

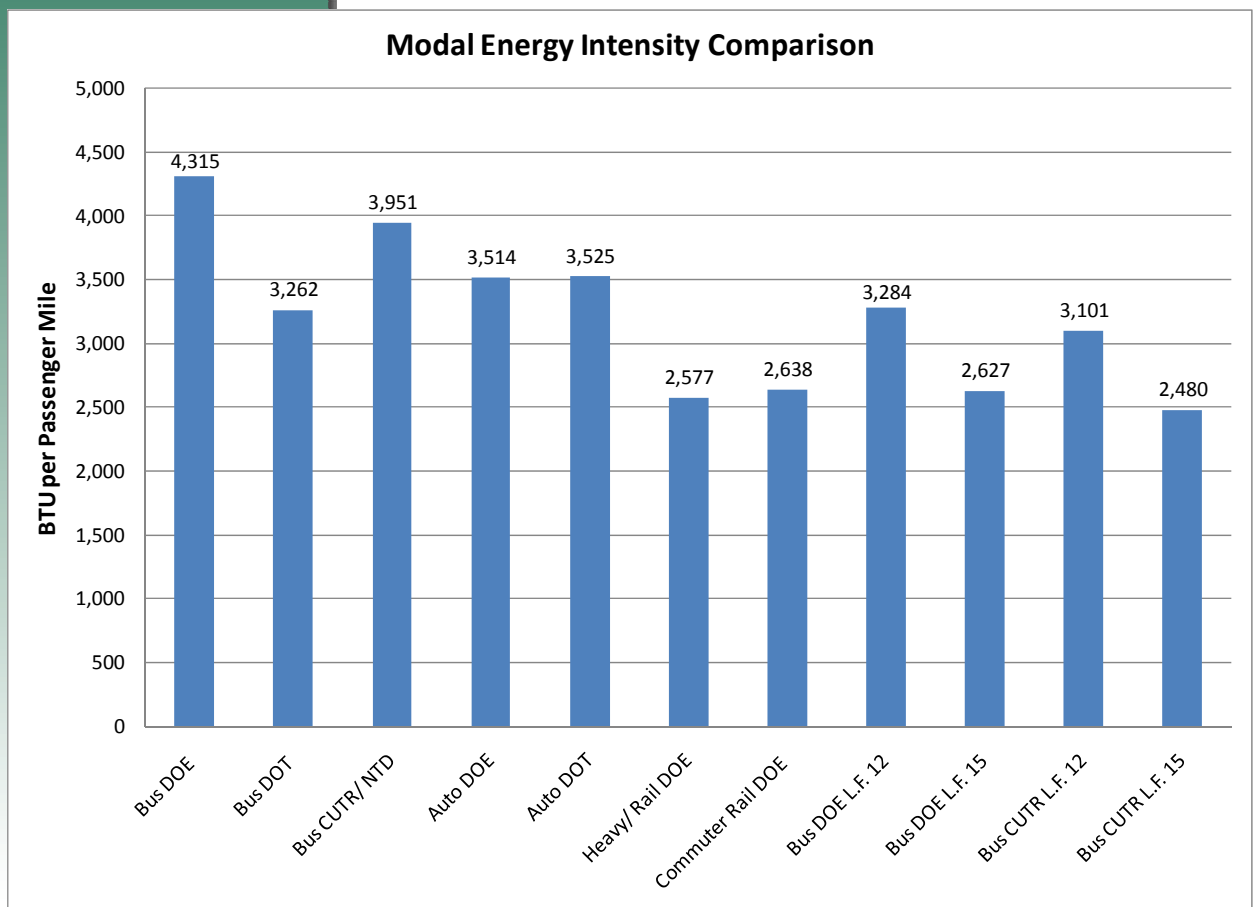
Prepared by

**National Center
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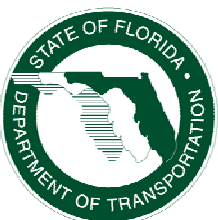
Exploration of Transit's Sustainability Competitiveness

March 2011
Final Report



Funded by

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Exploration of Transit's Sustainability Competitiveness

Draft Final Report

Prepared for



State of Florida Department of Transportation

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March 2011

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
 1 foot (ft) = 30 centimeters (cm)
 1 yard (yd) = 0.9 meter (m)
 1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in²) = 6.5 square centimeters (cm²)
 1 square foot (sq ft, ft²) = 0.09 square meter (m²)
 1 square yard (sq yd, yd²) = 0.8 square meter (m²)
 1 square mile (sq mi, mi²) = 2.6 square kilometers (km²)
 1 acre = 0.4 hectare (he) = 4,000 square meters (m²)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
 1 pound (lb) = 0.45 kilogram (kg)
 1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
 1 tablespoon (tbsp) = 15 milliliters (ml)
 1 fluid ounce (fl oz) = 30 milliliters (ml)
 1 cup (c) = 0.24 liter (l)
 1 pint (pt) = 0.47 liter (l)
 1 quart (qt) = 0.96 liter (l)
 1 gallon (gal) = 3.8 liters (l)
 1 cubic foot (cu ft, ft³) = 0.03 cubic meter (m³)
 1 cubic yard (cu yd, yd³) = 0.76 cubic meter (m³)

TEMPERATURE (EXACT)

$[(x-32)(5/9)]^{\circ}\text{F} = y^{\circ}\text{C}$

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
 1 centimeter (cm) = 0.4 inch (in)
 1 meter (m) = 3.3 feet (ft)
 1 meter (m) = 1.1 yards (yd)
 1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm²) = 0.16 square inch (sq in, in²)
 1 square meter (m²) = 1.2 square yards (sq yd, yd²)
 1 square kilometer (km²) = 0.4 square mile (sq mi, mi²)
 10,000 square meters (m²) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
 1 kilogram (kg) = 2.2 pounds (lb)
 1 tonne (t) = 1,000 kilograms (kg)
 = 1.1 short tons

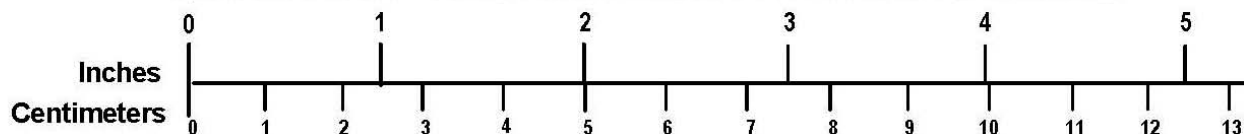
VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
 1 liter (l) = 2.1 pints (pt)
 1 liter (l) = 1.06 quarts (qt)
 1 liter (l) = 0.26 gallon (gal)
 1 cubic meter (m³) = 36 cubic feet (cu ft, ft³)
 1 cubic meter (m³) = 1.3 cubic yards (cu yd, yd³)

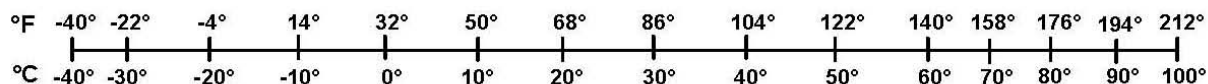
TEMPERATURE (EXACT)

$[(9/5)y + 32]^{\circ}\text{C} = x^{\circ}\text{F}$

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Executive Summary

The providers of public transit have a strong interest in sustainability. As a “mass” means of travel, public transit long has been acknowledged as an efficient mode, offering economy of energy use and space as a result of larger vehicles with considerably higher occupancy per vehicle. Empirical data on system performance validated that claim, and industry marketing regularly references energy efficiency as a public transit virtue.

With growing interest in climate change and greater anticipation of energy cost increases, being sustainable has implications for the financial efficiency of transit agencies and on the image and appeal that transit has to offer customers and prospective customers. Being more resource efficient can help the agency financially, increase its ridership and public support, and increase its contribution to broader national goals of moving toward a more sustainable transportation system. Collectively, these considerations provide strong motivation for transit to strive toward greater sustainability and articulate its contributions toward a more sustainable transportation system to the public and policy makers. Towards that end, this research initiative explores selected aspects of public transit’s sustainability.

This report provides a framework for discussing the energy impacts of public transit, then reviews selected information items from that framework to report on the energy efficiency of public transit operations. In addition to exploring data from current national and Florida transit agencies, it reviews the best current forecasts of future conditions regarding modal energy efficiency and provides information that can help planners as they conduct impact analyses for longer-range transit investments. The primary focus is on fixed-route bus operations, both as the dominant mode in Florida and as a means of bounding the research.

The data regarding the fuel efficiency of public transit bus travel have been explored in detail, with results that may be surprising to many. First, the message from the data is confused by differing sources and significantly different results. Closer scrutiny suggests that the actual performance for bus transit may be poorer than often reported, and far poorer than commonly perceived. Based on national averages, with today’s technologies and ridership levels, transit bus use is not a more fuel-efficient way to travel than auto, on average. (This does not apply to the marginal user who chooses to occupy available transit capacity, nor does it correct for context differences between transit travel environments and auto travel environments.) When adjusting for context differences, the modes appear to be virtually identical in terms of BTUs per passenger mile.

There is promising evidence that transit efficiency has improved over the past several years after a multi-decade decline in efficiency. Recent service cuts motivated by trying financial times are likely to result in further improvements as poorer-performing services are reduced. Promising trends for transit technology are apparent with hybrid and alternative-fueled vehicles

improving efficiency, but these improvements will be competing with a light vehicle fleet comprising vehicles subject to much stricter Corporate Average Fuel Economy (CAFE) standards in future years. The benefits of these new technologies are likely to be most pronounced in urban environments, resulting in the competitive battle for efficiency claims remaining challenging for transit bus.

The single most critical factor for transit efficiency is the ability of transit to attract larger loads on existing services. On average, transit operates with extensive excess capacity, and increasing the utilization of that capacity is a critical step in improving transit's contribution to sustainability goals. However, this is not without challenges, and the relatively tight clustering of agency average productivity indicates there are no easy ways to increase service utilization.

Looking ahead, the relative energy efficiency will be dependent on the pace of technology development and deployment in the respective modes and the utilization of transit. The path forward for auto efficiency will be shaped in the near term by the aggressive CAFE standards set for the next few years. The extent to which these standards translate into a more efficient fleet and the ultimate standards for subsequent years will determine the longer-term efficiency of light vehicle travel. The pace of transit technology adoption will be partially dependent on the resource commitments directed toward new technologies. This is perhaps more critical for transit vehicles as, currently, the relative costs of the new technologies are significantly more for transit bus than for light vehicles.

Trends of energy use for Florida transit properties that report energy use through the National Transit Database (NTD) also are presented. Florida has several agencies whose energy use per passenger mile of travel is well above industry averages, as would be expected, given Florida's relatively modest transit use levels. Several of the agencies have BTU-per-passenger-mile numbers above 5,000, well beyond the average levels of private vehicle travel and comparable to single occupant vehicle travel. Thus, many locations in Florida are not providing energy savings through their transit services.

This initial work also confirmed with empirical national data the relationship between travel and the presence of transit and the land use environment in which transit is provided. This work confirmed that proximity to transit does correlate with different travel behaviors that are more sustainable. Adults in households near transit travel less and generally on more efficient modes. The work uncovered a unique finding in that these behaviors varied significantly across income quartiles, as high income individuals in these locations did not travel less or necessarily on more efficient modes. This has potential significant implications on development policy.

The magnitude of the impacts on travel that are observed across development patterns has been a critical policy consideration in national and local transportation-land use policy. Risks and uncertainties surround leveraging this relationship. The ability of transit investment and/or

land use policy to create environments similar to those that now require less travel is dependent on both the willingness of additional persons to be attracted to those environments and the extent to which travel behaviors change to reflect those of current urban residents who have access to transit.

Finally, the non-propulsion energy cost of transit operations has been growing as transit has become more infrastructure-intensive. While efforts to adopt green standards are commendable and will help support overall efforts to improve transit energy efficiency, the industry has to be cognizant of the fact that efforts to increase the attractiveness of transit services through such things as transit centers and stations with various customer amenities also have ongoing energy operating costs.

Transit's role in addressing energy efficiency is a noble goal and one in which transit may be able to make a contribution in certain contexts. However, the industry will have to be highly disciplined in ensuring that it retains its relative competitiveness regarding energy efficiency by striving for well-utilized services and exercise care in vehicle specification and selection, logistics, and supporting infrastructure. The industry should exercise caution in energy savings claims, as the current performance is modest and not necessarily consistent with perceptions of high efficiency levels. The single best way to produce travel energy savings is to attract current light vehicle trips to existing transit services where capacity exists. Guideway modes can offer higher levels of energy efficiency due primarily to their high capacity, but this is premised on their deployment in markets where that capacity is utilized sufficiently to leverage the technology's energy-efficiency potential. Thus, opportunities to leverage this potential are relevant only in high volume locations.

Finally, an opportunity for transit to contribute to energy efficiency can be realized if transit can be successful in encouraging people to choose a residential location and adopt travel habits that are less reliant on private vehicle travel. The transportation planning profession is still learning about the extent to which urban design can induce development such that this efficiency can be leveraged.

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Introduction

The providers of public transit have a strong interest in sustainability. As a “mass” means of travel, public transit long has been acknowledged as an efficient mode, offering economy of energy use and space as a result of larger vehicles with considerably higher occupancy per vehicle. Empirical data on system performance validated that claim, and industry marketing regularly references energy efficiency as a public transit virtue.

With growing interest in climate change and greater anticipation of energy cost increases, being sustainable has implications for the financial efficiency of transit agencies and on the image and appeal that transit has to offer customers and prospective customers. Being more resource efficient can help the agency financially, increase its ridership and public support, and increase its contribution to broader national goals of moving toward a more sustainable transportation system. Collectively, these considerations provide strong motivation for transit to strive toward greater sustainability and articulate its contributions toward a more sustainable transportation system to the public and policy makers.

Towards that end, this research initiative is targeted towards exploring selected aspects of public transit’s sustainability. This research is integrated into a family of research initiatives at the state and federal levels that addresses various aspects of sustainability as it relates to public transit. This particular research project, “Exploration of Transit’s Sustainability Competitiveness,” is targeted to explore the empirical data and trends regarding transit’s energy consumption.

This report first provides a framework for discussing the energy impacts of public transit, then reviews selected information items from that framework to report on the energy efficiency of public transit operations. In addition to exploring data from current national and Florida transit agencies, it reviews the best current forecasts of future conditions and provides information that can help planners as they conduct impact analyses for longer-range transit investments. The primary focus is on fixed-route bus operations, both as the dominant mode in Florida and as a means of bounding the research.

Modal Energy Use Analysis Framework

Discussions of the role of public transportation in supporting a sustainable physical environment have to be based on a framework for discussion or analysis that underlies and bounds the discussion. Towards that end, this section outlines an overall framework for discussing energy use in the context of public transportation. For purposes of this analysis, sustainability is addressed from the perspective of energy use. Financial sustainability or other environmental impacts of mobility, such as direct and indirect impacts on habitats resulting from the space consumption associated with mobility choices and the subsequent land use patterns they enable or support, are not addressed directly in this analysis of transit sustainability.

The framework following is based on modifications and updating of a framework first developed by the Congressional Budget Office in the aftermath of the 1970 energy shortages. Having a framework is critical to understanding the implications of the findings that will be presented in subsequent sections of this report. Terminology and classifications of the various energy impacts vary across analyses; thus, it is important to have an understanding of the definitional and measurement framework to understand the observations and data in any given report on modal energy efficiency. As Figure 1 portrays, there are various measurement possibilities when trying to understand the energy use of various means of travel.

In addition to exploring the various measurements of energy use, there are issues associated with whether energy analysis is discussing hypothetical or potential energy efficiency versus actual or empirical energy efficiency. Closely related is the issue of whether or not the analysis is for present or anticipated future conditions.

Each of the possible measures of energy use, as noted in Figure 1, is briefly discussed below.


This exploration of transit's sustainability competitiveness focuses on the energy use aspects of public transportation. Select energy implications of transit are explored in detail.

Operating Energy Intensiveness

This is the most commonly used and perhaps simplest measure of energy use because the required data are relatively available. It is also, however, the most limited measure because it includes only the energy required to move the vehicle and power the vehicle's amenities (lighting, heating, air conditioning, etc.). This measure typically is represented as propulsion energy per passenger trip or per passenger mile. The measure of miles per gallon (or per kilowatt hour) that a vehicle can achieve has been widely used to describe vehicular fuel economy. To equate across fuel types, measures can be expressed in equivalent terms using British Thermal Units (BTUs). As vehicles have added amenities, especially air conditioning and heating, auxiliary energy uses have become more significant. Power for lighting, cameras and information systems, fare collection, kneeling, ramps or lifts, communications, etc., can add to the total vehicle energy consumption.

Operating energy intensiveness also incorporates a measure of modal capacity or use. The most common measure is passenger miles as that reflects the occupancy of the vehicle capacity over the travel path. Some analysts use measures per trip as they believe that reflects the energy cost of transportation for carrying out an activity regardless of the length of travel required to access that activity. Measures of energy use per "seat" or per "place" can provide insight into the inherent efficiency of the technology, but a truer analysis should reflect the actual or potential operating environment.

Figure 1 Transportation Energy Use Measurement Concepts¹

Complexity and Uncertainty	Basic Energy Use Component	Possible Measures of Energy Use					
	Propulsion energy per vehicle mile	Operating Energy Intensiveness	Energy Intensiveness	Lifecycle Energy Intensiveness	Modal Energy Intensiveness	Transportation Energy Impact	Total Energy Impact
	Average number of occupants						
	Fuel production and delivery			Lifecycle Energy Intensiveness	Modal Energy Intensiveness	Transportation Energy Impact	Total Energy Impact
	Facility and maintenance energy						
	Construction/recycling energy						
	Vehicle manufacturing /recycling energy						
	Mode of access			Lifecycle Energy Intensiveness	Modal Energy Intensiveness	Transportation Energy Impact	Total Energy Impact
	Network circuitry						
	Travel and location behavior changes			Lifecycle Energy Intensiveness	Modal Energy Intensiveness	Transportation Energy Impact	Total Energy Impact
	Non-travel energy consequences of transportation						

Empirical data to support operating energy intensiveness are derived from actual use and, as such, reflect the technology performance across the average operating context in which it operates and for which the data are available. It does not necessarily reflect the operating energy intensiveness comparisons that would be most appropriate if the technology were operated in similar contexts. In the context of comparison of transit with personal vehicle travel, this means that empirical operating energy intensiveness data compare transit use in the predominately urban and peak-period operating environments where most of the transit mileage is logged with average private vehicle use that reflects average light vehicle operations. Some analysts recognize the need to adjust or acknowledge this difference in carrying out comparisons; however, technology comparisons often go unqualified. This will be discussed more in subsequent sections.

¹ Framework based on significant modifications to framework in "Urban Transportation and Energy: The Potential Savings of Different Modes," Congress of the United States, Congressional Budget Office, December 1977.

Energy Intensiveness

Some analysts attempt to determine the energy used to produce and deliver the fuel for travel vehicles to the site of consumption. Different fuels have different amounts of energy consumed in finding or producing, processing, transporting, and storage. As this is very difficult to measure and allocate absent a location-specific energy intensiveness analysis, it is not a topic that will be addressed in this research. However, it should be acknowledged that delivering a BTU of tar-sands-extracted diesel fuel to New York may be far more energy intensive than delivering an equivalent number of BTUs of natural gas from Pennsylvania.

Life Cycle Energy Intensiveness

This measure is more comprehensive than energy intensiveness since it includes the energy used to operate stations and maintain vehicles as well as the energy used to construct travel ways and supporting infrastructure and to manufacture vehicles. For transit, propulsion energy is the largest single component of line-haul energy, with station and maintenance energy usually second. More recently, the energy cost of recycling or disposing of the assets after their useful life has been included in these calculations by some analysts.

Station and maintenance energy becomes more significant as these facilities become more significant. The physical size of these facilities and the amenity levels (heating, cooling, lighting, security, elevators, escalators, hot water, etc.) affect the energy use levels both in the construction and the ongoing operation. Construction energy use is related to the magnitude of the construction effort. Huge quantities of energy are needed to dig tunnels, make and haul concrete, and perform the thousands of other tasks that go into building transportation facilities. Since construction energy is expended only once, its use is amortized over the total mobility provided by the facility over its life. Thus, greater efficiency is realized when the asset scale is in proportion to the volume of travel accomplished on the facility. Vehicle manufacturing energy, like construction energy, is spent once for a product that has a long life. The result is a relatively small expenditure per vehicle mile. Vehicle manufacturing energy tends to be relatively small and of relatively modest importance in most comparisons of modal energy efficiency.

Life Cycle Energy Intensiveness is computed by adding to propulsion energy the energy needed to operate stations and maintain vehicles and roadways and the energy needed to construct facilities and manufacture vehicles. Energy for construction and manufacturing is converted to a per-mile basis using the estimated life, in vehicle miles, of roadways and vehicles, respectively. Computations are transformed to a passenger-mile basis by applying the average number of occupants used to compute energy intensiveness.

Modal Energy Intensiveness

Combining the additional energy consumed in access and circuitry with either life-cycle energy or energy intensiveness sometimes can result in shifts in relative modal energy efficiency. Many of the characteristics needed to estimate modal energy (for example, access distance and circuitry) are highly variable and poorly documented. Nevertheless, a balanced view of overall modal energy use must take these factors into account.

Most short transit trips are made by walking to a bus stop (or transit station), riding to another stop, and then walking to a destination. Long transit trips frequently involve making a trip by automobile or feeder bus to reach the main part of the system. In such cases, the access mode often requires more energy per passenger mile than the principal or line-haul mode. Access energy requirements must be included along with line-haul energy requirements if a full picture of transport energy consumption is desired. To allocate access energy requirements to the principal or line-haul mode, it is necessary to know what proportion of a typical trip is devoted to access. Given information on access energy per passenger mile, this proportion (access miles/total miles) can be used to allocate access energy to the total trip energy.

Since few passenger trips go directly "as the crow flies," some circuitry is inevitable in passenger travel.² In examining the energy efficiency of different modes, adjustments should be made for these additional, nonproductive miles of travel. As transit networks are less dense than roadway networks, in general, and often have a radial orientation requiring many connections to be made in a central location, there is likely to be more circuitry in transit travel. Thus, to get between any two given points, it is likely to involve traveling longer distances by transit, and this difference should be adjusted if the intention is to present modal energy intensiveness comparisons. Since many energy computations are made on a per-mile basis, a mode that requires nonproductive mileage would be given an unfair advantage in terms of its comparative energy efficiency if circuitry were not taken into account.

Modal energy measures would combine line-haul energy with access energy requirements, and then adjust the total for circuitry. The computation involves three steps. First, the line-haul energy requirements of each access mode are multiplied by the fraction of trips that use the mode for access, and these products are summed to yield the average energy required per passenger mile of access travel. Second, the average total energy (line-haul plus access) is computed, using as a weight the fraction of each trip that is accessed. Third, the average total energy is multiplied by the circuitry to obtain an estimate of total energy.

This final result is referred to here as modal energy intensiveness.

² As used here, circuitry refers to the door-to-door trip distance of a mode relative to the corresponding distance by automobile. Automobile is used as a base because it is generally the most direct form of urban passenger transportation.

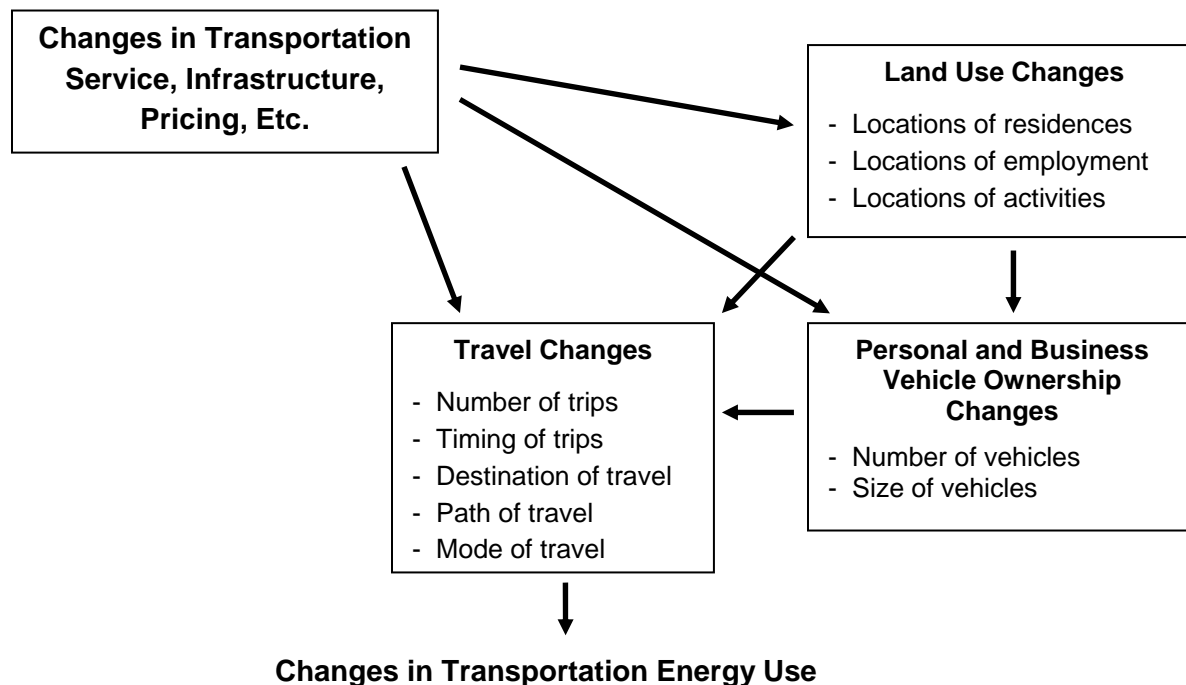
Transportation Energy Impact

In addition to the considerations mentioned above, the fuel savings of alternative urban transportation programs depends on how people use them relative to other existing systems. A full understanding of this is more complex than just understanding the mode shift between modes. Programs to promote energy-efficient urban transportation modes attempt to shift travelers from modes that are relatively inefficient in terms of energy to modes that are efficient. Usually, the goal is to get people out of their cars and into self-propelled modes (bike and walk) or onto public or group transportation of some sort. Experience with improvements in public transportation, however, shows that new systems also attract patrons from other public transportation services and carpools, as well as people who did not travel previously. In evaluating the changes in total energy consumption when a new program or investment is introduced, a realistic comparison can be made only if there is a full understanding of how travel behavior is affected.

Among the elements of travel behavior that may be affected by policy, service, or investment are number of trips, timing of trips, destination of travel, path of travel, and mode of travel. Changes in transportation choice, pricing, network configuration, etc., are likely to have some direct impacts on travel behavior. In addition, transit investments in services and facilities increasingly are intended to alter travel behavior indirectly, as the change in transportation service impacts people's location decisions for residences, workplaces, and activities as well as private vehicle ownership. Specifically, in the case of transit, it often is hoped that a transit investment will result in location decisions that leverage the transportation investment changes and result in reductions and shifts in travel demand that produce energy impacts beyond simply shifting person miles between modes.

Figure 2 presents a diagram of these relationships. These interactions are complex, dynamic, and influenced by a host of considerations beyond transportation policy and investment and can occur over years. Nonetheless, this holistic perspective reflects theoretical and empirically-supported relationships and is of growing interest to policy makers in light of climate change and energy cost/availability concerns. Given these relationships, the collective energy impacts of significant changes in transportation options and performance characteristics can be far more significant than energy impacts that might be attained solely by shifts in modes. Hence, fully understanding the energy/sustainability impacts of transportation policy and investment remain very relevant to policy formulation.

Figure 2 Responses to Transportation Changes that Impact Energy Use



Efforts to quantify the nature of the energy impacts of individual policy initiatives and investments or families of changes are complex and can involve a variety of simulations or methods of forecasting the various components of change. The methods vary from attempts to isolate the individual factors and their impacts to aggregate comparisons across contexts, with qualified attribution of the different traits being able to create the measured differences in aggregate energy use. The validity of these aggregate analyses often are challenged regarding the tendency for self selection of environments by certain individuals and questions as to whether or not that behavior can be caused in other individuals as a result of transportation policy and investment decisions.³ Examples of complex scenario analysis of transportation policies targeted at influencing travel are provided in the report "Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions."⁴

Total Energy Impact

Total energy impacts goes a step beyond measuring transportation energy impacts to include the changes in energy use for non-transportation purposes that might be brought about by the changes in transportation. For example, if transportation investment and policy can bring about different land use densities and patterns, those differences might translate into differences in

³ For a comprehensive discussion, see Boarnet and Crane, *Travel by Design*, Oxford University Press, 2001.

⁴ Cambridge Systematics, Inc., "Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions," prepared for Moving Cooler Steering Committee, July 2009.

energy use for heating and cooling infrastructure, distribution of utilities, building construction, operating services, etc. Evaluating this type of energy impact required an even more sophisticated analysis framework and is fraught with complexity, questions regarding causality, and uncertainty. Literature on the “cost of sprawl” provides some insight into this issue.⁵

Figure 2 highlights the two topic areas that are discussed in this report. First, attention will be directed at exploring operating energy intensiveness. This is a very visible and fundamental measure of sustainability to which the public relates, as their decisions on mode choice and vehicle purchase and use impact comparisons of energy intensiveness across modes and technologies. Transit vehicle purchase and operating decisions affect the energy intensiveness of the transit mode, and individual decisions on personal vehicle ownership and use as well as governmental policies such as Corporate Average Fuel Economy (CAFE) standards affect the performance of the light vehicle fleet. For all modes, utilization levels of the vehicles are critically important to attained energy intensiveness.

This comparison, while far simpler than some of the subsequent evaluations that are outlined in Figures 1 and 2, remains complex due to data availability, uncertainty of how trends will track going forward, and lack of data to enable true context-specific comparisons. This is discussed in detail in the subsequent section.


The second area that is addressed, in a limited fashion, involves Transportation Energy Impacts, at the other end of the spectrum in terms of inclusiveness of transportation energy use. This area is addressed by comparison of differences in aggregate travel demand across developments that have access to transit and those that do not. While the methodology employed is exploratory in nature, it serves to provide a perspective on the composite energy impact that potentially could be attained if the presence of transit is successful in transforming the land use and behaviors of the surrounding areas to match those of transit-available areas.

Operating Energy Intensiveness: Auto versus Transit - Summary of Literature

This section specifically provides a synthesis of the literature regarding the energy efficiencies of different modes of surface transportation. This section presents the data found and analysis performed during the conduct of the research and focuses primarily on the comparison of urban transit buses and private light-duty passenger vehicles in its assessment. The principal resources that were used for analyzing transportation energy consumption in the U.S. include:

⁵ TCRP Report 74, “Costs of Sprawl—2000,” Transportation Research Board — National Research Council, National Academy Press, Washington, D.C., 2002.

Figure 3 Transportation Energy Use Measurement Concepts – Focus Areas

Complexity and Uncertainty	Basic Energy Use Component	Possible Measures of Energy Use					
	Propulsion energy per vehicle mile	<u>Operating Energy Intensiveness</u>	Energy Intensiveness	Lifecycle Energy Intensiveness	Modal Energy Intensiveness	<u>Transportation Energy Impact</u>	Total Energy Impact
	Average number of occupants						
	Fuel production and delivery						
	Facility and maintenance energy						
	Construction/recycling energy						
	Vehicle manufacturing /recycling energy						
	Mode of access						
	Network circuitry						
	Travel and location behavior changes						
	Non-travel energy consequences of transportation						

The Transportation Energy Data Book, prepared annually by the U.S. Department of Energy (DOE), Center for Transportation Analysis, Energy and Transportation Science Division, Oak Ridge National Laboratory, Tennessee. Editions 28 and 29 were used in this analysis.

National Transportation Statistics, also prepared each year, by the Bureau of Transportation Statistics, Research and Innovative Technology Administration, U.S. Department of Transportation. The 2009 report was the most recent available at the time that the majority of the analysis was conducted. The 2010 version became available at the conclusion of the writing, and some data were incorporated.

Annual Energy Outlook, the annual report produced by the U.S. Energy Information Administration, U.S. DOE. The 2010 Early Release version data were available for analysis.

Public Transportation Fact Book, the annual American Public Transportation Association's (APTA) 2009 document was used primarily, although data from earlier versions were accessed, and some information from the 2010 release is incorporated.

Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2009, U.S. Environmental Protection Agency

While other articles and reports were reviewed, those listed here were relied on heavily as the main sources of data.

This analysis focuses on transit buses and light-duty vehicles. This decision was based on the automobile's use of fossil fuel and attendant air quality issues and the fact that many urbanized areas in Florida and the U.S. rely on the transit bus as the principal public transportation mode. Even when accounting for all of the public transportation ridership on rail in the northeastern U.S., transit buses account for the highest percentage of passenger miles of all of the transit modes.

Overview of U.S. Transportation Fuel Use and Emissions

In 2008, the transportation sector in the U.S. consumed 28 percent of all of the energy used nationally. Of that use, 84 percent of the energy to move passengers and goods was in the form of gasoline and diesel, with the remainder comprising aviation jet fuel, natural gas, and other alternative fuels.⁶ The portion of U.S. petroleum consumption used by transportation had been growing over time as electric utilities and the industrial sector have shifted from petroleum to other sources. These sources continue to come overwhelmingly from fossil fuels, but the transportation sector is, by far, the leader in the consumption of petroleum. Figure 4 illustrates the trend in petroleum consumption since the “first oil crisis” was experienced in the U.S. in 1973.

