



**THE ROUTE TO CARBON AND
ENERGY SAVINGS:
TRANSIT EFFICIENCY IN 2030 AND 2050**

FINAL REPORT

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EXECUTIVE SUMMARY

Many studies have now documented the role of public transportation in reducing auto usage and creating development and travel patterns with lower carbon impacts. Corporate and governmental climate action plans promote increased transit ridership as a method to reduce transportation greenhouse gas (GHG) emissions, because travelers who switch from private vehicles to public transportation significantly reduce energy use and GHG emissions.

As transit agencies respond to the call to action presented by these climate action plans by expanding service, they face the countervailing challenge of reducing their own operational emissions. This report identifies a portfolio of strategies that transit agencies can take to reduce the energy use and GHG emissions of their operations and estimates the potential impacts of those strategies in 2030 and 2050. Using interviews and current literature, a portfolio of 17 high-priority strategies were selected for analysis based on their potential for reducing GHG emissions over the medium and long term.

This report finds that a rail transit agency that takes aggressive climate action could reduce the GHG footprint of its fleet against today's levels 55% to 78% by 2030 and 81% to 94% in 2050 with a fleet of light-weight, efficient vehicles running on renewable energy. Bus transit agencies can also achieve significant savings with several different low-carbon fuel options—clean electricity, biofuels, and hydrogen produced using carbon capture and storage. Even using conventional fuels, improvements in vehicle technology and operations can create large energy and GHG savings for transit.

The majority of transit agency energy use and GHG emissions come from operating the vehicles used to provide transit service. As a result, most of the strategies in this study involve improving the efficiency of revenue vehicles and operations. This report also examines several strategies that focus on the larger GHG footprint of a transit agency. The transit efficiency strategies analyzed in this report are as follows:

Vehicles and Fuels

1. **Hybrid Vehicles:** Vehicles that operate on two or more fuels
2. **Biofuel:** Fuel derived from plants or algae
3. **Electric Buses:** Vehicles that run on stored or grid-supplied electricity
4. **Fuel Cell Buses:** Vehicles that use fuel cells for propulsion, especially hydrogen fuel cells
5. **Weight Reduction and Right-Size Vehicles:** Lighter weight buses and trains, as well as vehicles of all types sized to meet demand
6. **Regenerative Braking:** Capture and use of energy usually lost as heat during braking

7. **Auxiliary Systems Efficiency:** Reducing the demand of non-propulsion energy uses, such as air conditioning
8. **Personal Rapid Transit:** Fixed guideway transit with 2 or 4 person cars
9. **Renewable Power:** Low-carbon electricity for transit vehicles or facilities

Operations and Maintenance

10. **Operational Efficiency:** Changes in the ways vehicles are operated, such as routing or acceleration
11. **High Global Warming Potential (GWP) Gases:** Chemicals used in systems, such as air conditioners, that have global warming impact many times that of carbon dioxide
12. **Maintenance:** Upkeep of vehicles and systems to ensure maximum possible efficiency

Other

13. **Construction and Lifecycle Impacts:** Transit system construction projects and the upstream emissions associated with transit activity
14. **Non-Revenue Vehicles, Employee Commute, and Employee Travel:** Vehicles that are not part of the transit revenue service fleet
15. **Facilities:** Transit system buildings including stations, offices, and maintenance facilities
16. **Land Use:** Community location efficiency to increase transit ridership and reduce vehicle use
17. **Ridership and Occupancy:** Improving transit emissions per passenger mile by increasing transit vehicle occupancy

There is no one-size-fits-all solution to reducing transit agency emissions. Transit agency needs vary based on weather, topography, and other operational conditions. Existing infrastructure and regional differences in the price and carbon intensity of energy will also drive future decision making. By laying out a portfolio of climate mitigation strategies for transit agencies and estimating their GHG and energy reduction potential in 2030 and 2050, this document can be used as a reference to help agencies understand which actions are best suited to help them meet their climate and energy goals.

Each strategy analyzed in this report is compared against a current day “base case” relevant to that strategy. For example, the energy and GHG savings of a hybrid diesel bus in 2030 and 2050 is compared to a present day 40 foot diesel transit buses, while the energy and GHG saving potential of facility energy efficiency upgrades is compared to typical 2010 building energy use. Figure 1 and Figure 2 show the potential GHG savings of each strategy analyzed in this report against its respective base case using the data and methods described in this report and its Appendix. The savings percentages shown

should only be compared in terms of the relative effectiveness of a strategy in reducing GHG emissions in its own area. There is large potential to significantly reduce the emissions of high global warming potential (GWP) gases, such as air conditioner refrigerant by 2050, but these represent a very small share of transit agencies' overall emissions, and reducing emissions in this area will not address vehicle fuel emissions.

Figure 1. GHG Reductions of Transit Strategies 2030

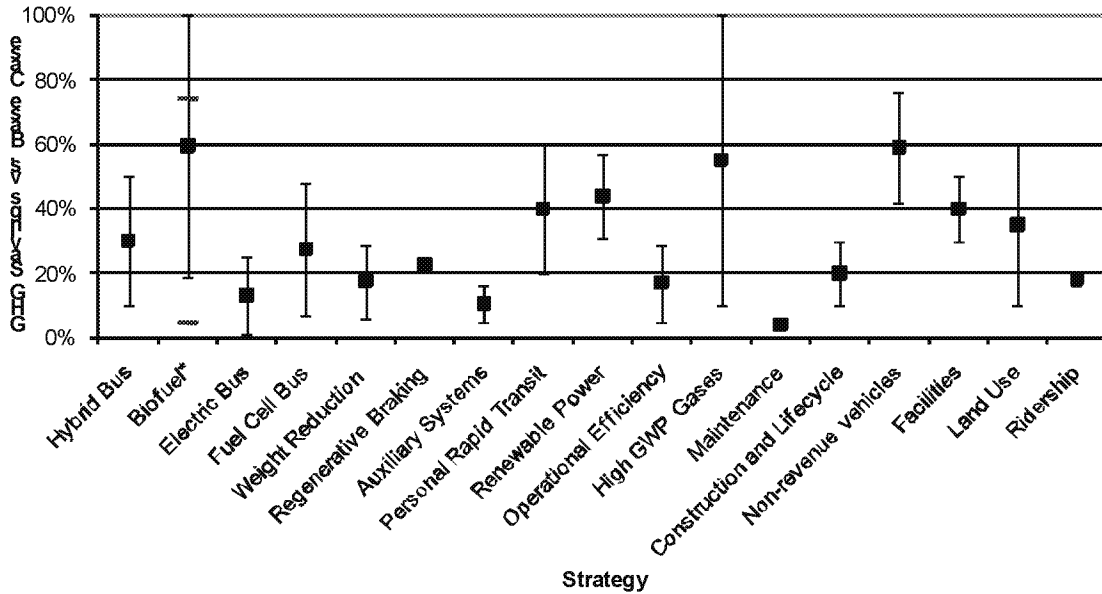
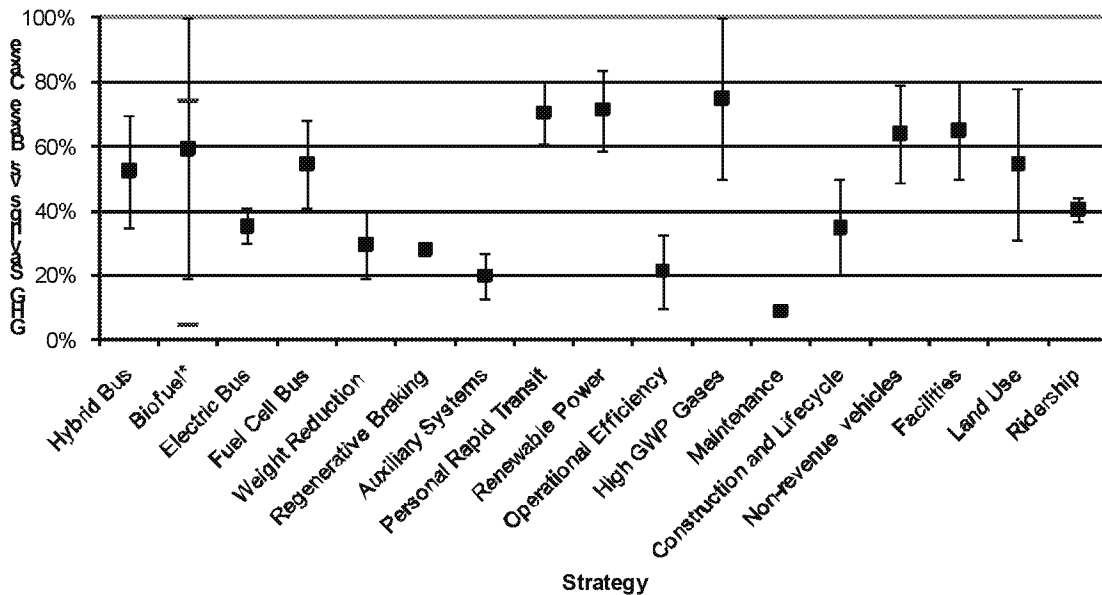


Figure 2. GHG Reductions of Transit Strategies 2050

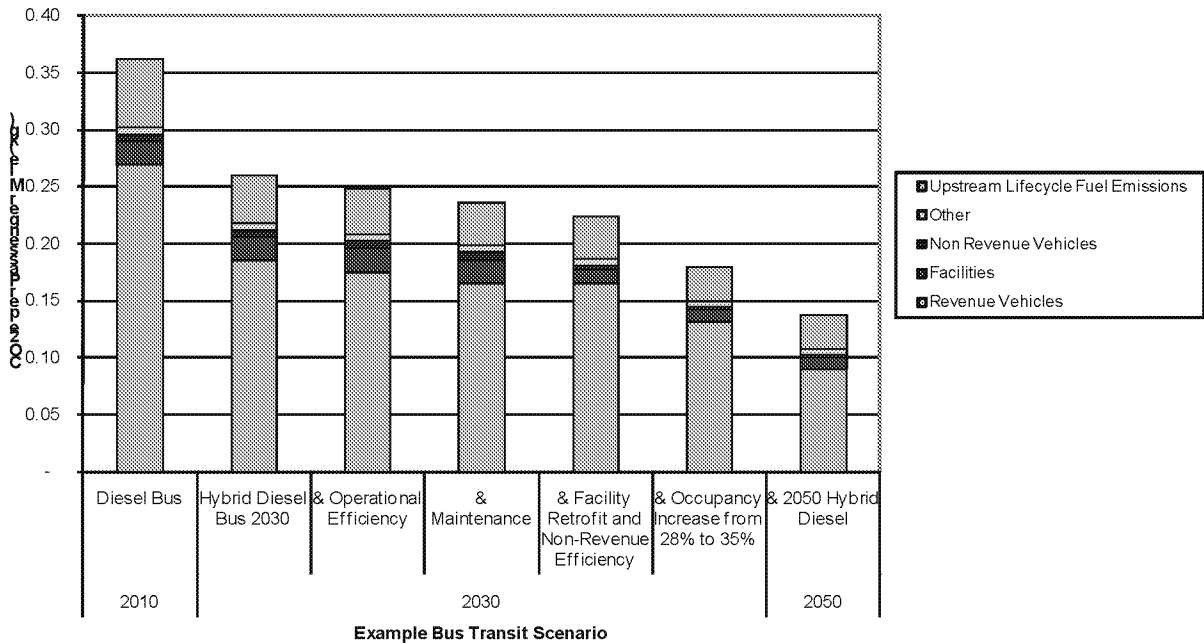


**Note, in this study lifecycle emissions are analyzed separately from direct emissions and are discussed in the Construction and Lifecycle strategy. However, Biofuels have significant upstream lifecycle emissions which are often considered when making procurement decisions, so the range of lifecycle impacts of biodiesel are shown as red lines in Figure 1 and Figure 2 for comparison purposes. For more information see the Appendix.*

The exact impact of efficiency improvements will vary across agencies and future technology projections are uncertain. Therefore, most of the energy and GHG savings presented in this analysis are presented as ranges. However, two hypothetical transit agency scenarios have been created combining the mid-points of strategy outcomes to demonstrate the scale of impact an agency-wide climate and energy efficiency action strategy can have.

Figure 3 shows the potential GHG emissions per passenger mile in 2030 and 2050 of an example bus transit agency that adopts hybrid diesel technology while also gaining efficiency through operational and maintenance improvements. This efficient diesel hybrid scenario assumes the transit agency also makes improvements in facility and non-revenue vehicle energy efficiency. As the efficient diesel hybrid bus transit agency in this example makes efforts to increase vehicle occupancy from an average 28% to 35%, it further drives down its emissions metrics to 0.18 kg carbon dioxide equivalents (CO₂e) per passenger mile in 2030. Additional efficiency improvements in hybrid fleet technology by 2050 reduce overall emissions even further in this scenario resulting in an emissions rate of 0.14 kg CO₂e per passenger mile by 2050, a 62% reduction from 2010 levels.

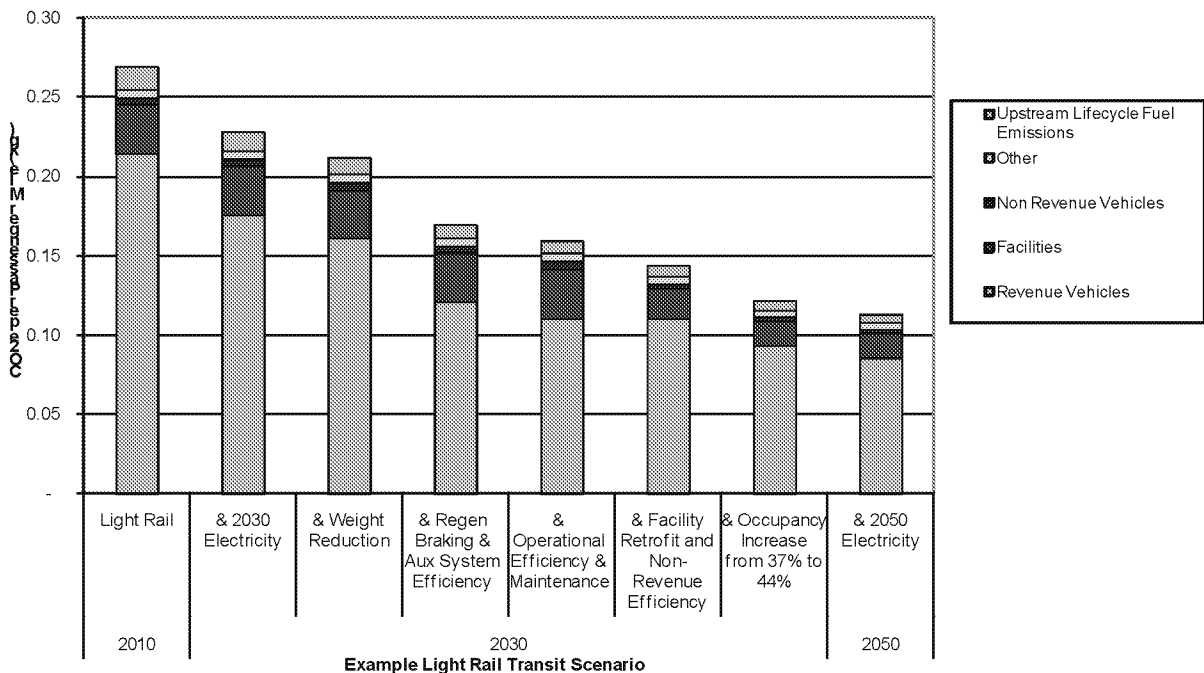
Figure 3. Hypothetical Efficient Bus Transit Agency GHG Emissions in 2030 and 2050



Transit agencies operating rail systems will benefit from a different set of technology and fuel improvements than bus systems. Therefore a second hypothetical transit agency scenario has been created for a light rail transit system as is shown in Figure 4. In this light rail system, grid electricity is used to power a light rail fleet that has become more efficient through weight reduction, regenerative braking, and improvements in auxiliary systems. Operational improvements and maintenance further enhance energy savings in this scenario. The emissions profile of the high efficiency light rail system in this example benefits from the gradual decarbonization of the U.S. electric supply forecasted by 2030 and 2050.

When the full hypothetical GHG inventory of the transit agency in this scenario is taken into account, it has an emissions metric of 0.11 kg CO₂e per passenger mile in 2050. This value includes vehicle occupancy increases, energy efficiency retrofits at transit agency facilities, and fuel economy gains among non-revenue vehicles. Substituting other electric rail modes in this example produces similar rates of emissions reductions, so while the emissions values will be different for commuter rail and heavy rail, the trend would look the same as the hypothetical light rail system in Figure 4, thus duplicate charts for those modes are not reproduced here.

Figure 4. Hypothetical Efficient Light Rail Transit Agency GHG Emissions in 2030 and 2050.



These two scenarios show how a new generation of transit vehicles that are energy efficient and use low-carbon fuels is making it possible for transit agencies to substantially cut fuel use and GHG emissions. Efficiency improvements in maintenance,

facilities, and other elements of transit operations can cut organizational emissions even further. This report provides details on these strategies and shows how the transit agencies of 2030 and 2050 could provide transportation options that help communities reduce their contributions to global climate change far below today's levels.

I. PURPOSE OF DOCUMENT

INTRODUCTION

As transit agencies adopt new technologies and take action to improve energy efficiency and reduce their climate change impacts, what are the potential energy and greenhouse gas (GHG) savings of those actions in 2030 and 2050? This document uses interviews, current literature and analysis to address these questions and is intended to serve as a resource to transit agencies as they seek to create climate action plans and sustainability plans.

Many studies have now documented the role of public transportation in reducing auto usage (usually measured as vehicle miles traveled, or VMT) and creating development and travel patterns with lower carbon impacts.^{1, 2,3,4,5} Public transportation is an integral part of many climate action plans, because travelers who switch from private vehicles to public transportation significantly reduce energy use and GHG emissions. The impact of this modal shift will be even greater if the transit systems in the U.S. improve vehicle efficiency, streamline operations, and adopt lower-carbon fuels.

There is no one-size-fits-all solution to reducing transit agency emissions. Transit agency needs vary based on weather, topography, and other operational conditions. Existing infrastructure and regional differences in the price and carbon intensity of energy will also drive decision making. By laying out a portfolio of climate mitigation strategies for transit agencies and estimating their GHG and energy reduction potential in 2030 and 2050, this document can be used as a reference to help agencies understand which actions are best suited to help them meet their climate and energy goals.

Myriad state and local government climate action plans and policies impact transit agencies in the U.S. today. Increasingly, transit agencies are called on to face the dual challenge of both reducing the emissions of their operations and expanding ridership to lower emissions associated with personal vehicle use in the communities they serve. Many transit agencies are implementing initiatives to improve air quality, decrease costs, and increase energy security through energy efficiency, which can also reduce GHG emissions. This document aims to help transit agencies as they balance what may seem like competing goals, and to articulate a path from existing practices to a set of broader climate mitigation strategies.

Global warming is a long-term problem, and the deep emissions reductions required to minimize the worst impacts of climate change will take time to implement, especially considering issues of vehicle stock turnover and infrastructure investments. As transit agencies develop sustainability and climate change plans with long-term goals, this

document seeks to serve as a resource to help estimate the potential benefits of the various actions transit agencies can take over the mid- to long-term.

RECENT RESEARCH

Several comprehensive documents relating to the role of public transit in mitigating climate change have been released over the past year and have served as important references for this study. We briefly summarize the most important of these documents here. Rather than duplicate what has already been written, this document seeks to build on this existing work to analyze the potential GHG and energy savings of transit-related climate strategies in 2030 and 2050.

- In *TCRP Synthesis 84: Current Practices in GHG Emissions Savings from Transit*, published in 2010, researchers from ICF International used surveys, literature, and interviews to summarize actions being taken by transit agencies around the country to address transportation's contribution to climate change. The study finds that all of the 41 transit agencies in its survey are planning or implementing GHG reduction strategies, though climate change mitigation may not be the primary reason for action. The GHG reduction strategies considered in the synthesis in order by participation rate are: 1) Increasing Vehicle Passenger Loads; 2) Vehicle Operations and Maintenance; 3) Mitigating Congestion; 4) Alternative Fuel and Vehicle Types; 5) Other Energy Efficiency/Renewable Energy Initiatives; 6) Expanding Transit Service; 7) Construction and Maintenance; and 8) Promoting Compact Development.⁶
- Another key recent document is the U.S. Department of Transportation's Report to Congress, *Transportation's Role in Reducing U.S. GHG Emissions*, published in April 2010, which looks at the benefits of GHG mitigation strategies across all modes in the transportation sector. The report finds that transit expansion in combination with land use changes, bicycling and walking could reduce U.S. transportation emissions 2% to 5% by 2030 and 3% to 10% by 2050. Alternative fuels and vehicle technology improvements are also discussed, and hybrid transit buses are estimated to have 10% to 50% GHG reduction potential. Transit plays a role in every major strategy identified in the report; discussion of low carbon fuels, vehicle efficiency, transportation system efficiency, reduction of carbon-intensive travel activity, carbon pricing, and transportation planning and investment all include either possible efficiency improvements for and expansion of public transit.⁷
- Following the passage of the Energy Independence and Security Act of 2007 (EISA) and the prospect of creating fuel efficiency standards for medium and heavy-duty vehicles for the first time, the National Research Council created a Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty

Vehicles. The committee's 2010 publication, *Technologies and Approaches to Reducing the Fuel Consumption of Medium-and Heavy-Duty Vehicles*, provides a comprehensive review of fuel efficiency opportunities in this sector, including transit buses. A package of transit bus technology improvements are analyzed that could achieve a 48% reduction in fuel usage per vehicle by 2015 to 2020. Engine thermal efficiency improvement, hybridization, weight reduction, transmission improvements, and low rolling resistance tires are all found to be successful efficiency strategies for urban transit buses. Aerodynamic improvements are found to be less successful in transit buses than other heavy duty vehicles, because of the low travel speed of urban transit vehicles.⁸

- The 2010 Federal Transit Administration (FTA) report, *Public Transportation's Role in Responding to Climate Change*, is a brief, clear summary of GHG emissions and passenger travel in the U.S. today. Using data from the National Transit Database, U.S. Environmental Protection Agency (EPA), and the National Household Transportation Survey, the average transit trip is found to emit just 47% of the CO₂ per passenger mile of a single occupant personal vehicle. GHG emissions rates are also explored in light of vehicle occupancy, travel activity, land use, transit mode differences, and lifecycle impacts. The paper includes a detailed appendix that compares transit GHG intensity among the major transit modes and transit systems in the U.S.⁹
- In August 2009, the American Public Transportation Association's Climate Change Standards Working Group published the *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit*, which addresses the issues of GHG accounting from a transit agency perspective. The document provides methods for documenting transit agency organizational emissions and also describes a protocol for estimating the GHG emission mitigation benefits that transit brings to a region.¹⁰

ORGANIZATION OF THIS DOCUMENT

This document provides an overview of the potential energy and emissions savings by 2030 and 2050 of transit agency technology and operational improvements. The document is organized into six sections and an Appendix as follows:

- Section I introduces the topic;
- Section II provides a framework for thinking about the role of transit in the U.S. carbon footprint;
- Section III briefly discusses current transit energy and GHG emission reductions practices;
- Section IV discusses the methods used to analyze potential energy and GHG savings in 2030 and 2050;
- Section V presents the results of the analysis in summary form; and

- Section VI provides a conclusion.

The Appendix of this document discusses in detail each of the energy and GHG mitigation strategies modeled in this study. It is designed as a catalog of savings opportunities, with detailed assumptions to enable transit agencies to adapt and use the data in their planning. The strategies analyzed in the appendix are:

Vehicles and Fuels

1. **Hybrid Vehicles:** Vehicles that operate on two or more fuels
2. **Biofuel:** Fuel derived from plants or algae
3. **Electric Buses:** Vehicles that run on stored or grid-supplied electricity
4. **Fuel Cell Buses:** Vehicles that use fuel cells for propulsion, especially hydrogen fuel cells
5. **Weight Reduction and Right-Size Vehicles:** Lighter weight buses and trains, as well as vehicles of all types sized to meet demand
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7. **Auxiliary Systems Efficiency:** Reducing the demand of non-propulsion energy uses, such as air conditioning
8. **Personal Rapid Transit:** Fixed guideway transit with 2 or 4 person cars
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Operations and Maintenance

10. **Operational Efficiency:** Changes in the ways vehicles are operated, such as routing or acceleration
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Other

13. **Construction and Lifecycle Impacts:** Transit system construction projects and the upstream emissions associated with transit activity
14. **Non-Revenue Vehicles, Employee Commute, and Employee Travel:** Vehicles that are not part of the transit revenue service fleet
15. **Facilities:** Transit system buildings including stations, offices, and maintenance facilities
16. **Land Use:** Community location efficiency to increase transit ridership and reduce vehicle use
17. **Ridership and Occupancy:** Improving transit emissions per passenger mile by increasing transit vehicle occupancy

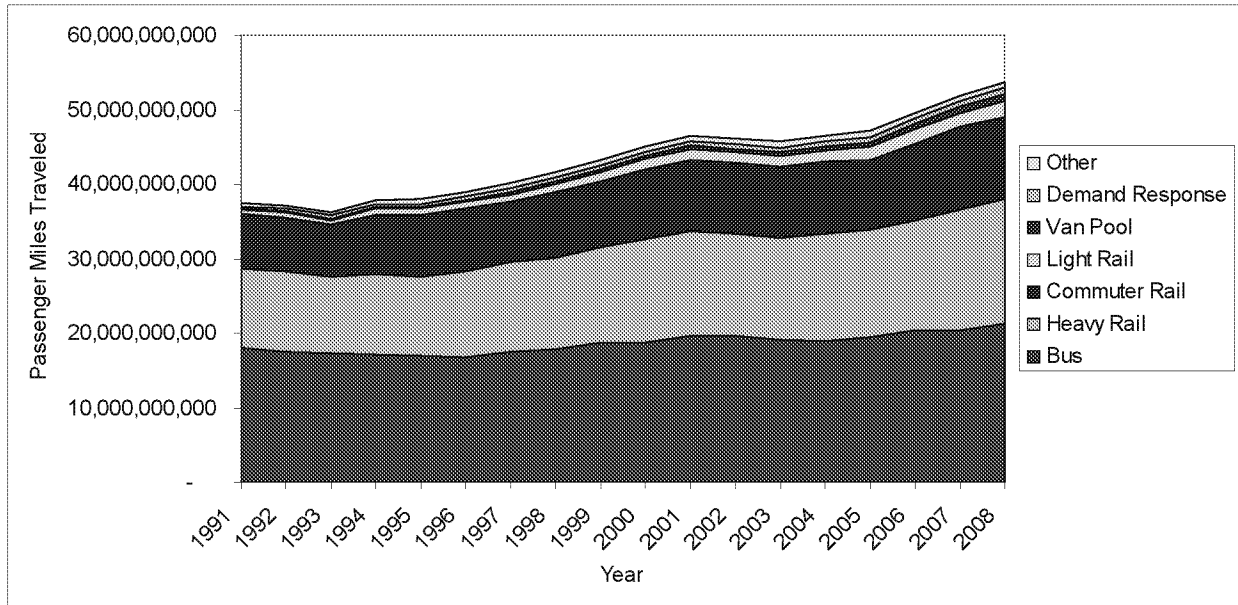
II. THE ROLE OF TRANSIT IN AMERICA'S CARBON FOOTPRINT

Transportation GHG emissions are a large and growing part of the U.S. GHG inventory. In 2008, transportation activity emitted 1,790 million metric tons of carbon dioxide equivalents (CO₂e), or 32% of the total U.S. emissions that year. GHG emissions from transportation grew 20% from 1990 to 2008, while overall emissions grew 18% during that period.¹¹ The growth in transportation emissions has been caused by increased vehicle travel and relatively flat fuel economy resulting in higher on-road petroleum use. As the U.S. works to address its impact on global climate change and decrease its dependence on foreign energy sources, transportation energy and emissions reductions – and the role public transit can play in enabling them – have come into focus.

CLIMATE BENEFITS OF TRANSIT

Public transportation serves a vital role in the U.S. effort to address global climate change. Transit ridership has been growing substantially in recent years, as the chart of passenger miles by mode in Figure 5 demonstrates. With passengers taking 10 billion trips and traveling 54 billion miles in 2008 (the most recent year for which data are available), transit removes a significant number of cars from the road.¹² In addition to the direct fuel and emissions savings transit creates by providing an alternative to personal vehicles, public transportation indirectly supports GHG reductions by influencing development patterns to support walking, biking, shorter trips, and transportation trip reduction. Transit ridership also relieves on-road congestion, which enables drivers to get to their destinations more efficiently and use less fuel.¹³ As a result, the total GHG savings from transit ridership today could be in the range of 37 million metric tons CO₂e.¹⁴ While researchers will continue to refine the precise numbers, it is clear that the overall inventory of GHGs in the U.S. today, and therefore the scale of the climate problem we have to contend with, is smaller than it would be if transit were not an option available to travelers.

Figure 5. U.S. Transit Passenger Miles Traveled by Mode 1991-2008



Source: U.S. Department of Transportation, Federal Transit Administration. *National Transit Database*. Table TS2.1 2009.

TRANSIT'S ORGANIZATIONAL GHG FOOTPRINT

Despite all of the ways that transit lowers emissions in the communities it serves, every public transportation agency has a GHG footprint itself. Public transportation vehicles traveled over 5 billion miles in 2008 and emitted as much as 14 million metric tons of carbon dioxide.¹⁵ Public transportation's GHG emissions account for less than 1% of total U.S. transportation emissions, but it is a significant source— as a point of comparison, this was on the same order of magnitude as the total GHG emissions from all sources in Denver in 2005.¹⁶ Many strategies to reduce GHGs from public transportation create additional benefits in terms of reduced air pollution emissions and lower fuel costs, making an even stronger case for action.

By far largest source of transit agency emissions are GHGs associated with revenue vehicle fuel use. Other emissions from transit agencies, including energy used at facilities, non-revenue vehicles, and fugitive emissions (such as from air conditioning), are likely 30% or less of a transit agency's overall GHG footprint.

Transit agencies consumed 6.5 trillion kilowatt hours (kWh), 714 billion gallons of diesel fuel, and 308 billion gallons of other fuel to power transit revenue vehicles in 2008.¹⁷ Transit agencies adopting alternative fuels and new efficient vehicle technologies at unprecedented rates, but there is still plenty of room for efficiency improvements to create a low-carbon transit fleet for the 21st Century.

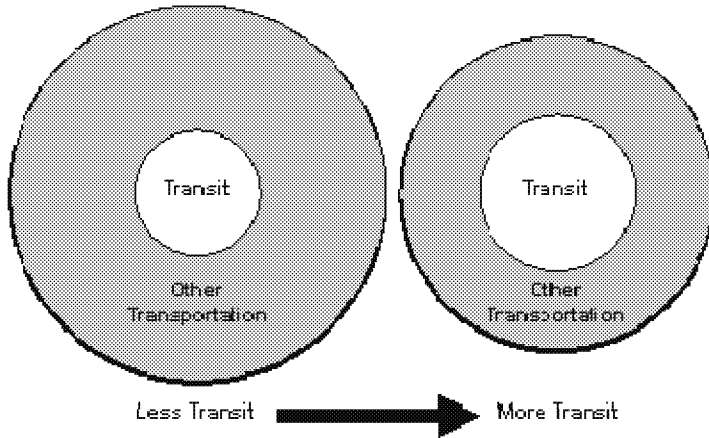
TRANSIT'S ROLE IN 2030 AND 2050

Public transportation has shown strong ridership in the 2000's with passenger travel growing slightly faster than on-road vehicle travel. Efforts to address global climate change may drive even more growth in transit use. Many federal, state, and local plans to mitigate global climate change are looking to the increased use of public transportation, i.e. modal shift away from private automobiles, as a way to achieve significant additional GHG reductions while helping households control their travel expenses.

It is not just public agencies focused on the emissions of transit. The relative emissions savings of transit can be a motivation for riders. The newly developed GHG accounting standards for corporate value chain reporting require reporting the emissions of employee commuting.¹⁸ This new requirement will have companies around the world using emissions metrics, such as CO₂e per passenger mile, for transit agencies in the communities they operate as part of their corporate GHG reporting. Moreover, as companies set goals to reduce employee travel emissions they may promote transit ridership as a lower-carbon commuting and business travel alternative.

Responding to this potential new demand for transit and expanding transit service without significantly increasing the efficiency of transit vehicles or reducing the carbon intensity of fuel will have the effect of increasing transit agency emissions. However, the emissions reduction created as new transit riders drive their personal vehicles less may be even greater. Additionally, transit expansion can promote land uses that reduce the overall need for vehicle travel in a region, and transit use contributes to fuel savings through on-road congestion relief for drivers. The net result is an overall emissions reduction in the region. Figure 6 illustrates this relationship: emissions from the transportation sector overall shrink, while transit's share of those emissions grows due to increasing the number of routes, frequency and size of vehicles, and service hours to meet travel needs.

Figure 6. Transportation GHG Emissions: Two Scenarios



Source: Adapted from Timothy Papandreu, LA Metro as cited in New York, Metropolitan Transportation Agency. “Greening Mass Transit & Metro Regions: The Final Report of the Blue Ribbon Commission on Sustainability and the MTA.” 2009.

VEHICLE STANDARDS AND EMISSIONS

Light Duty Vehicles

This study addresses how transit agencies can maximize their role in solving the climate change problem, but it is worth discussing efficiency trends in personal cars as well. As mentioned above, one of the major GHG benefits of transit is that it serves as a replacement to carbon-intensive personal vehicle travel. Therefore, it is important to understand the likely trends in personal vehicle GHG emissions through 2050 to put the strategies for transit energy and GHG emissions reductions over that period into context.

Reducing the climate change impact of personal vehicle travel requires a three-pronged approach—decarbonizing fuel sources, improving the efficiency of vehicles, and providing alternatives to personal vehicle trips. There are several recent federal regulatory efforts aimed at improving the fuel efficiency of cars and light trucks. Corporate Average Fuel Economy (CAFE) Standards finalized in 2010 will require new vehicles to have an average fuel efficiency of 34.1 miles per gallon (mpg) by 2016. Additionally, the U.S. Environmental Protection Agency has issued a standard that requires cars and light trucks to emit on average no more than 250 grams of carbon dioxide (CO₂) per mile by 2016. Manufacturers will be able to meet that requirement with improvements such as air conditioner redesigns, but if they were to meet it entirely with fuel economy improvements they would achieve a 35.5 mpg average by 2016.¹⁹

Another rulemaking process has begun to set standards for 2017-2025 model years, which will reduce the carbon-intensity of personal vehicles even further.²⁰ These standards only apply to new vehicles; at any given time the average vehicle on the road is significantly less efficient than the fuel standard for new vehicles. In 2008, the average on-road fuel efficiency for passenger cars was 22.6 mpg²¹ while the standard since 1990 has been 27.5 mpg.²²

Given the regulatory efficiency standards developed in recent years, the U.S. Department of Energy, Energy Information Administration’s Annual Energy Outlook (AEO) forecasts that the average light-duty vehicle on the road in 2030 will have a fuel economy of 28 mpg (Table 1).²³ Extrapolating this trend out to 2050 suggests an average on-road fuel economy of 36 mpg that year, or about 0.25 kg CO₂ per vehicle mile for a gasoline vehicle. A fuel economy at this level results in a 58% reduction in emissions per vehicle mile against today’s rate of 0.43 kg CO₂ per vehicle mile for gasoline cars and light trucks.

Table 1. Personal Vehicle Fuel Economy and GHG Emissions

| | 2008 | 2030 | 2050 |
|---|------|------|------|
| Fuel Economy (mpg) | 20.5 | 28 | 36 |
| CO₂e per vehicle mile (kg) | 0.43 | 0.31 | 0.24 |
| Passengers | 1.6 | 1.6 | 1.6 |
| CO₂e per passenger mile (kg) | 0.27 | 0.20 | 0.15 |
| Source: 2008 Fuel Economy from FHWA. <i>Highway Statistics 2008</i> , Table VM-1. 2009, 2030 Fuel Economy from EIA <i>Annual Energy Outlook 2010</i> , Table A7. 2010, 2050 calculated based on EIA 1.3% annual growth. | | | |

The expected growth in light duty vehicle efficiency is not enough to decrease personal transportation’s overall contribution to global climate change. The AEO forecast shows that fuel efficiency increases are offset by forecasted growth in vehicle miles traveled, so that total light duty GHG emissions in 2030 are equal to 2008 levels in the AEO forecast.²⁴ A MIT study, *On the Road in 2035*, reached similar conclusions, finding that even with a high rate of adoption of new technologies light duty vehicle fuel use in 2035 might be just 10% below 2000 levels.²⁵

Heavy Duty Vehicles

Improvements in personal vehicles do not eliminate the GHG reduction benefit of transit ridership, but as personal vehicles become more efficient, transit vehicles must improve as well to continue to provide the same or better net GHG reduction relative to autos. In addition to reducing transit vehicle emissions, transit agencies can help reduce

the overall transportation GHG emissions in their regions by increasing transit vehicle occupancy, supporting sustainable land uses, and making the most of transit's ability to reduce congestion.

A May 2010 Presidential Memorandum authorized the U.S. Environmental Protection Agency and the National Highway Traffic Safety Administration (NHTSA) to begin a process to set vehicle efficiency standards for heavy duty vehicles, including buses, beginning with model year 2014.²⁶ The role of transit vehicles in this rulemaking remains to be seen. At the time of this writing NHTSA states that urban buses are "potentially" covered by the rulemaking,²⁷ while U.S. EPA states that it "would" regulate urban buses as heavy duty vehicles under the Clean Air Act.²⁸

The fuel economy standards that will come out of this regulatory process is unknown at this time, but NHTSA states,

"While the medium- and heavy-duty truck sector is very diverse and opportunities to reduce GHGs and increase fuel economy vary, preliminary estimates indicate that large tractor trailers – representing half of all GHG emissions from this sector – could reduce GHG emissions by as much as 20% and increase fuel efficiency by as much as 25% by 2018 through the use of existing technologies."²⁹

Regulations and incentives for heavy duty fuel economy, GHG emission reduction, and local air quality improvement will all influence the rate of improvement in and adoption of new transit technology. This report does not attempt to judge the impacts of future policies. Rather, the analysis presented in Section IV of this report estimates the potential energy and GHG emissions profile of transit technologies in 2030 and 2050 based on current technology trends and potential future technology developments as identified through literature and interviews. Then, based on what is possible, we create several energy and emissions scenarios for the transit agency of 2030 and 2050.

III. CURRENT PRACTICES IN GHG REDUCTION AND ENERGY EFFICIENCY

CLIMATE ACTION PLANS

In 2003, the Center for Neighborhood Technology (CNT) documented “strategies for reducing transportation emissions – increasing the use of transit, changing land-use patterns, and adopting energy-efficient technologies and fuels in transit fleets” in *TCRP Report 93: Travel Matters: Mitigating Climate Change with Sustainable Surface Transportation*. Since that time, the technologies available to public transportation operators have advanced; capital investments and operating decisions have been influenced by substantially fluctuating fuel prices and economic conditions; the methods and data for analyzing the GHG reduction potential of public transportation improvements have evolved; and scientific studies have brought into question the life-cycle benefits of fuels previously viewed as green solutions. Furthermore, the call for GHG reductions has grown as climate action plans and laws have been developed at the organization, local, state, and federal level. Many climate action plans, such as those in Chicago and New York, look to transit as part of the solution for reducing the GHG footprint of communities.³⁰

Public transportation authorities are beginning to develop sustainability plans, track their climate change impacts, and set GHG reduction goals as well – for example, the New York Metropolitan Transportation Authority’s Blue Ribbon Commission on Sustainability and the MTA issued a final report in 2009,³¹ the Chicago Regional Transportation Authority has started a Green Regional Transit Plan that is expected to be completed in 2010,³² and the American Public Transportation Association (APTA) issued its, *Recommended Practice for Quantifying GHG Emissions from Transit*, in August 2009.³³ More and more, transit agency staffs include employees with titles such as “sustainability manager.”

GHG emissions are linked to every aspect of transit agency operations, so a comprehensive climate action plan must look at all agency systems. As a result of this increased focus on energy and GHG emissions, transit agencies are finding innovative new ways to reduce their overall environmental impact, often cutting operation and fuel costs at the same time.

Transit agencies have reported their vehicle operations and fuel use for years through the National Transit Database program, but now that transit agencies are preparing GHG inventories we have for the first time a clear view as to the overall energy use and GHG emissions of transit operations. Data from a few of these early GHG inventories are in Table 2. While the specifics vary depending on modes operated, type of vehicles and fuel used, the carbon-intensity of electricity in the region, and more, in every case

the overwhelming majority of transit agency GHG emissions come from the fuel and electricity used to propel revenue transit vehicles.

Table 2. GHG Emission Inventories of Four Transit Agencies

| | BART (2007) | LA Metro (2008) | NY MTA (2008) | AC Transit (2006) |
|--|-------------|-----------------|---------------|-------------------|
| GHGs from Transport | 73% | 93% | 81% | 95% |
| GHGs from Facilities and Other | 27% | 7% | 12% | 7% |
| Total Metric Tons CO ₂ e | 82,438 | 478,000 | 2,302,837 | 68,479 |
| GHGs from Revenue Vehicles | 68% | 91% | 79% | 93% |
| GHGs from Non-Revenue Vehicles | 5% | 2% | 2% | 2% |
| Notes: Assumes all BART non-electric mobile emissions are non-revenue. AC Transit revenue includes some non-revenue diesel usage. Sources: San Francisco Bay Area Rapid Transit (BART). <i>Bart Greenhouse Gas Inventory</i> , December 2008. Los Angeles County Metropolitan Transit Authority (LA Metro). <i>Towards a Sustainable Future. June 2009 Baseline Sustainability Report</i> , 2009. Dana C. Coyle. <i>Greenhouse Gas Reporting for Transit Fitting the MTA into The Climate Registry's General Reporting Protocol</i> . Metropolitan Transportation Authority (NY MTA). Presentation to The Climate Registry Transit Industry Meeting. March 17, 2010. Alameda-Contra Costa Transit District (AC Transit) 2006 <i>Environmental Sustainability Report</i> , 2008. | | | | |

PERFORMANCE METRICS

The Climate Registry (TCR), which provides a reporting platform for organizational GHG emissions in North America, created a set of transit-industry-specific reporting metrics in 2010. The performance metrics are designed to enable tracking of transit GHG efficiency over time. The metrics also allow comparison of the carbon-intensity of transit service across agencies. Finally, those calculating the GHG impacts of transit ridership, such as for state, local, and corporate GHG inventories, can use the metrics as a tool in their analysis. The three metrics supported by TCR are 1) GHG emissions per passenger mile traveled, 2) GHG emissions per vehicle mile, and 3) GHG emissions per revenue vehicle hour.³⁴

Table 3 shows an example of the use of these performance metrics with the four transit agency GHG inventories discussed above. Because the metrics use the total GHG inventory of the transit agency, rather than just vehicle fuel use, the emissions per passenger mile tend to be higher than those reported in the literature. For example, BART's GHG inventory shows 32% of its emissions come from facilities and non-revenue vehicles, so its performance metrics are at least that much higher than a measure of purely vehicle energy use emissions would be. Because all of the GHG emissions sources in a transit agency, from station lighting to office computer electricity use, ultimately go toward the mission of transit service provision, the TCR metrics give a view into the emissions created in the practice of supplying transit service.

Table 3. GHG Performance Metrics for Four Transit Agencies

| | BART (2007) | LA Metro (2008) | NY MTA (2008) | AC Transit (2006) |
|---|---------------|-----------------|----------------|-------------------|
| CO ₂ e per Passenger Mile Traveled (kg) | 0.06 | 0.23 | 0.14 | 0.33 |
| CO ₂ e per Vehicle Mile (kg) | 7.49 | 3.50 | 7.40 | 2.82 |
| CO ₂ e per Revenue Vehicle Hour (kg) | 228.15 | 53.47 | 89.82 | 38.23 |
| Passenger Miles Traveled | 1,369,850,022 | 2,111,182,501 | 16,580,030,403 | 209,399,847 |
| Vehicle Miles | 11,002,647 | 136,606,770 | 311,051,915 | 24,616,985 |
| Revenue Vehicle Hours | 361,332 | 8,939,860 | 25,638,190 | 1,817,463 |
| Note: BART is Heavy Rail, AC Transit is Bus, LA Metro and NY MTA include multiple modes. Sources: GHG data see sources in Table 2. Indicator data U.S. Department of Transportation, Federal Transit Administration. National Transit Database, RY 2006, 2007, and 2008 Databases. | | | | |

The analysis presented in this report uses the first two indicators – GHG per passenger mile and GHG per vehicle mile – as primary metrics in comparing the potential GHG emissions savings of transit mitigation strategies in 2030 and 2050. GHG emissions per revenue vehicle hour is discussed in the context of the Operational Efficiency strategy in the Appendix.

GHG MITIGATION

Transit agencies are adopting cutting edge technologies that are helping to lower their GHG emissions. With their high visibility in communities, transit vehicles have become traveling demonstrations of some of the newest energy technologies in recent years, including hybrid electric propulsion, hydrogen fuel cells, and biofuels. In 2009, the federal Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) program granted transit agencies from around the country funds for innovative GHG mitigation actions. The 43 projects funded provide a view into the types of GHG mitigation actions being undertaken by transit agencies across the U.S. The TIGGER projects include advanced vehicles, flywheel energy storage, wind turbines, photovoltaics for electricity and hydrogen production, facility energy efficiency retrofits, and geothermal heating.³⁵

The current boom in innovation around transit vehicle technologies means that that there is a wide variety of choices for transit agencies seeking to improve the efficiency of their fleet. In some sense it is like the Wild West with so much new technology territory and agencies struggle to evaluate technology options on an even playing field.³⁶ Agencies are working together to share best practices, which can increase GHG

savings by improving the success rate of projects and speeding up the pace of implementation.^{37,38} Efforts to combine orders across agencies to reduce the cost of procurement of new technologies are also being made.³⁹ Transit agencies cannot allow GHG mitigation actions to adversely affect service, so information on performance of new strategies and technologies in the field is essential. The National Renewable Energy Laboratory and U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy are working closely with transit agencies to do real-world testing of cutting-edge transit vehicles so that providers can understand the performance of vehicles in action, rather than just in simulations.^{40,41}

ADAPTATION STRATEGIES

While this research focuses mainly on climate mitigation – efforts to reduce GHG emissions that cause global warming – climate action plans often address both climate mitigation and another type of climate action known as adaptation. A transit agency climate adaptation plan looks at the likely impacts of a changing climate on transit operations and infrastructure and seeks to design a set of strategies for to prepare for and protect the agency from those impacts.

Global climate change will affect different places in different ways, so adaptation needs to be a locally specific strategy. If a region is expected to receive more intense storms a transit agency may need to look at the risks associated with flooding. If an increased number of high heat days is a particular issue, impacts on infrastructure such as rail tracks and pavement should be explored. High heat days may also strain electrical infrastructure as residential and business air conditioning needs increase, which will have greater impact on transit agencies that use electricity to power vehicles.

Some climate strategies will benefit from both mitigation and adaptation efforts. For example, efforts to reduce energy use through building retrofits and efficient heating and cooling equipment can help transit agencies keep energy use low while adapting to increased summer heat. Transit agencies that incorporate greenways or permeable pavements along transit infrastructure can provide stormwater management that helps with increased storm intensity as well as reduces the energy needs of stormwater treatment. Additionally, expanding public transportation can help households reduce personal transportation emissions, and it may also provide a public safety function in coastal areas that need a robust transportation infrastructure to enable storm evacuation (especially important for low-income households, the elderly, and other vulnerable populations).

IV. METHODOLOGICAL APPROACH

The research presented in this document has two objectives:

- 1) Identify specific strategies (including, but not limited to, changing technologies and operating practices) to reduce energy use and greenhouse gas emissions by public transportation systems (primarily focused on transit operations)
- 2) Estimate potential reductions in energy use and greenhouse gas emissions that may be achieved by 2030 and by 2050 through the implementation of these strategies by public transportation systems.

In this section the methods used to collect and prioritize GHG and energy use reduction strategies for analysis are discussed. This is followed by an explanation of the analysis methods used to model GHG savings estimates in 2030 and 2050.

2030 AND 2050 TIMEFRAMES

Climate change is a phenomenon that is global in scope and has a very long timeframe. Many GHGs emitted into the atmosphere today will continue to persist up to 100 years from now and some will persist beyond then. Additionally, the major transformations needed to make deep reductions in GHG emissions involve infrastructure and capital investments that take decades to implement. Therefore, many climate action plans look at both near-term action and longer term goals for reducing climate impact. Climate scientists estimate that a 50-85% reduction below 2000 global GHG emissions levels by 2050 is required to stabilize the climate at 2.0-2.4 degrees Celsius above pre-industrial temperatures. Such an increase in global temperatures will have impacts on water supplies, natural habitats, flooding, droughts, fires, and storm intensity. But, stabilizing at that level may avoid even greater impacts in those areas and others that could occur without action.⁴²

In addition to serving as common timeframes for discussing climate change mitigation, 2030 and 2050 represent a reasonable long-term planning time frame for transit agencies. The average transit bus in 2008 was 7.5 years old.⁴³ If transit buses last an average of 12 years, the transit bus fleet will turn over at least twice by 2030 and four times by 2050. The Federal Transit Administration's minimum service life policy for fixed guideway rolling stock is 25 years,⁴⁴ and the average age of rail vehicles in 2008 was 19.5 years,⁴⁵ so most of these vehicles will be replaced by 2030 and again by 2050.

Some aspects of transit technology in 2050 cannot be conceived of today. It is unlikely a transit agency in 1970 could have predicted the many uses of global positioning systems (GPS) and smart card technologies in 2010. Similarly, is it possible that we will have entirely new ways to manage and interact with transit networks, or that an entirely new mode of transit could be developed that would replace our current options by 2050.

However, it is fair to assume that much of transit technology in 2050 will be recognizable to today's transit expert. Transit buses have improved in many ways since 1960, but a 1960's era bus is still recognizable as a transit vehicle. This is even truer in the case of rail modes which take longer to develop and have extended lifecycles—vintage streetcars from the 1920's operate today in New Orleans, San Francisco and other areas, and the New York subway system celebrated its 100th birthday in 2004.⁴⁶

SELECTING GHG AND ENERGY USE REDUCTION STRATEGIES

Strategies for reducing energy use and addressing GHG emissions at transit agencies were identified through literature reviews and expert interviews. An interview script of 24 questions was developed to guide one hour interviews that occurred in May and June 2010. Ten interviewees were selected from a pool of 50 potential interviewees identified. Interviewees were selected based on expertise specific to the research, possession of real-world knowledge and data beyond the literature, and availability.

Over 100 GHG and energy use reduction strategies were drawn from the literature and interviews. These strategies were grouped by mode and category (e.g. Vehicle Technology, Alternative Fuels, and Operations). Strategies were ranked by three main criteria:

- Transit Agency GHG Reduction Potential (1 Low-3 High)
- Community GHG Reduction Potential (1 Low-3 High)
- Implementation Timeframe (Short, Medium, Long)

A diverse portfolio of highly ranked strategies was selected for analysis. Strategies were chosen to address the major parts of a transit agency's GHG inventory. Because the primary source of transit agency GHG emissions come from vehicle fuel use, the largest number of strategies were selected from those that can improve vehicle efficiency. Some strategies that had relatively small impacts were combined into groups. For example, eco-driving, deadheading, and Intelligent Transportation Systems are all included under the larger strategy of Operational Efficiency.

Of the 17 strategies chosen, 15 focus on reducing the energy use and GHG emissions of transit agency operations. Two strategies, "Land Use" and "Ridership and Occupancy," are slightly different. These have the potential to increase transit operational efficiency, but are also focused on transit's larger impact as a GHG reduction strategy in the community. A transit agency that adds riders to an existing route may not reduce its own organizational GHG footprint, but it will improve its GHG per passenger mile performance while contributing to communitywide emissions reductions.

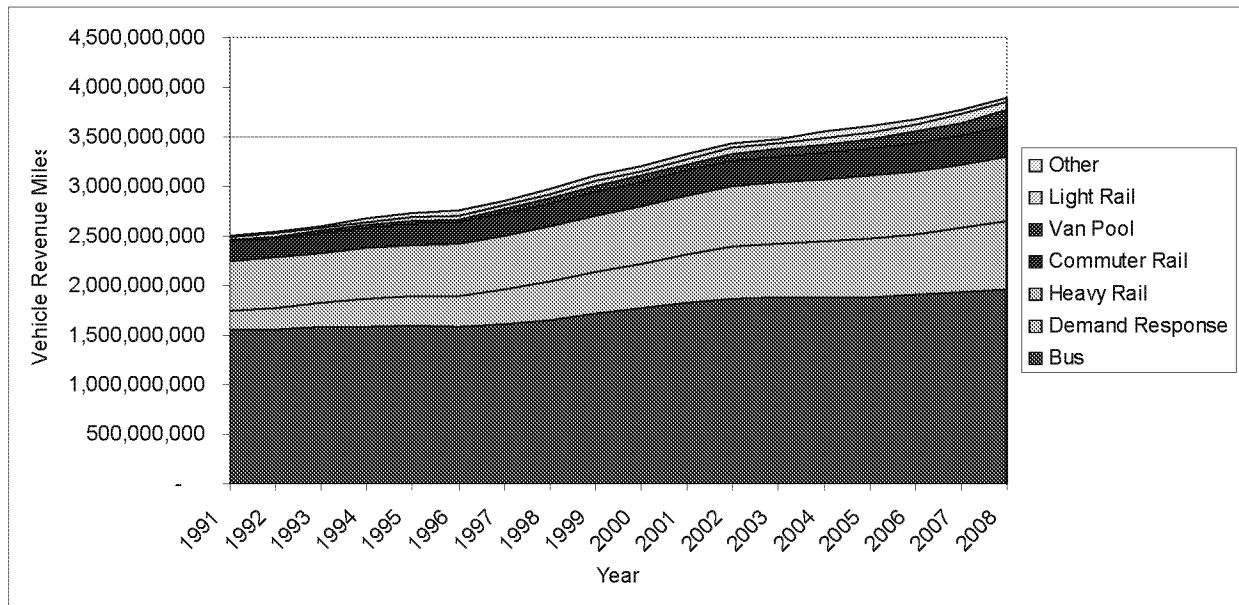
While the body of literature on transit energy use and GHG emissions is large and growing, data on real-world performance outcomes remain relatively scarce. This is especially true when looking at cutting edge technologies and practices. GHG and

energy savings values were selected with preference for published, real-world outcomes over hypotheticals. Assumptions used when making savings projections to 2030 and 2050 are documented in the discussion of each strategy in the Appendix. In many cases a range of values is evaluated to represent the variance in possible outcomes depending on implementation details.

Strategies are analyzed against existing technology and practice to develop potential GHG and energy saving values for 2030 and 2050. The primary transit modes addressed are buses, commuter rail, heavy rail, and light rail. Some less common transit modes, like ferry boats, may be included in the discussion of appropriate strategies, but are not specifically analyzed.

As is illustrated in Figure 7, demand response service represents a large and growing portion of transit agency vehicle miles and vehicle fleet. This mode presents a significant analysis challenge because the vehicle technology used is quite variable—ranging from light duty passenger cars to buses. As such, this mode is not analyzed specifically, but many of the strategies discussed in this report, such as biofuels and maintenance, are applicable to demand response and it is hoped that transit agencies can use the information provided here in their demand response planning as well.

Figure 7. U.S. Transit Revenue Vehicle Miles by Mode



Source: U.S. Department of Transportation, Federal Transit Administration. *National Transit Database*. Table TS2.1 2009.

MEASUREMENT METRICS

Vehicle efficiency for passenger cars is typically measured in miles per gallon (mpg) in the U.S. The variation in type and operating conditions for transit vehicles makes miles per gallon a less straightforward measure of fuel efficiency for transit than it is for personal transport. A small bus that seats 20 people might use less fuel per vehicle mile than a large bus that seats 40, but if one has to use two small buses to carry the same number of passengers as the large bus, the relative efficiencies of the vehicles on a per passenger mile basis are opposite what the vehicle efficiency measure might imply. However, using fuel per passenger mile as the only metric of efficiency may cause variances in occupancy rates to overshadow the impacts of vehicle technology improvements. For example, a bus getting 3.6 miles per gallon that is fully occupied will have a much higher per passenger efficiency than the same bus at 50% occupancy.

Another efficiency measurement option is fuel use per seat mile. This measure eliminates the variability caused by occupancy, but it introduces two other issues—transit vehicles typical allow both seated and standing passengers, so seats may not reflect the true capacity of the vehicle, and similar vehicles may have unequal numbers of seats because they use different seating configurations. For example, the Houston Metro recently removed 8 light rail seats on a trial basis to make room for bicycles.⁴⁷

In this document vehicle efficiency among similar vehicles is primarily compared on a per vehicle mile basis to emphasize the relative fuel efficiency benefits of various transit technologies and strategies. Vehicle occupant capacity and per passenger mile efficiency are discussed secondarily as a way to compare efficiencies among dissimilar vehicles. Additionally, increasing transit vehicle occupancy is discussed as a separate strategy—a way to improve transit efficiency on a per passenger basis no matter which vehicle technology is used (just as carpooling is a way to increase personal vehicle efficiency on a per passenger basis whether one is driving a new hybrid car or an old gas guzzler).

The primary GHG emitted by transit vehicles, CO₂, is directly related to the amount of fuel used (though it varies by fuel type) so CO₂ emissions measurements face the same dilemma as fuel efficiency and will be handled in the same manner—GHG emissions will be discussed primarily on a per vehicle mile basis, with comparison to a per passenger mile basis and vehicle capacity used basis where such a comparison helps to place those values in context.

GHG EMISSIONS CALCULATIONS

GHG calculations are performed using a standard method of Activity x Emissions Factor = GHG Emissions. For example, 1 gallon of diesel fuel use is multiplied by its emissions factor of 10.18 kg CO₂ per gallon to get 10.18 kg CO₂. The combustion of fuel results in emission of three of the six GHGs discussed in this study—CO₂, methane (CH₄) and nitrous oxide (N₂O)—so, emissions of each gas were calculated separately.

The impact of a GHG relative to CO₂ is known as its global warming potential (GWP). When summing up a set of different GHGs each is first multiplied by its GWP to normalize it by its climate change impact, and the sum of the weighted gases is then labeled carbon dioxide equivalent (CO₂e). The GWPs used in this study are shown in Table 4 and come from the Intergovernmental Panel on Climate Change’s Second Assessment Report. Over time these values have been refined with additional research, so later IPCC publications offer slightly different (and more accurate) GWP values. But, international reporting procedures still require national governments to use the Second Assessment Report values, so those values are used here to harmonize this analysis with data from U.S. EPA and others.

Table 4. Global Warming Potentials

| GHG | GWP (100 Year Time Horizon) |
|--|--------------------------------|
| Carbon Dioxide (CO ₂) | 1 |
| Methane (CH ₄) | 21 |
| Nitrous Oxide (N ₂ O) | 310 |
| Sulfur Hexafluoride (SF ₆) | 23,900 |
| Hydrofluorocarbons (HFCs) | Varies: 140 to 11,700 |
| Perfluorocarbons (PFCs) | Varies: 6,500 to 9,200 |

Source: J.T. Houghton, et. al, Eds. *Climate Change 1995: the Science of Climate Change: Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change..* 1996. Table 4.

GHG EMISSIONS OF TRANSPORTATION ENERGY SOURCES

CO₂ emissions in transportation are directly proportional to fossil fuel use—the combustion process that drives most vehicles today combines carbon in the fuel with oxygen from the air to form CO₂ that is released into the atmosphere, a reaction that releases energy to propel the vehicle. Default GHG emissions factors for transportation fuels in the literature are not perfectly consistent, in part because the chemical composition of fossil fuels can vary. This study has relied primarily on the GHG emissions factors from U.S. EPA, which has worked with the U.S. Department of Energy to develop default GHG emissions factors for national reports and recent regulatory reporting requirements. The energy density and CO₂ emissions factors used in this study for current transportation fuels are shown in Table 5.

Table 5. CO₂ Emissions and Energy Densities of Transportation Fuels

| Fuel | Anthropogenic CO ₂ per Million BTU (kg) | Biogenic CO ₂ per Million BTU (kg) | High Heating Value (Million BTU per Gallon) | Anthropogenic CO ₂ per Gallon (kg) |
|---|--|---|--|--|
| Distillate Fuel Oil No. 1 | 73.25 | 0 | 0.139 | 10.18 |
| Distillate Fuel Oil No. 2 | 73.96 | 0 | 0.138 | 10.21 |
| Biodiesel (100%) | 0 | 73.84 | 0.128 | 0 |
| Liquefied Petroleum Gas (LPG) | 62.98 | 0 | 0.092 | 5.79 |
| Motor Gasoline | 70.22 | 0 | 0.125 | 8.78 |
| Ethanol (100%) | 0 | 68.44 | 0.084 | 0 |
| Fuel | Anthropogenic CO ₂ per Million BTU (kg) | Biogenic CO ₂ per Million BTU (kg) | High Heating Value (Million BTU per Standard Cubic Foot) | Anthropogenic CO ₂ per Standard Cubic Foot (kg) |
| