recent studies agree that the slowing of VMT growth observed over 1995–2007 will likely be sustained going forward. A slowdown in labor productivity or population will also decrease growth rate. The combined effects are not linear, however. The stabilizing trends of women's employment participation, aging population, and average household size may simultaneously reduce income growth.

Oil Prices Effect on Vehicle Miles Traveled and Energy Consumption

The AEO2010 High Oil Price Case assumes tighter world oil supplies resulting in correspondingly higher crude oil prices. In real terms (2008$), crude oil rises to $210 in 2035, compared to the Reference Case prices of $133. GDP and population growth rates are not meaningfully affected, though the industrial mix is different under the different oil price cases compared to the Reference Case. Table 1-3 shows the effect of changing crude oil price on light-duty vehicle VMT and projected efficiency.

In the High Oil Price Case, LD vehicle VMT is 5% lower in both 2035 and 2050 compared to the Reference Case. Energy consumed by LD vehicles declines by a greater percentage than VMT because the higher fuel costs lead to purchases of more fuel-efficient vehicles. The results are reversed in the Low Oil Price Case. VMT increases because the fuel costs decrease and average vehicle fuel efficiency declines.

Table 1-4 shows energy price elasticity, which is the ratio of the percent change in energy consumed from the percent change in fuel price. It can be disaggregated into the elasticity of VMT less the elasticity of fuel efficiency. For projections to 2035, the AEO2010 results are consistent with academic research on price elasticities of energy demand. Green and Plotkin[7] indicate studies from the 1990s found long-term VMT elasticity around -0.2, while Small and Van Dender,[8] using state cross sectional time series data from 1997–2001, found long-term VMT elasticity of -0.11. VMT elasticities of -0.14 and -0.20 for 2035 from the AEO2010 cases are in this range. Small and Van Dender also found energy consumption elasticity equal to -0.31; again the AEO results of -0.29 and -0.28 for 2035 are reasonably close.

The calculated elasticities for energy consumption and fuel efficiency in the outlook period to 2050 are outside the range of academic findings. The High Oil Price Case postulates oil prices range between $185 and $230 per barrel between 2020 and 2050. This is well above historical prices, and at no time in history have prices remained elevated for 20 to 30 years. No study using actual data, therefore, exists to reflect the calculations from the extrapolated projections.

Still, a fuel efficiency elasticity of 0.42 calculated for 2050 may be possible. Twenty to thirty years of high oil prices would be long enough for manufacturers to develop more fuel-efficient vehicles and

7 David L. Green and Steven E. Plotkin, *Reducing Greenhouse Gas Emissions from U.S. Transportation,* prepared for the PEW Center on Global Climate Change, January 2011.

8 Kenneth A. Small and Kurt Van Dender, "Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect," U.C. Irvine Economics Working Paper #05-06-03, University of California, Irvine, April 2006. Shorter version published in *Energy Journal* 28, no. 1 (2007): pages 25-51.

				Values Indexed to Reference Case Values by Year								
	Gasoline (2008$/GGE*)			LD Vehicle VMT			LD Vehicle Energy Consumed			Miles/GGE†		
	High Oil Price Case	Ref Oil Price Case	Low Oil Price Case	High	Ref	Low	High	Ref	Low	High	Ref	Low
2035	5.83	4.04	2.22	95	100	112	90	100	118	106	100	95
2050	6.37	4.79	2.43	95	100	112	84	100	119	113	100	94

* GGE (gallon gasoline equivalent) is 125,000 BTU. Gasoline includes ethanol blend.
† Miles/GGE is efficiency of vehicle stock.

***Table 1-3.** Light-Duty Vehicle VMT, Energy Consumption, and Fuel Efficiency from the AEO2010 High, Reference, and Low Oil Price Cases*

	High Oil Price Case			Low Oil Price Case		
	VMT	Energy	MPG	VMT	Energy	MPG
2035	-0.14	-0.29	0.16	-0.20	-0.28	0.09
2050	-0.18	-0.60	0.42	-0.17	-0.26	0.09

Note: Percent difference in variable between the oil price case and reference case for the given year relative to the percent difference in gasoline price.

Table 1-4. *Price Elasticities*

for the entire LD vehicle fleet to be replaced. The corresponding energy elasticity of -0.60 essentially implies drivers will choose significantly more efficient vehicles to keep the cost of driving a relatively constant share of their budgets without significantly reducing miles traveled.

Alternative Passenger Modes to Reduce LD Vehicle VMT

Alternative passenger transportation modes include bus (transit, intercity, and school) and passenger rail (transit, intercity, and commuter). In 2009, total public transit modes accounted for only 1.4% of passenger miles traveled.[9] The AEO2010 projects fuel consumption for alternative modes to grow about 1% per year and account for 1.3% of transportation fuel consumed in 2035.

Alternative passenger modes are a small and fragmented sector, but have received considerable attention in studies focused on the potential to reduce LD vehicle use in order to reduce fuel consumption, GHG emissions, and road congestion. Mass transit also promotes compact urban development, which could further limit LD vehicle VMT growth.

The vast number of studies are not discussed here, but the reader is directed to sources that summarize recent work on reducing LD vehicle VMT with alternate modes or more efficient use of LD vehicles. Green and Plotkin offer a brief description of existing programs and issues.[10] *Moving Cooler* proposes multiple strategies for increasing utilization of alternatives and estimates their impact on GHG emissions.[11] It draws heavily from a literature review on transportation elasticities by Todd Litman.[12] The U.S. Department of Transportation's *Transportation's Role in Reducing Greenhouse Gas Emissions* similarly offers a review of strategies and an evaluation on their effectiveness.[13] The Center for Neighborhood Technology provides a brief description of recent studies in *The Route to Carbon and Energy Savings.*[14]

The potential of alternative passenger transportation modes, however, relies heavily on simultaneously increasing system services, utilization rates, and economic efficiency. Given these challenges, the LD vehicle and alternative passenger mode projections in this study follow the AEO2010 and do not incorporate significant passenger mode switching.

Medium- and Heavy-Duty Vehicle VMT

The truck sector consists of MD vehicles (Class 3-6) such as local delivery and service vehicles, and HD vehicles (Class 7&8) which are dominated by long haul and regional haul vehicles, but also include vocational applications such as refuse, cement, and construction dump trucks. In 2010, HD vehicles accounted for 81% of energy consumed and 75% of the VMT for the combined truck

9 Research and Innovative Technology Administration, Bureau of Transportation Statistics, "Table 1-40: U.S. Passenger-Miles (Millions)," in *National Transportation Statistics*, Internet Edition.

10 Green and Plotkin, *Reducing Greenhouse Gas Emissions,* section 2.5.

11 Cambridge Systematics, Inc., *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions,* published by the Urban Land Institute, July 2009.

12 Todd Litman, *Transportation Elasticities: How Prices and Other Factors Affect Travel Behavior,* Victoria Transport Policy Institute, November 2008.

13 U.S. Department of Transportation, "Section 5.0: Strategies to Carbon-Intensive Travel Activity," in *Report to Congress, Transportation's Role in Reducing U.S. Greenhouse Gas Emissions, Volume 2: Technical Report*, April 2010.

14 Center for Neighborhood Technology, *The Route to Carbon and Energy Savings: Transit Efficiency in 2030 and 2050,* prepared for Transit Cooperative Research Board, Transportation Research Board of The National Academies, November 2010.

Class 3-8. The growth in HD vehicle VMT closely parallels the growth in the goods-producing sector of the economy, particularly manufacturing. MD vehicle VMT more closely aligns with the growth in GDP, which includes services, wholesale and retail sectors, along with the goods-producing sector.

Key concepts discussed in this section are as follows:

- MD and HD vehicle VMT is relatively insensitive to oil prices.
- Road congestion and operational changes could alter the projected trucking services demand.

MD and HD Vehicle VMT is Relatively Insensitive to Oil Prices

While trucking services are sensitive to economic activity, they are not very sensitive to oil prices. Under the alternative oil price cases, VMT for MD and HD vehicles are within 5% of the Reference Case in 2035 and 2050. This follows because the GDP growth is not significantly different under the different oil price cases. The composition of GDP does change, however, and this causes VMT of the two truck class groups to respond modestly in opposite directions under the High and Low Oil Price Cases.

Table 1-5 shows the growth in GDP and manufacturing under the High and Low Oil Price Cases. In the lower portion of the table are the indexed values of VMT, fuel efficiency, and energy consumption relative to the Reference Case.

Under the High Oil Price Case, manufacturing grows slightly slower and services slightly stronger than the Reference Case. This increases VMT for MD vehicles and reduces it for HD vehicles relative to the Reference Case. The reverse occurs in the Low Oil Price Case.

For MD vehicles, fuel efficiency under the High Oil Price Case exceeds the Reference Case and falls short of it in the Low Oil Price Case. Higher fuel prices justify efficiency-enhancing technologies and lower prices discourage them. It follows that fuel consumption varies by less than VMT under the two oil price cases.

Fuel efficiency of HD vehicles under the oil price cases varies within 1% from the Reference Case, causing fuel consumed to change proportionately with VMT. This implies that within the AEO2010, technologies that are cost effective under the Reference Case are cost effective in the Low Oil Price Case and no new technologies become cost effective under the High Oil Price Case.

The discussion to this point has focused on the effect economic activity and fuel prices have on the demand for trucking services. Possible structural changes to the freight and transportation system are not incorporated in the projections for this study. They may, nonetheless, affect VMT and energy requirements and are discussed below for completeness.

	Billions of Truck VMT				Fuel Efficiency (Miles/Gallon Gasoline Equivalent)				Real GDP			Value of Manufacturing Shipments (2008$)		
	High Oil Price Case		Low Oil Price Case		High Oil Price Case		Low Oil Price Case		High	Ref	Low	High	Ref	Low
	MD	HD	MD	HD	MD	HD	MD	HD						
Avg. Annual Growth Rates 2010–2035	3.5%	1.8%	3.2%	2.1%	0.4%	0.6%	0.1%	0.5%	2.8%	2.7%	2.7%	2.0%	2.1%	2.2%
2035 Indexed to Reference Case	104	97	97	104	102	100	96	99	101	100	99	98	100	104

Note: MD = medium-duty vehicles; HD = heavy-duty vehicles.

Table 1-5. *Summary Truck VMT, Efficiency, and Indicators from the AEO2010 Reference and Oil Price Cases*

Congestion: Impact and Possible Mitigation Opportunities

A significant uncertainty to projected fuel efficiency is a worsening of roadway congestion. Current research outlines the correlation between fuel consumption and congestion for MD and HD vehicles.[15] According to the 2010 Urban Mobility Report from the Texas Transportation Research Institute: "In 2009, congestion caused American drivers to travel 4.8 billion hours more and to purchase an additional 3.9 billion gallons of fuel for a congestion cost of $115 billion."[16] The trucking industry's share of the extra cost was $33 billion.[17]

The 2005 Federal Highway Administration report *Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation* summarized national trends in congestion, highlighted the importance of travel time reliability, and described several strategies for reducing congestion issues.[18] The strategies were grouped into three broader categories: adding more base capacity, operating existing capacity more efficiently, and encouraging travel and land use patterns that use the system in a way that produces less congestion. While all of these strategies would reduce congestion, the operational strategies were shown to alleviate congestion in the short term and in many cases were the most cost effective. One strategy specific to the trucking industry was the electronic screening of vehicles. Vehicles equipped with a transponder would transmit the relevant information to roadside weight stations/inspection facilities without stopping. The authors noted, however, that operational strategies alone were not sufficient to address the nation's congestion issue.

Route optimization systems are another specific step that motor carriers can take to avoid congestion, reduce fuel consumption, and enhance productivity. A significant market penetration of wireless communication and GPS systems provides the potential platform to implement a wide variety of Intelligent Transportation Systems (ITS). The Motor Carrier Efficiency Study utilized funding from the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) to examine the potential applications of several wireless technologies to enhance motor carrier productivity, reduce fuel consumption, and avoid congestion.[19] These applications included wireless load notification and selection, which would allow railroads and motor carriers to coordinate loads, thereby reducing empty miles traveled. They also included truck-specific congestion avoidance, which would provide truck specific alternate route information to reduce costly travel delays.

Opportunities from changing regulations that govern operations are also being studied. Changing the existing weight and length limits could improve fuel efficiency. A discussion of the regulations and a summary of studies measuring the favorable impact of higher productivity vehicles on trucking fuel efficiency and consumption is available in Topic Paper #3, "Truck Transportation Demand," on the NPC website, prepared for the Truck Demand Subgroup by American Transportation Research Institute (ATRI). The discussion was submitted by the ATRI and covers operational risks and opportunities in truck freight and transportation systems. Some who oppose longer and higher weight roadway vehicles focus concerns on safety and on the potential that trucking would reduce fuel efficiency and increase emissions for those shipments that would otherwise travel via railroads and waterways. The issue is under debate in the federal and state legislatures. This study remains neutral on the issue.

Air Transportation

Air transportation accounted for approximately 10% of transportation energy demand in 2010. According to the AEO2010, energy consumption for air travel by 2035 will be up 26% over 2010 levels. The primary measure underlying the growth is an increase in seat miles[20] of nearly 38%. Over

15 National Research Council of the National Academies, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles*, 2010, pages 32-36. http://www.nap.edu/catalog.php?record_id=12845.

16 David Schrank, Tim Lomax, and Shawn Turner, *2010 Urban Mobility Report,* Texas Transportation Research Institute, December 2010.

17 Ibid.

18 Cambridge Systematics and Texas Transportation Institute, *Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation,* Federal Highway Administration, September 2005.

19 Paul Belella, Michelle Maggiore, Nathan Rychlik, Eric Beshers, Tracy Manzo, Stephen Keppler, Sam Fayez, and Jeff Ang-Olson, *The Motor Carrier Efficiency Study, Phase 1 Report,* The Federal Motor Carrier Safety Administration, February 2009.

20 Seat miles are equal to revenue passenger miles divided by the fraction of seats filled, called the load factor. The impact of growth in revenue passenger miles on transportation services provided is partially offset by increases in the load factor.

this same period, fuel economy improves by about 12%. However, similar to other modes, uncertainty exists with the underlying drivers of air transportation demand.

Revenue passenger miles in the AEO2010 are projected to grow approximately 1.4% per year on average. This is less than the 3.9% growth experienced between 1978 and 2009. Current industry projections range between 2.9% and 3.9%. Projections that indicate a slowing from historical growth may be influenced by expected capacity constraints or other limiting factors. Figure 1-4 summarizes a few of the available projections.

The variance between the industry and AEO2010 traffic projections has a material impact on the outlook in jet-fuel demand. The AEO2010 projects jet-fuel consumption to increase 0.9% per year out to 2035, whereas the Federal Aviation Administration is projecting 1.9% growth.

The AEO and industry expect a different fleet mix, which contributes to the difference in fuel consumption estimates. The AEO2010 projects a mix of aircraft that is more dependent on smaller regional jets, which mirrored the U.S. airline industry fleet profile when energy prices were low. However, the economics of regional jet operations have been negatively impacted by increases in jet fuel prices. Industry expects regional jets to have a smaller share of the market in the future as a result of efforts to reduce labor cost and manage revenue together with the expectation of continued rising oil prices.[21] Meanwhile, the 70- to 90-seat aircraft market is expected to grow. Traditional single- and twin-aisle aircraft are also expected to grow as passenger trip lengths increase and as international markets continue to flourish. Accordingly, the combination of larger average aircraft size and longer average flight stage lengths implies greater aggregate fuel consumption than anticipated by the AEO2010. Detailed analysis of the future air demand is covered in Topic Paper #1, "Air Transportation Demand," posted on the NPC website.

While the National Petroleum Council acknowledges the uncertainty in the projection of

21 Smaller regional jets refers primarily to the 50-seat market.

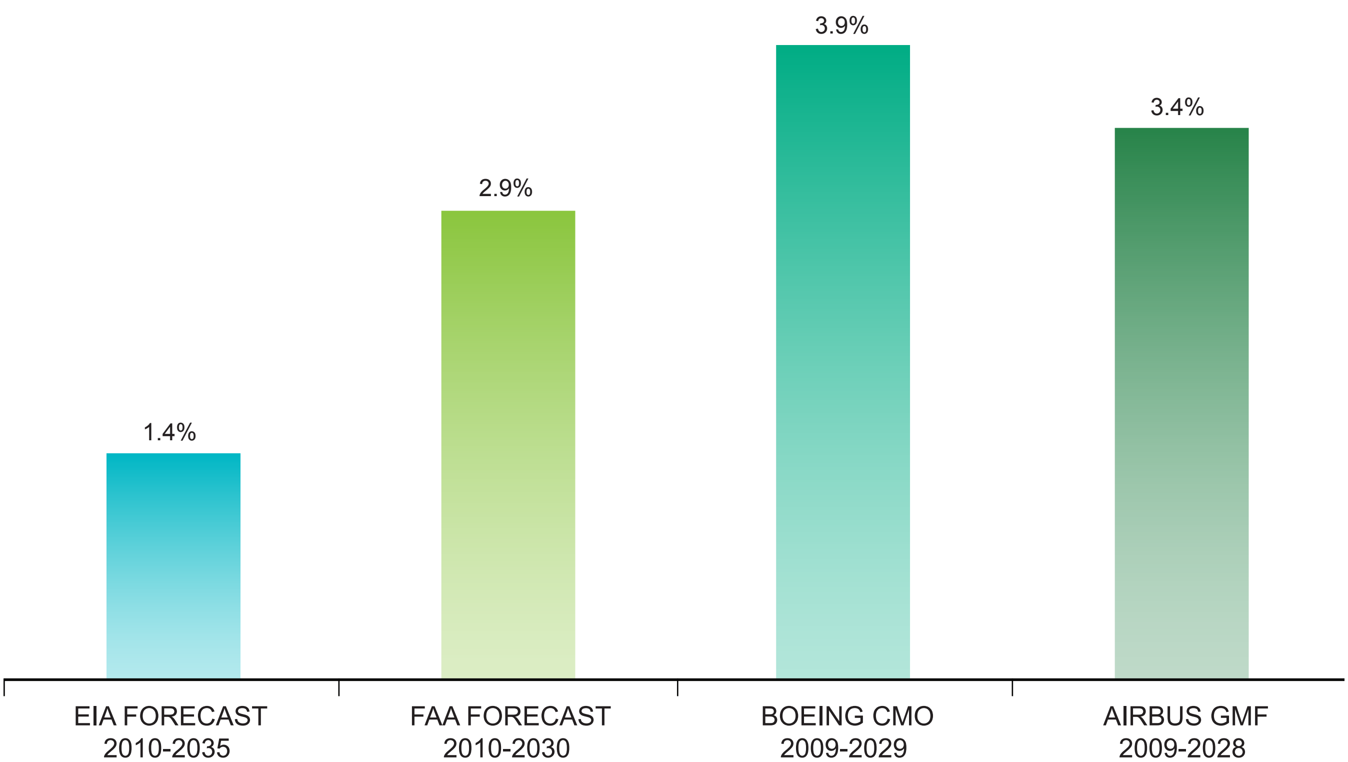


Figure 1-4. *Government Agency and Industry Growth Rate Comparisons (Percent Compound Annual Growth Rate in Passenger Miles)*

passenger seat miles, this study's quantitative analysis is based on the AEO2010 projections through 2035 and extrapolations post 2035. Extrapolating trends to 2050, the Council assumes energy consumption for air transportation will be approximately 34% higher than in 2010.

Rail Transportation

Freight rail accounted for 2% of fuel consumed in 2010 and 42% of intercity freight ton-miles in 2007, the latest data available. For comparison, intercity truck ton-miles accounted for 32% of freight.[22,23] Rail is thus significant to transportation energy consumption for the freight that it takes off the roads.

Key issues discussed in this section are:

- Projections of rail ton-miles are closely tied to growth of specific industries.
- Regulatory and operational changes could significantly alter the rail services projections.

Rail Service Projections are Closely Tied to Coal Production and Intermodal Growth

The AEO2010 projects Class I[24] rail ton-miles in 2035 will be 37% higher than 2010, a 1.3% compounded annual growth. Under the High Oil Price Case, ton-miles are 3% higher in 2035 compared to the Reference Case because oil, agriculture and coal mining shipments are all higher. Higher oil prices support increased biofuel and coal-to-liquid production. Under the Low Oil Price Case, rail ton-miles were within 1% of the Reference Case.

The Reference Case projection of 1.3% annual growth in rail ton-miles is about half the historical growth rate, but the risks of it being under or over stated are about evenly balanced. Actual growth averaged 2.5% annually between 1980 and 2008, supported by the growth in Powder River Basin coal production and an increase in intermodal container traffic associated with the influx of imports through West Coast ports.[25] Coal growth has slowed, but strong intermodal growth may continue.

Coal accounted for 47% of Class I railroads' tonnage originated in 2009.[26] Coal production in short tons grew over 2% annually between 1980 and 1990, and then slowed from 1990 to 2001 to 0.8% growth.[27] Between 2001 and 2008, two cyclical peak years of production, it grew just 0.5% on an average annual average basis. Consistent with the slowdown in coal production, originated carloads of non-containerized goods were flat between 1990 and 2006.[28]

Conversely, the growth rate for intermodal units originating from ports has been 3.6% per year since 1985.[29] Use of intermodal units have been highly correlated with goods imports since 1988.[30] The AEO rail ton-miles is estimated using industrial sector shipments only, and so misses the intermodal growth component related to imported goods in their projections.

Freight rail fuel efficiency in the AEO2010 is projected to improve just 0.1% per year in terms of ton-miles per diesel gallon equivalent. This is well below the 2.5% annual improvement experienced between 1980 and 2009. Industry estimates range between 1.3 and 2.5% per year. (See Topic Paper #2, "Rail Transportation Demand," on the NPC website for discussion on freight rail fuel efficiency.) Due to the long capital replacement cycle of the industry—locomotives have a 40-year life, for instance—full deployment of new technologies takes roughly 30 years. The industry's estimated range for fuel efficiency improvements is therefore based on certain technologies in the midst of deployment.

As with truck, the rail freight projections are based on the projected growth and industrial mix in the economy. The AEO2010 projections with

22 Research and Innovative Technology Administration, Bureau of Transportation Statistics, "Table 1-46a: U.S. Ton-Miles of Freight," *National Transportation Statistics*, Internet Edition, http://www.bts.gov/publications/national_transportation_statistics/html/table_01_46a.html.

23 Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 30,* June 2011. Prepared for U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.

24 U.S. Class I railroads include Norfolk Southern, CSX Corp., BNSF, Kansas City Southern, and Union Pacific.

25 Federal Railroad Administration, Department of Transportation, "Freight Railroads Background," February 2008, http://www.fra.dot.gov/downloads/policy/freight5a.pdf.

26 Association of American Railroads, Policy and Economics Department, "Railroads and Coal," August 2010, http://www.aar.org/~/media/aar/backgroundpapers/railroadsandcoal.ashx.

27 U.S. Department of Energy, Energy Information Administration, "U.S. Coal Production."

28 Association of American Railroads and Atlantic Systems, U.S. railroad traffic originated: intermodal car loadings.

29 Ibid.

30 Bureau of Economic Analysis, Department of Commerce, U.S. GDP: Imports: Goods.

extrapolations to 2050 do not address uncertainties and opportunities related to the rail transportation system that are associated with possible regulatory changes and/or modifications to operations.

Regulatory and Operational Changes Add Uncertainty to Rail Ton-Mile Projections

Environmental regulations that would reduce the consumption of coal pose a significant risk to the current Class I business model. Changes in the mix of freight, depending on the volume and time to adjust, could pose financial challenges that would likely reduce investment in infrastructure and equipment. This could slow the rail services growth projected for the non-coal sectors and increase the growth in freight transportation by HD vehicles.

Opportunities for improving rail system efficiencies and modal shift include improvements in material handling equipment for loading and offloading intermodal containers, and as described in the truck section, use of wireless communications to better coordinate loads with motor carriers.

Growth in warehouse centers and expansion of the hub and spoke model is another opportunity. Producers or importers ship freight via rail to a warehouse located near the population center where it will be further processed or consumed. There the freight is broken into truck loads and shipped to its final destination. The chief challenge is building and financing the infrastructure required.

Water Transportation

Water freight transportation accounted for 4% of transportation energy consumed in 2010, and the AEO2010 projects it will maintain that share through 2035. Domestic shipping was 13% of total intercity freight ton-miles in 2007,[31] the last year data for all modes was available. Domestic shipping, which includes inland waterways, lakewise, coastwise, and intraport transport, accounted for 25% of energy consumed by water transportation, or about 1% of total transportation energy. Bunker fuel for international shipping accounted for the remaining 3%.

Domestic shipping ton-miles peaked in the 1980s and in 2008 were down to levels last seen in the late 1960s.[32] Despite this downward trend, the AEO2010 projects that domestic shipping ton-miles will grow on average 0.4% per year through 2035. International shipping energy consumption is tied to gross imports and exports and is expected to grow 0.6% per year.

Similar to rail, water shipping is an important alternative mode of transporting freight versus road transport. Failure to maintain water freight competitiveness with other modes has the possibility of increasing on-road congestion, fuel consumption, and emissions.

For this analysis, the NPC uses the AEO2010 shipping and energy consumption projections to 2035 with extrapolation of trends from 2035 to 2050.

Modal Shifts

Freight transportation services by road, rail, and water accounted for 25% of total transportation energy consumed in 2005 and is projected to rise to 28% by 2035. The key factors driving freight services are the overall growth in economic activity and the industrial composition of the total output. The freight modal shares are determined by the share each mode has in transporting goods for specific industries and the relative size of the industries to total output. For instance, rail is the primary carrier of coal and other mined products, so its modal share is higher under conditions that favor mining in the industrial mix of the economy.

The AEO2010 does not project shifts in modal share based on strategies of competing modes within an industrial sector or changes to regulations. The implication is that if one mode becomes relatively more efficient over the projection horizon, the projected services demanded does not reflect a shift toward that mode. Fuel demand by that mode will grow more slowly, or possibly decline, due to the efficiency improvement, but will not be offset by increases in demand for services. This is a limitation in the AEO projections and the NPC extrapolations.

Transportation energy efficiency improves if freight is moved from on-highway truck to rail

31 Research and Innovative Technology Administration, Bureau of Transportation Statistics, "Table 1-46a: U.S. Ton-Miles of Freight," *National Transportation Statistics*, Internet Edition.

32 Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 30*, June 2011. Prepared for U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.

or water. Attempts have been made to quantify the relative ton-mile fuel efficiency of the modes in order to estimate the potential impact on fuel consumption and emissions from shifting specific amounts of freight to alternate modes.[33,34] The challenge with such analyses is that freight and freight corridors and transportation modes are not homogeneous. The potential to shift freight is a function of the amount of freight that is modally competitive.

The Center for Urban Transportation Research at the University of Southern Florida provided a literature review of studies investigating shippers' modal choice and grouped factors into total logistics costs, physical attributes of goods being shipped, distance of the shipment, and modal characteristics such as trip time and reliability, and handling quality.[35] Their purpose was to provide policy makers with information to assist in creating policies that would encourage modal shifts. From the perspective of this study, it highlights the complexity of shippers' decisions and the limited substitution potential of one mode for another.

Winebrake and Corbett proposed an analytical approach to estimate the potential that modal shifts could have on energy consumption. Their framework requires an estimate of the share of freight in which the cargo is compatible for the modes, an estimate of the share of shipments where both infrastructures exist, and an estimate of the share of shipments in which the shift is economically feasible. The product of these shares reflects the set of freight shipments with compatible characteristics and so could potentially shift modes. Their framework is a way to conceptualize the challenges of measuring the opportunity and managing expectations on the potential. They do not offer a national estimate of freight that is compatible across modes.

Despite the challenges of evaluating the opportunities, modal shifts from truck to rail or water will generally reduce energy consumption. Information technologies are being developed to assist shippers in evaluating their mode choices. The same technologies can be used by policy makers to understand the gaps along a freight corridor and evaluate possible solutions. Winebrake, et al.[36] describe such a geospatial information system model, GIFT, developed jointly by the University of Delaware and Rochester Institute of Technology. It analyzes the cost, energy, and emission attributes of alternative routes between nodes. The user can choose which of these criteria the system should optimize. In other work, Winebrake and Corbett[37] argue that most information systems treat alternative modes as strict substitutes, but benefits can accrue when they are treated as complements as the GIFT system does.

Demand Uncertainty

At the inception of this study, the AEO2010 was the most recent outlook. As this study developed, additional editions of the Annual Energy Outlook were released, with the AEO2012 Early Release being the most recent. Comparisons between the more recent editions of the Annual Energy Outlook and the study Reference Case highlight the degree of uncertainty that exists in the projection of transportation energy demand.

A high degree of uncertainty exists in the key indicators and resulting projections of transportation services demanded. In addition, as the foregoing discussions indicated, uncertainty regarding regulations and operational innovations add to the uncertainty of the projections. Changes in one or more of these areas can have significant impact on the projections for transportation services and energy consumption, as seen by the comparison of the AEO2010 with more recent editions.

Comparing the VMT projections for on-road modes in recent AEO editions highlights the degree

33 James C. Kruse, Annie Protopapas, Leslie E. Olson, and David H. Bierling, "Table 13. Summary of Fuel Efficiency," in *A Modal Comparison of Domestic Freight Transportation Effects on the General Public*. Texas Transportation Institute, December 2007, Amended March 2009. Report prepared for U.S. Maritime Administration and National Waterways Foundation.

34 PEW Center on Global Climate Change, Climate TechBook, Freight Transportation, June 2010, p.12 table 1, http://www.pewclimate.org/technology/factsheet/FreightTransportation.

35 The Center for Urban Transportation Research, University of South Florida, Analysis of Freight Movement Mode Choice Factors, 2004. Report for Florida Department of Transportation, Rail Planning and Safety, Award # B-D238.

36 James J. Winebrake, James J. Corbett, Aaron Falzarano, J. Scott Hawker, Karl Korfmacher, Sai Ketha, and Steve Zilora, "Assessing Energy, Environmental, and Economic Tradeoffs in Intermodal Freight Transportation," *Journal of the Air and Waste Management Association* 58, no. 8 (August 2008): pages 1004-1013.

37 James J. Winebrake and James J. Corbett, "Chapter 13: Improving the Energy Efficiency and Environmental Performance of Goods Movement," in *Climate and Transportation Solutions: Findings from the 2009 Asilomar Conference on Transportation and Energy Policy*, Institute of Transportation Studies, University of California, Davis, March 2010.

of uncertainty and the risk in setting policy to achieve an absolute level of energy consumption or GHG emission in the future. Figure 1-5 shows that by the year 2035, LD vehicle VMT is 14% lower in the AEO2012 Early Release compared to the AEO2010 and MD vehicle VMT is 16% lower, while HD vehicle VMT is about even.

In the AEO2012 Early Release, GDP is only 2% lower by 2035, which does not by itself explain the lower VMT for LD and MD vehicles. There is a structural difference in the macroeconomic assumptions between the two outlooks. For example, personal disposable income in the AEO2010 is 80% of GDP compared to 74% in the 2012 Early Release. This results in an 8% reduction in the LD vehicle fleet and 7% reduction in VMT per vehicle. Similarly, the value of shipments by 2035 in the 2012 Early Release was 18% lower than in the AEO2010. This contributed to the lower MD vehicle VMT. Industrial sector output was less than 1% lower in the 2012 Early Release, which resulted in little change in HD vehicle VMT.

While this uncertainty is recognized, the primary focus of this study is on comparing the impact of different fuel-vehicle systems. This is accomplished by holding demand constant using the AEO2010 projections. The NPC findings are stated in relative terms and are directionally and ordinally valid.

DEMAND FOR TRANSPORTATION SERVICES – KEY INSIGHTS AFFECTING STUDY FINDINGS

- Transportation services demanded—VMT, air passenger seat miles, and freight ton-miles—are projected to grow through the study horizon. This follows because they are largely determined by economic and population growth.
- Transportation services are less sensitive to energy prices than is energy consumption. Higher energy prices increase the cost of operating vehicles and so discourage use; but higher prices also encourage adopting more efficient vehicles. The combined effects cause energy

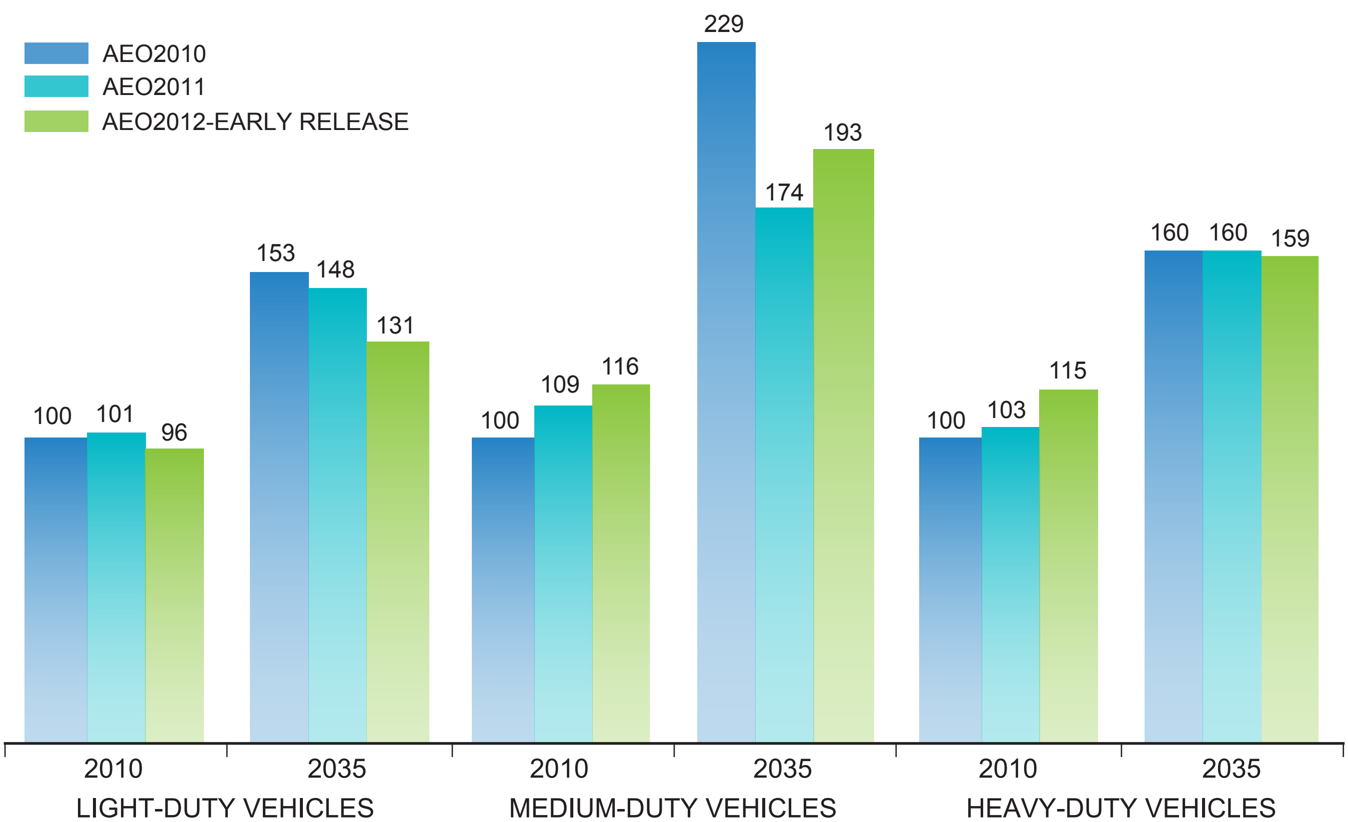


Figure 1-5. *Comparison of Vehicle Miles Traveled by On-Road Modes Across AEO Editions (Values Indexed to AEO2010 Values by Mode – 2010 = 100)*

consumption to fall proportionally more than transportation services.

- LD vehicle VMT is projected to continue increasing but the rate of growth is slowing due to projected trends in demographics, economic activity, and stabilizing labor participation rates, household size, and use of alternate modes of transport.
- Air transportation demand, expressed in seat miles, is expected to continue to grow; however, industry projections for future growth are much higher than assumed in the AEO2010.
- Growth in truck services—MD and HD vehicle VMT—are largely determined by economic activity, with MD vehicle VMT growth more closely tied to the services and retail trade sectors and HD vehicle VMT more closely tied to manufacturing. HD vehicles are used in long-haul and regional-haul applications and account for about 75% of total truck VMT.
- Freight rail transport constitutes a relatively small portion of energy demand, but a much larger share of total freight movements. Rail ton-mile growth will depend on changes to coal transport balanced by opportunities for increased intermodal service.
- Waterborne transportation demand is projected to increase despite a historical downward trend in domestic freight and product movements, largely on the basis of increased international shipping.
- Significant uncertainty exists in projecting transportation services demand.