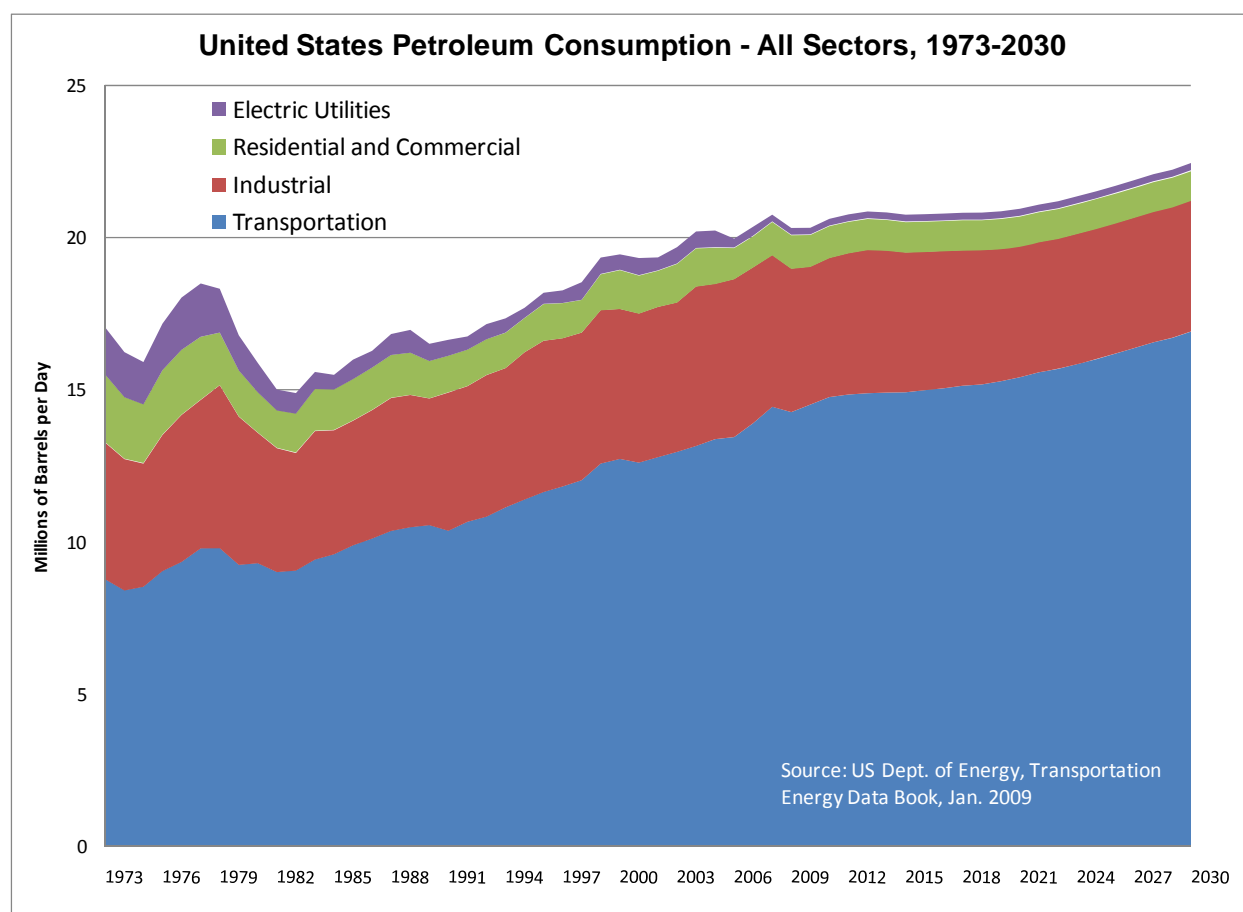
The graph in Figure 4 also illustrates the projections for petrol consumption through 2030 based on the DOE's forecasts. The data indicate that, currently, about 14.4 million barrels per day of petroleum are consumed by the transportation sector nationally, with consumption projected to rise to nearly 17 million by 2030. In the future, transportation is expected to continue to consume the majority of petroleum, with its share increasing, even taking into account increased vehicle fuel efficiency.

Figure 5 was developed from data in the 29th edition of the *Transportation Energy Data Book* and illustrates that while transportation is not the biggest contributor to greenhouse gas (GHG) emissions in the U.S., it continues to contribute the highest level of carbon dioxide (CO₂).⁷

⁶ Energy Information Administration Annual Energy Review, 2009.

⁷ U.S. Department of Energy, *Transportation Energy Data Book*, July 2010.

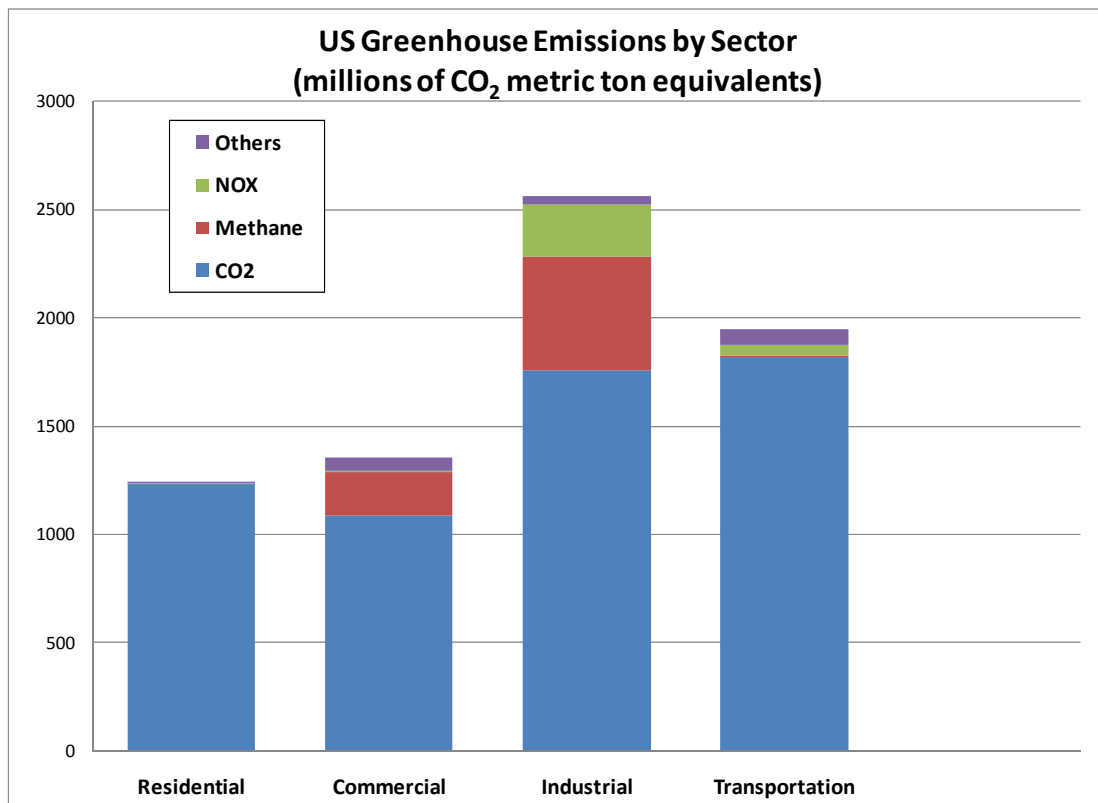
Figure 4 Petroleum Consumption by Sector⁸



Sixty-two percent of the CO₂ emissions in the transportation sector were attributable to automobiles and light duty vehicles in 2008 with all highway transport contributing 85 percent (the difference made up by heavy duty trucks and buses). Air transport was the next largest contributor followed by rail, water and pipeline. It should be noted that the transportation sector's percentage of carbon emissions from the burning of fossil fuel has grown at an average annual rate of 1.1 percent from 1990 to 2008 and from 31.6 percent to 33.2 percent of the U.S. total for the same period.

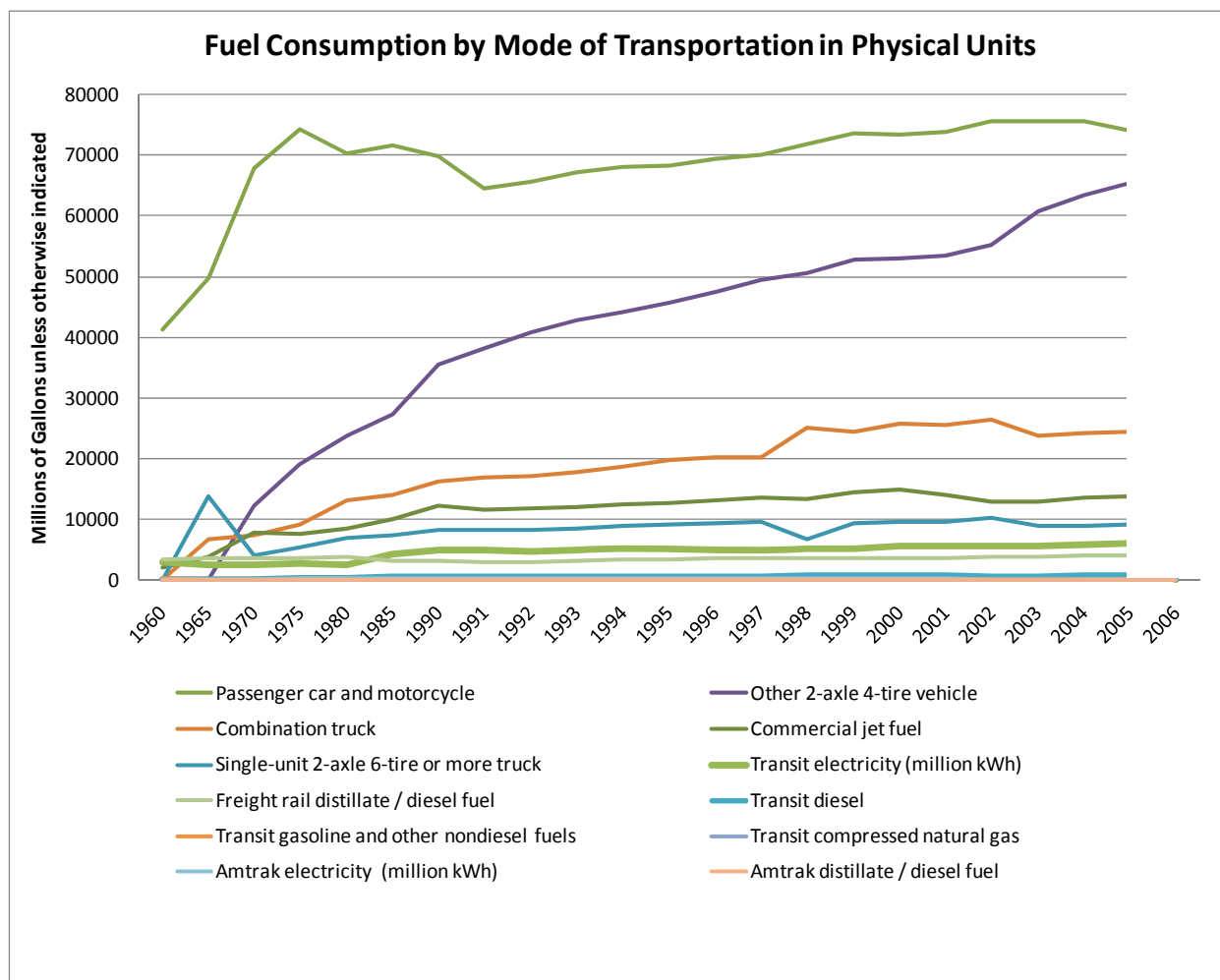
⁸ U.S. Department of Energy, *Transportation Energy Data Book*, January 2009.

Figure 5 U.S. Greenhouse Emissions by Sector



The Bureau of Transportation Statistics (BTS) of the Research and Innovative Technology Administration, U.S. Department of Transportation, tracks the fuel consumption of various modes of transportation. Figure 6 graphically depicts these data from 1960 to 2005 as reported in their latest National Transportation Statistics report. The graph shows the dramatic increase of the energy use of other 2-axle, 4-tire vehicles over the last two decades due to a shift from automobiles to sport utility vehicles for personal transportation. The graph plots “physical units” of energy and displays both gallons of fuel with kilowatt hours of electricity, depending on the mode of transportation. The overall energy use for public transportation is barely visible on the graph as the category of “transit diesel” is indicated by the light blue line just above the x-axis in Figure 6.

Figure 6 Fuel Consumption by Transportation Mode⁹



While this comparison says something about the absolute consumption of energy, it is of limited use when attempting to compare one mode of transportation with another. To move to that evaluation, a common energy unit is necessarily used. A British Thermal Unit (BTU) is a unit of heat equal to the amount of heat required to raise one pound of water one degree Fahrenheit at one atmosphere pressure and is typically used to compare energy use across fuel types. Since most transportation energy consumption is reported in gallons or kilowatt hours, a BTU equivalent can be used for assessment. Although the BTU equivalencies can vary slightly from source to source, in general, Table 1 outlines the BTU equivalents by fuel type. The table, created from data from the NAFA Fleet Management Association, also lists the gasoline gallon equivalent of all of the fuels currently used in passenger transportation.

⁹ U.S. Department of Transportation, Research and Innovative Technologies Administration, Bureau of Transportation Statistics, National Transportation Statistics, Table 4-5, accessed February 2010.

Table 1 Energy Equivalents of Transportation Fuels¹⁰

Fuel Type	Unit of Measure	BTUs Per Unit	Gallon Equivalent
Gasoline, regular unleaded (typical)	gallon	114,100	1.00 gallon
Gasoline, RFG (10% MBTE)	gallon	112,000	1.02 gallons
Diesel (typical)	gallon	129,800	0.88 gallons
Liquid natural gas (LNG) (typical)	gallon	75,000	1.52 gallons
Compressed natural gas (CNG) (typical)	cubic foot	900	126.67 cu. ft.
Liquefied petroleum gas (LPG or propane)	gallon	84,300	1.35 gallons
Methanol (M-100)	gallon	56,800	2.01 gallons
Methanol (M-85)	gallon	65,400	1.74 gallons
Ethanol (E-100)	gallon	76,100	1.50 gallons
Ethanol (E-85)	gallon	81,800	1.40 gallons
Bio diesel (B-20)	gallon	129,500	0.88 gallons
Electricity	kilowatt hour	3,400	33.53 kwhrs

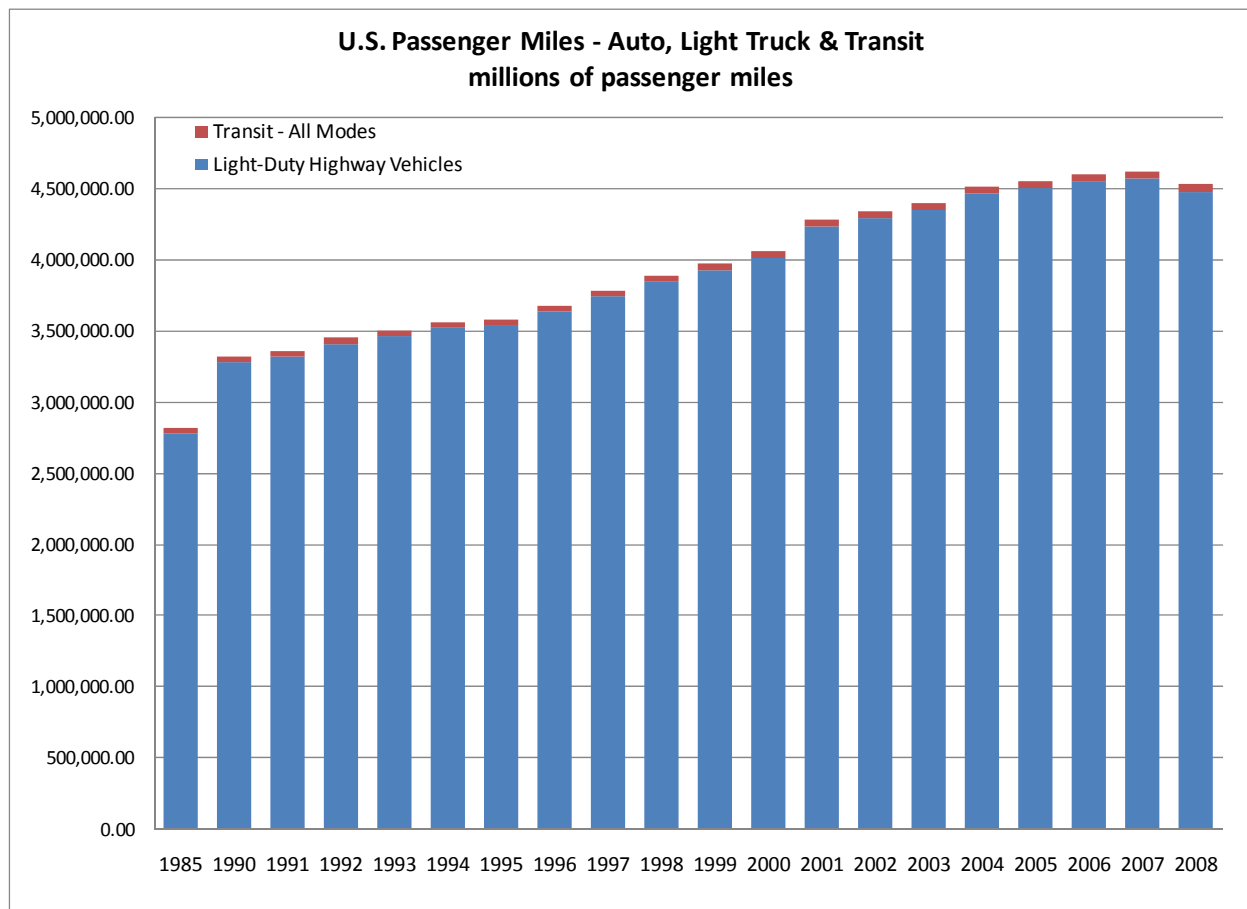
As Table 1 indicates, it takes only 0.88 gallons of diesel fuel to generate the same energy as contained in 1 gallon of gasoline. Conversely, ethanol at a 100 percent blend takes 1.5 gallons to equal 1 gallon of regular unleaded gasoline. The kilowatt hour conversions are useful in comparing electrified commuter, light and heavy rail systems with bus and auto transport.

Modal Usage

Before comparing the surface transportation modes by energy use or emissions produced, some context as to the use of the modes in absolute terms is helpful. Vehicle miles traveled (VMT) is the typical measure for the extent of highway travel, while passenger miles of travel (PMT) is a more robust statistic for measuring the extent of transit use. BTS converts VMT to PMT by using the relevant auto occupancy rates for specific years. While auto and light truck passenger travel continue to be many times more pervasive than transit, PMT and VMT have been declining in recent years as transit ridership has been growing since approximately 1995.

¹⁰http://www.nafa.org/Content/NavigationMenu/Resource_Center/Alternative_Fuels/Energy_Equivalents/Energy_Equivalents.htm.

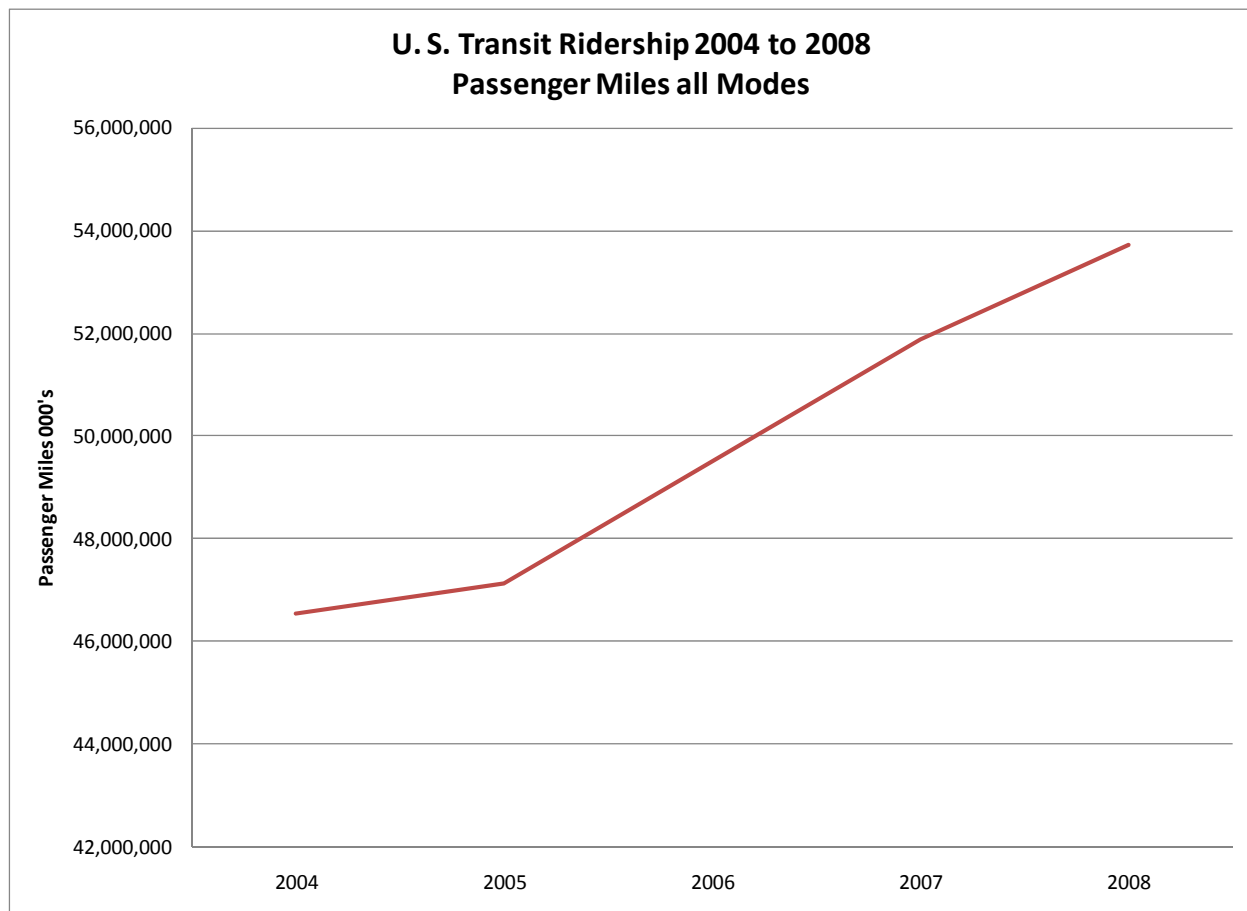
Figure 7 Auto and Transit Passenger Miles of Travel – 1985-2008¹¹



The reversal of highway VMT growth can be attributed to the current economic recession, while the gains in transit ridership have been linked to the increase in highway fuel costs that occurred from 2000 to 2009 and increases in transit service being provided. Figure 8 illustrates the trend in transit ridership expressed in passenger miles from 2005 to 2008. Annual growth rates for the period ranged from 1.2 percent from 2004 to 2005 to 5.0 percent from 2005 to 2006.

¹¹ U.S. Department of Transportation, Research and Innovative Technologies Administration, Bureau of Transportation Statistics, National Transportation Statistics, Table 1-37, accessed February, 2010. http://www.bts.gov/publications/national_transportation_statistics/html/table_01_37.html.

Figure 8 U.S. Transit Passenger Miles – All Transit Modes¹²

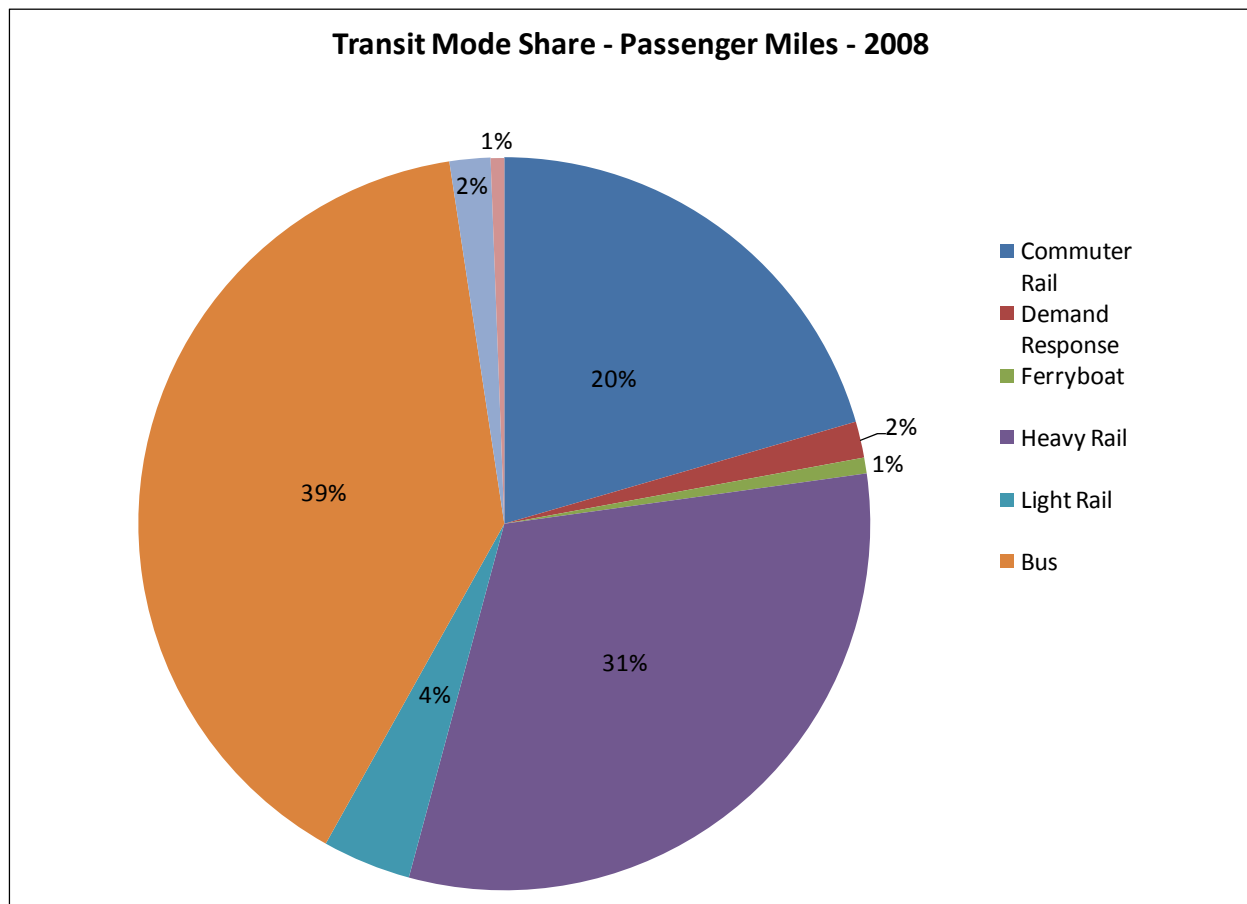


As different transit technologies have varying energy usage profiles, it is important to differentiate passenger miles by the type of transit service provided. While transit bus is the most widely available form of public transportation, it represents only 39 percent of the passenger miles traveled based on the latest National Transit Database (NTD) information available. Because of the longer average trip length and the high levels of rail service in the largest transit markets, rail modes (light rail, heavy rail, commuter rail) combine to account for over half of all passenger miles of transit travel. Figure 9 shows the transit mode shares for 2008.

The shares of passenger miles shown for 2008 have remained relatively constant since 2004, with some reduction in bus from 40.6 percent to the current 39 percent and increases in light rail from 3.4 percent to 3.9 percent, commuter rail from 20.9 percent to 21.5 percent, and heavy rail from 30.8 percent to 31.1 percent.

¹² U.S. Department of Transportation, Federal Transit Administration, National Transit Database, Table 19, 2004-2008.

Figure 9 Percent of Transit Passenger Miles by Mode – 2008¹³



Modal Energy Use Compared

An assessment of public transportation from an environmental sustainability competitiveness standpoint can begin by comparing the energy and emissions associated with the movement of passengers. Understanding how public transport stacks up against other modes is crucial to any conclusions on its ability compete from an environmental perspective. The most frequently referenced data on this modal comparison come from the BTS National Transportation Statistics Report and the DOE *Transportation Energy Data Book*. Unfortunately, these data do not collate very well for the transit bus mode. In both cases, modal energy intensity is measured in BTUs per passenger mile. This measurement seems a reasonable method. Caution is urged by the DOE not to use the data for modal comparisons, yet transportation professionals and researchers routinely look for the few sources available to enable them to do precisely this. Figure 10 illustrates the data reported by BTS for passenger cars, other light-duty vehicles, transit motor bus, and Amtrak. It indicates that, when measured in BTUs per passenger mile, the transit bus lost ground to the auto between 1980 and 2000. Two main drivers could affect

¹³ U.S. Department of Transportation, Federal Transit Administration, National Transit Database, Table 19, 2004-2008.

this trend: ridership and vehicle fuel efficiency. Intercity rail (Amtrak) is shown as the least intensive when measured in this manner, but data since 2001 have not been reported. Based on these data and the recent trend of the transit motor bus, it would appear that the transit bus mode is more energy efficient than light-duty vehicles. This information, taken in conjunction with the growth in the other 2-axle, 4-tire vehicle, would also support transit's efficiency. Table 2 provides the actual reported figures for the most recent year's data available from BTS.

Figure 10 Energy Intensity by Mode – U.S. DOT¹⁴

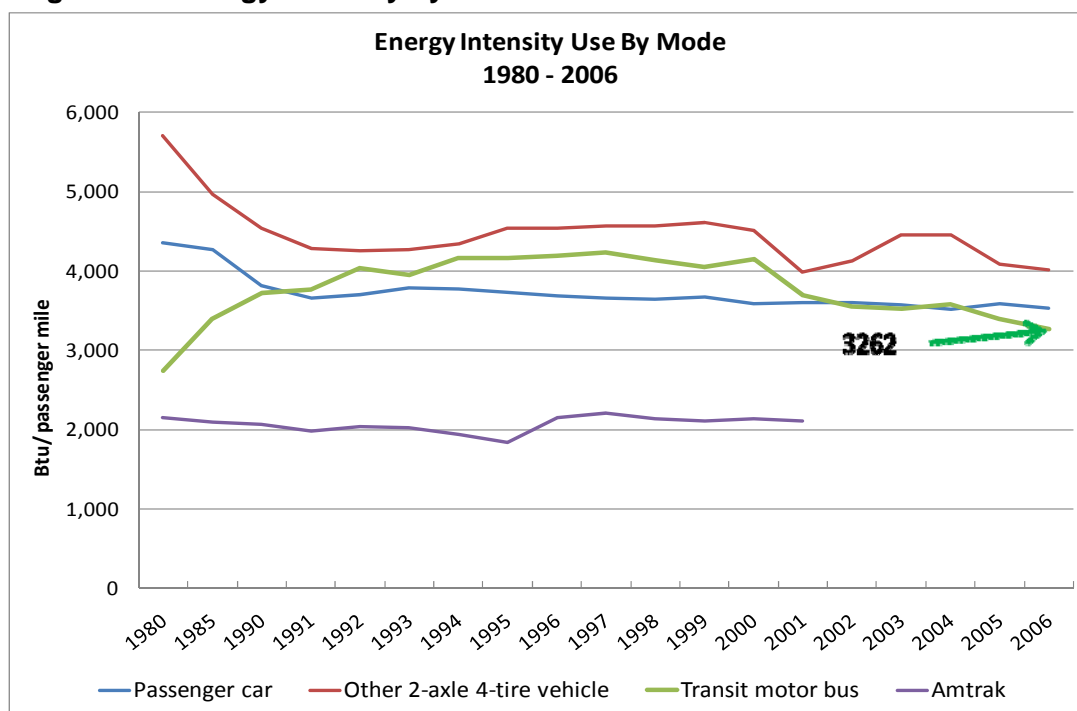


Table 2 Modal Energy Intensity – 2006¹⁵

Mode	BTU/ Passenger Mile
Passenger Car	3,525
Other 2-axle, 4-tire vehicle	4,016
Transit Motor Bus	3,262
Amtrak	2,100*

*2001 data

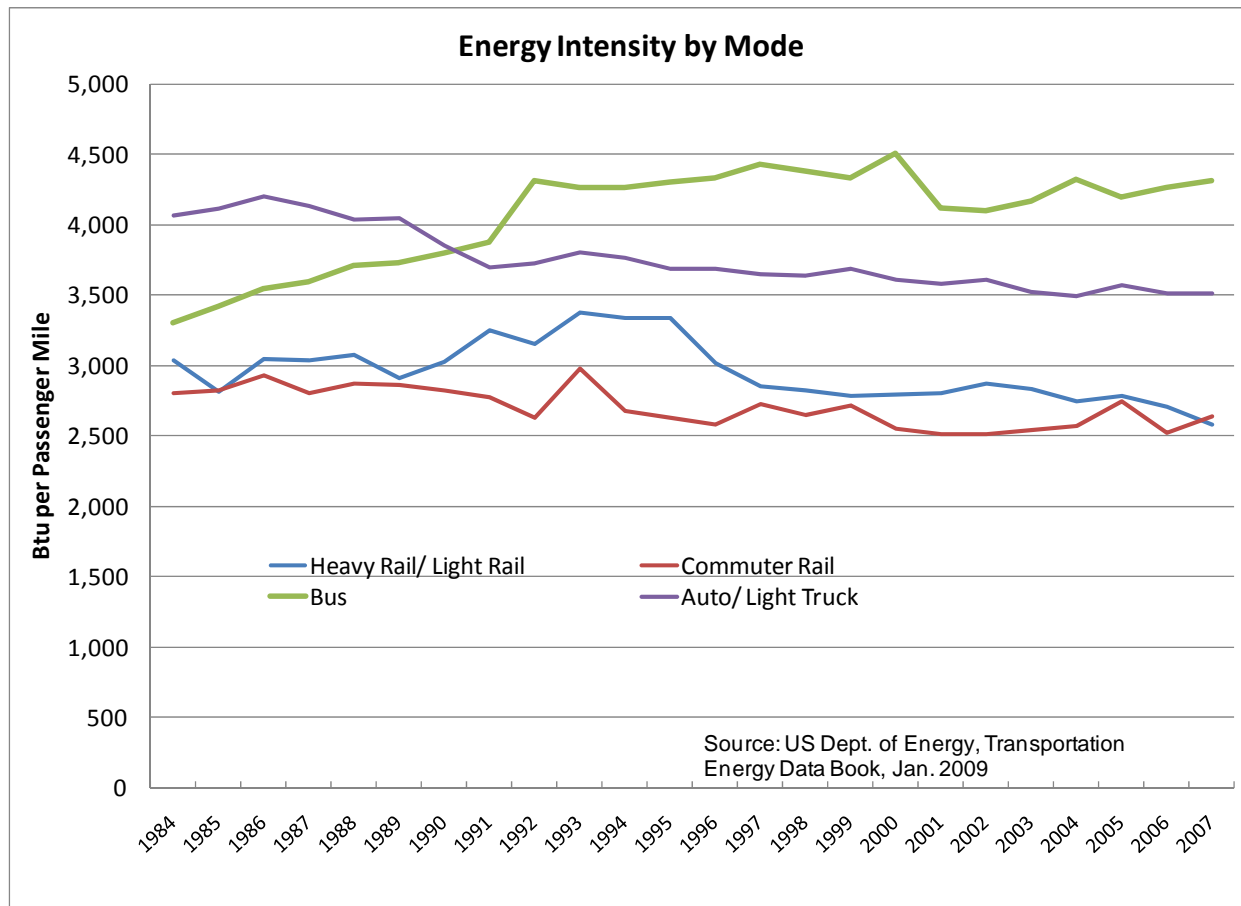
Figure 11 shows similar data, again expressed in BTUs per passenger mile, but is taken from the *Transportation Energy Data Book*. While the passenger car figure is very close to that reported above in the BTS figures, the number for buses is significantly different. In fact, the BTUs per passenger mile is reported as 4,315 versus the 3,262 shown in Table 2. After

¹⁴ U.S. Department of Transportation, Research and Innovative Technologies Administration, Bureau of Transportation Statistics, National Transportation Statistics, Table 4-20, accessed February, 2010.

¹⁵ *Ibid.*

checking the source data, it was found that the calculations in the *Transportation Energy Data Book* come from information published in the *APTA Public Transportation Fact Book*. These data were then compared with data reported in the NTD, which yielded yet another figure for bus BTUs per passenger mile. Some of the differences between the NTD and APTA data may be explained in discrepancies in the amount of fuel reported to have been used. This required further investigation, and the researchers are continuing to work to define these differences.

Figure 11 U.S. DOE Energy Intensity by Transportation Mode¹⁶



Upon further examination, it became apparent that agencies purchasing bus service (contracting) were inconsistently reporting fuel consumption. Up until 2009, the reporting of fuel used by agencies contracting for bus service was discretionary. The 2009 NTD reporting requirements now include fuel type and usage for all purchased and directly-operated motor bus service (these data will be publicly available shortly). Before 2009, researchers made a calculation that included only agencies that directly operated their service and also excluded the eight agencies mentioned above. The resultant BTUs per bus passenger mile, in this case, was 4,740. This figure is even higher than the DOE estimate of 4,259.

¹⁶ U.S. Department of Energy, *Transportation Energy Data Book*, January 2009.

Another ambiguity in the NTD reporting of fuel consumption relates to alternative fuels or fuels other than gasoline or diesel. The instructions for reporting natural gas consumption tells agencies to "...report compressed natural gas (CNG) in gallon equivalents of either gasoline or diesel fuel.... In order to apply the factors, you should determine what type of fuel the revenue vehicle would have likely used if it were not powered by CNG." Without knowing what portion of the fuel use is reported as "replacing" gasoline and what portion would replace diesel, the BTU calculation becomes even more uncertain. Given that over 18 percent of the transit bus fleet operated on CNG or liquid natural gas in 2009,¹⁷ this could cause significant variances in energy intensity calculations.

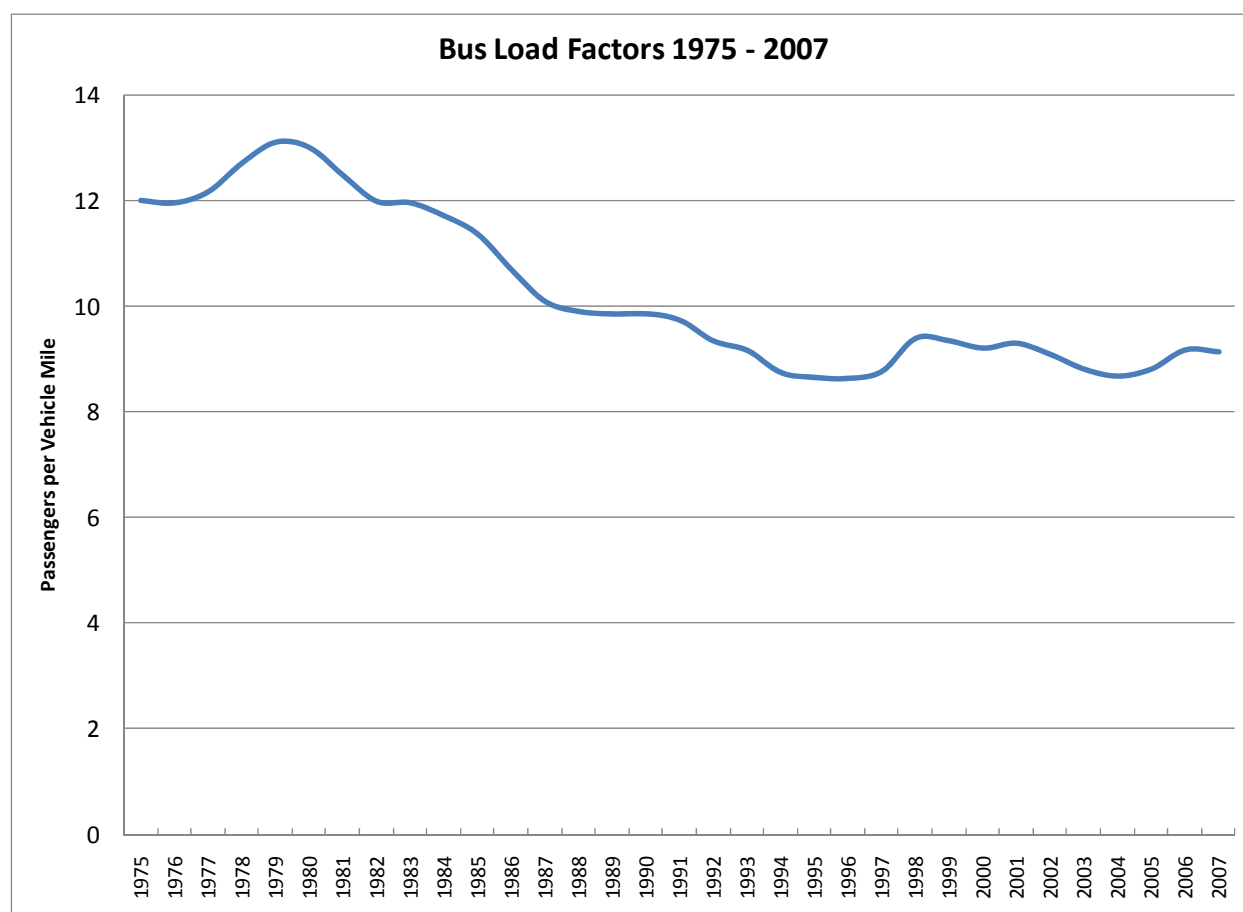
It should be noted that the DOE reporting relies on data from APTA and that since 1995 BTS has used data from the NTD. Adding to the uncertainty of these figures are the constant revisions that take place on historical data as new versions of reports become available. After reviewing the reports referenced for this analysis, researchers found that the BTS publication revised all of the transit bus energy intensity data going back to 1996 and Amtrak data going back to 1992. This paper does not reflect those recent revisions and, more importantly, despite attempts to quantify the modal energy comparisons for the study sponsor, this issue appears to continue to be a moving target that must be monitored. Another published report, the American Bus Association's "Report on Comparison of Modal Energy and Emissions," puts the transit bus BTU per passenger mile at 4,245.

While the bus energy intensity calculations vary widely, the data examined show that rail, particularly commuter, intercity, and heavy, are the most energy-efficient modes on a BTUs-per-passenger-mile basis. Concern over the different bus figures is significant because transit bus systems provide the most immediate and widespread opportunities for attracting "choice riders" to a mode other than private light-duty vehicles. This opportunity, coupled with the calculated energy intensities for automobiles and transit buses, does not make for a very compelling competitive argument for the most available public transportation option.

Looking behind the data exposes the real opportunity for transit bus from an energy competitiveness standpoint. As mentioned earlier, the two factors driving the energy use of any mode are the efficiency of the vehicle and the number of passengers that vehicle moves. Figure 12 graphs the calculated bus load factors from 1975 to 2007 using data from APTA. Through the "second energy crisis" of 1979, passenger load factors grew to 13 passengers per vehicle mile (not revenue mile). Afterwards, a downward trend began, and the decline continued until the late 1990s. The load factor has leveled off to about nine passengers per vehicle mile through the 2000s.

¹⁷ *Public Transportation Fact Book*, American Public Transportation Association, 2009.

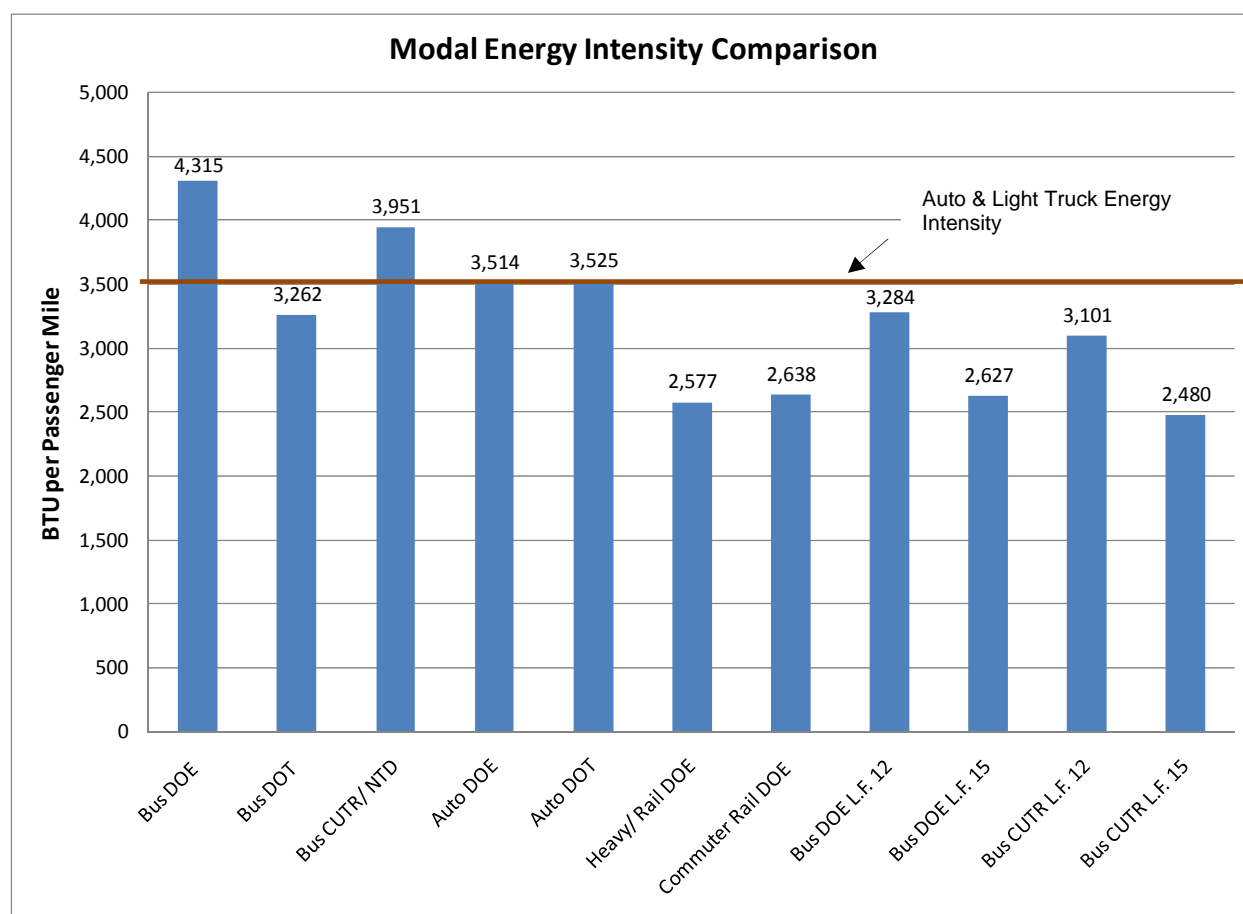
Figure 12 U.S. Bus Passengers per Vehicle Mile



It is instructive to look at the energy competitiveness of transit bus if there was an upward trend in ridership and load factors. These scenarios are only illustrative and assume that the fixed-route bus system can absorb additional demand during the periods. Researchers calculated the BTUs per passenger mile at load factors of 12 and 15 passengers per vehicle mile.

It is obvious that increasing the passenger loads of the existing bus system would reduce the energy use of buses relative to other modes of transit and to automobiles. As an indicator of how much more competitive the bus mode would be, the researchers calculated the BTUs per passenger mile for the DOE-reported data, the figures reported by BTS, and for the researchers' estimate based on 12 and 15 passengers per vehicle mile. The results, along with the other modal energy intensity figures, are presented in Figure 13.

Figure 13 Modal Energy Efficiency at Various Bus Passenger Load Factors



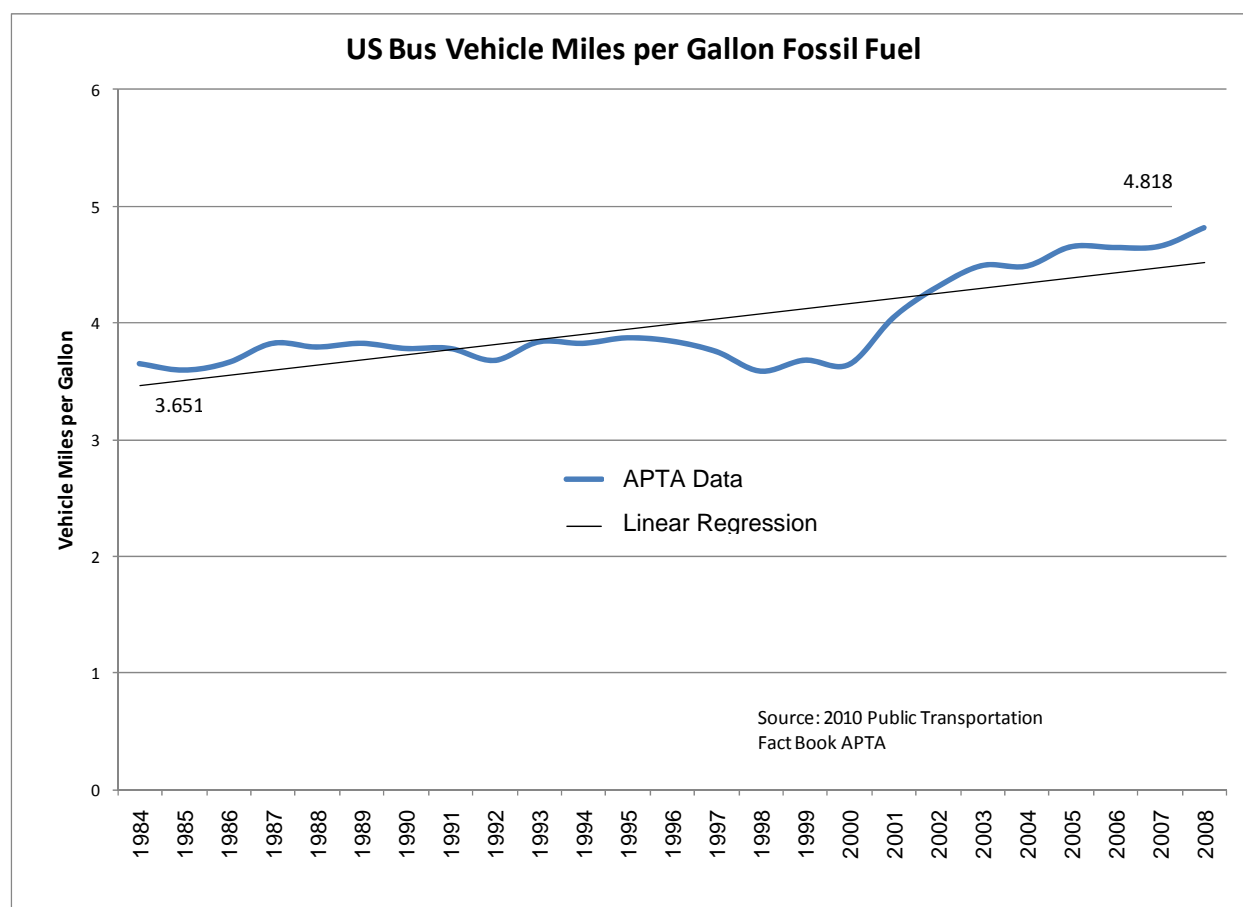
The BTS figure for bus (“Bus DOT”) already is shown to be lower (less energy intensive) than the automobile and light truck figures. The DOE *Transportation Energy Data Book* and the researchers’ bus figures (calculated based on all of NTD less eight agencies with reporting anomalies) are higher than the transportation competitors. With an increase to a passenger load factor of 12 passengers per vehicle mile that was experienced in the 1970s, all energy intensity numbers are lower than autos and light trucks. Moving to a load factor of 15 passengers per vehicle mile would make the bus system at least as competitive as the rail modes. While 15 passengers per vehicle mile may not be realistic in most circumstances, moving that factor higher presents another incentive to agencies to employ aggressive tactics to increase ridership, and may provide additional rationale for policy makers to invest more heavily in agency programs that help encourage new transit riders.

Looking at the other side of the equation, the fuel efficiency of transit buses was examined. As is the case with any conclusions drawn from aggregate data at the national level, there are significant variances by locale. This is particularly true when it comes to an examination of vehicle fuel efficiency. Fuel efficiency for urban transit buses can vary widely based on the

vehicle model, power plant, duty cycle, operator behavior, physical terrain, climate, and type of fuel used.

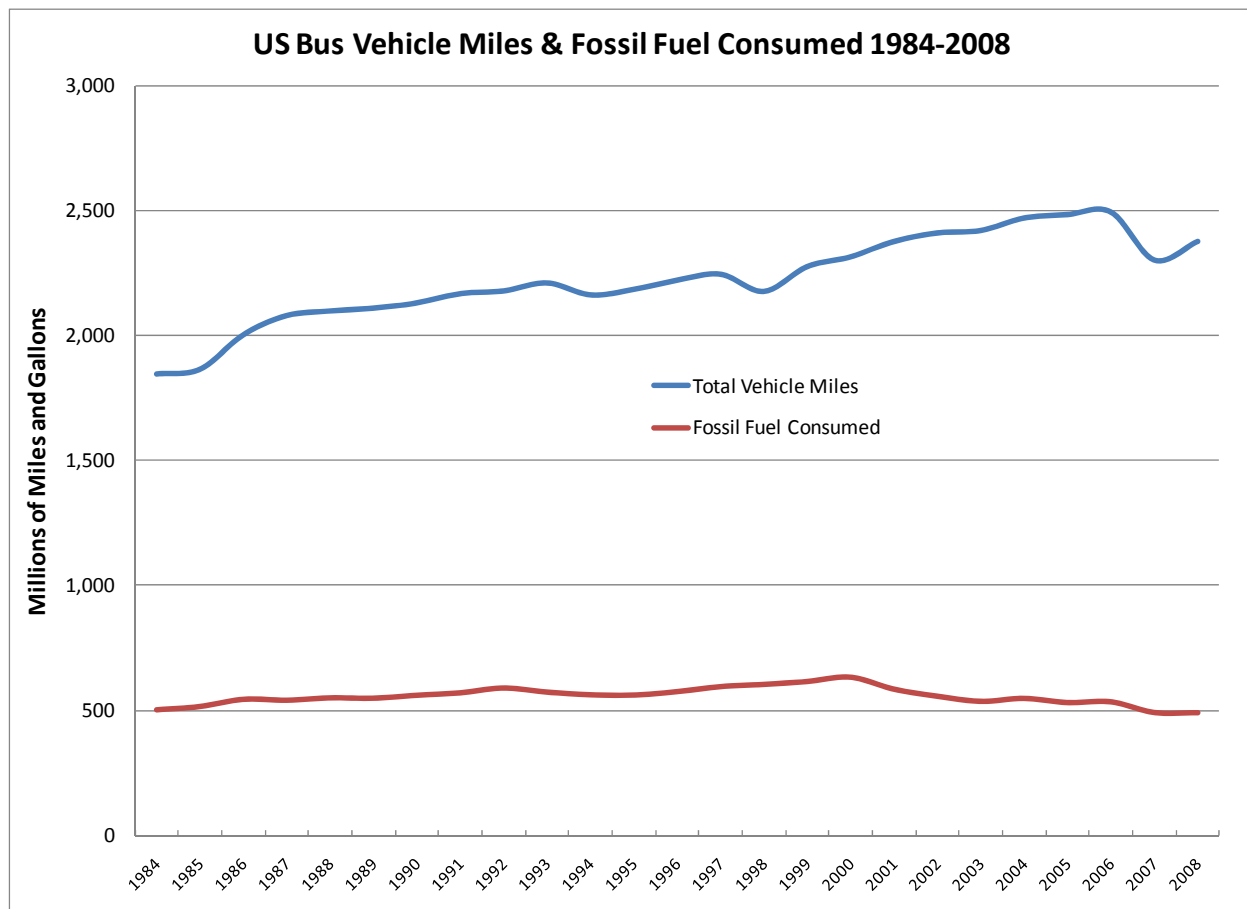
On average, transit buses have become more fuel efficient in recent years, even in light of the additional emissions requirements that have been phased in. Hybrid electric buses fueled by ultra low sulfur diesel (ULSD), gasoline, and other power plants are becoming more commonplace, with some agencies claiming nearly 7 miles per gallon for a 40-foot bus. Even with more modest gains in fuel efficiency, the introduction of more of these vehicles will help continue the trend depicted in Figure 14. The fuel efficiency of the bus fleet nationally has improved from over 3.5 miles per gallon of fossil fuel in 1985 to almost 5 miles per gallon in 2008. This trend is even more impressive when presented graphically in the absolute number of vehicle miles that the fleet has logged and the total gallons of fossil fuel consumed. These data are presented in Figure 15.

Figure 14 U.S. Transit Bus Fleet Fuel Efficiency – 1984-2008¹⁸



¹⁸ *Public Transportation Fact Book*, American Public Transportation Association, 2010.

Figure 15 Transit Bus Fleet Use and Energy Consumption¹⁹



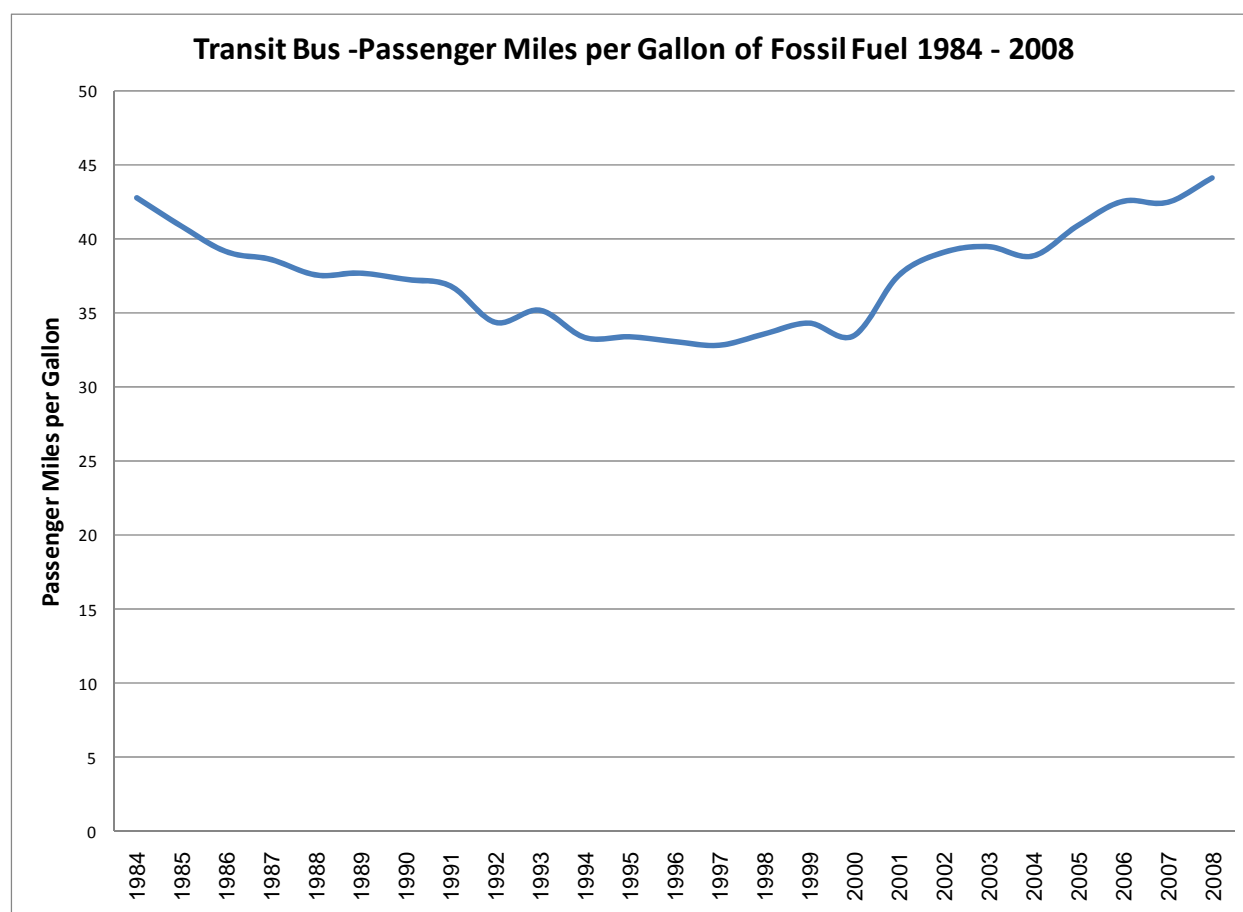
With current transit bus load factors at around 9 passengers per mile and a vehicle efficiency of approximately 5 miles per gallon, one would expect the passenger miles per gallon to be around 45. Figure 16 illustrates the data taken from the earlier tables referenced in the *Transportation Energy Data Book* and indicates the positive trend that is resulting from increased vehicle efficiency and transit bus ridership.

While NTD data were first collected in the 1980s, and older data are limited, transit bus vehicles reported greater efficiencies in earlier decades. The vehicles were lighter, and air conditioning was not available. Lifts and ramps were not required, reducing weight, and lighting, heating, and other amenities were less energy intensive. In 1960, transit buses were reported to average 5.5 MPG.²⁰

¹⁹ *Public Transportation Fact Book*, American Public Transportation Association, 2010.

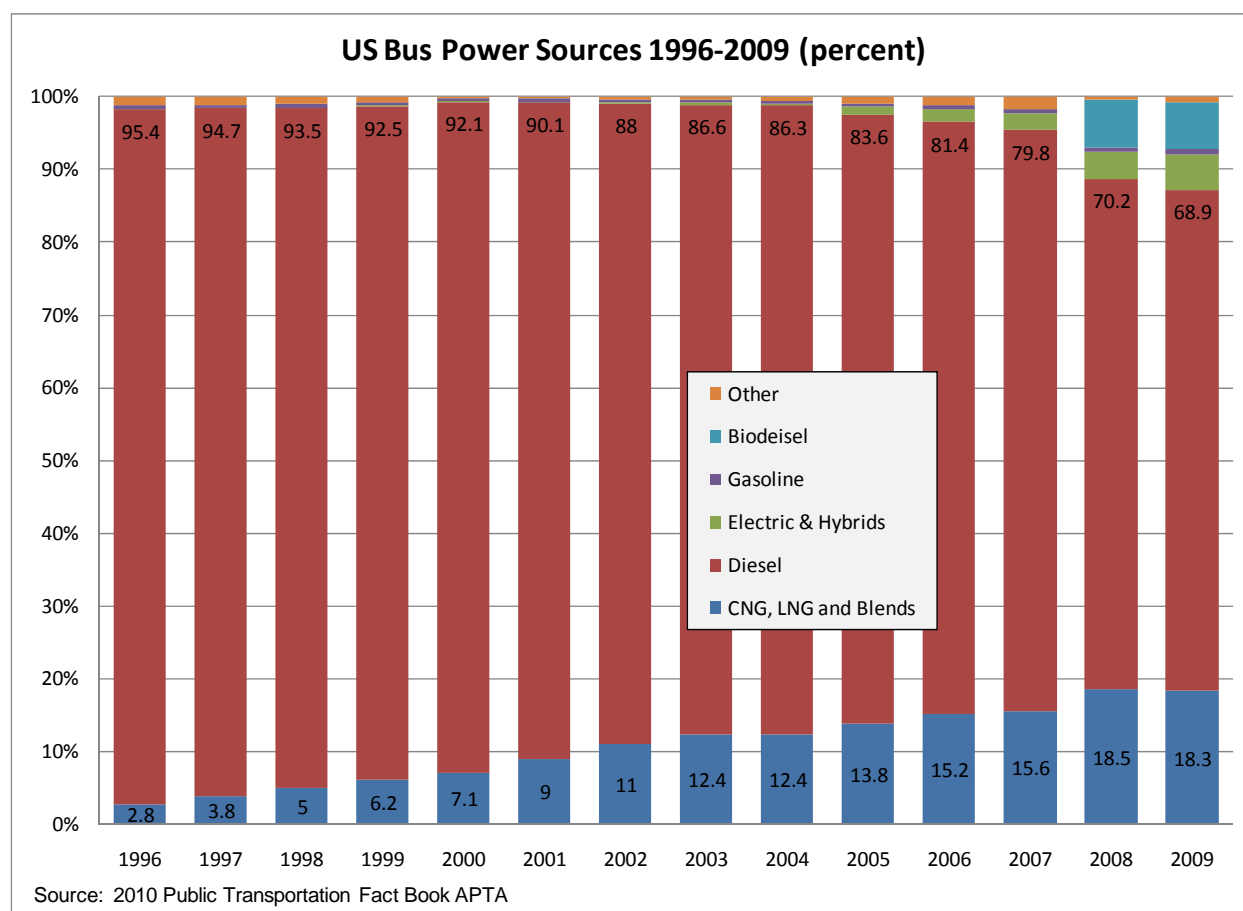
²⁰ "Trends in Transit Bus Financial and Operating Characteristics, 1960-1975," U.S. DOT, Sept. 1977 (DOT-P-30-78-43), p. 8-7, Table 8-3: "Diesel Fuel Gallons Consumed Per Bus Mile." This shows steadily declining fuel economy from 5.52 miles/gallon in 1960 to 4.43 miles/gallon in 1975.
http://www.lafn.org/~dave/trans/energy/does_mt_saveE.html#s4

Figure 16 Transit Bus Passenger Miles per Gallon – 1984 to 2008



Some of the increases in transit bus fuel efficiency can be attributed to the introduction of alternatives to the traditional heavy-duty diesel vehicles. Diesel-powered buses represented around 95 percent of the transit fleet in 1996. The steady growth of CNG-powered vehicles, increased use of biodiesel, and the growth in hybrid electric bus numbers have reduced that percentage of diesel-powered vehicles to fewer than 69 percent in 2007, according to data from the APTA *Transportation Fact Book*. Figure 17 graphs the trend in power sources for U.S. transit buses from 1996 to 2009.

Figure 17 Transit Bus Power Source – 1996 to 2009²¹

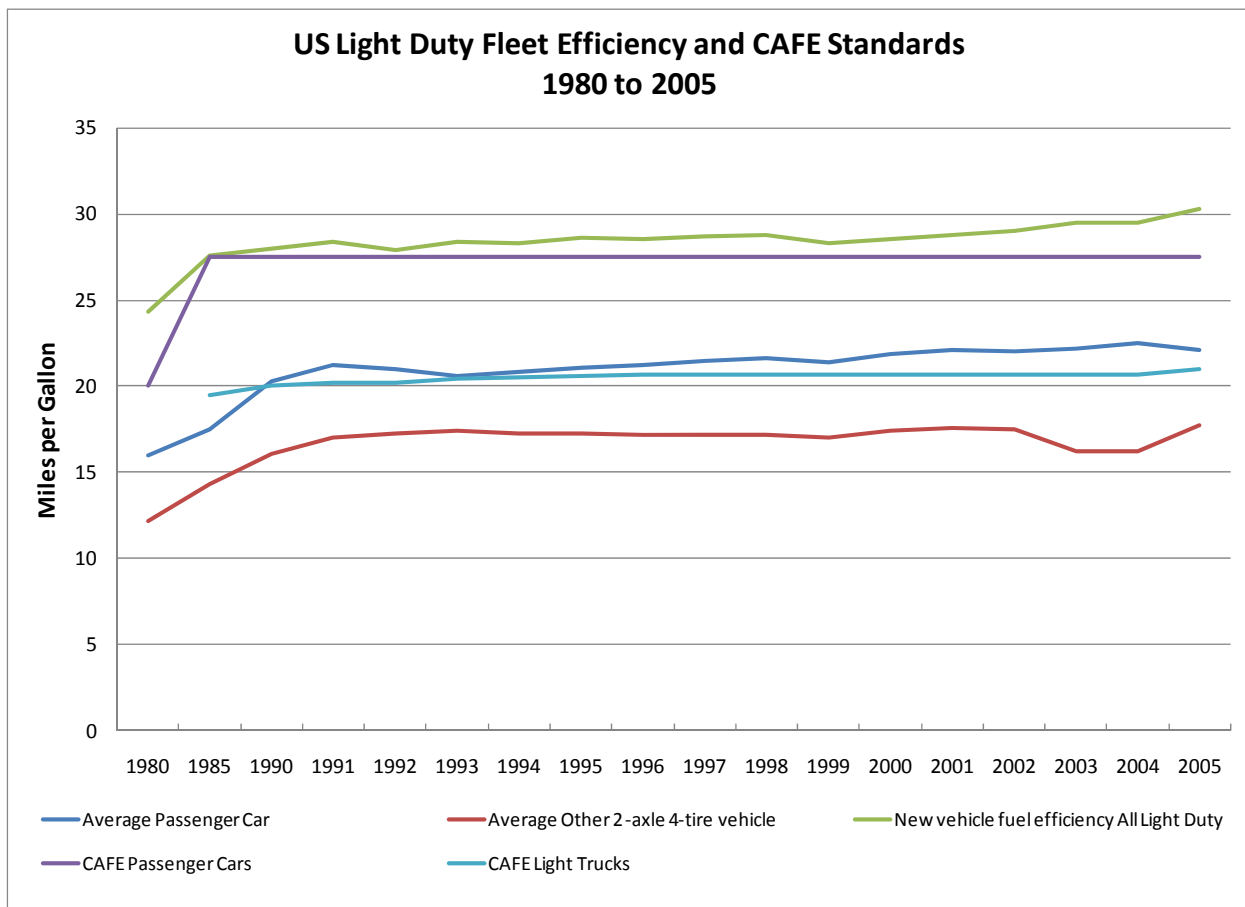


With a picture of the transit energy use and trends somewhat clear, a comparison to light duty vehicles is presented next. The first graph in this series is taken from the BTS data and compares the Environmental Protection Agency's (EPA) CAFE standards with the actual fleet efficiency and data for new light-duty vehicles entering the fleet. Several trends are apparent. The first is that since the CAFE standards were introduced in 1975, they have remained relatively unchanged. The standard for passenger cars has remained at 27.5 miles per gallon (mpg) since 1985, and for light trucks it has risen modestly from 19.5 mpg to 23.1 mpg for the same period. These data are illustrated in Figure 18.

During the preparation of this report, both the EPA and the U.S. DOT through the National Highway Transportation Safety Administration (NHTSA) have published final rules affecting the light-duty and medium-duty passenger vehicles (from 8,500 to 10,000 pounds Gross Vehicle Weight Rating) fleet efficiency. The EPA published GHG standards for autos and light trucks, and NHTSA has issued complementary new CAFE standards.

²¹ *Public Transportation Fact Book*, American Public Transportation Association, 2010.

Figure 18 U.S. Fleet Efficiency and CAFE Standards – 1980 to 2005



Expressed in grams per mile, the new standards for GHGs will differ by a vehicle's size or "footprint" and are to be in place for the model year 2012 vehicle production run. Table 3 lists the allowable CO₂ emissions expressed in grams per mile (g/mi) and the complementary fuel mileage (mpg).

The new GHG standards average a CO₂ emission rate of 250 grams per mile by model year 2016 with an estimated mpg equivalent of 35.5 for the combination of light duty trucks and passenger autos. Rules that would apply to 2017 and beyond currently are being formulated and will include a similar approach for heavy-duty vehicles, likely impacting urban transit fleets. Although in the early stages, comments are now being sought for input to the rules proposal.

Table 3 EPA GHG Reductions and Fuel Economy – Issued April 1, 2010²²

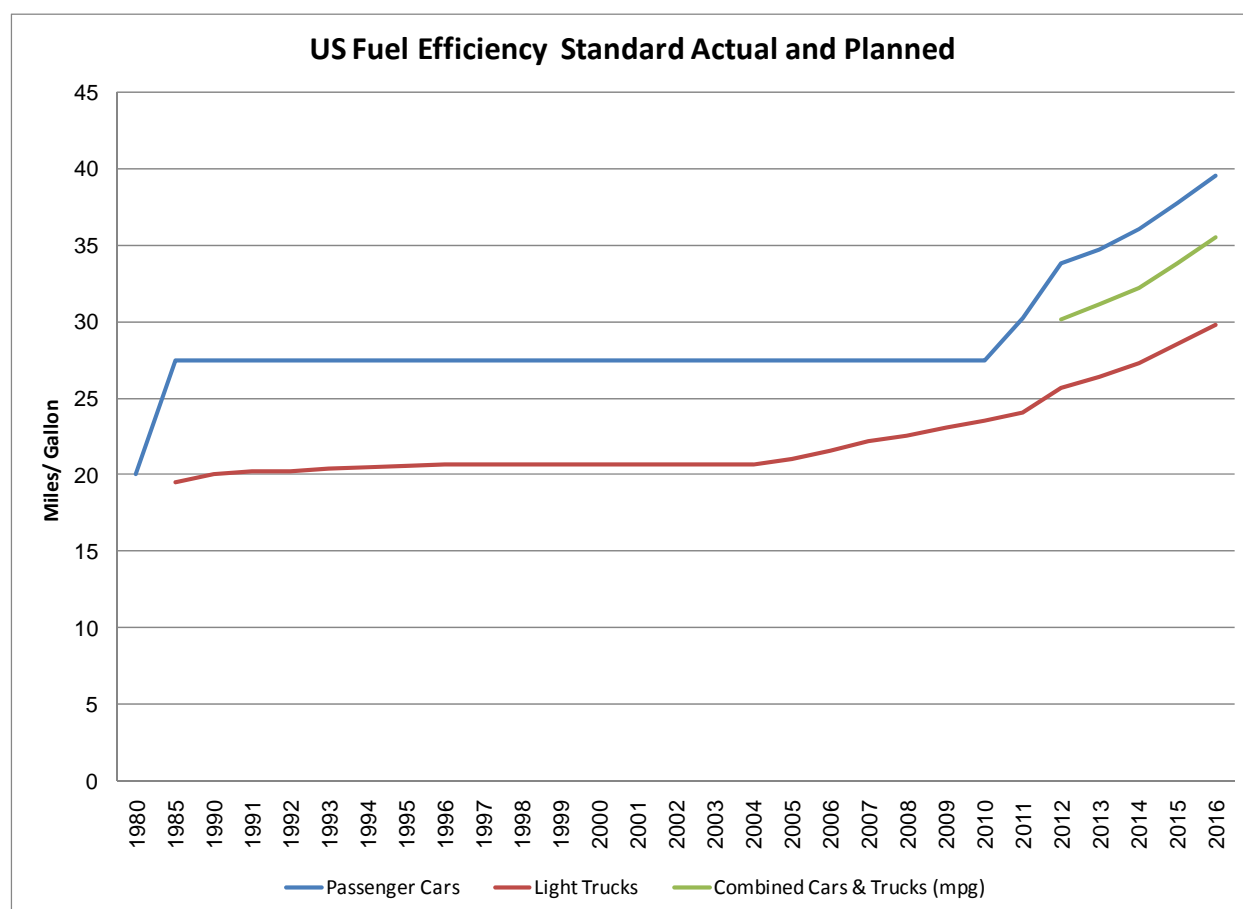
Projected Fleet-Wide Emissions Compliance Levels under the Footprint-based CO₂ Standards (g/mi) and Corresponding Fuel Economy (mpg)					
	2012	2013	2014	2015	2016
Passenger Cars (g/mi)	263	256	247	236	225
Light Trucks (g/mi)	346	337	326	312	298
Combined Cars & Trucks (g/mi)	295	286	276	263	250
Passenger Cars (mpg)	33.8	34.7	36	37.7	39.5
Light Trucks (mpg)	25.7	26.4	27.3	28.5	29.8
Combined Cars & Trucks (mpg)	30.1	31.1	32.2	33.8	35.5

Figure 19 extends the trends shown in Figure 18 based on the new federal rules that were published May 7, 2010. The fleet efficiency for new autos is expected to increase by 31 percent from 2011 to 2016 and 24 percent for light trucks during the same period. This must be put into a perspective that recognizes that the actual consumption of fuel in the field will remain significantly lower than the annual standards. The most obvious reason is that the standards placed on new vehicles improve the efficiency of the additional and replacement units entering the fleet only. Even after the “ramp up” of more fuel-efficient vehicles, historically, there remained a 4-6 mpg spread between the standard and actual use of fuel. Other factors contributing to this spread include the rating of a vehicle under ideal test conditions versus the multitude of variables affecting fuel mileage in the field. A distinct advantage that transit should have over autos in this area is that of regular preventive maintenance. Transit agency requirements and their culture typically place a very high priority on maintaining the equipment in top condition, and a centrally-maintained fleet is more likely to sustain peak vehicle performance over its life.

Vehicle life now and in the future also will be a factor. Heavy-duty buses typically are amortized over an approximate 12 year life; however, older vehicles are common, and mileage is a more critical factor in fleet retirement decisions. Currently, light vehicle life at salvage is nearly 17 years; however, use during the life is heavily front-end weighted. The economic conditions, pace of evolution in technology and vehicle performance, and other factors will determine future vehicle lives and use profiles. These factors then will influence the actual performance of the in-place respective vehicle fleets over time.

²² Final Rule, EPA-420-F-10-014, April 2010.

Figure 19 U.S. Fuel Efficiency Standards – Light Duty Vehicles 1980-2016



A comparison of passenger cars with transit buses from an energy standpoint was presented earlier by examining BTUs per passenger mile. A more familiar method may be to compare the passenger miles per gallon of fuel used or passenger miles per gallon. This is not as accurate as the BTU method for looking at absolute energy use, as diesel fuel has a higher energy density, but the absolute number of gallons does have implications for fuel production, emissions, fuel transportation and distribution.

Shown earlier in Figure 16, the transit bus mode currently is averaging around 45 passenger miles per gallon of fossil fuel. The average passenger car fuel mileage was shown in Figure 18 for 2005 to be 22.1 mpg. If the commonly-used occupancy rate for auto travel of 1.6 persons per vehicle is used, then the passenger mile per gallon rate for autos is 35.4. Using this method and adjusting for fuel equivalencies would benefit the transit results, as would normalization of mpg for city and “highway” driving conditions. The differences in this measure versus the BTU per passenger mile is a topic that requires further investigation and points out the acuteness of the reporting problems associated with this issue.

To further understand the significance of making adjustments for travel context, the research team used National Household Travel Survey (NHTS) data to determine what types of adjustments to operating speeds, fleet characteristics, and occupancies would be required to produce better comparisons between the modes for travel in similar environments. This implicitly assumes that the same travel would occur but simply would shift between transit and auto. This presents a counterfactual case and is inherently an estimate. The energy intensiveness of travel in the absence of transit can only be speculated. If, as transit planners often argue, land use patterns would be different without transit, then it would be disingenuous to calculate the impacts of transit while holding the socio-demographic and development context constant. However, with appropriate caveats, these assumptions are necessary to estimate the impacts on energy use of having transit services.

Even if land use and social-demographics are assumed to be constant, some share of the travel would not occur, as some trips would be foregone and others would be shorter. Some travel would revert to others modes, and some would end up as auto travel. Even for travel that would divert to auto, the occupancy can only be speculated, as there are no data on the average group size of transit travelers or the probability that transit travelers would be able to become drive-alone auto travelers. The current light vehicle travel data is for all national travel, a significant share of which is longer-distance travel on the interstate system and travel in environments far removed from the urban environments where transit travel occurs. A more realistic look at light vehicle operations in environments similar to that which exists in transit-served areas is a more appropriate context for comparisons of energy use. This has significant implications, as the typical modal energy use comparisons focus on gross national averages and do not adjust for context conditions.

Three elements of context were looked at and each is discussed below; adjustments in auto mileage were estimated based on these context conditions:

1. Urban personal light vehicle fleet of transit accessible individuals versus national fleet.
2. Urban average travel speed versus national travel speed.
3. Urban auto occupancies versus national average occupancies.

1. The light vehicles operated by persons living in locations accessible to transit are slightly more efficient than the overall average fleet personal vehicle fleet. This follows from the observations of small vehicles and fewer light trucks in urban environments due to limited parking and other travel and traveler characteristics. NHTS 2001 data, which included appended data on the efficiency of the vehicle fleet owned by surveyed respondents, indicates that persons with access to transit own vehicles that attain 0.47 mpg better than the national average. Persons defined as having access to transit were those who lived within 0.3 miles (airline distance) from a transit route or stop. Thus, auto travel by persons in the geography of transit service is likely to be on more efficient vehicles, which slightly increases the relative efficiency of auto travel as an alternative to transit.

2. Adjustments to efficiency caused by travel speed differences also were estimated based on NHTS data on average travel speed by place of residence. Residents living in locations where transit is accessible travel, on average, 2.2 miles per hour slower than the national average speed. Vehicles are less efficient at lower speeds, particularly in stop-and-go travel conditions. While it is not possible to get precise driving-cycle efficiency comparisons for trips that might switch from transit to auto, using the average speed difference provides one means of more accurately equating these two types of travel. Based on review of the relationships between speed and vehicle efficiency, data suggest that this is the equivalent of diminishing fuel efficiency by approximately 0.63 mpg.²³ This relationship has changes over time, and various studies and researchers have used different equations to characterize the relationships. After reviewing the research, an estimate was made.

3. Average vehicle occupancies are nearly identical between urban and national travel profiles; however, transit travel is more proportionally weighted to work-trip and peak-period travel where occupancies are typically lower. Thus, again based on NHTS data analysis, urban travel private vehicle occupancies are estimated to be 10 percent lower than national averages for purposes of comparison to transit travel (1.47 percent versus 1.63 percent for urban averages). There are no available data on the average group size of travelers on transit, and it is difficult to estimate how current transit passengers might travel relative to auto occupancies if transit were not available. In the absence of these data, it is reasonable to make the assumption based on trip purpose. This has the effect of reducing private fleet efficiency by approximately 10 percent for comparison to transit bus.

The composite effect of these changes was used to adjust the auto fuel efficiency estimate to 3,525 BTUs per passenger mile (Figure 13) for auto travel to more closely represent urban auto travel conditions. The composite effect suggests that a more appropriate number for comparison between urban travel by transit bus and urban travel by private vehicle would be approximately 3,900 BTUs compared to the research team's calculated bus energy fuel efficiency estimate of 3,951.

Table 4 Urban Travel Context Efficiency Adjustments

BTUs per gallon	114,100
Average BTUs per passenger mile	3,525
Passenger miles per gallon	32.4
Vehicle miles per gallon	19.9
Vehicle size adjustment (MPG)	0.47
Operating speed adjustment	-0.63
National average occupancy	1.63
Urban occupancy for adjustment	1.47
Revised BTUs per passenger mile	3,938

²³ "Measuring Urban Transportation Performance: A Critique of Mobility Measures and Synthesis," Joe Cortright, Impresa and CEOs for Cities, funded by the Rockefeller Foundation, September 2010; Energy Data Book 29, Table 4.27, U.S. Department of Energy, 2010.

Future Modal Energy Efficiency Comparisons

Planning for future transportation infrastructure typically has revolved around a 30-year planning horizon, with some analysts articulating the need for even longer planning time frames as we address systems that impact longer range development trends and make decisions whose impacts occur over several future decades. It is not uncommon for projects to be implemented over one or more decades and financed over 30 years. Thus, it is logical to evaluate the merits of projects based on a future point in time – often referred to as a design year. This is intended to provide those evaluating the merits of particular investments with an opportunity to understand the impacts of the projects with data that might be representative of the average performance of the investment over the life of that investment. The discussion below is restricted to transit bus; however, a similar analysis could be conducted for other transit modes.

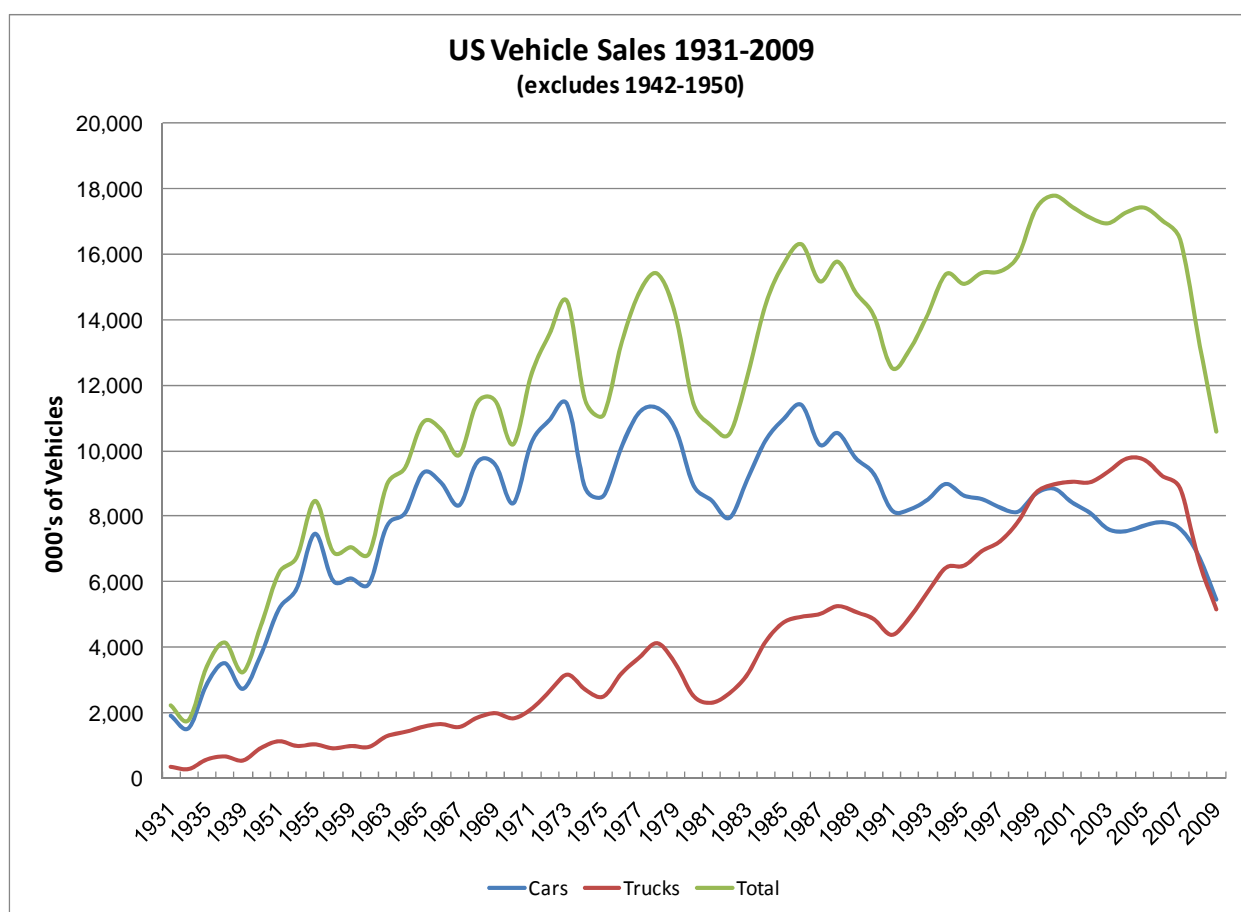
In the case of understanding the energy impacts of transportation investments, the anticipated pace of change in both the energy use characteristics of the modes, and the importance of energy use and the related emissions factors results in it being a critical evaluation aspect of future transportation investments. One of the motivations for this project was to provide some guidance and data to support those who will estimate future energy efficiency comparisons across different transportation investment scenarios. Energy use and subsequent emissions often are important considerations in public transit investment analysis. In times of stable energy efficiency performance, it is less critical to understand future prospects regarding energy efficiency. However, that is far from the current case, as energy prices and availability as well as climate change concerns have motivated aggressive actions to change the energy efficiency of both transit and auto modes. This includes new more stringent regulations for performance such as the new CAFE standards as well as aggressive investment in transit technologies that will impact energy use. In addition to understanding the energy implications of new vehicle technologies, it is necessary to understand the probable utilization levels in order to understand the performance on a per-passenger-mile basis.

How bus versus auto comparisons will look in the future is a highly speculative question, given the uncertainties of heavy-duty vehicle engine efficiencies, transit ridership trends, transit service changes, and the replacement rate of autos and light trucks. The discussion earlier in this report documented the variation in estimates of energy use for public transit bus services today, which, not surprisingly, are exacerbated when forecasting future conditions. Following a discussion of the various factors at play, some scenarios of comparative future performance are presented. The discussion focuses first on vehicle technologies, then on logistics and demand levels that impact overall energy performance.

Future Auto Energy Efficiency

One element that will influence future light vehicle energy efficiency is the nature of new vehicle demand. New car sales as a percentage of the national fleet have declined from 7.3 percent to 6.6 percent from 2003 to 2007. The current recession has had an enormous impact on passenger car sales, which could indicate that when economic recovery does occur, the demand for the new, more fuel-efficient automobiles could increase overall fleet efficiency at faster than historical rates. Figure 20 graphically displays new car and truck sales over time. While the cyclical nature of the units sold is apparent, the most dramatic element of the graph is the decline in sales from 2008 to 2009.

Figure 20 U.S. Vehicle Sales – 1931 to 2009²⁴



The 2009 total figures drop to levels that were seen in 1981 and 1969. With the additional households and vehicles currently registered, even a slow economic recovery would seem to include some pent-up demand for new vehicles that will be produced under the new, more aggressive fuel efficiency regulations. This will increase the passenger-mile-per-gallon figure for autos and light trucks and decrease the BTUs per passenger mile.

²⁴ Ward's Automotive, <http://wardsauto.com/keydata/historical/UsaSa01summary/>.

Various prognosticators have addressed the issue of the future of the automobile and produced estimates of its energy intensiveness. On May 19, 2009, President Obama proposed a new national fuel economy program that adopts uniform federal standards to regulate both fuel economy and GHG emissions while preserving the legal authorities of U.S. DOT, EPA, and California. The program covers model year 2012 to model year 2016 and ultimately requires an average fuel economy standard of 35.5 miles per U.S. gallon in 2016 (of 39 miles per gallon for cars and 30 mpg for trucks), a jump from the current average for all vehicles of 25 miles per gallon. Recent notice of intent of proposed rulemaking from the EPA addressed CAFE standards for the 2017-2025 years:

We analyzed a range of potential stringency scenarios for model year 2025, representing a 3, 4, 5, and 6 percent per year estimated decrease in GHG levels from the model year 2016 fleet-wide average of 250 gram/mile (g/mi). Thus, the model year 2025 scenarios analyzed in the TAR range from 190 g/mi (calculated to be equivalent to 47 miles per gallon, mpg) under the 3 percent per year reduction scenario to 143 g/mi (calculated to be equivalent to 62 mpg) under the 6 percent per year scenario.²⁵

Another source of perspectives on future light vehicle energy efficiency is vehicle technology experts such as the authors of the book *Reinventing the Automobile: Personal Urban Mobility for the 21st Century*, who indicate BTUs per mile changes from near 4,000 currently to approximately 1,500 BTUs when vehicles transition to electric battery.²⁶ A review of these works suggests several characteristics of future light vehicle technology and energy intensiveness that will impact the comparative efficiency of light vehicles relative to transit bus.

The ultimate composition of the future vehicle fleet will be impacted by several interrelated factors – the pace of technology change, consumer acceptance, regulation, and energy pricing. In recent decades, most of the technology improvements in light vehicles have been cashed in on higher performance vehicles and larger vehicles with the shift to large shares of truck, van, and sports utility vehicles in the personal vehicle fleet. The size of the fleet expanded until late in this decade, and vehicles continued to meet functional needs and provide entertainment and serve as image/ego items for some consumers. Fuel prices and sensitivity to energy availability and climate concerns appeared to have dampened the shift from autos to light trucks when pump prices rose, but that change appeared short-lived as fuel prices declined after the summer 2008 spike. Acceptance of hybrid technology, diesel fuel, flex-fueled vehicles, and all electrics are not yet fully understood and may change as the technologies mature and new perceptions of these technologies replace historical perceptions. Capital cost differences for new, innovative propulsion technologies that produce energy efficiencies generally have not been sufficient to provide a payback within the vehicle life, resulting in part of the motivation for incremental investment being altruistic motives, tax or other incentives, or expectations of meaningfully higher fuel prices within the vehicles' operating life. A combination of maturation of

²⁵ http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/NOI_2017+_10132010.pdf

²⁶ Mitchell, Borroni-Bird, and Burns, *Reinventing the Automobile: Personal Urban Mobility for the 21st Century*, MIT Press, Boston, 2010.

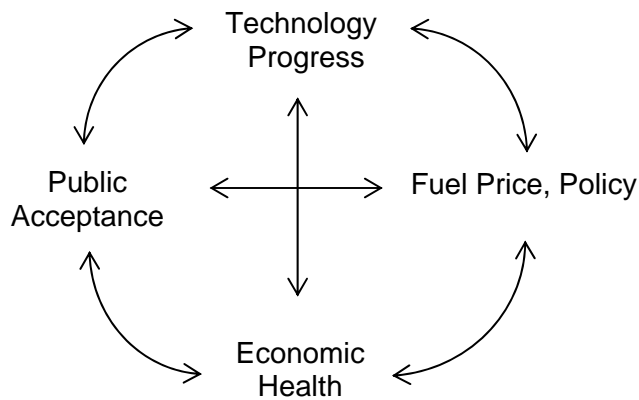
technologies, economies of scale (perhaps aided by CAFE standards or other regulations), and higher fuel prices is likely to alter this relationship.

The other major consideration in vehicle technology that impacts energy intensiveness is vehicle size and weight. Changes in vehicle size and materials can reduce the weight, a critical factor in energy efficiency. One of the virtues of personal vehicles is the prospect that energy-efficient motives can result in a move toward a closer matching of vehicle size with consumer space needs. Multi-vehicle households, in particular, have the opportunity to select vehicles to serve specific needs, including choosing small urban vehicles for urban use. Many of the prognosticators exploring the future of the automobile envision significant changes in vehicles, including resizing for more energy-efficient urban operation. This is particularly relevant for multi-vehicle households that can deploy vehicles for a specific application and is similarly very relevant for comparison with urban public transit. It is probable that the greatest improvements in vehicle energy efficiency will be for urban travel. Hybridization with regenerative braking and engine shutoff when stopped in traffic and size reductions are more likely to be adopted in the urban fleet. Electric vehicles and alternatively-fueled vehicles also are likely to be more common in urban operation where trip lengths are shorter and there is more likely to be alternative-fuel infrastructure implemented sooner. Incentives for alternatively-fueled vehicles such as recharging stations, preferential parking, dedicated lanes, or access to high occupancy vehicle lanes also are more probable in urban operation. Thus, one might expect the relative performance of the urban auto fleet to move toward efficiency faster than the overall fleet that might still contain larger vehicles suited for larger groups and intercity travel. The overall health of the economy also will be a factor. While a strong economy will allow the public to absorb higher energy costs, it will also allow the public to purchase new vehicles and perhaps additional vehicles to conserve energy.

For purposes of comparing future vehicle efficiency between public transit bus and urban auto operation, it is likely that changes in urban fleet auto performance will be faster than for the overall auto travel market.

However, the ultimate efficiency of the vehicle fleet is highly uncertain and influenced by numerous factors, as shown in Figure 21. In light of these uncertainties, the use of future scenarios of energy efficiency is felt to be the most realistic way to understand future comparative energy efficiency across modes.

Figure 21 Vehicle Technology Adoption Considerations



Future Bus Energy Efficiency

Future transit bus energy efficiency will be impacted by several of the same factors that will influence future auto efficiency. These include the pace of technology improvement, economic health, fuel costs, and transit agency acceptance and willingness to deploy new technologies. Much of the technology improvement in transit buses is supported by efforts to improve the energy efficiency of the national heavy vehicle fleet; however, there are industry initiatives supported by the Federal Transit Administration to support new transit vehicle technologies, with a goal of tripling transit fuel efficiency to 12 miles per diesel fuel equivalent.²⁷ Other sources indicate that an aggressive program of technology adoption can result in 40-50 percent fuel savings for new vehicles in the 2015-2020 time frame.²⁸

There are several characteristics of the transit fleet that impact the nature of technology change. Because of the urban operating environment with constrained vehicle speeds, vehicle aerodynamics are not critical consideration in energy efficiency (nor are they for autos operating in urban environments). Vehicle size is not a meaningful variable in attaining improved fuel efficiency. Unlike the auto fleet that is expected to become smaller on average, bus sizes are constrained by peak capacity needs and are not expected to be reduced systematically for the same markets where peak capacity needs define vehicle size. Within the fleet, operators may strive to match vehicle size to needs more closely, but a general downsizing of vehicles is not likely.

Transit vehicles consume 25-30 percent of their energy to operate auxiliary systems (heating, air conditioning, lighting, signage, etc.), a level exacerbated by frequent door opening and closing to enable passengers to load and unload.^{29,30} Transit vehicles are centrally and fueled operated, a characteristic that makes them more amenable to the introduction of new fuels or technologies. Being frequently owned and operated by the public sector has resulted in these fleets being used as technology demonstration vehicles, and there is a strong bias toward energy efficiency in vehicle purchases (even when not cost effective) to sustain the image of public transit as a fuel- and emissions-friendly means of travel. Transit vehicles typically are amortized over a 12-year operating life; however, many fleets keep vehicles in operation far longer due to the high cost of vehicle replacement. This contrasts with an approximate 17-year life to scrapping for light vehicles. Buses tend to have long operating hours; thus, it can be difficult to effectively deploy propulsion systems that need fueling/charging at high frequencies.

²⁷ "Electric Drive Strategic Plan," Federal Transit Administration, September 2010.

²⁸ "Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles," TIAx LLC for National Academy of Sciences, 2009.

²⁹ "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles," National Academies Press, Washington, D.C., 2010.

³⁰ "Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles," TIAx LLC for National Academy of Sciences, 2009.

Logistics of Vehicle Use

Within industries, one way to conserve resources is to deploy assets as efficiently as possible. In the transportation industry, this has received a great deal of attention in the freight area, as communications and information systems have enabled industries to effectively deploy their equipment to increase productivity and, hence, save energy. Within the arena of personal travel, there is less that falls within the realm of logistics that could reduce travel and, hence, increase the efficiency of overall travel. However, tactics such as chaining trips or making shorter trips is one common strategy that has been influenced by energy costs.

The other concept in logistics focuses on eliminating non-productive travel. Energy data sets use per-vehicle-mile as the denominator. All mileage is counted, as there is no way to separate out mileage not associated with meeting traveler needs (the equivalent of non-revenue miles in bus operations). Arguably, vehicle mileage associated with accommodating the needs of the vehicle (as opposed to the occupants) would be considered unproductive mileage and, if eliminated, would improve net efficiency by reducing overall mileage. Thus, extra mileage associated with fueling the vehicle or taking it to and from service could be considered wasted mileage. However, there are no data on this mileage to adjust net passenger benefitting mileage.

Within the transit industry, there are means of separating out vehicle mileage that is not part of the productive service of passengers. This typically is measured as the difference between revenue mileage (mileage where the bus is in service of passengers) and total vehicle mileage. The difference is the amount of travel the bus makes to get to and from the points of service. Mileage spent in operator training or shuttling vehicles between service facilities also would be included in vehicle mileage but not revenue mileage. With the transit industry, this number is typically 10 to 15 percent of total mileage. It varies based on the nature of the operating agency and the distances necessary to travel from the bus garage(s) to the point of service. Various operating strategies also influence the number, including the extent of long distance commute service and whether or not the out-of-direction travel is considered as in-service travel (some operators with little demand in the off-peak direction choose to not operate in-service and instead send their buses back to the start of peak direction service by the fastest possible route). There is no compelling case that can be made to suggest that bus logistics will meaningfully change enough in the future to adjust the net fuel use per revenue mile; however, as energy costs get greater, there is likely to be greater scrutiny of service and efforts to leverage efficiencies wherever possible.

Vehicle Utilization

Historically, auto utilization has declined as vehicle availability has increased and household size has declined. Those trends appear to have stabilized in the past decade, and the most recent years have seen a retraction in vehicle ownership levels, presumably associated with the economy, but perhaps partially attributable to an aging population and greater communication

capabilities, thus dampening young drivers' desires to become vehicle owners. However, vehicle occupancy has remained relatively stable over the past decade, and there is no compelling case to argue for meaningful changes in the future that will affect energy efficiency per person mile of travel. Much higher energy costs without offsetting efficiency improvements could induce greater vehicle occupancies (currently averaging approximately 1.6 for all person travel) but also could detract from the pace of shifting to smaller vehicles.

Transit is a different case. Historically, the loads on transit buses have been declining, as ridership growth has not kept pace with service expansion (see Figure 12). In addition, the capacity of buses has declined for a given size vehicle, as handicapped lifts or ramps, driver areas, wheelchair tie-down areas, and wheel well intrusion in to the bus interior space for low-floor vehicles has reduced the available passenger seating and floor space. Comfort standards for seat size and spacing also can reduce capacity as the industry tries to offer greater comfort to attract the ever-larger average American.

The desire to provide a transit choice to travelers has outpaced the actual growth in transit demand. Most recently (post 2007), budget pressures on transit agencies have resulted in cuts to unproductive service and signs that the industry is becoming more productive. Gauging the public will and willingness to fund future service expansion will partially determine the future trend with respect to average passenger loads. The second critical factor will be the public's desire to travel and choose transit.

Future vehicle utilization will be influenced by the nature of future demand growth. The most productive transit services tend to be urban services that operate in corridors with mixed land use that creates demand in both directions of travel throughout the course of the day. Longer-distance commutes in highly-peaked work-trip-focused travel corridors tend to be less productive, as the vehicle fills up gradually in the peak direction and operates virtually empty in the off-peak direction and at off-peak travel times. Anecdotal evidence from the fuel price spike in the summer of 2008 indicates that fuel-price-induced capacity pressures seemed to be on these longer-distance commute routes. This is logical, as these trips tend to offer a potentially meaningful auto mileage savings for travelers and, hence, can motivate the desire to shift these trips to transit. Short local auto trips, on the other hand, do not use enough fuel to offset the fare cost and wait time inconvenience of shifting to transit to save fuel costs.

While energy prices will increase the public pressure to provide transit alternatives based on the presumption of energy efficiency, transit agencies will have to discipline the delivery of service to focus limited resources on those markets that can deliver energy-efficient travel. These same considerations might influence other aspects of service design, with route circuitry and stop spacing altered to improve the efficiency of service and the productivity of the vehicle and operator labor.

The scenarios presented in the remainder of this section specifically address the productivity of service by integrating it into the scenarios' development.

Future Comparative Efficiency of Personal Vehicle and Bus Transit Travel

A spreadsheet tool was developed to explore the possible scenarios of the future relative energy efficiency of light vehicle versus bus transit travel. The spreadsheet allows the user to input various assumptions and see the resulting relative performance. As planners explore investments for the future, it is critical to be able to present reasonable analyses that address the comparative energy efficiency. In addition to comparative data, the results present absolute energy use data that are important to understanding the possible change from current conditions and to assess the criticality of energy efficiency in the context of overall decision factors such as costs and benefits to travelers. As there are expectations of improved energy efficiency by all modes, the absolute energy use data are relevant in understanding the magnitude of the contribution of travel in the context of overall energy consumption.

Light Vehicle Energy Efficiency

Future light vehicle efficiencies as measured in BTUs are extrapolated based on forecasts and policy as it relates to CAFE standards. These standards do not ensure the attainment of the prescribed levels, and attained operating performance in real world conditions has lagged CAFE standards by varying amounts, as the standard measurements methods have changed over time. Thus, the analysis adjusts between CAFE standards and the best measures of attained operating energy efficiency. The greatest uncertainty surrounds the ability of the technologies combined with consumer preferences to respond to the more aggressive CAFE standards in some scenarios.

For purposes of integrating new vehicles into the fleet, the spreadsheet assumes that 10 percent of the mileage in a given year is operated at the efficiency of the current year's vehicles and the remaining 90 percent operates at the prior average efficiency levels. This is a judgment based on the fact that utilization of newer vehicles in a fleet is higher than average, as these vehicles typically are more reliable and used as primary vehicles and older vehicles within a household revert to more specialized or secondary uses. While more rigorous empirical analysis could quantify this relationship, its uncertainty over time is such that when combined with the other uncertainty factors, it is not critical to the information provided by the scenarios. Tables 5 and 6 are images of the spreadsheet used to develop scenarios of light vehicle energy intensiveness. The sheets incorporate various adjustments to reflect urban conditions. The Urban Driving Cycle Adjustment incorporates the fact that the average urban fleet is more efficient than the average national fleet and that the urban travel conditions with slower speeds and more stop-and-go driving is inherently less energy efficient than the national average

Table 5 Light Vehicle Travel Energy Efficiency Scenario Calculations

[illegible]

driving cycle. These two adjustments are partially offsetting, resulting in the more dominant driving cycle differences reducing the urban energy efficiency relative to the national average.

The second significant adjustment is for urban occupancy levels. As noted previously, it is now known what the resultant behavior of transit travelers would be if transit services were not available, but it can be assumed that they would behave similar to other urban travelers (versus national average for travel). Thus, occupancy is assumed to be lower, reflecting a greater share of work travel, which has lower occupancies.

The rate of change for vehicle energy efficiencies is based on the announced CAFE standards for the 2011 to 2016 time period and at the low range of the annual rate of change (3%) for the subsequent years from 2017 to 2035. Scenarios can be developed for any range of annual efficiency changes.

This set of assumptions results in the BTUs per passenger mile level declining from 3,866 in 2010 to 1,745 in 2035, a reduction of 55 percent and the equivalent to 45 vehicle miles per gallon fuel efficiency – about the level of a larger motorcycle today but below the level of some hybrid vehicles currently available.

These substantial reductions in energy use per passenger mile are partially a result of the aggressive CAFE standards in the 2011 to 2016 time period. Should credits or shifts in the fleet composition between cars and other light vehicles or a market unwillingness to hit these targets result in the standards not being met, it could result in these estimates being too optimistic.

However, transportation planners do need to recognize that it is highly probable that urban travel energy use will be well below current levels in the future even without meaningful mode shifts. Anticipated technology and consumer vehicle decisions could result in the absolute level of urban travel energy consumption being half the levels today for the same population and, even accounting for average population growth, energy use beyond 2030 could be 25 percent below today's levels.

Transit Bus Energy Efficiency

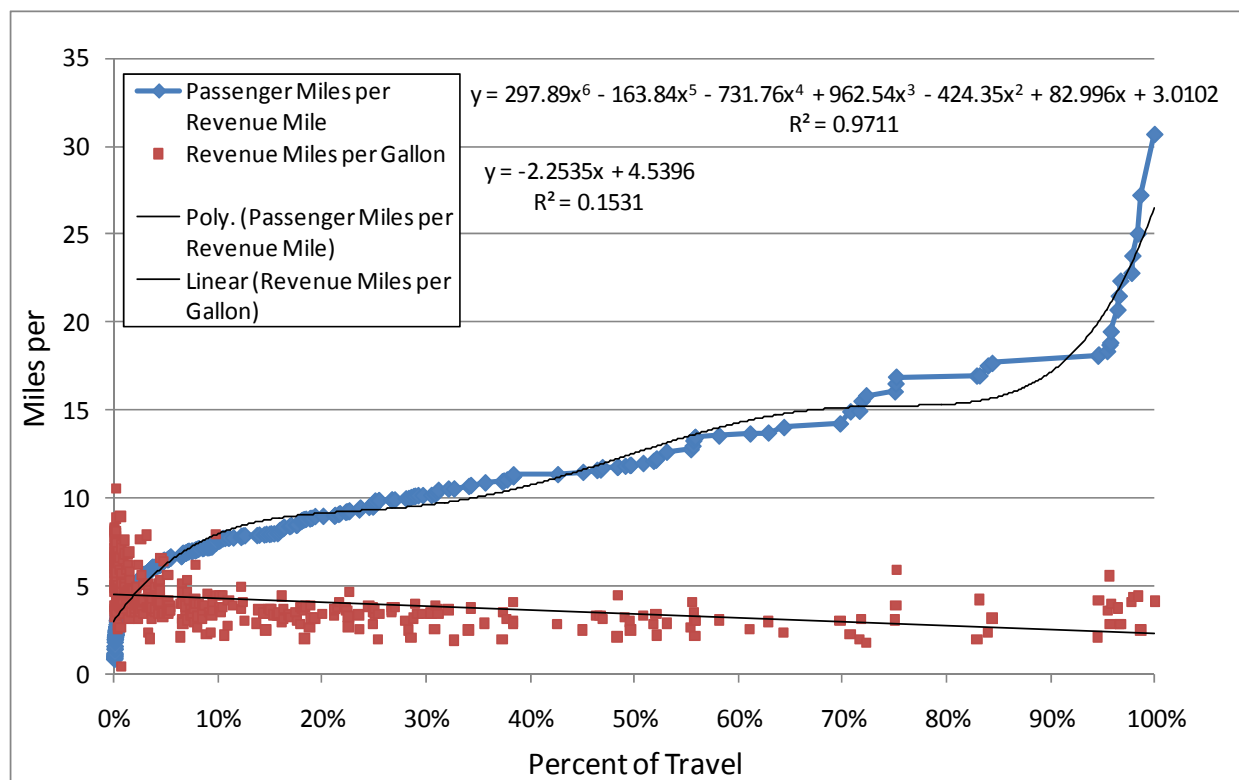
As noted earlier in this report, there is a great deal of contradictory data regarding transit bus fuel efficiency, making it difficult to define a starting point for efficiency comparisons. The scenario analysis relies on the research team's derivation noted previously in this work as a starting point for analysis. In addition, 2008 and 2009 NTD data were analyzed to explore some of the relationships between energy use and service productivity as that is a critical factor in energy efficiency.

It is important to recognize the nature of transit energy use and productivity when talking about efficiency performance. Transit agencies have very different operating environments, and performance varies based on the nature of their fleet, local topography and weather, local

service design, and local demand characteristics. Service design can include such factors as stop frequency but also more impactful features such as the extent of express operation. Policies on logistics with respect to vehicle deployment also can impact vehicle mile and revenue mile ratios and, ultimately, energy efficiency per passenger mile.

As the data in Figure 22 indicate, the performance of transit agencies varies, particularly at the tails of the distribution. The data are based on a 2008 NTD sample of directly-operated motorbus service for which aggregate energy use data were available. It does not consider the nature of the vehicle fleet (vehicle size), nor does it extract data on the particular fuel source, instead relying on the reported gallons used. The data show greater fuel efficiency than data developed and reported previously that extracted individual agency reports and adjusted for the fuel type. Thus, these data were used only to understand the relationships between fuel efficiency and service productivity and to understand the variation in the data across agencies. Newer 2009 data also were reviewed but found to be less clean, with more properties showing data that looked illogical based on some simple screens such as vehicle miles per gallon.

Figure 22 Transit Service Productivity Distribution



The blue (upper) line on Figure 22 plots the passenger miles per revenue mile for the nearly 400 agencies in the sample analyzed. This is a cumulative distribution graph based on ranking by agency productivity level and weighted by agency passenger miles. Thus, it shows what share of agency average trips are delivered with a given level of productivity. According to this

analysis, 50 percent of passenger trips are served with a productivity of greater than or equal to 11.15 passenger miles per revenue mile (if vehicle miles were in the denominator, the number would be approximately 10% lower).

The right-hand tail of the distribution, with productivity levels above approximately 18 passenger miles per revenue mile, most likely includes agencies with express services that operate with full buses or other unique situations. The far-left-hand tail generally represents small agencies with social service priorities of meeting travel needs and not necessarily accommodating large volumes of travel. The remaining 90 percent of the passenger travel between these tails shows a relatively uniform distribution of service productivity. The equation in Figure 22 describes this line and is used in the spreadsheet to allow the user to make assumptions about future service productivity and see the corresponding change in energy efficiency.

The lower distribution of points indicates the revenue-mile-per-gallon values for the corresponding agencies. The purpose of looking at this was to explore the relationship between service productivity and energy efficiency. Generally, it is expected that more highly-used services also would be services where the vehicles operate less efficiently. There would be heavier loads, more stops and delays for boarding and alighting passengers, generally a more congested, slower operating speed environment (associated with higher density and greater transit use), a larger vehicle, and perhaps more auxiliary energy use. This relationship was borne out, but the observation is subtle. It should be noted that 53 percent of transit passenger miles occurs on vehicles attaining less than 3 revenue miles per gallon of fuel.

Table 6 presents the section of the scenario tool that outlines the transit energy efficiency assumptions. There are several characteristics that drive the future energy efficiency. First, an adjustment capability allows the analyst to input an adjustment factor for transit route circuitry. This is to account for the average difference in travel distance between point of origin and point of destination by bus versus auto. The research team is not aware of any available data that purport to have developed an average number for this factor, but 1.02 (a 2% increase in distance for bus travel) was used for purposes of calculation. Bus networks are less dense than the roadway network, and routes often deviate from a direct path to accommodate greater convenience for major attractors, so it would be expected that some of the passenger travel by bus would not occur for a more direct path. Route networks with a radial orientation could produce much greater travel circuitry. The 2 percent assumption seems a very conservative estimate of such a circuitry factor.

Second, an adjustment is made between the new vehicle fuel efficiency in a normal service cycle and that attained on street performance of the average fleet. The spreadsheet shows a new vehicle energy efficiency of 5.2 miles per gallon of diesel fuel in 2008. This number is then used as the base for calculating the change in new vehicle efficiency due to technological improvements. The base value is not critical, as it is adjusted to replicate field data on actual performance within the calculations.

Third, the energy efficiency improvement rate is expressed as an annual percentage change. This number, adjustable by the analyst, is currently set to match the 3 percent per year rates also used for light vehicle improvements.

Fourth, the service productivity adjustment capability allows the analyst to assume different levels of service utilization in percentages changes from the mean 50 percent level. This change is applied uniformly over the analysis period to indicate the impact of service productivity on relative energy efficiency.

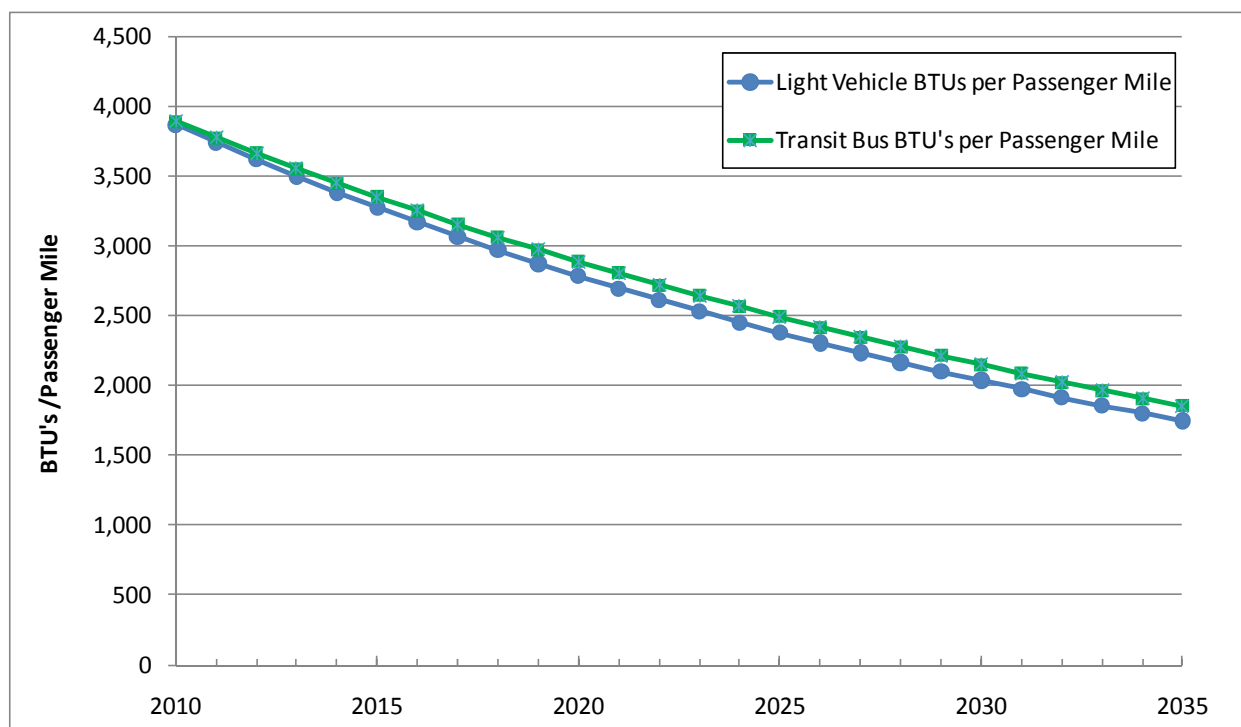
Scenarios

Several scenarios are presented below. These scenarios contrast the relative performance of light vehicles and transit buses in terms of their future energy intensiveness. The scenarios outline various forecasts of how the energy efficiency of the respective modes might change in the future based on technology and policy considerations being discussed in the literature. Scenarios are discussed after they are presented.

Scenario 1 or Base Scenario

This uses the existing service utilization and the CAFE standards for cars and the 3 percent per year efficiency improvements for auto beyond 2017 and transit throughout the analysis period.

Figure 23 Base Scenario



This scenario indicates that the relative energy efficiency changes only slightly, with the auto advantage growing slightly due to the relatively aggressive CAFE standards for the 2011 to 2016 period and the subsequent influence of those new vehicles on the fleet performance. Attaining these CAFE standard performance levels will not be accomplished by technology improvements alone but will require shifts toward a larger share of the auto fleet being autos and smaller autos than has historically been the case in recent years. As the transit bus fleet does not have that opportunity, it is logical to expect that the performance of the light vehicle fleet might improve faster than the transit fleet, absent some intervening policy or other changes.

Scenario 2 or Base Scenario with Aggressive Transit Technology Deployment

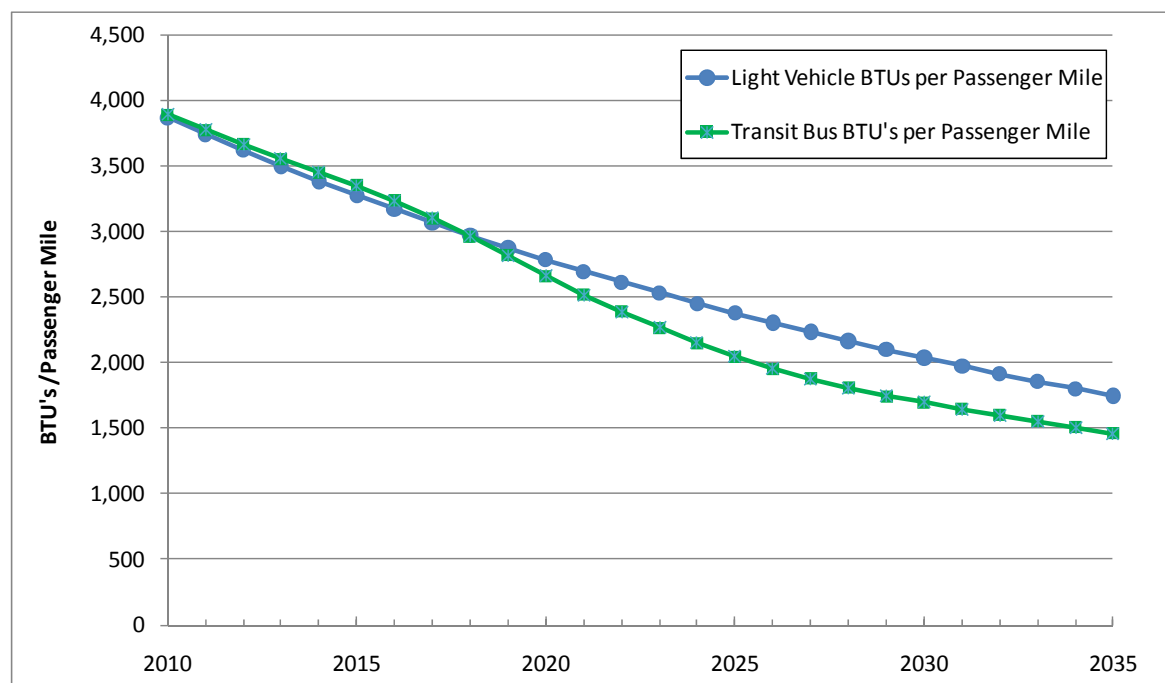
This scenario is the same as the base scenario with the exception of the assumption of aggressive technology deployment in transit in the 2016-2020 time frame. In these years, it is assumed that the fuel efficiency of the new fleet improves 8 percent per year, which is consistent with some industry scenarios calling for rapid deployment of hybrid and other technologies to substantially alter the transit fleet. This scenario shows the bus fleet gaining an advantage over light vehicle travel late in the decade as new vehicles grow their share in fleets. Beyond 2020, this scenario assumes that fleet efficiencies continue to improve at the rate of 3 percent per year. Energy-efficient alternatives currently have substantial price premiums per vehicle, so this would require significant new revenues directed to vehicle replacement or substantial progress in bringing down the marginal cost of technologies that enable improved fuel efficiencies.

As shown in Figure 24, this results in the relative per-passenger-mile efficiency of transit bus travel improving in the post 2019 time frame to where transit bus is more fuel efficient. As in all cases, the technology changes in new vehicles take many years to be fully reflected in the overall fleet performance as vehicles are replaced over time.

This scenario tests the concept of improving the attained efficiency of transit bus by working to improve the productivity of services. This could result from meaningful changes in public acceptance and use of transit, as motivated by economic or environmental considerations, or it could result in greater discipline and careful design in the deployment of services, effectively utilizing the increasing amounts of information available on service use via intelligent transportation technologies. This scenario presumes that transit service operates at average load factors equivalent to the current 60th percentile level. This would mean that the passenger miles per revenue mile numbers would increase from approximately 11.15 to approximately 12.30. This seemingly modest change is counter to the longer-term industry trend of declining service productivity. Improving productivity has been observed in the past few years in many agencies as financial pressures have forced them to cut back unproductive service, thus improving the average performance. The natural desire to grow service and to be equitable to the service area in terms of providing base services, even for challenging markets, has made it difficult for transit agencies to focus exclusively on productivity. This challenge is not likely to go

away, but resource constraints coupled with high energy costs and household budget constraints curbing vehicle ownership might make productivity improvements more probable than in the prior decades.

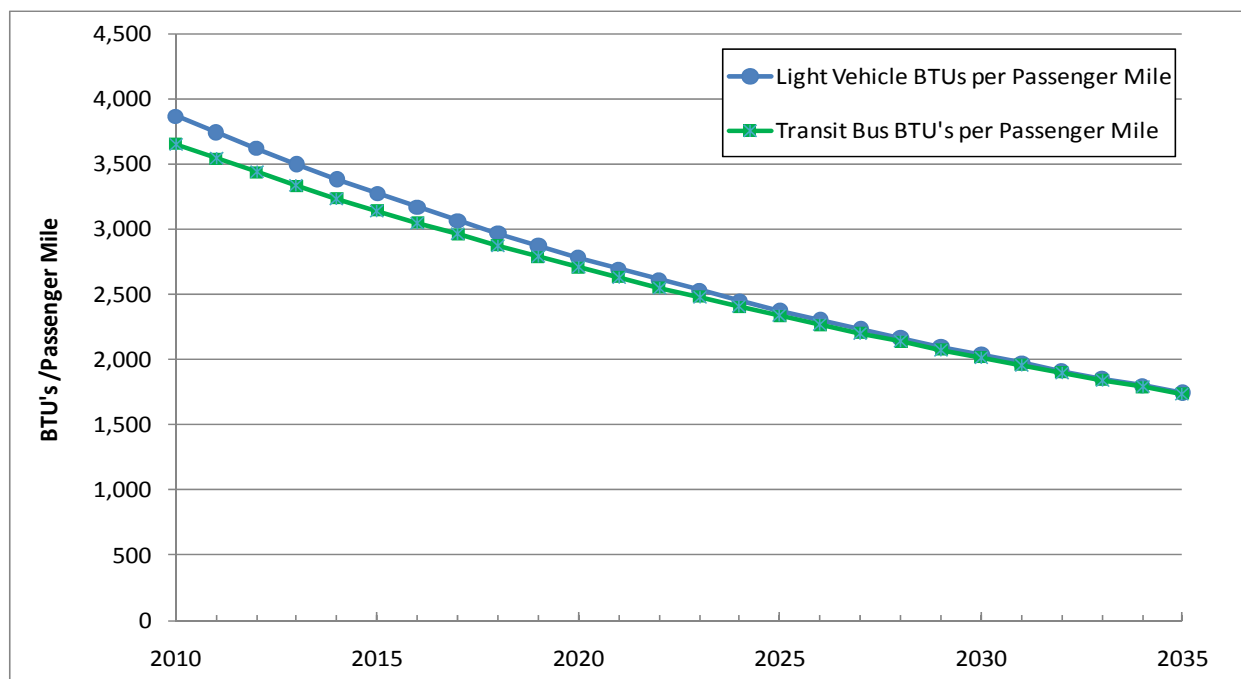
Figure 24 Base Scenario with Aggressive Transit Technology Deployment



Scenario 3 or Base Scenario with Transit Productivity Improved to 60th Percentile

This scenario, which does not include the aggressive transit technology deployment assumption, shows transit bus being more efficient than auto travel in early years but the aggressive CAFE standards result in the gap closing over time.

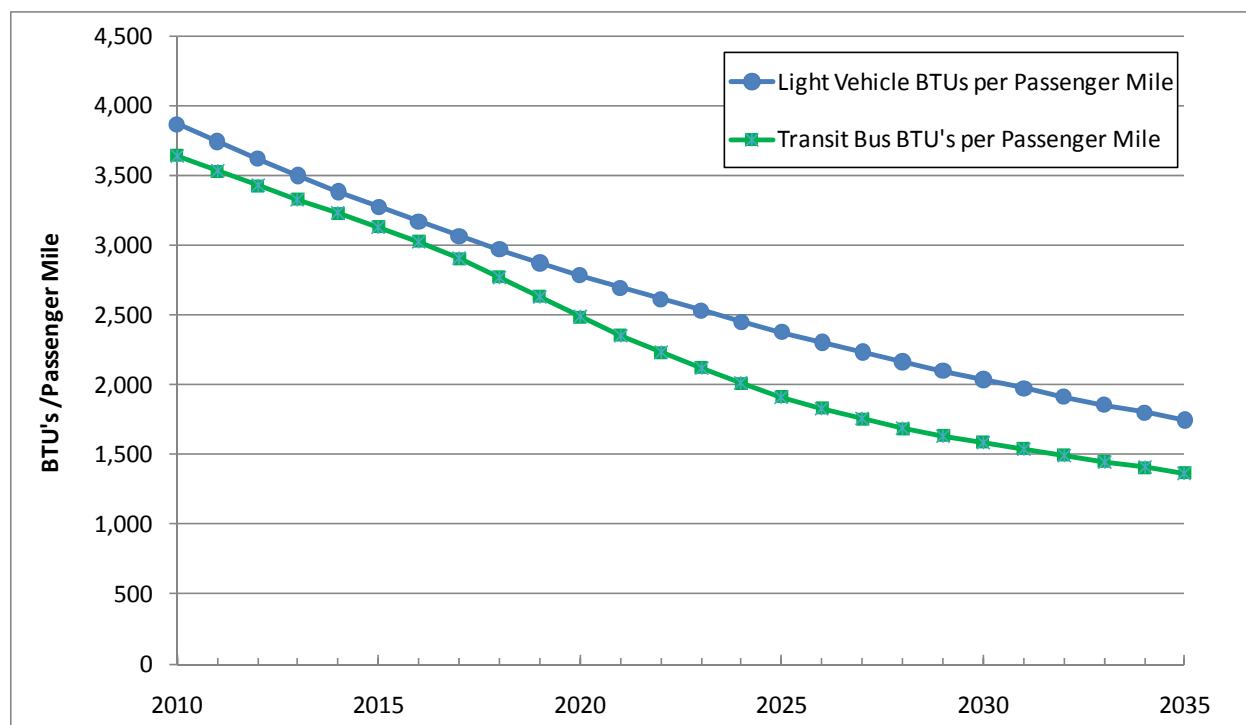
Figure 25 Base Scenario with Transit Productivity Improved to 60th Percentile



Scenario 4 or with Aggressive Transit Technology Deployment and Transit Productivity Improved to 63rd Percentile

This scenario exemplifies a situation where transit productivity improves quite significantly to the current 63rd percentile level (where the average load factor increases to the 63rd percentile level of current load factors; 11.15 to 13.5) and there is aggressive technology deployment. Given the relationship between service productivity and vehicle efficiency, this level of productivity gave the best comparative performance of bus and auto until load factors got very high. This is a result of the relationship between productivity and vehicle efficiency that is embodied in the data presented in Figure 22. While different equations could alter the optimization to some extent, planners must realize that productivity improvements are critical but they tend to be associated with declining vehicle energy efficiency as the vehicle stops more, has a heavier load, the doors open more, etc., which typically degrades energy efficiency. Thus, the idea in terms of improving energy efficiency is most promising in cases where the increase in loads does not lead to a deterioration of vehicle efficiency. Situations such as increased loads on one-to-one services such as express routes might exemplify this type of improvement.

Figure 26 Base Scenario with Aggressive Transit Technology Deployment and 63rd Percentile Productivity



Findings Regarding Future Transit Energy Efficiency

While this analysis was restricted to fixed-route bus services, many of the observations have broader implications.

Long range planning energy impact analyses should use context-specific information.

As noted in the prior discussion and borne out by the empirical data, performance with respect to energy efficiency is influenced by a host of factors, including the local service design and operating conditions and the local bus fleet mix and characteristics. While future local assumptions should be informed by national data and the best available information on future conditions, local plans should not default to national means but rather reflect how the local context might evolve. It should be understood that both technology and efficiency improvements will come with respective costs and are not predestined due to higher energy costs. Moving toward greater energy efficiency is counter to trends over the past few decades and a nontrivial challenge for the transit industry.

Productivity improvements are critical opportunities for attaining greater energy

efficiency. These improvements are not dependent on technology change or new investment but rather on how well the service is managed and utilized by the local market. While the social

service motivations for providing transit services remain strong and are not governed by energy efficiency, aspirations of providing an energy-efficient public transit service will require discipline in order to deliver on that promise. If service expands faster than market acceptance, then productivity is likely to decline. Alternatively, if ridership can grow faster than service, contrary to recent general industry-wide trends up until recently, then energy efficiency can be improved.

Technology improvements in the transit fleet directed at improving propulsion efficiency (as well as auxiliary equipment energy use) will be required for transit to be competitive with auto travel in terms of energy efficiency. New CAFE standards are destined to make the auto and light vehicle fleets significantly more energy-efficient over the next decade and beyond as new technologies are integrated into the fleet. Many of the features that will improve light vehicle energy efficiency will be particularly relevant for urban travel of the type that is most comparable to transit bus travel. Hybrid vehicles, alternative fuels, and smaller vehicle sizes all are attributes that are likely to be integrated in the urban fleet more intensively than the total fleet. Hybrid treatment, for example, shows the greatest efficiency improvement in slow to moderate speed operation with stop-and-go travel cycles – the type characteristic of urban travel. Thus, urban light vehicle travel efficiency is likely to improve even faster than overall efficiency and make the transit-auto comparisons more challenging.

New transit technology currently is premium priced and challenges agencies with respect to both affordability and cost effectiveness justification. While there are certainly different types of hybrid technologies and numerous factors that influence the resultant performance (weather, topography, nature of bus route, driver training and experience, mechanical condition, etc.) and cost, the bottom line is that the economic payback from such an investment is not accomplished within the life of the vehicle. In fact, some back-of-the-envelope calculations for some Florida applications suggest it might take two or three vehicle lifetimes for there to be an economic payback from hybrid vehicles – an obvious impossibility in the real world. While such investments still might offer positive public image benefits and be motivational for staff, to rationalize such an investment requires placing an extraordinary premium on the energy and climate change benefits well beyond those reflected in the current pricing of energy.

Interestingly, a quick review of a mixed sample of domestic hybrid cars, trucks, and SUVs indicates a cost difference for hybrid products of approximately 20 percent and a difference of nearly 33 percent in terms of energy efficiency (mpg). Forty-foot diesel coaches, on the other hand, appear to be delivering energy efficiency improvements of under 20 percent and still carry cost premiums over 60 percent. In fact, some paratransit-sized vehicles with hybrid power trains can cost twice as much as non-hybrid vehicles.³¹

Logistics improvements in transit operations will become increasingly important as energy costs increase and transit agencies become more sensitive to energy consumption. The number and locations of operating facilities, route design, decisions on

³¹ "How Much Green for the Green?" Planetizen Blog, June 2009, <http://www.planetizen.com/node/39389>.

operator assignment (taking operators to routes rather than bringing buses back to the garage for shift changes), and even decisions on using simulators for training to reduce on-street training expenditures might be part of efforts to optimize energy effectiveness. The selection of vehicle sizes for the fleet and their assignment to the various service types will be part of the logistics efforts to optimize energy efficiency.

The energy impacts of travel may be less significant over time. Unless the various initiatives to reduce energy use in vehicles fail and travel growth outpaces current expectations, energy consumption by person travel is likely to decline in real terms and in share. Thus, the relative importance of urban travel energy efficiency is likely to be less critical in terms of its share of the energy use (presuming that other energy use sectors do not improve proportionally). However, this may be offset if the criticality of energy cost and availability result in it being a more important consideration in transportation policy in the future.

Based on available data, urban travel energy efficiency is not likely to be a critical factor in determining relative modal investment strategies in the future. Based on the scenarios reviewed, the direct energy saving benefit is either nonexistent or modest and unlikely to change dramatically over time. Depending on the various factors noted in the analysis and scenarios, the future comparisons of energy use across modes are likely to be influenced by context and not provide a compelling case for dramatic policy changes. Indirect energy benefits, as discussed previously, or other considerations are likely to be more critical.

Future modal energy comparisons should be based on logically-consistent scenarios for bus and light vehicle modes. The analysis should use anticipated energy intensiveness of the modes for similar points in time and assume logically-consistent technological progress for all modes. For example, an analysis focusing on a 2030 design year should consider the light vehicle fleet in place at that time, compared to the transit fleet in place at that time. Absent some compelling logic, it could be assumed that technologies such as hybridization and alternative fuels will progress such that technological improvement will occur in similar paces in both modes or that there are credible agency forecasts based on economic and other factors that might be the basis for differential deployment assumptions across the modes.

Florida Transit Agency Propulsion Energy Use Data

On the following pages are graphics that report the energy use trends of Florida transit agencies that have submitted NTD energy use data. These data present the trends over the past several years for the reporting properties. Seventeen of the 30 properties that provide fixed-route service are included, but this includes the vast majority of the state ridership and service, as it tends to be the smallest properties that do not file NTD data or do not report energy use data. The order of the figures is based on the sequence order of the NTD identification numbers.

The graphics raise a number of points of which planners should be cognizant. Data are not available for many segments of the portfolio of services operated. Some of this is due to the

fact that services are privately operated and, in some cases, the agencies do not report NTD data. While the data provide a sufficiently rich sample to glean a good understanding of the performance of systems and the variation in that performance across properties, it is far from complete.

There are apparent anomalies in the data in various years. Some of these are noted as being the result of switches in fuel types, and other may be due to significant fleet changes or simply data quality issues. As is the case with national data, it does build the case for encouraging a national initiative to audit transit energy use in order to reach a stronger consensus on what BTUs-per-passenger-mile numbers should be used for national policy making. It also suggests that individual agencies be encouraged to take energy use data very seriously in light of the importance of energy use to transit and the financial implications, as energy costs have increased and energy is now a much higher share of total transit operating costs.

Finally, the absolute level of energy performance of Florida transit is not strong. Many Florida agencies have fixed-route transit energy use in BTUs per passenger mile in excess of 5,000, well above the numbers for the national average and for auto travel. This is not surprising, as it is well documented that Florida's transit use, while showing positive trends, lags national performance. The challenges that have confronted transit in Florida – low to modest densities and dispersed activity centers with high auto ownership and tolerable levels of congestion, parking cost, and other factors – translate into an environment that makes it challenging to operate energy efficient transit services.

Figures 27 through 55 present agency energy efficiency data. These figures report data for those Florida agencies where data is available. Data is reported for all transit modes where available. Thus, one is able to compare energy efficiency across the modes. Data is presented in terms of three metrics: consumption per vehicle mile, consumption per passenger trip, and consumption per passenger mile.

Figure 27 Manatee County Motorbus Energy Consumption Per Unit of Travel

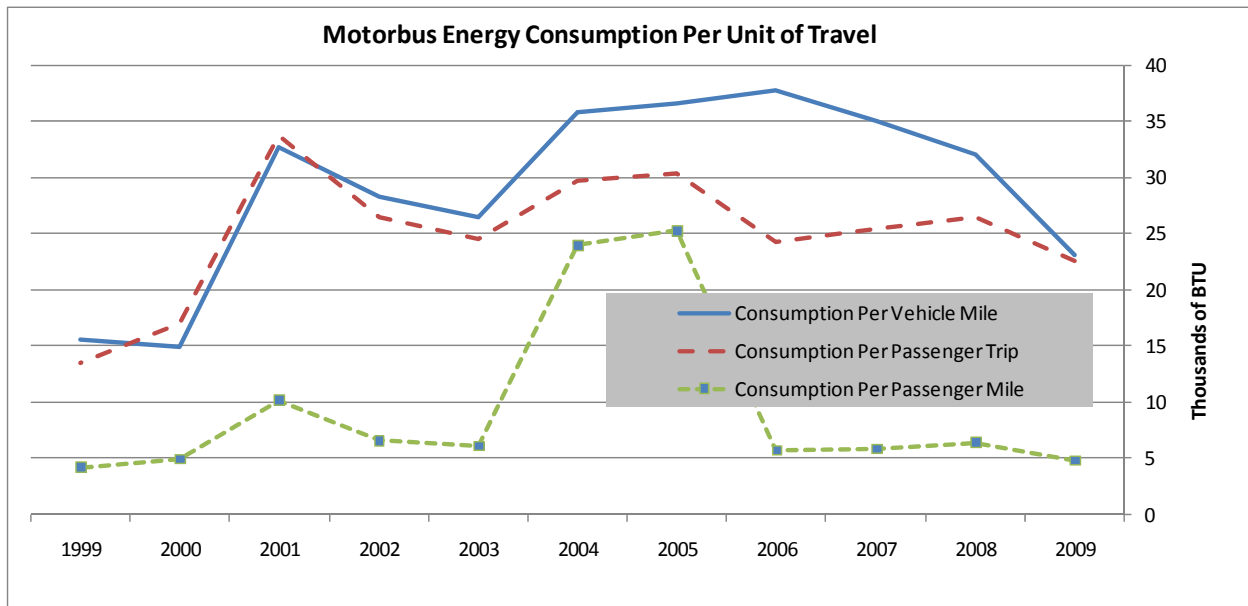


Figure 28 Manatee Demand Response Energy Consumption Per Unit of Travel

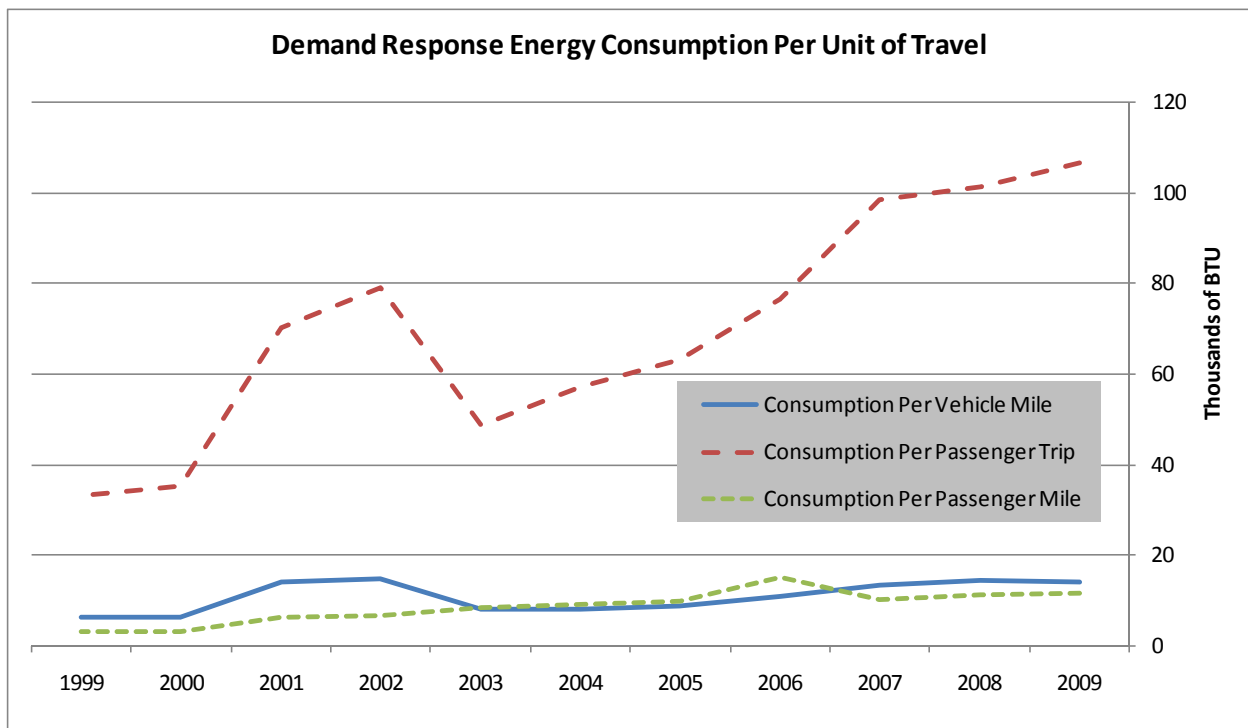
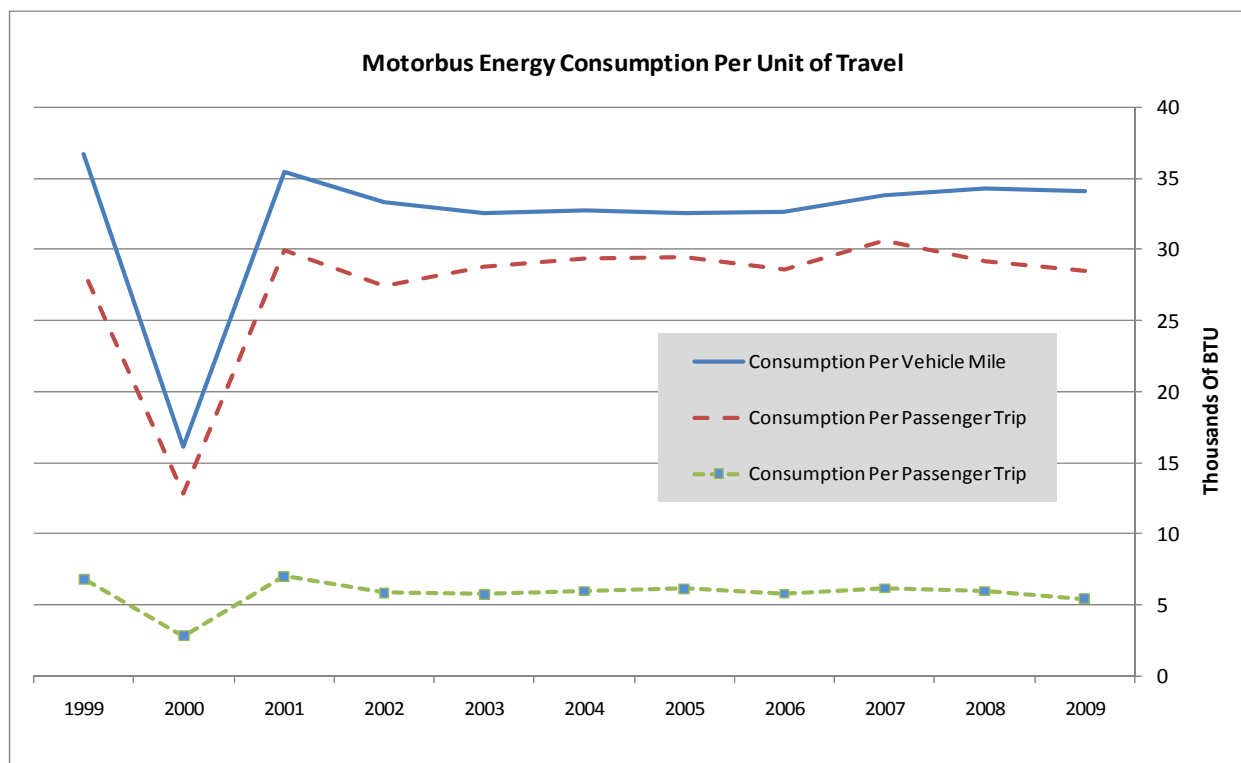
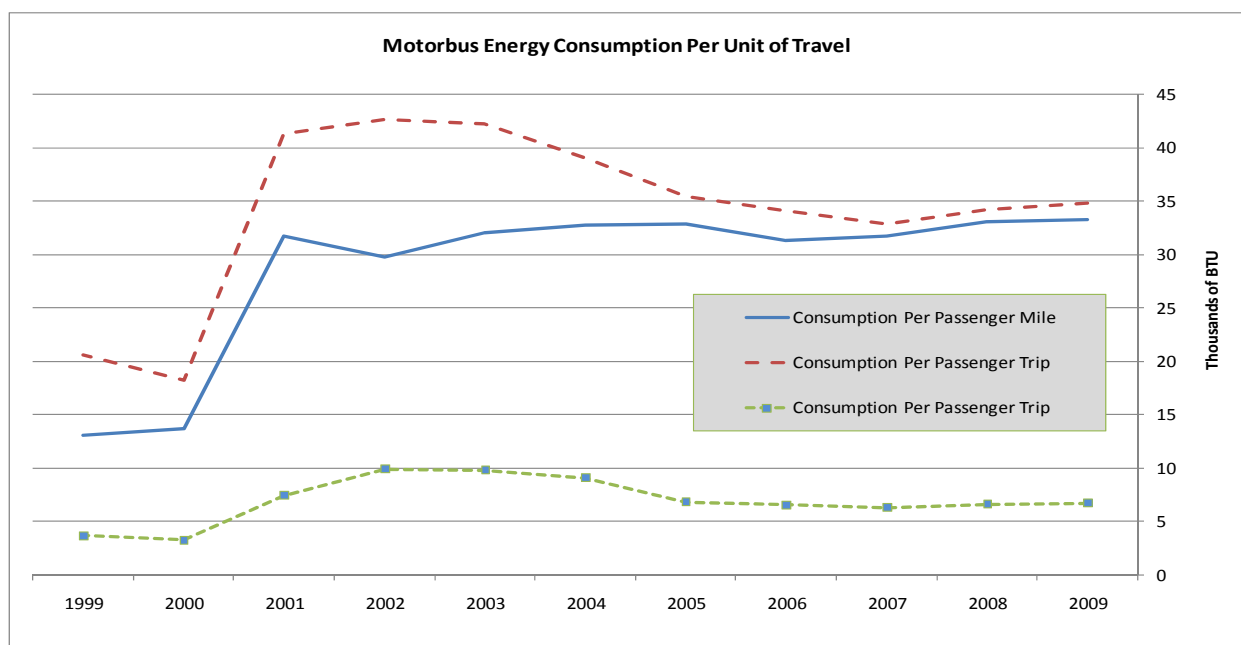


Figure 29 Pinellas Motorbus Energy Consumption Per Unit of Travel



Note: 2000 data impacted by shift in fuels for Diesel to LPG for some of the fleet.

Figure 30 Lee County Motorbus Energy Consumption Per Unit of Travel



Note: Diesel to LPG shift in 2001.

Figure 31 Broward County Motorbus Energy Consumption Per Unit of Travel

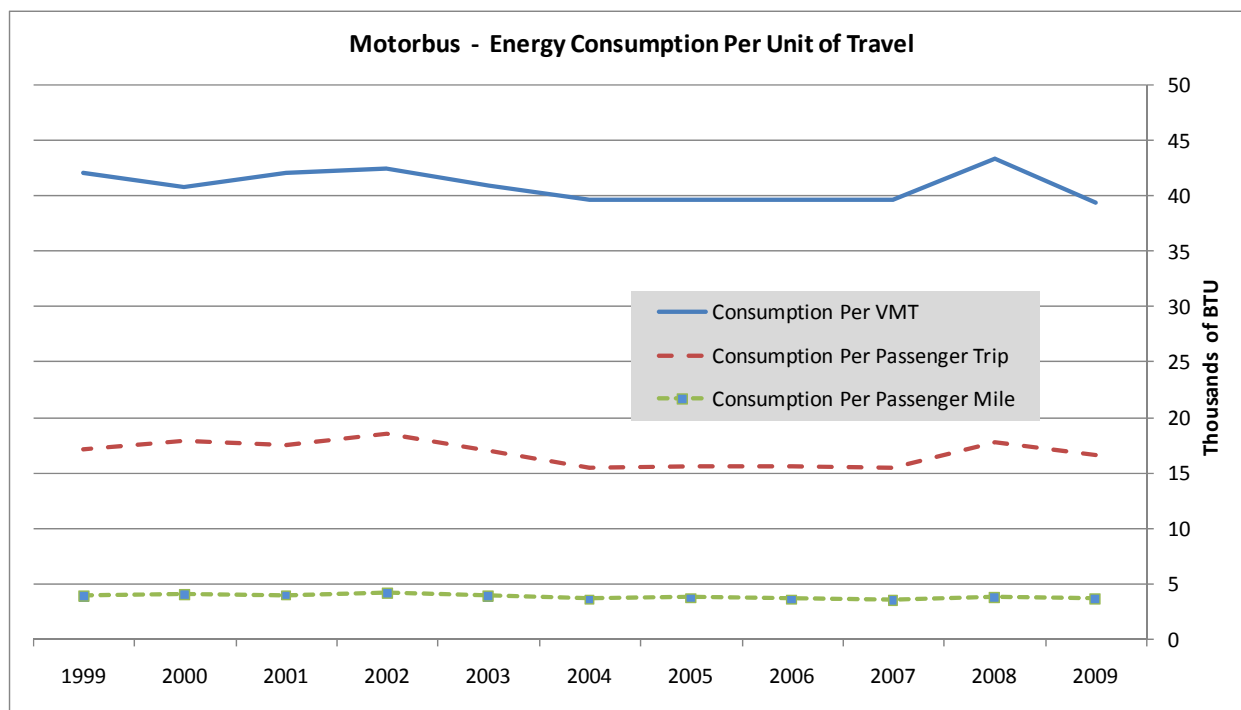
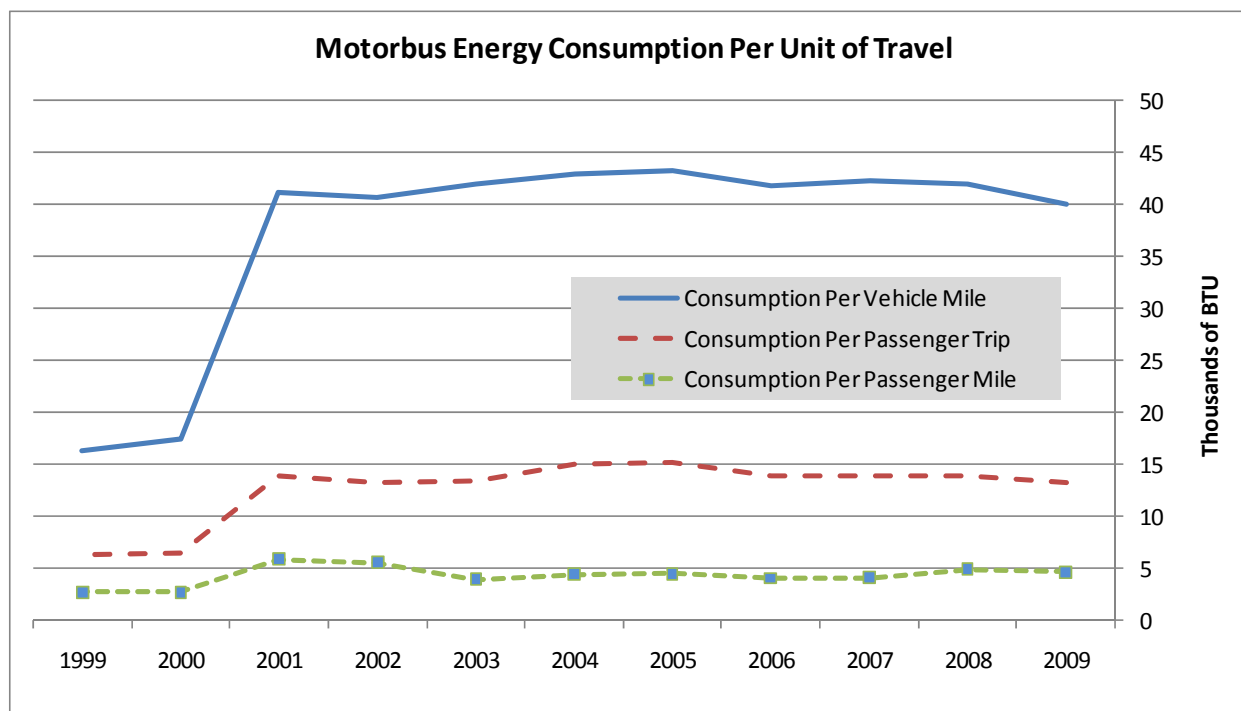


Figure 32 City of Gainesville Motorbus Energy Consumption Per Unit of Travel



Note: Shift from Diesel fuel to LPG in 2001.

Figure 33 City of Lakeland Motorbus Energy Consumption Per Unit of Travel

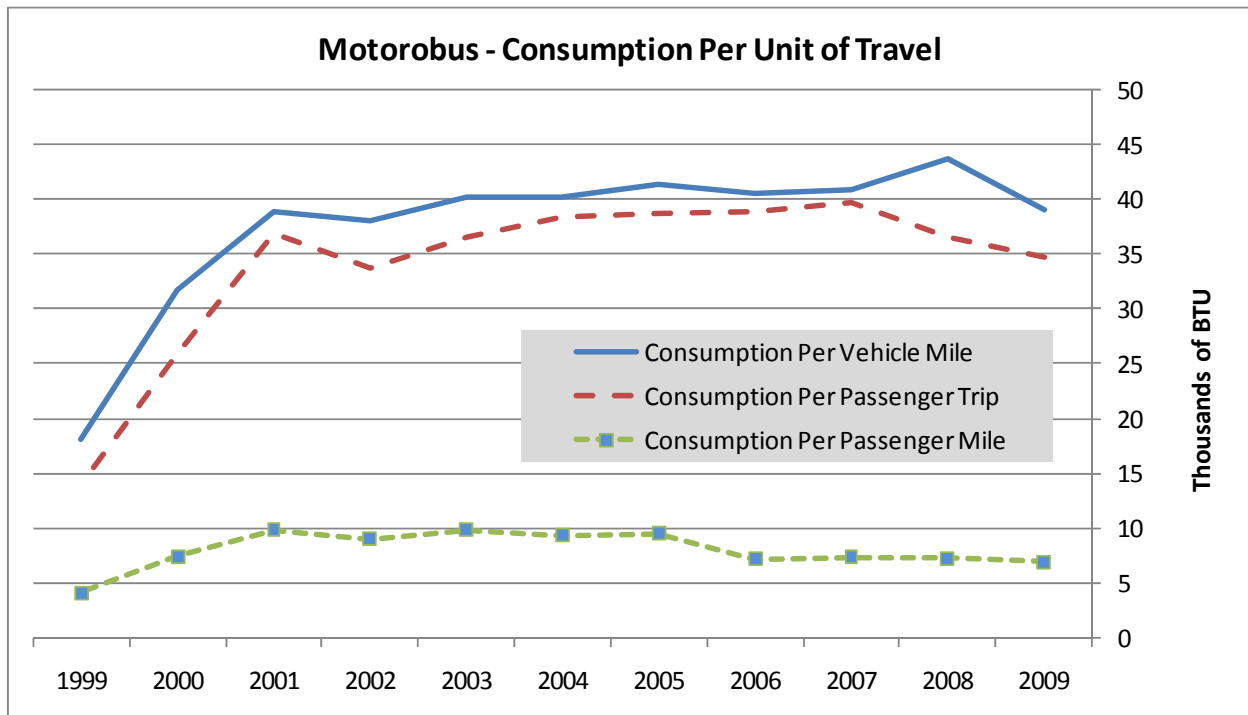


Figure 34 City of Lakeland Demand Response Energy Consumption Per Unit of Travel

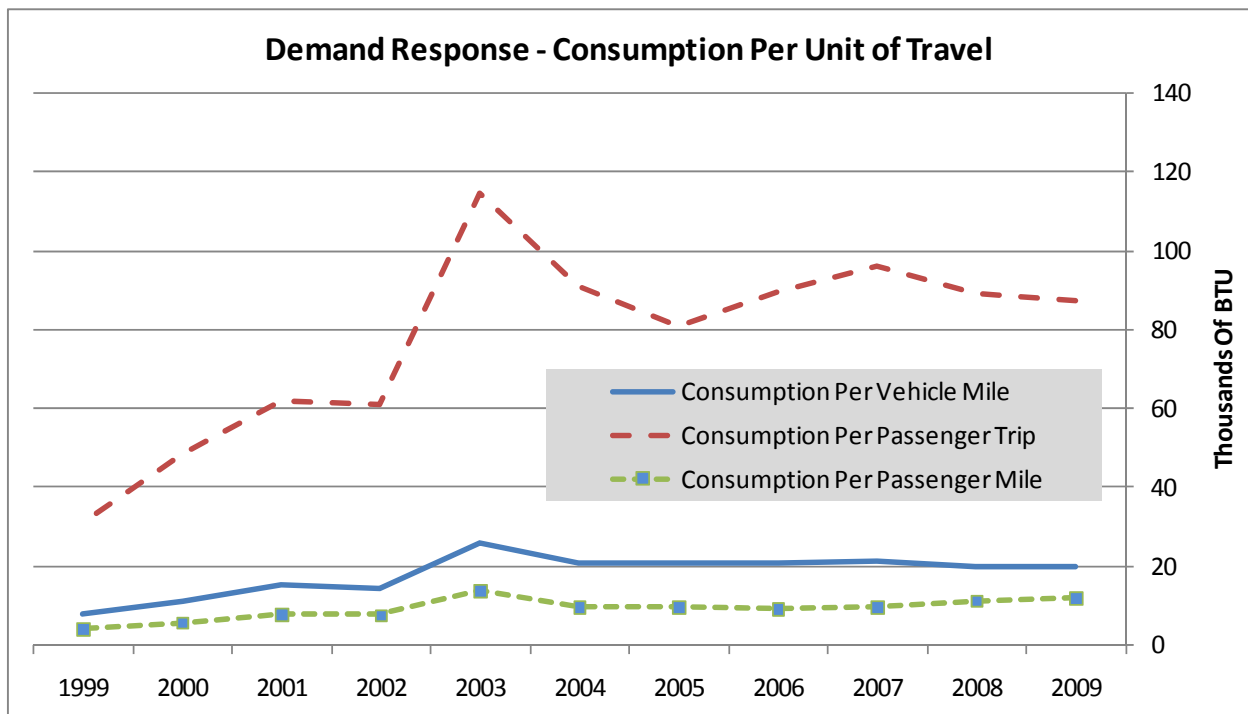
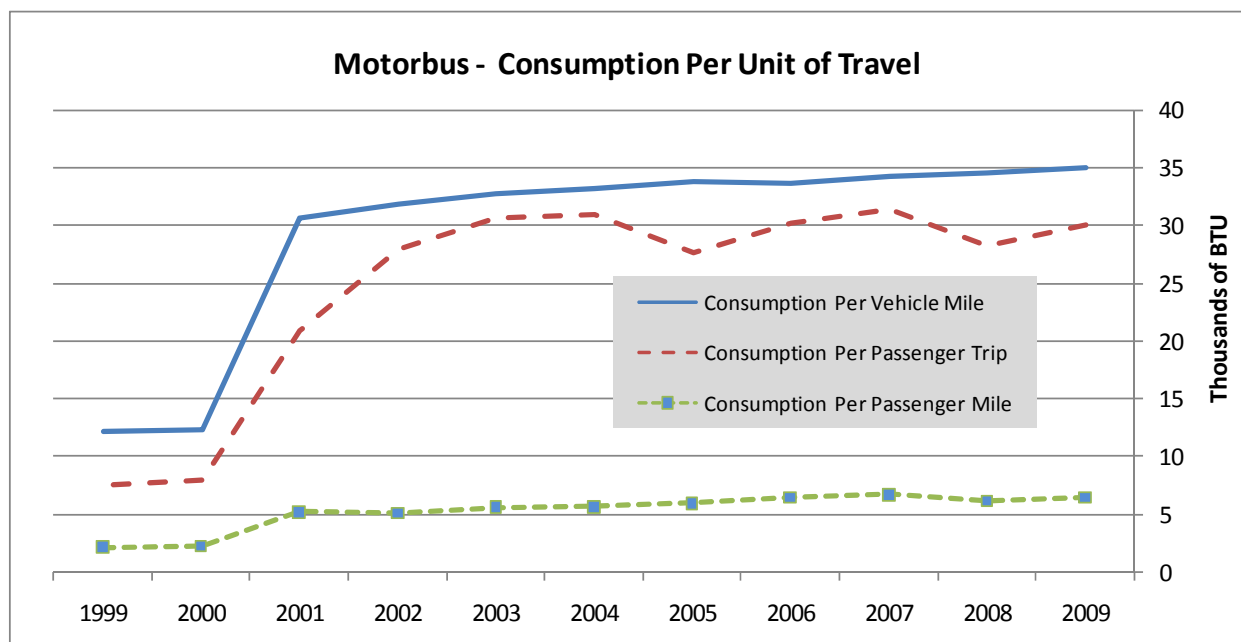


Figure 35 Volusia County Motorbus Energy Consumption Per Unit of Travel



Note: Shift from LPG to gasoline in 2001.

Figure 36 Volusia County Demand Response Energy Consumption Per Unit of Travel

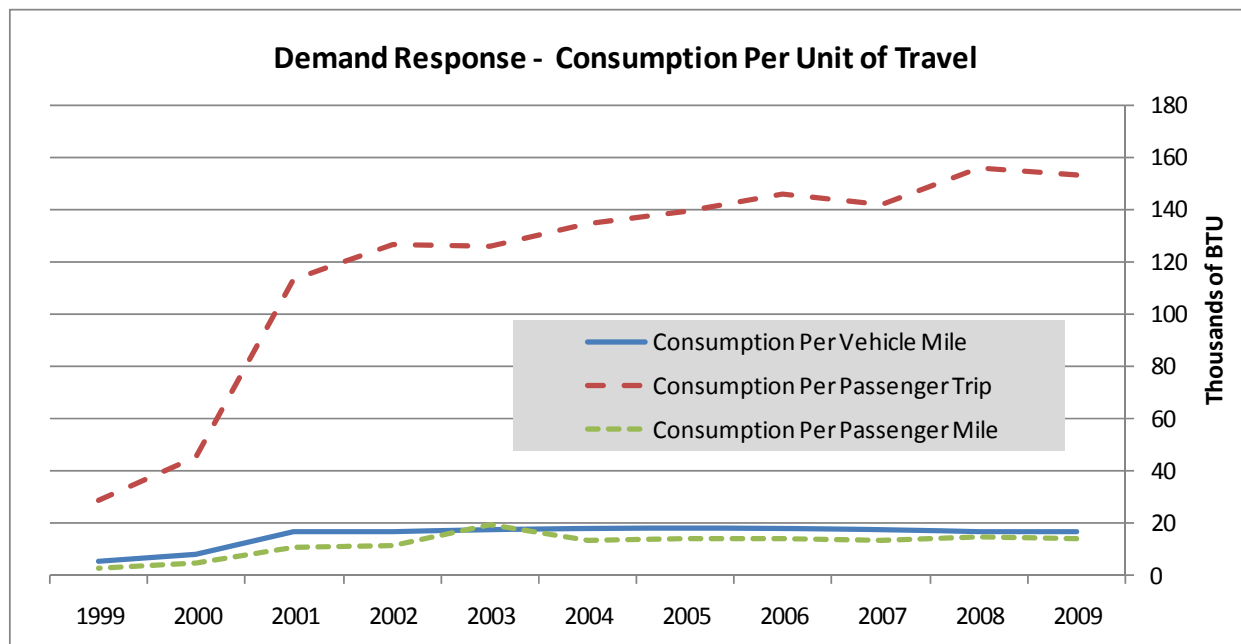


Figure 37 Volusia County Vanpool Energy Consumption Per Unit of Travel

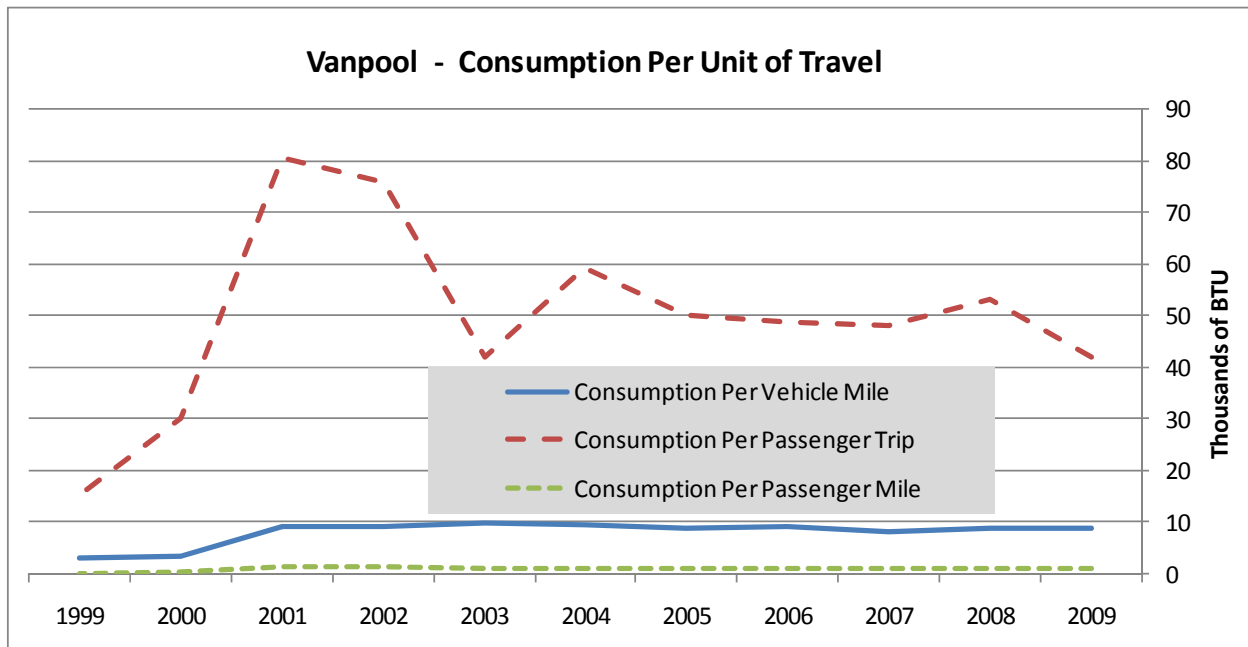


Figure 38 Miami-Dade County Motorbus Energy Consumption Per Unit of Travel

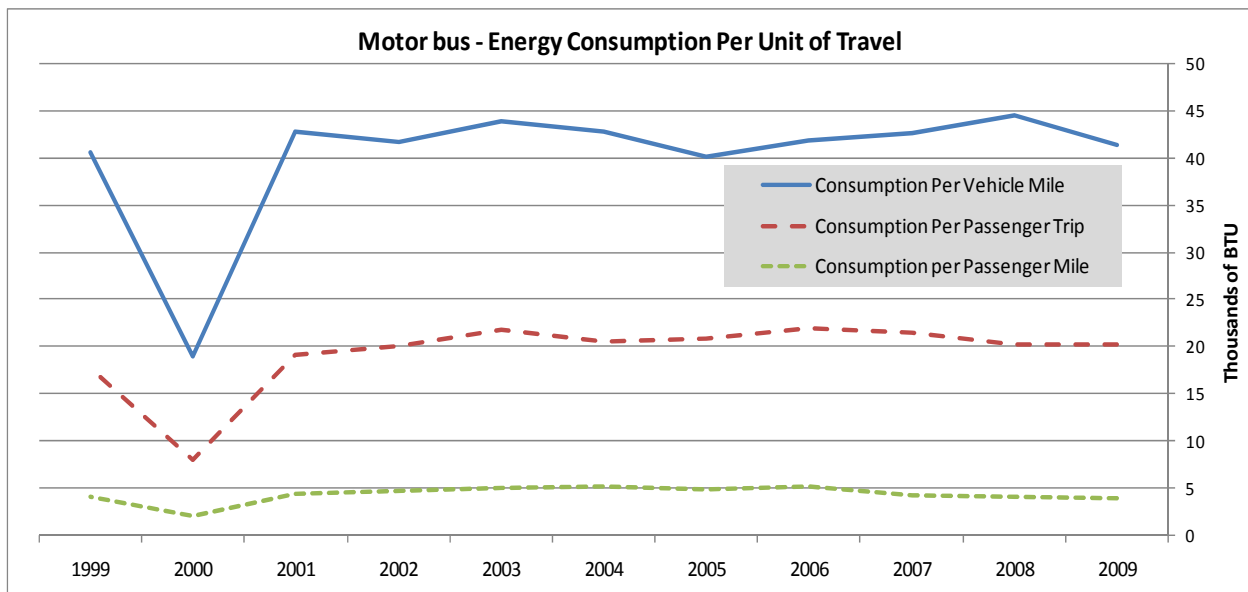


Figure 39 Miami-Dade County Heavy Rail Energy Consumption Per Unit of Travel

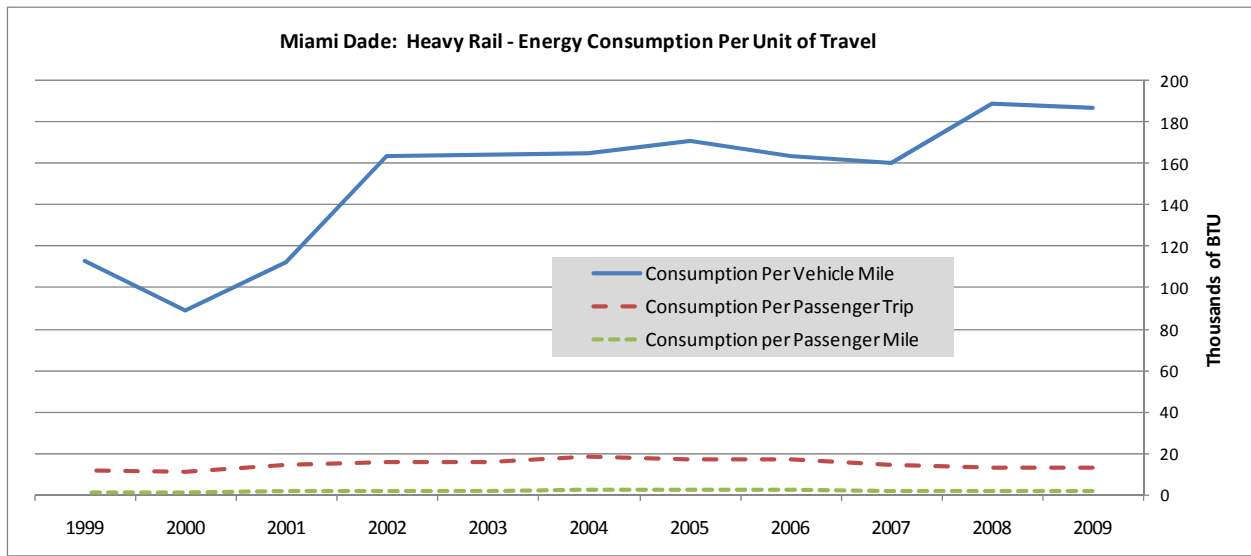


Figure 40 Miami-Dade County Automated Guideway Energy Consumption Per Unit of Travel

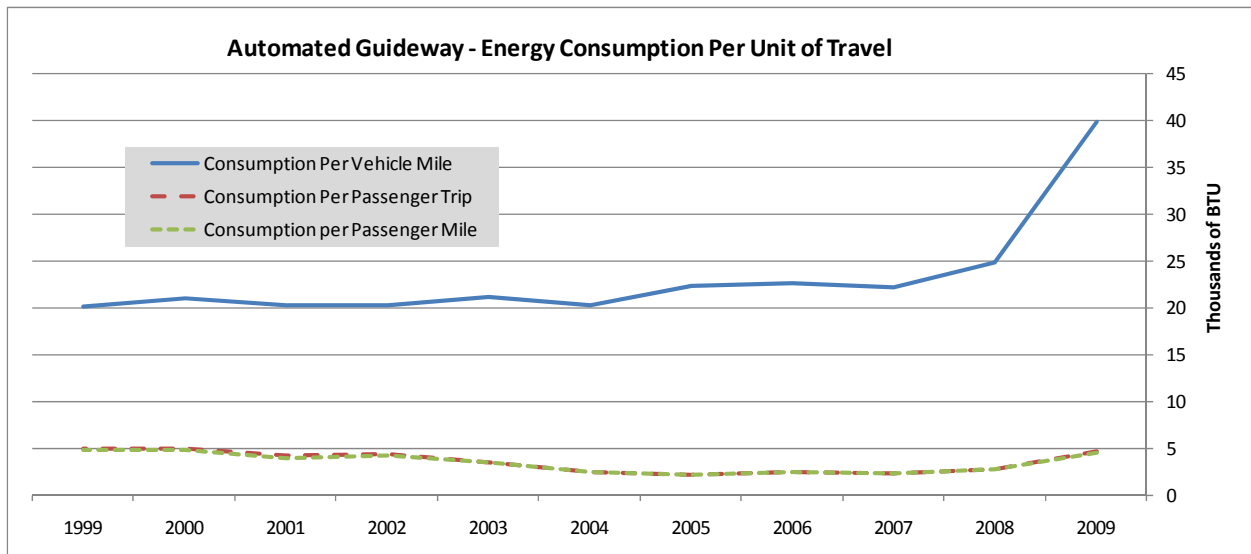


Figure 41 Central Florida Regional Transit Motorbus Energy Consumption Per Unit of Travel

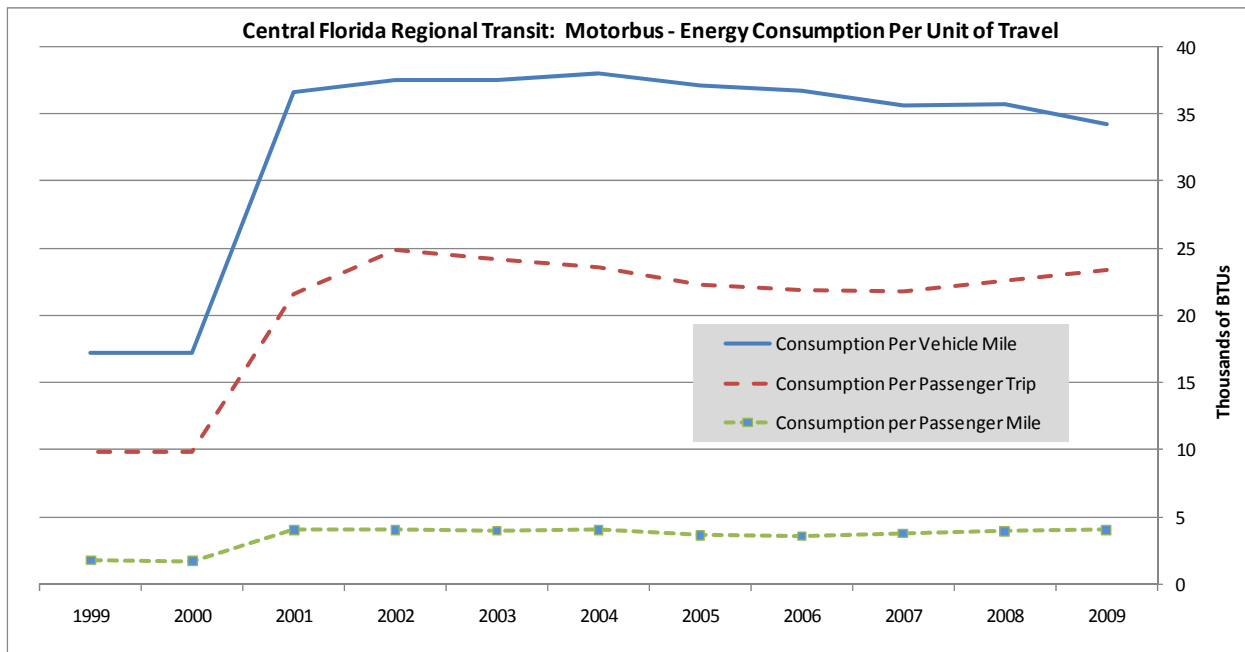


Figure 42 City of Tallahassee Motorbus Energy Consumption Per Unit of Travel

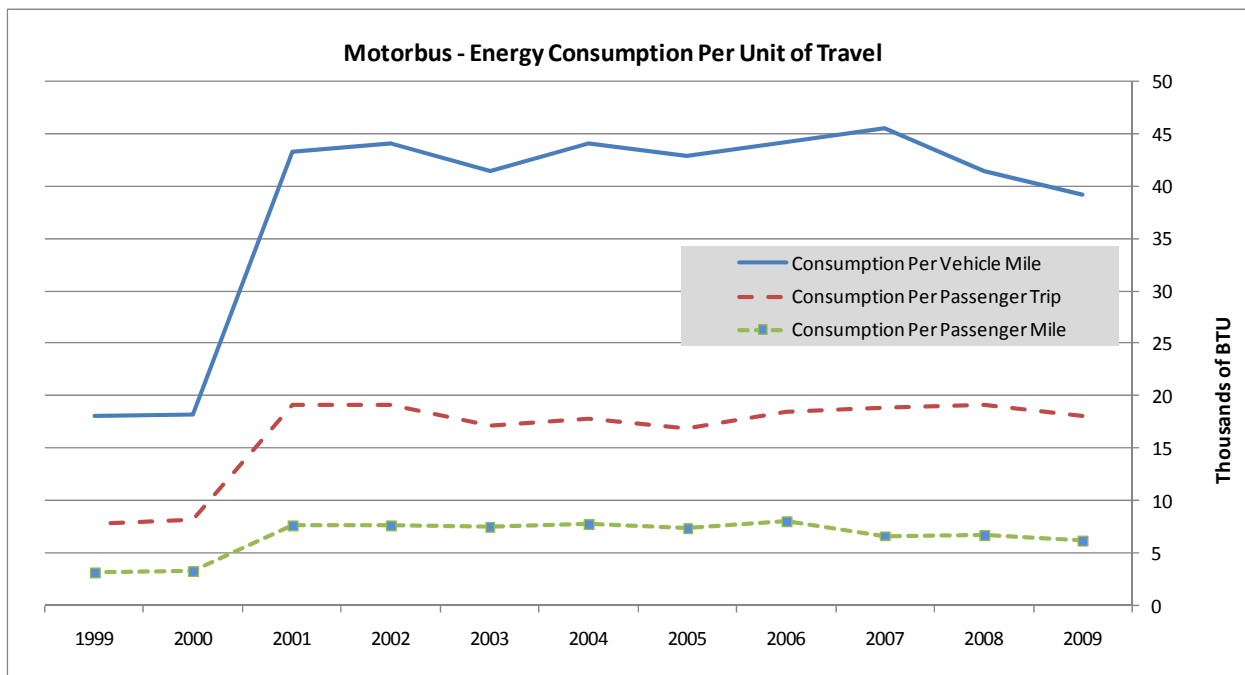


Figure 43 City of Tallahassee Demand Response Energy Consumption Per Unit of Travel

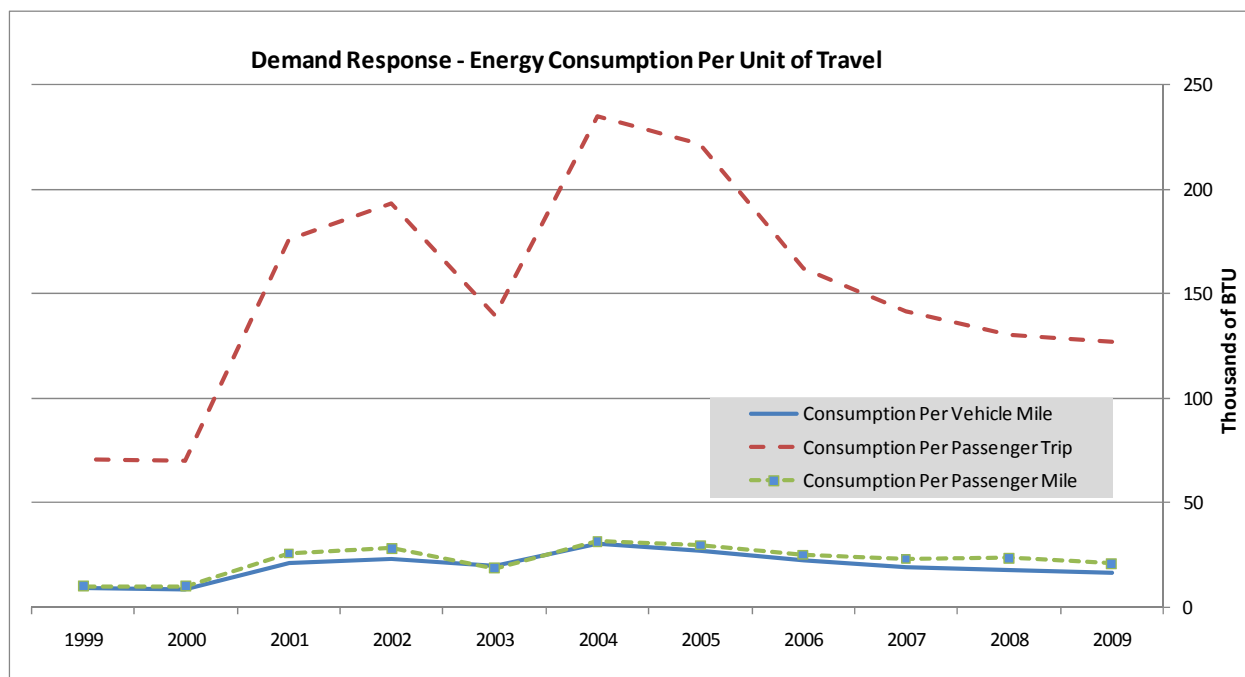


Figure 44 City of Palm Beach Motorbus Energy Consumption Per Unit of Travel

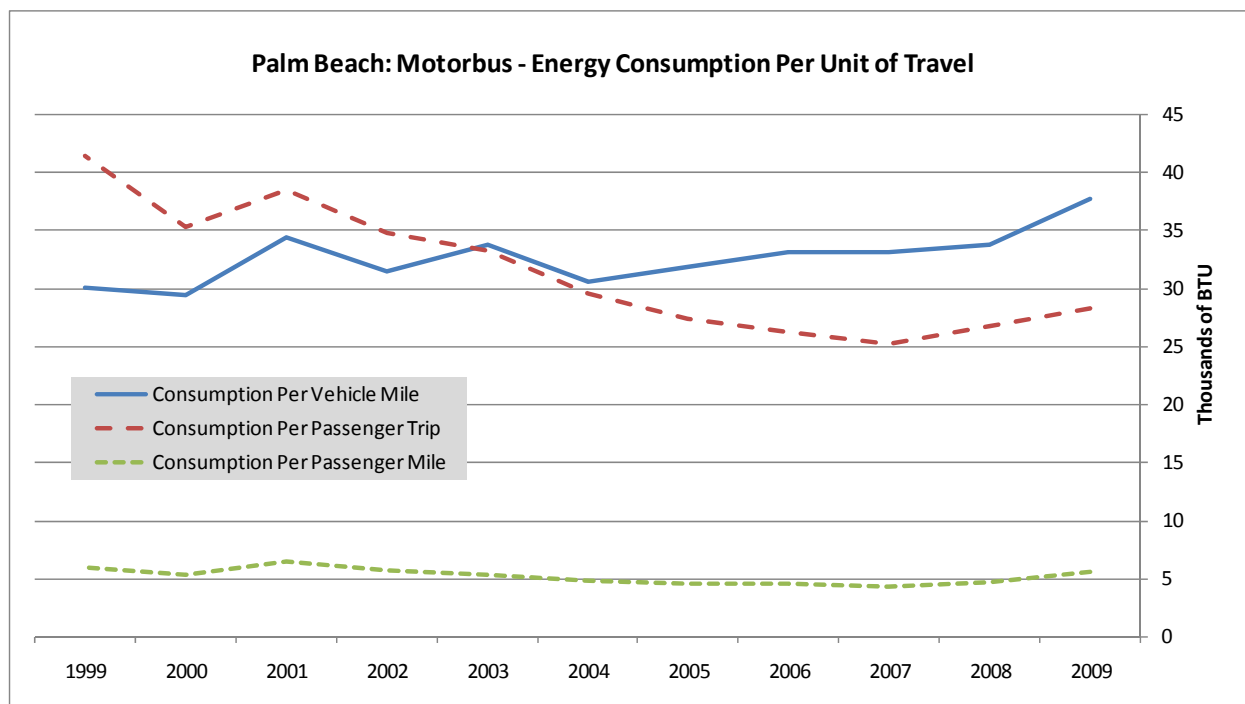


Figure 45 Escambia County Motorbus Energy Consumption Per Unit of Travel

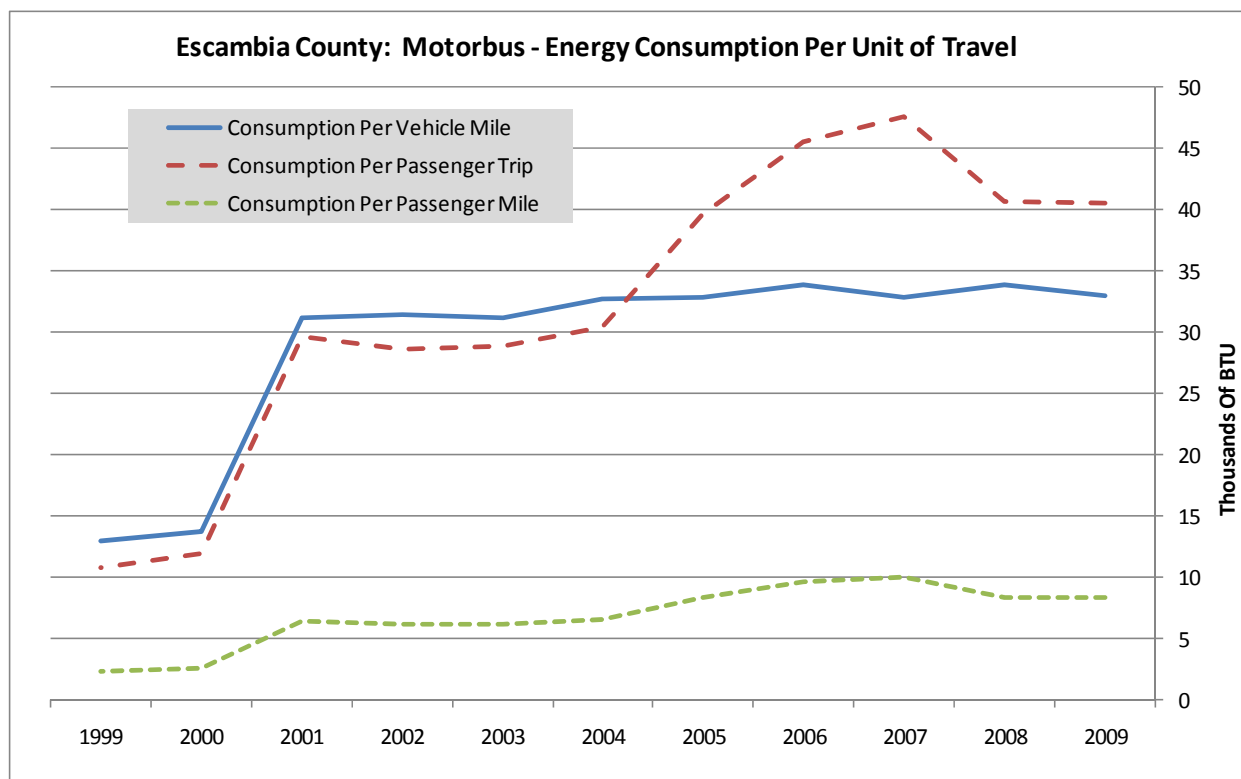


Figure 46 City of Jacksonville Motorbus Energy Consumption Per Unit of Travel

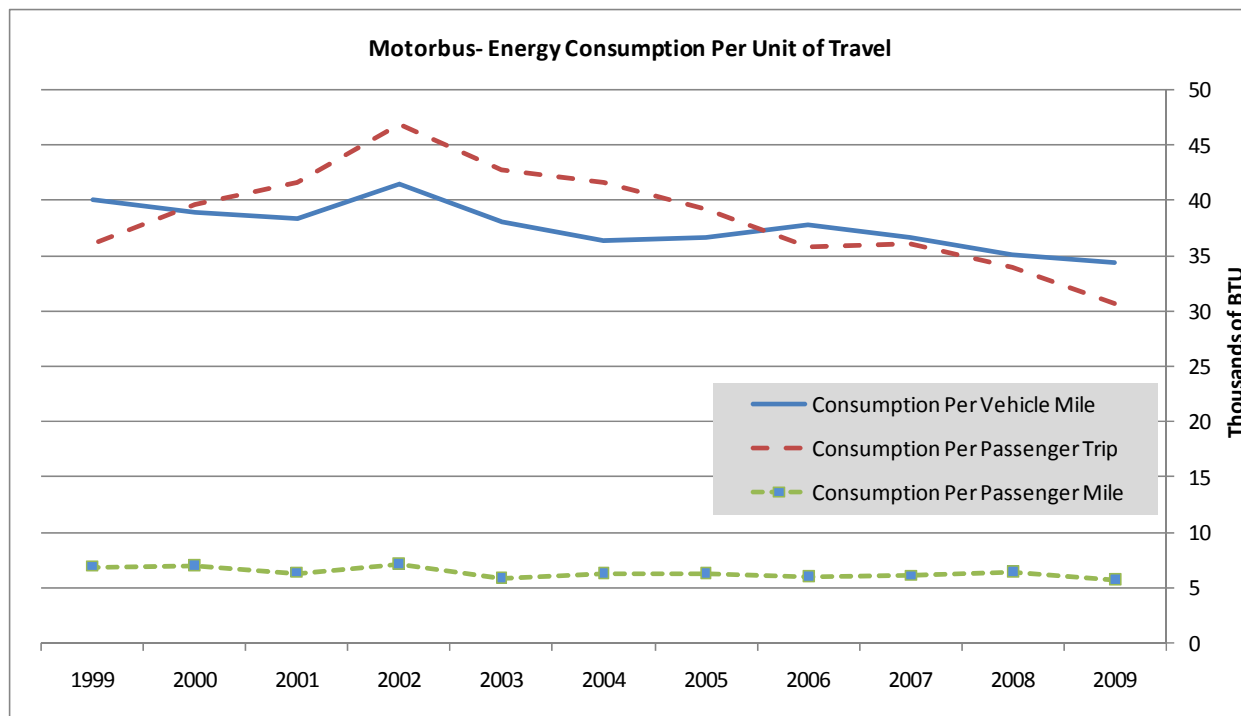


Figure 47 City of Jacksonville Automated Guideway Energy Consumption Per Unit of Travel

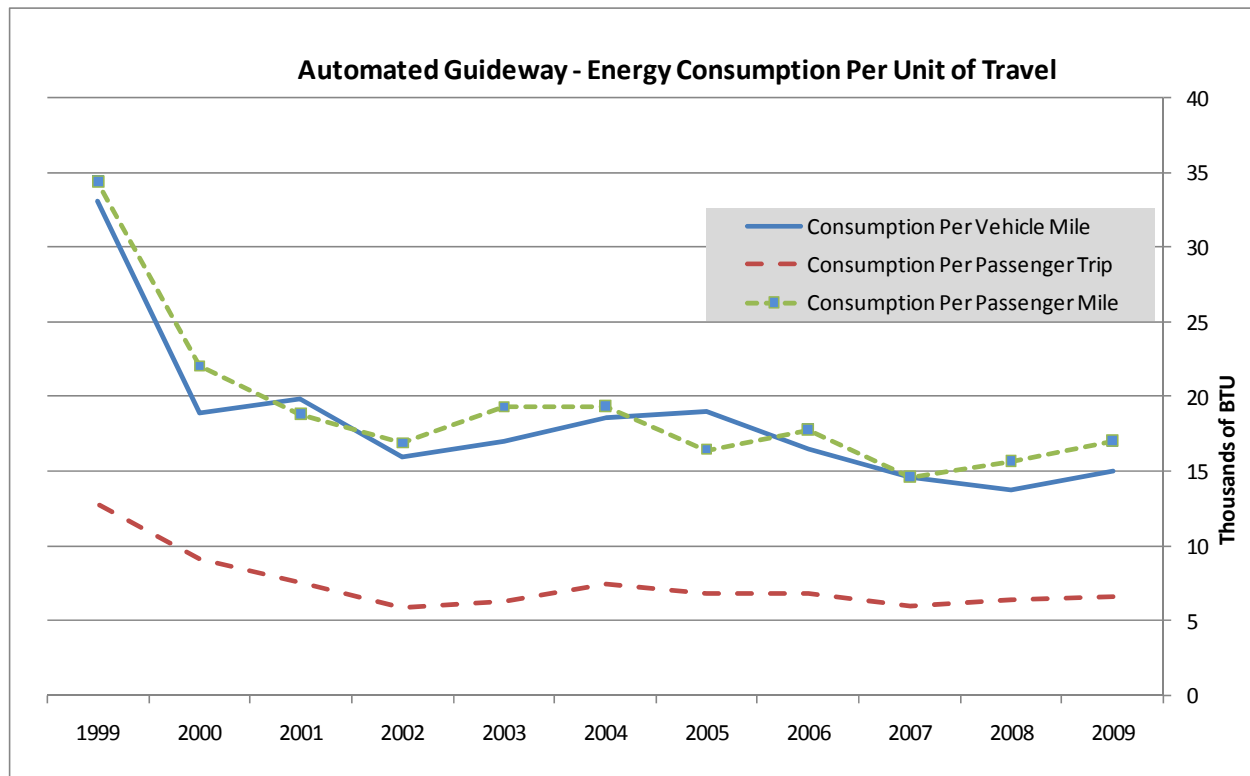


Figure 48 HART Motorbus Energy Consumption Per Unit of Travel

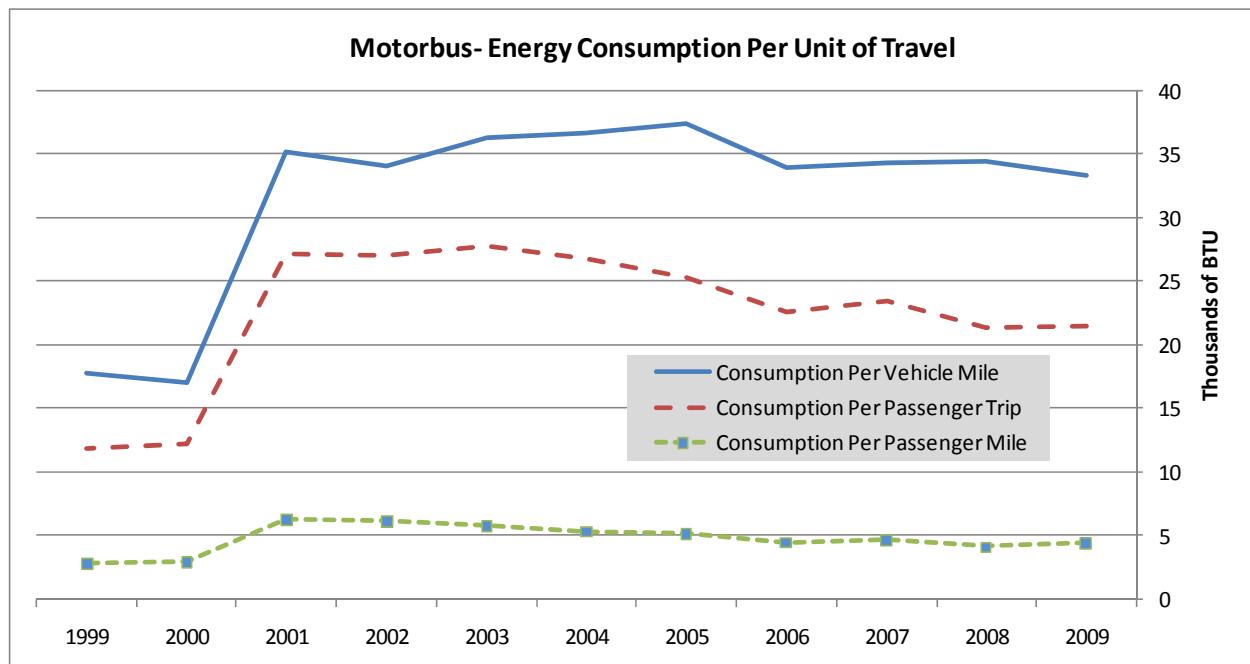


Figure 49 HART Demand Response Energy Consumption Per Unit of Travel

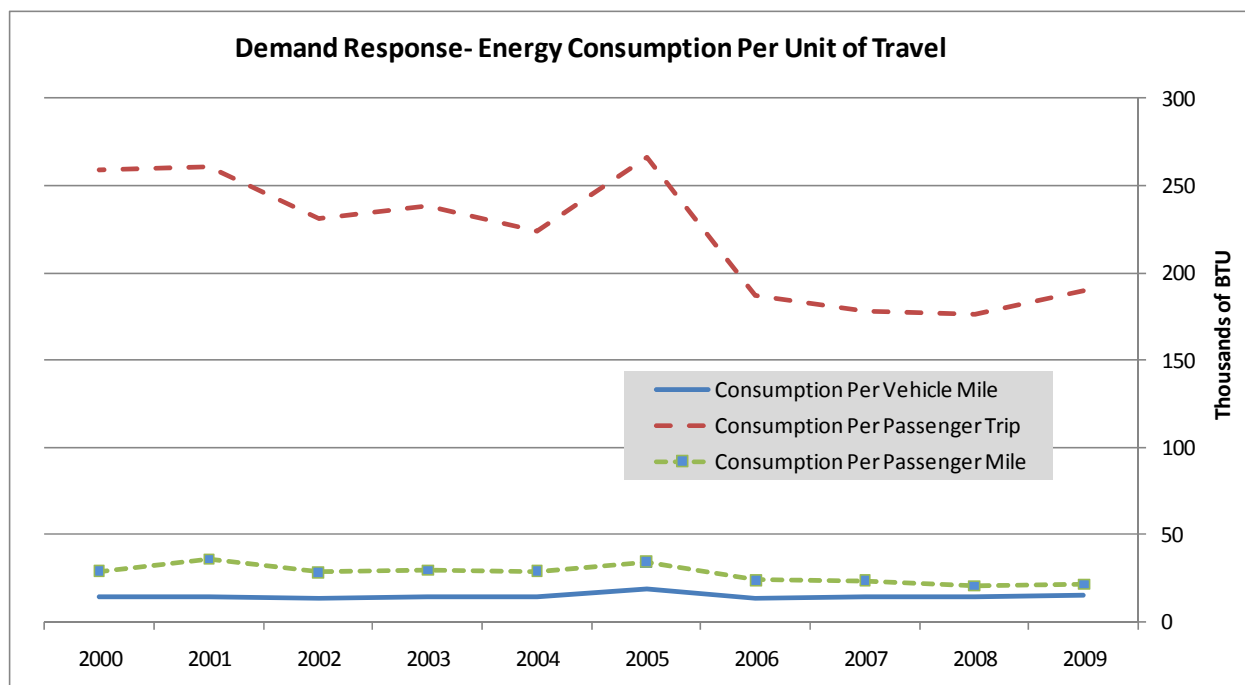


Figure 50 Pasco County Motorbus Energy Consumption Per Unit of Travel

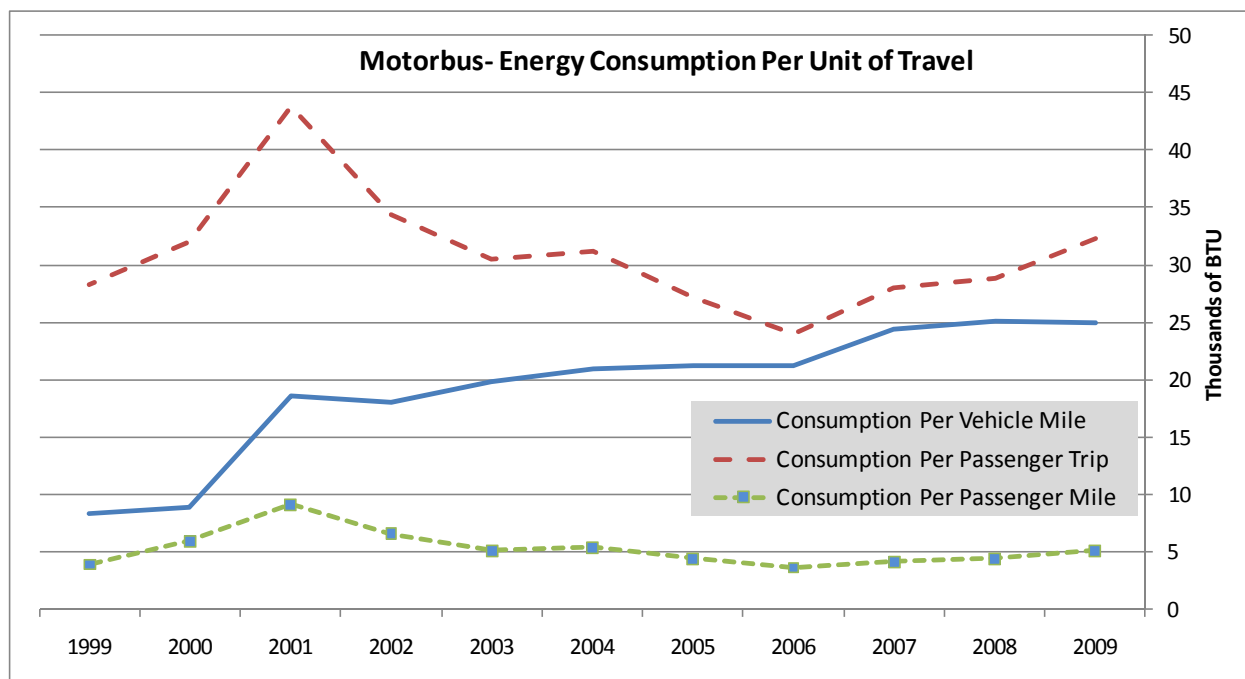


Figure 51 Pasco County Demand Response Energy Consumption Per Unit of Travel

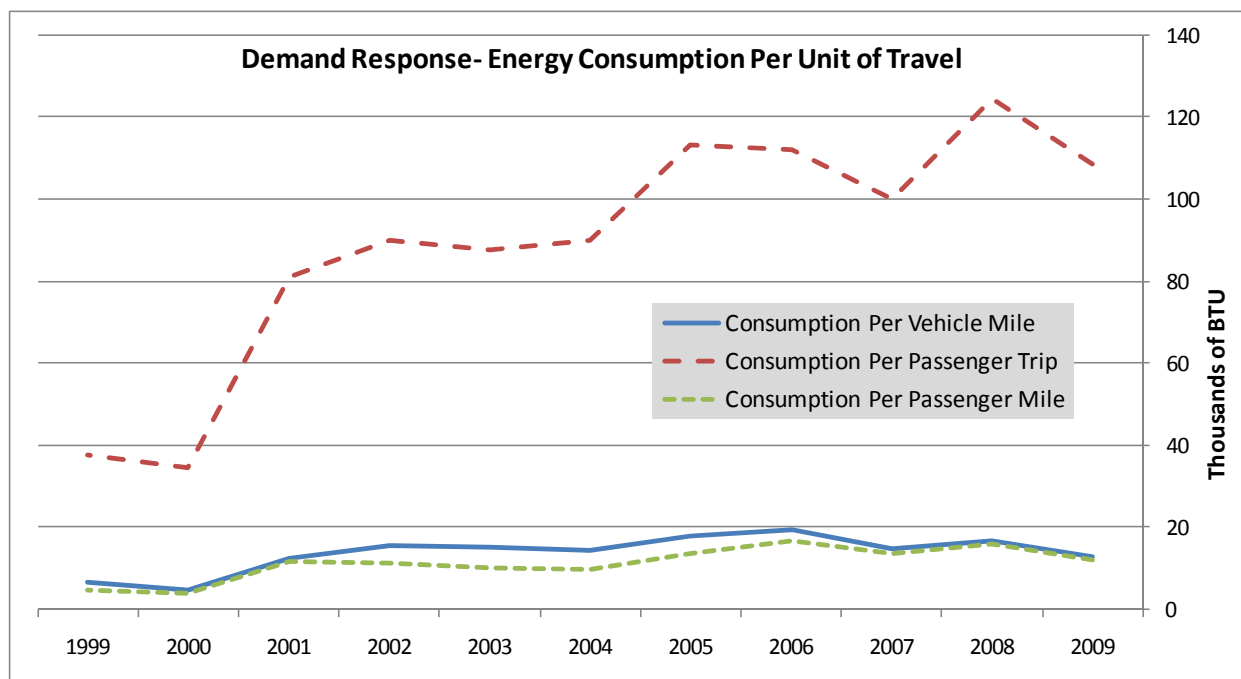


Figure 52 SCAT Motorbus Energy Consumption Per Unit of Travel

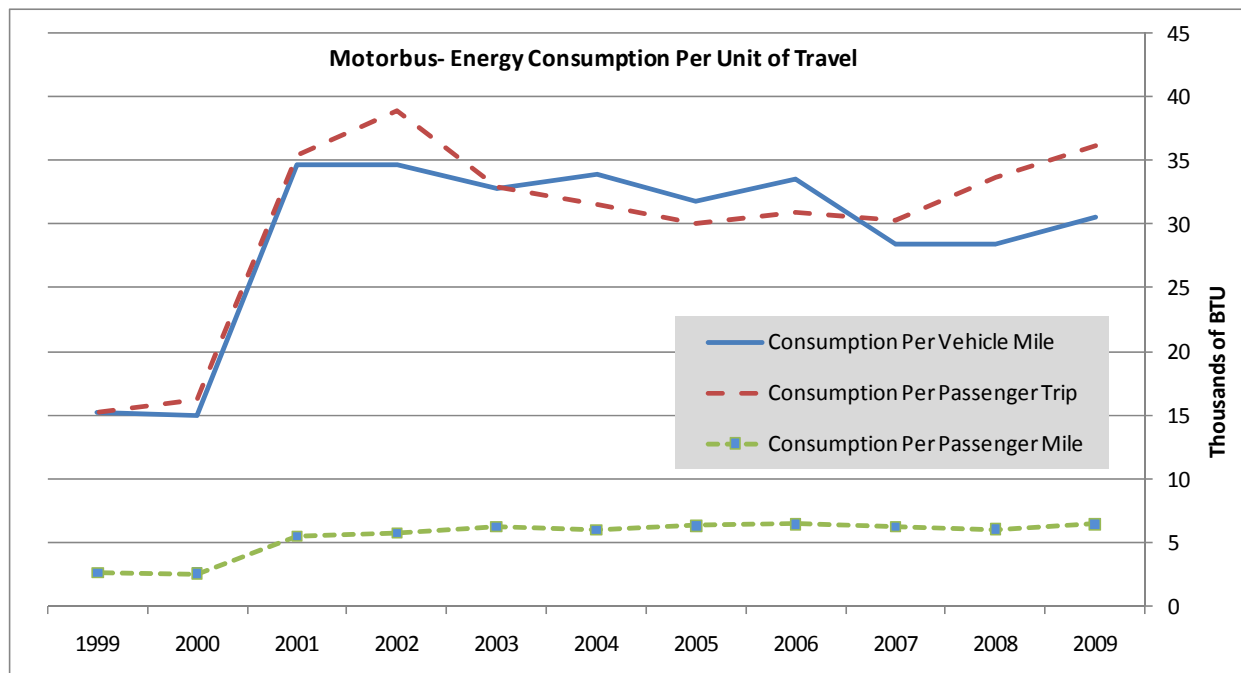


Figure 53 SCAT Demand Response Energy Consumption Per Unit of Travel

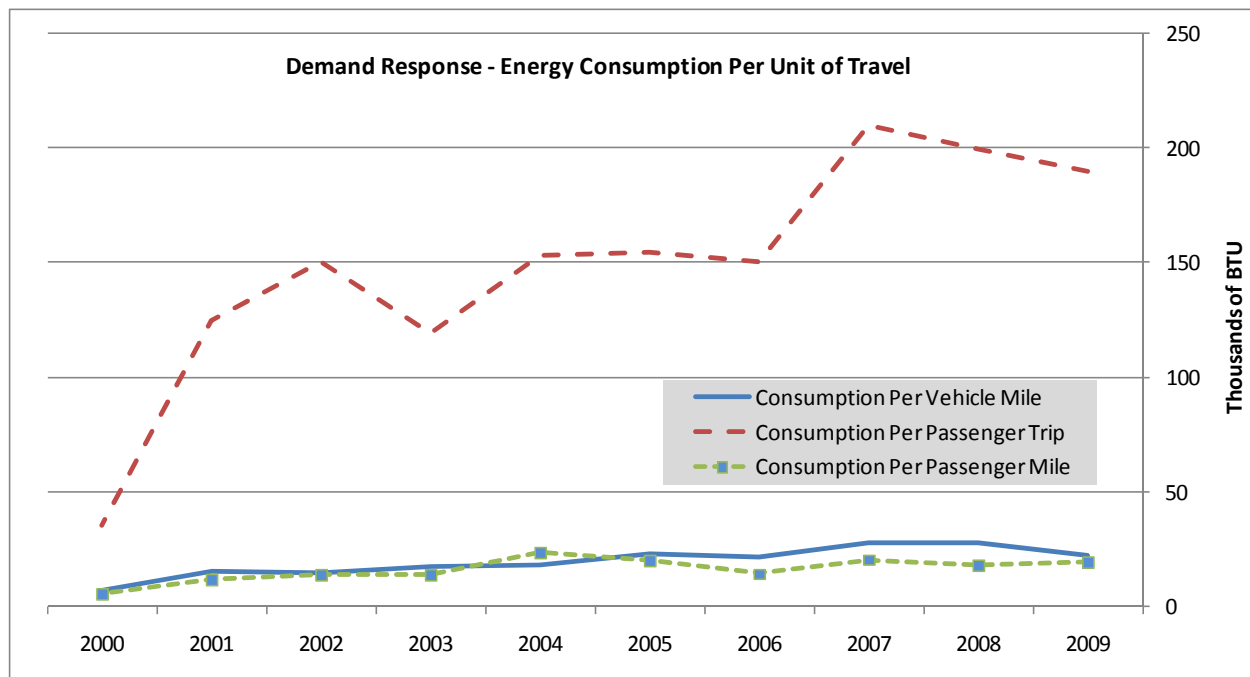


Figure 54 Space Coast Motorbus Energy Consumption Per Unit of Travel

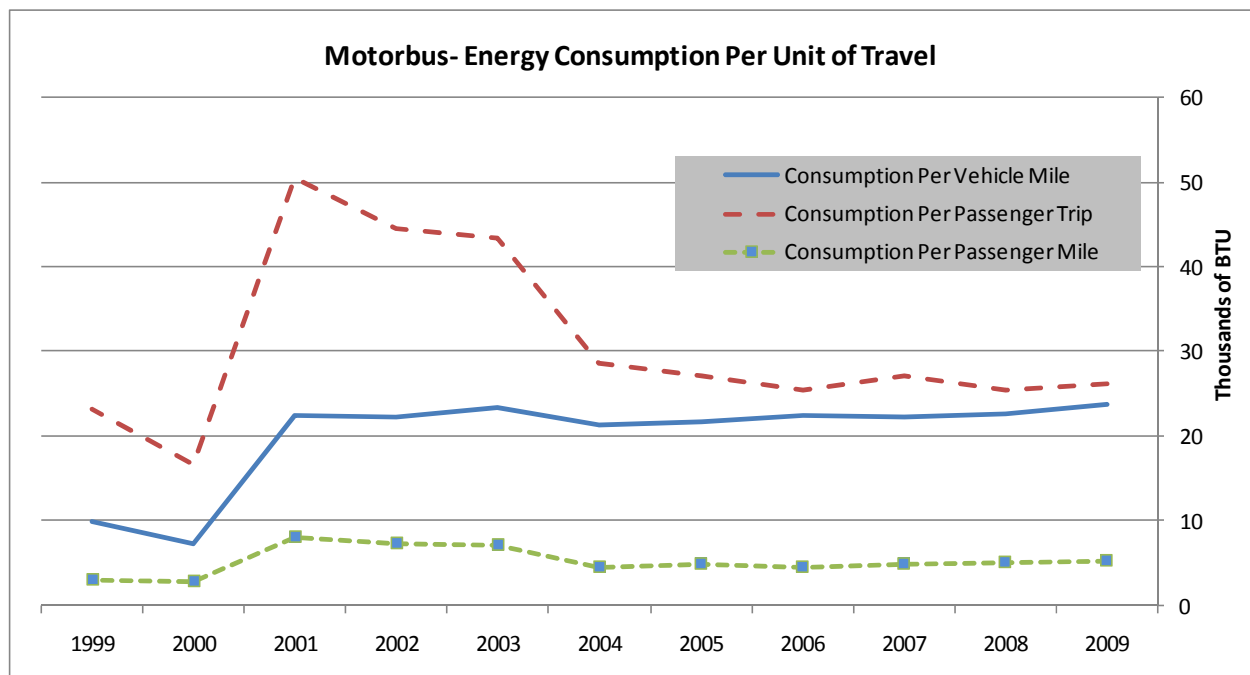
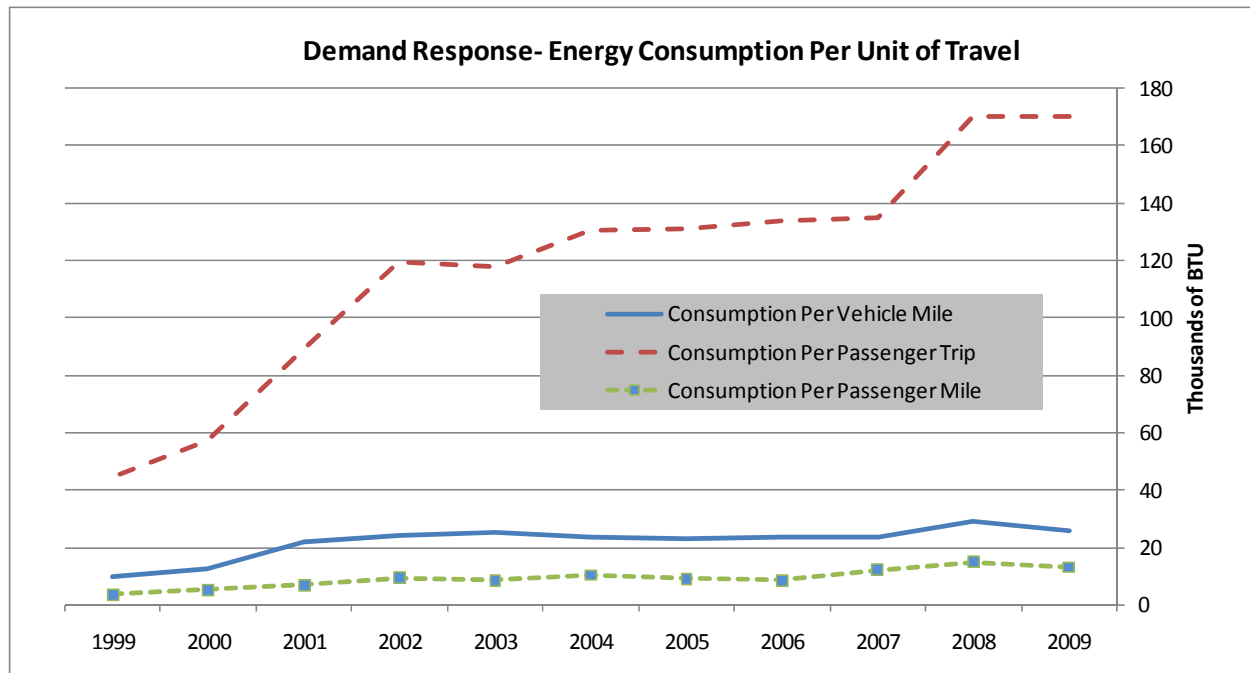


Figure 55 Space Coast Demand Response Energy Consumption Per Unit of Travel



Emissions Discussion

The focus of this report has been on fuels and energy. Assuming for the short run that a significant percentage of transit buses will be powered by heavy-duty diesel engines, the documents reviewed for this paper reveal some significant differences in the emissions profiles of gasoline and diesel power plants. Beginning with CO₂, diesel produces about 15 percent more of this GHG than does gasoline. This is not surprising, given that diesel has about 14 percent more energy than gasoline by volume (see Table 1). While diesel engines have a real disadvantage in nitrogen oxide emissions (NO_x), they produce very little carbon monoxide (CO) when compared to gasoline power plants. The CO₂ grams per gallon in Table 4 below are taken from the *Transportation Energy Data Book* (Table 11.11), which is referenced extensively in this paper. The passenger miles per gallon calculated earlier for buses and automobiles are then applied to derive the CO₂ grams per passenger mile for both gasoline automobiles and diesel powered transit buses, using the previously mentioned occupancy rates.

Table 7 Calculated CO₂ Emissions per Passenger Mile – Bus and Auto

	CO ₂ Grams/Gal	Passenger Miles/Gal	CO ₂ g/Passenger Mile
Gasoline Auto	8,788	35.4	248.2486
Diesel Bus	10,084	45.0	224.0889

By this measure, the transit mode produces 10.8 percent less CO₂ per passenger mile than the auto mode.

While GHGs are a main focus of mobile emissions because of their impact on climate change and the atmospheric trapping of heat, there are pollutants in transportation emissions with health and environmental effects. Diesel-burning engines long have been criticized when NO_x emissions are examined as the pollutant. NO_x is a contributor to smog and is associated with health concerns. The recent introduction of mandated ULSD for highway uses enabled the introduction of additional emission controls on diesel engines to reduce particulate matter and the use of catalysts to reduce NO_x. Sulfur content for over-the-road diesel was reduced from 500 parts per million (ppm) to less than 15 ppm. Figure 55 plots the NO_x emissions for gasoline and diesel engines from 1990 to 2007. Unfortunately, the dataset does not include the impacts of the model year 2007 diesel engines and the accompanying use of ULSD. Nonetheless, the reductions in diesel NO_x emissions have been significant over the last 20 years.

Another mobile source pollutant is carbon monoxide, and over 50 percent of this poisonous gas is traced to on-the-road sources. As stated, CO emissions for diesel power plants always have been less than for gasoline engines. Just as progress has been made in the NO_x area for diesel engines, Figure 56 illustrates that gasoline emissions of CO have dropped dramatically since 1990.

Figure 56 NO_x Emissions Gasoline and Diesel Engines – 1990-2007³²

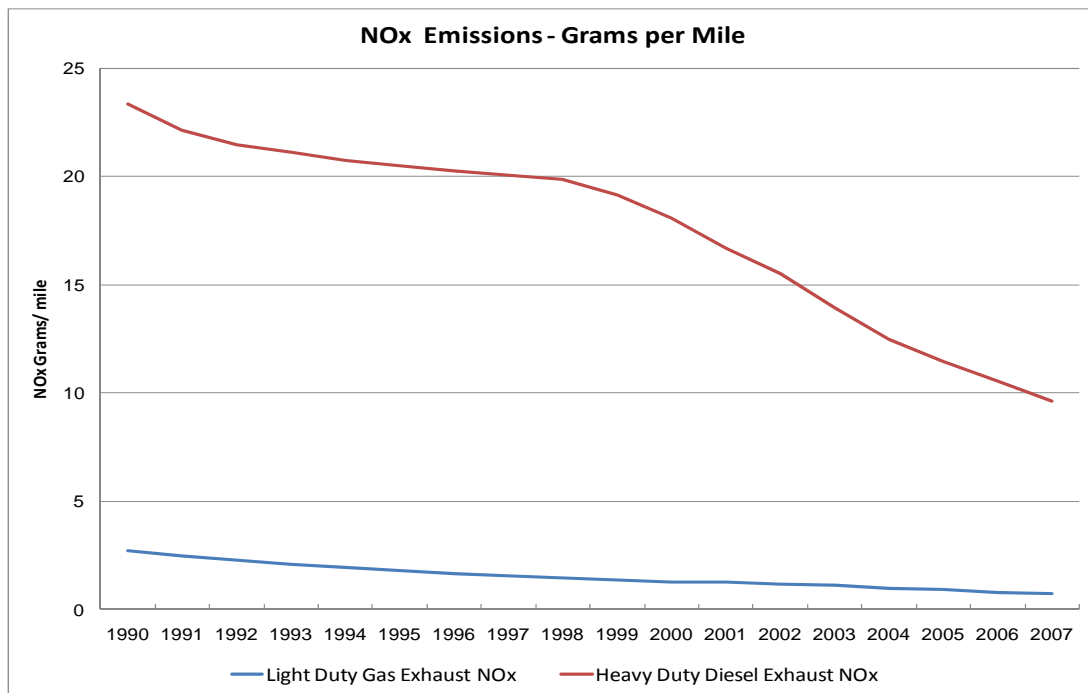
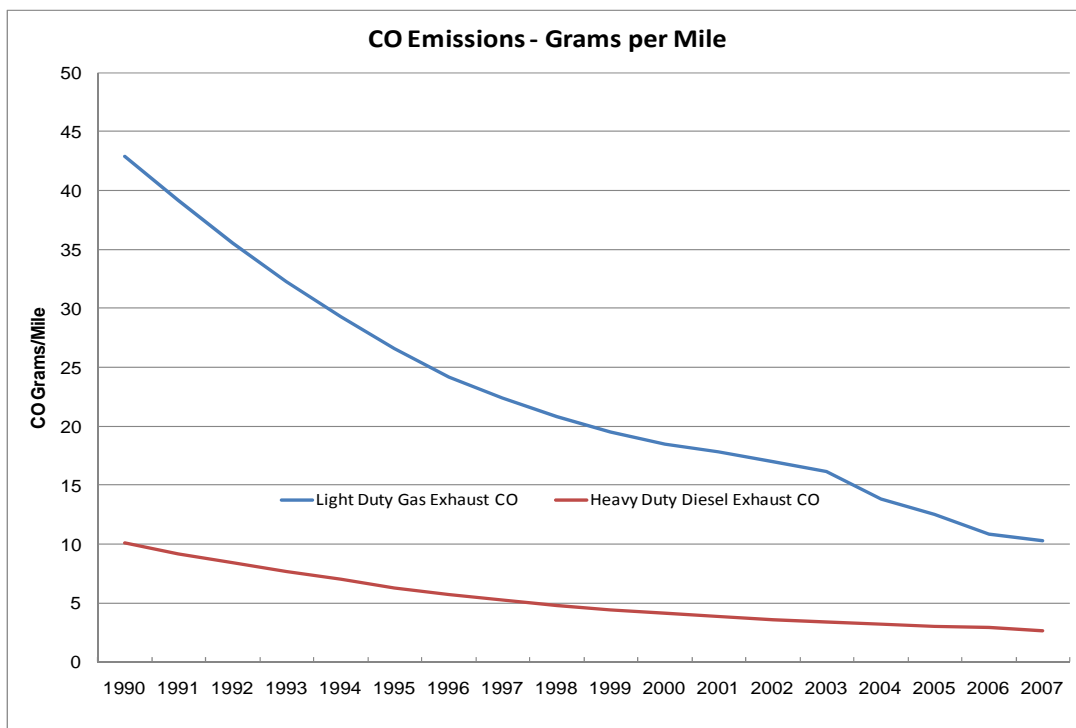


Figure 57 Carbon Monoxide Emissions Gasoline and Diesel Engines – 1990-2007³³

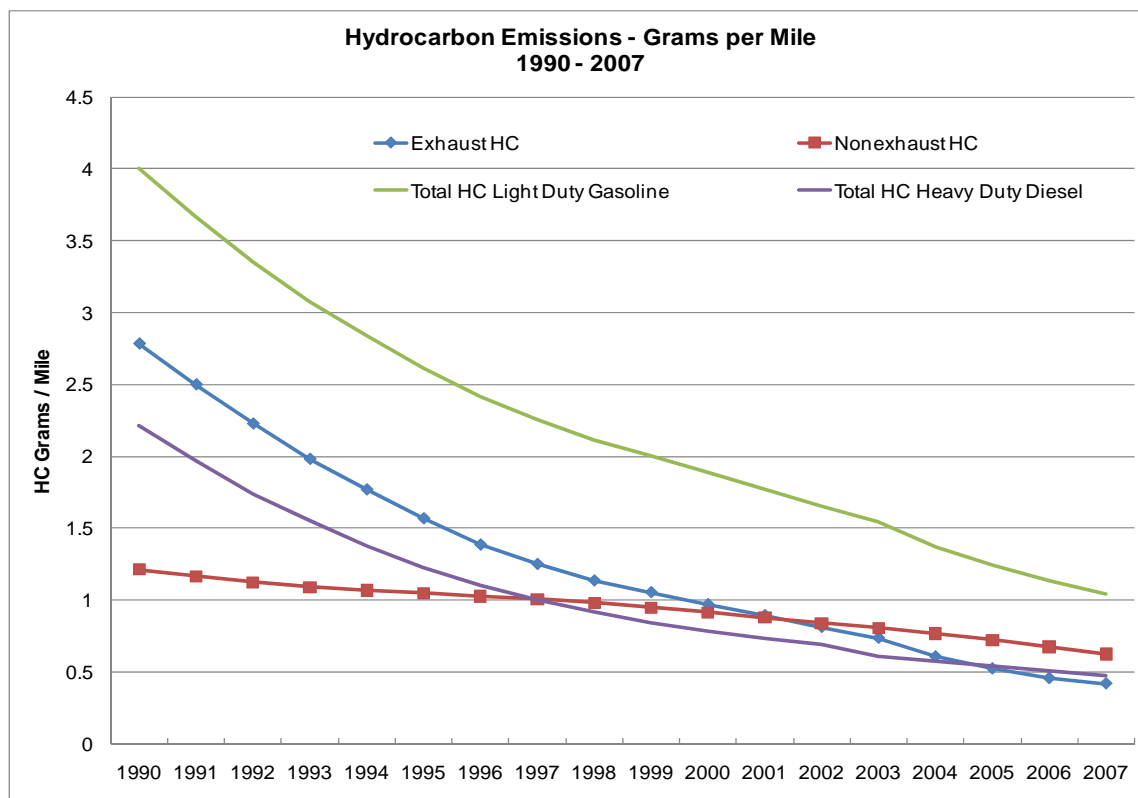


³² U.S. Department of Transportation, Research and Innovative Technologies Administration, Bureau of Transportation Statistics, National Transportation Statistics, Table 4-38.

³³ *Ibid.*

The final pollutant reviewed is hydrocarbons (HC). Produced from incomplete combustion and evaporation, this pollutant has been tied to the creation of smog and ground-level ozone production. Evaporative and emission controls installed on vehicles have had positive impacts on this pollutant, 29 percent of which is still tied to highway mobile sources. Figure 57 plots the HC emissions from gasoline and diesel engines since 1990.

Figure 58 HC Emissions Gasoline and Diesel Engines – 1990-2007



Conclusions Regarding Bus versus Light Vehicle Energy Intensiveness

With the plethora of data available and routinely reported, it seems a straightforward matter to objectively evaluate the relative competitiveness of public transportation from an environmental sustainability standpoint; however, a review of the most used and relied-upon sources of energy data contradicts this premise. It is an understatement to conclude that undertaking cross-modal environmental sustainability comparisons is a complex effort. Making matters worse is the seemingly contradictory data that emerge when examining a few well-regarded sources of information. Through the conduct of this effort, it was revealed to the researchers that there is a recognition of issues with the data a national level and, more importantly, that steps are being taken to correct some of the basic reporting matters.

There appear to be enough data to conclusively show that today rail transit, particularly heavy and commuter rail, are the least energy-intensive modes of surface passenger transportation. However, as this paper has attempted to point out, the case for transit bus is somewhat clouded, due mostly to the conflicts in data relating to energy intensity per passenger mile. This is of particular concern since the most urbanized areas have established fixed-route bus, systems providing an immediate alternative to the single occupant (or the 1.6 person occupied) automobile.

When examining various modes of transportation, it is imperative to consider the diversity of energy densities and differences in emissions produced. It is probably even more important to recognize that the general national data may be of little relevance to a specific region or city. The national data for highway vehicle emissions and energy use include a significant accounting of vehicle miles traveled, emissions, and fuel use for travel in rural areas and for long-distance trips. The national transit data are skewed towards the profile of energy and passenger data for urban areas. This difference alone changes the modal energy comparisons, as noted in the prior discussion. These adjustments are sufficient to remove the auto energy efficiency advantage reported in national data sources.

The emission profiles of various modes also must be carefully considered when making an environmental assessment of transportation across modes. An example could be a comparison of bus transport using gasoline-hybrid electric propulsion with diesel-powered ferry or rail service that is not yet required to meet the on-road diesel emission standards. A simple “energy intensity” comparison of BTUs per passenger mile served would be of dubious value in this case.

The vulnerabilities of using generalized national data for a specific analysis have been identified in this report. Operating and geographic variances can skew results of energy and emission comparisons significantly. Topography, operator differences, climate, training, vehicle duty cycle, equipment configuration, and maintenance practice differences are just some of the factors that significantly can impact vehicle fuel efficiency and the resultant environmental assessment. Additionally, equipment production and scrap considerations often can affect environmental impact comparisons. Data to support this kind of analysis do not appear to be readily available in consistent formats.

What is clear from this effort is that transit bus appears competitive with private vehicle transport from an environmental perspective when urban context data are used for comparative analysis. The future of the modal comparisons will be impacted by both the relative pace of deployment of energy efficiency enhancing technologies and the utilization levels of transit. The recent enactment of aggressive CAFE standards for the near term and the exploration of even more stringent standards in the future have the prospect of creating a very serious challenge to transit to remain competitive should those CAFE standards produce the intended private vehicle operating fleet. Transit technology will require more aggressive adaption of efficient

technologies and/or greater productivity to remain competitive. The strategies and tactics required to be employed to meet this challenge are well known to the agencies. As transit organizations face difficulties in meeting reduced budget targets, they are constantly searching for methods to reduce operating costs, of which fuel is a significant component, and to increase productivity on their routes, which translates into increased load factors. These are complementary objectives to increased energy efficiency but are far easier to justify if the economics of moving toward more efficient technologies are encouraging.

The analyses carried out to support this research confirmed in the research team's minds the importance of a national effort to improve the reporting of energy use data within the transit industry. Anomalies across the NTD data set were readily apparent, and the completeness of the data was limited the degree of confidence the user can place in it. A full review of the data should be carried out, and information such as fuel type and whether or not other anomalies such as service vehicles fuel use being included should be better understood. It is important that there be a consistent national metric for industry average fuel use and that the context and nuances of fuel efficiency data be understood. This includes understanding the variations associated with different vehicle sizes in fleets.

Transportation Energy Impacts

Near the other end of the spectrum of possible measurement strategies for understanding the energy impacts of transportation is the category of measurement of Transportation Energy Impacts. By focusing on all transportation impacts, aggregate data on energy use for transportation and aggregate measures of transportation consumed can be used to make comparisons of differences in total energy use as a function of the total amount and type of travel that takes place

in a referenced area. This is best done on larger geographic scale where aggregate data are available. Often, this is done in the context of exploring differences in urban area densities and development patterns. Various studies dating back several decades to recent reports such as *Moving Cooler* and *Driving and the Built Environment*; *The Effects of Compact Development on Motorized Travel, Energy Use, and CO₂ Emissions* explore the relationships and findings between transportation and energy use. *Urban Form, Energy and the Environment: A Review of Issues, Evidence and Policy* provides a helpful summary and context for understanding the

Evidence from the Literature

Finding 2: The literature suggests that doubling residential density across a metropolitan area might lower household VMT by about 5 to 12 percent, and perhaps by as much as 25 percent, if coupled with higher employment concentrations, significant public transit improvements, mixed uses, and other supportive demand management measures.

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body of research in this area.³⁴ These works are most powerful in establishing relationships between urban form and density and total energy use and less able to disaggregate the role of mode mix in influencing energy use.

When looking only at modal energy intensiveness data, analysts often point out that the ability of transit to influence energy use and, hence, sustainability is not dependent solely on its in-vehicle energy intensiveness, but rather is more dependent on the ability of transit to enable and support an overall urban development pattern and travel behaviors that are more unsustainable. To understand the potential significance of this claim, experimental analysis of travel behavior for persons with walk access to transit is compared to persons without to gain some insight into the veracity of these hypotheses. The reader is cautioned that the cause-and-effect relationship between transportation and land use is very complex, the provision of given transportation mode mixes and networks does not ensure a given land use pattern, and a given land use pattern does not ensure a given set of travel behaviors and transportation energy use. The strength and extent to which causality can be inferred or leveraged is critical to interpreting the implication of observed difference in travel as a result of different transportation and land use combinations. A full discussion of this is available in *Travel by Design*.³⁵

In spite of the appropriate qualifications and questions about causality, understanding the difference in travel and, hence, energy use between urban locations with transit and those without is a legitimate basis for understanding the potential of transit to impact sustainability. Toward that end, an analysis was conducted as part of this research to look at overall travel differences in travel between urban residents who live near transit and those that do not. This analysis is based on exploration of the 2001 NHTS data.³⁶

The 2001 NHTS data has information about the distance to transit for the respondents. Travel behaviors for urban residents for those households near transit (less than 0.3 miles) were compared to those who lived more than 0.3 miles from transit for the U.S. As income tends to be correlated with travel behavior and location, the data were disaggregated to four income categories: \$0-19,999 annual household income, \$20,000-39,999, \$40,000-69,999 and \$70,000 and greater. Measures of trips and person miles of travel by mode were derived for adults (age 18+) and children. Tables 8 and 9 and Figure 58 present these results.

³⁴ Anderson, Kanaroglou, and Miller, "Urban Form, Energy and the Environment: A Review of Issues, Evidence and Policy," *Urban Studies*, Vol. 33, No. 1, 7± 35, 1996.

³⁵ Boarnet and Crane, *Travel by Design*, Oxford University Press, 2001.

³⁶ For full information on the 2001 NHTS survey, see <http://nhts.ornl.gov/introduction.shtml>.

Table 8 Person Miles of Travel by Income and Nearness to Transit for Urban Area Adults, Daily Per Capita Person Miles of Travel – 2001 NHTS Analysis

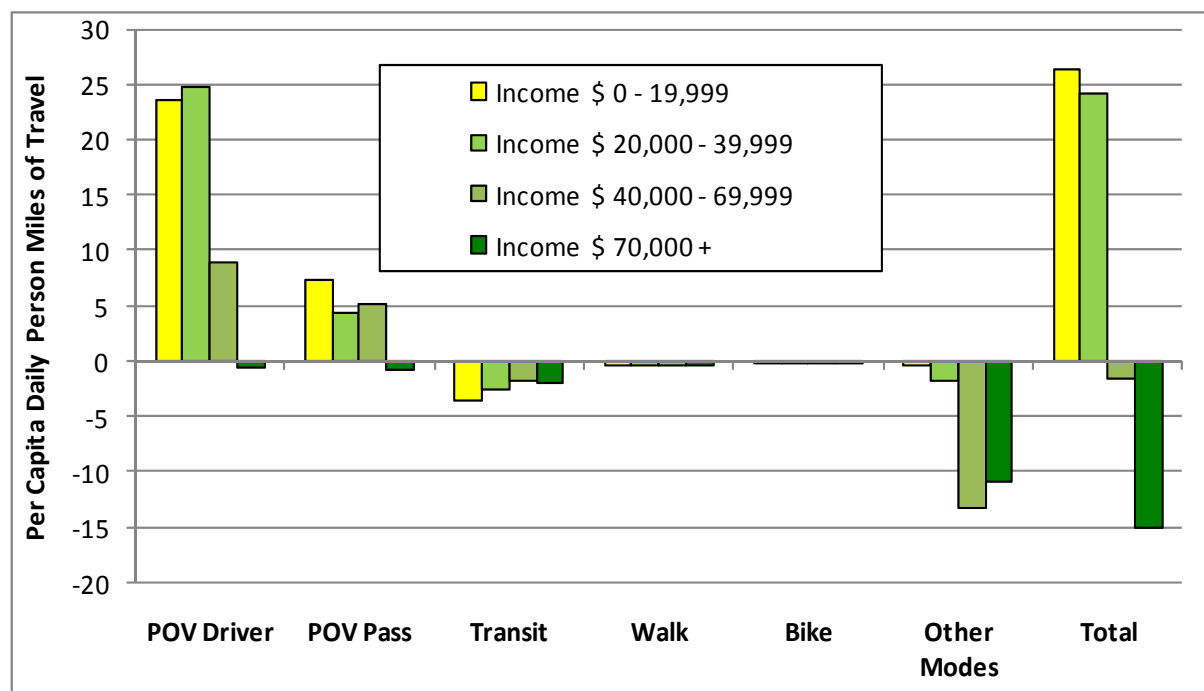
Distance to Transit		Household Annual Income				Total
		\$0 - 19,999	\$20,000 - 39,999	\$40,000 - 69,999	\$70,000+	
Distance to bus line or rail station is ≤ 0.3 miles	Population 18+ years of age	5,394,275	6,223,390	6,584,863	6,613,272	24,815,800
	Daily PMT	58	106	126	148	112
Distance to bus line or rail station is > 0.3 miles	Population 18+ years of age	3,396,805	5,928,670	8,320,738	10,569,701	28,215,914
	Daily PMT	85	130	125	133	124

Table 9 Travel Behavior Differences for Urban Area Adults Who Have Limited Transit Access, Daily Per Capita Person Miles of Travel – 2001 NHTS Analysis

	Household Annual Income				Total
	\$0 - 19,999	\$20,000 - 39,999	\$40,000 - 69,999	\$70,000 +	
POV Driver	23.57	24.85	9.00	-0.60	16.08
POV Pass	7.24	4.42	5.11	-0.84	3.64
Transit	-3.54	-2.59	-1.86	-2.03	-2.36
Walk	-0.43	-0.46	-0.42	-0.46	-0.45
Bike	-0.10	-0.13	-0.11	-0.31	-0.16
Other Modes	-0.31	-1.81	-13.28	-10.91	-4.80
Total	26.43	24.28	-1.56	-15.15	11.96

Note: Analysis for urban (per NHTS urban versus rural classification) adult residents (age 18+). Residents were grouped into those who live within 0.3 miles of a bus line or rail station and those who live farther away. The table numbers are the differences in miles of travel by mode for those not near transit minus those near transit.

Figure 59 Travel Behavior Differences for Urban Area Adults Who Have Limited Transit Access, Daily Per Capita Person Miles of Travel – 2001 NHTS Analysis



Interpretation of Results

The results in Tables 8 and 9 and Figure 59 are not inconsistent with prior studies of the travel impacts of residential locations in proximity to transit. However, these results are unique in that they are for a far broader set of data (national urban areas) and they disaggregate the travel behavior changes by income and by mode.

Using the total column in Table 8, the data suggest an average decline of 11.96 miles of all travel per adult per day as a result of living in proximity to transit. Personal vehicle travel declines 19.72 miles per day, which is partially offset by increases in transit (2.36 miles), walk (0.45 miles), bike (0.16 miles), and other modes (4.8 miles – taxi, ferry, air, etc.). Thus, while living near transit (and behaving like those who currently do) results in modest potential impact in terms of energy use by using slightly more transit (presuming use of transit that is more energy efficient), the larger energy use benefits would be attributable to the fact that total travel declines and additional travel switches to other less energy intensive modes (bike, walk).

Review of the data with respect to income levels reveals some fascinating results. The effect of living in proximity to transit is far stronger for lower-income persons. For the highest income group (2000 household income greater than \$70,000), individuals in proximity to transit actually travel more with significant use of “other” modes. As “other” modes include air travel, we believe these data signify that more wealthy urban residents may travel slightly more modestly

locally but use other modes such as rental cars and air travel to access more distance attractions such as second homes or vacation locations – apparently more so than similarly wealthy residents who live outside of transit service areas. Other income groups appear to behave consistent with observed trends, transit use declining slightly with income.

Non-Propulsion Energy Use for Transit

Analysts prefer to focus on propulsion energy as a first frontier in understanding modal efficiency, as it is both easier to understand and easier to evaluate based on available data. However, a more rigorous analysis would include efforts to capture the energy used for the various support facilities that enable the operation of the services. This would include the major facilities that are used to house equipment and staff, as well as facilities that accommodate passengers. Thus, heating and cooling of bus garages and office spaces, bus shelter lighting, transit center utilities, parking lot lighting, and related support utilities impact the energy profile of the mode. Historically, these have been incidental energy uses dwarfed in significance by propulsion energy and, in many cases, they are harder to quantify and allocate to modes and translate into equivalent metrics for painting a picture of total energy use. Shared facilities and a mix of energy types are among the challenges.

Even more challenging would be attempting to conduct a similar analysis for light vehicle travel. Determining the methods by which roadway-travel-supporting activities use energy is difficult. Roadway lighting and maintenance facilities could be quantified, but attempting to capture the energy costs for the infrastructure that supports roadway travel would be extremely challenging. The utilities of gas stations and auto repair facilities, auto dealerships, and snow plows, for instance, could be attributed as supporting energy uses required to enable light vehicle travel. Residential garage utilities and commercial facilities that provided parking would appropriately have energy expenditures that supported light vehicle travel. Such types of comparisons are beyond the scope of this research.

While detailed quantitative analysis is not possible here, it is possible to address some issues that should be under consideration by transit agencies as they examine and plan for their own energy efficiency.

Overall Conclusions

The roll of public transit in supporting sustainability objectives is twofold – first, to offer a more resource-efficient mode of travel, and, second, to enable and encourage persons to locate such that their travel needs can be met with less travel and more efficient travel means. The work on this project has shed light on both of these issues.

The data regarding the fuel efficiency of public transit bus travel has been explored in detail, with results that may be surprising to many. First, the message from the data is confused by the differing sources of data and significantly different results. Closer scrutiny suggests that the

actual performance for transit bus may be poorer than often reported and far poorer than commonly perceived. Based on national averages, with today's technologies and ridership levels, transit bus use is not a more fuel efficient way to travel than auto, on average. (This does not apply to the marginal user who chooses to occupy available transit capacity, nor does it correct for context differences between transit travel environments and auto travel environments.) When adjusting for context differences, the modes appear to be virtually identical in terms of BTUs per passenger mile.

There is promising evidence that transit efficiency has improved the past several years after a multi-decade decline in efficiency. Recent service cuts motivated by trying financial times are likely to result in further improvements as poorer-performing services are reduced. Promising trends for transit technology are apparent, with hybrid and alternative-fueled vehicles improving efficiency, but these improvements will be competing with a light vehicle fleet comprising vehicles subject to much stricter CAFE standards in future years. The benefits of these new technologies are likely to be most pronounced in urban environments, resulting in the competitive battle for efficiency claims remaining challenging for transit bus.

The single most critical factor for transit efficiency is the ability of transit to attract larger loads on existing services. On average, transit operates with extensive excess capacity, and increasing the utilization of that capacity is a critical step in improving transit's contribution to sustainability goals. However, this is not without challenges, and the relatively tight clustering of agency average productivity indicates that there are no easy ways to increase service utilization.

Looking ahead, relative energy efficiency will be dependent on the pace of technology development and deployment in the respective modes and on the utilization of transit. The path forward for auto efficiency will be shaped in the near term by the aggressive CAFE standards set for the next few years. The extent to which these standards translate into a more efficient fleet and the ultimate standards for subsequent years will determine the longer-term efficiency of light vehicle travel. The pace of transit technology adoption will be partially dependent on the resources commitments directed toward new technologies. This is perhaps more critical for transit vehicles, as the current relative cost of the new technologies is significantly more than is the case for light vehicles.

Trends of energy use for Florida transit properties that report energy use through NTD also are presented. Florida has several agencies whose energy use per passenger mile of travel is well above industry averages, as would be expected, given Florida's relatively modest transit use levels. Several of the agencies have BTUs-per-passenger-mile numbers above 5,000, well beyond the average levels of private vehicle travel and comparable to single occupant vehicle travel. Thus, many locations in Florida are not providing energy savings through their transit services.

This initial work also confirmed with empirical national data the relationship between travel and the presence of transit and the land use environment in which transit is provided. It also confirmed that proximity to transit does correlate with different travel behaviors that are more sustainable. Adults in households near transit travel less and generally more on more efficient modes. The work uncovered a unique finding in that these behaviors varied significantly across income quartiles, as high income individuals in these locations did not travel less or necessarily on more efficient modes. This has potential significant implications on development policy.

The magnitude of the impacts on travel that are observed across development patterns has been a critical policy consideration in national and local transportation-land use policy. Risks and uncertainties surround leveraging this relationship. The ability of transit investment and/or land use policy to create environments similar to those that now require less travel is dependent on both the willingness of additional persons to be attracted to those environments and the extent to which travel behaviors change to reflect those of current urban residents who have access to transit.

Finally, the non-propulsion energy cost of transit operations has been growing as transit has become more infrastructure-intensive. While efforts to adopt green standards are commendable and will help support overall efforts to improve transit energy efficiency, the industry has to be cognizant of the fact that efforts to increase the attractiveness of transit services through such things as transit centers and stations with various customer amenities also have ongoing energy operating costs.

Transit's role in addressing energy efficiency is a noble goal and one in which transit may be able to make a contribution in certain contexts. However, the industry will have to be very disciplined in ensuring that it retains its relative competitiveness regarding energy efficiency by striving for well-utilized services and must exercise care in vehicle specification and selection, logistics and supporting infrastructure. The industry should exercise caution in energy savings claims, as the current performance is modest and not necessarily consistent with perceptions of high efficiency levels. The single best way to produce travel energy savings is to attract current light vehicle trips to existing transit services where capacity exists. Guideway modes can offer higher levels of energy efficiency due primarily to their high capacity, but this is premised on their deployment in markets where that capacity is utilized sufficiently to leverage the technology's energy-efficiency potential. Thus, opportunities to leverage this potential are relevant in only high-volume locations.

Finally, an opportunity for transit to contribute to energy efficiency can be realized if transit can be successful in encouraging people to choose a residential location and adopt travel habits that are less reliant on private vehicle travel. The transportation planning profession is still learning about the extent to which urban design can induce development such that this efficiency can be leveraged.

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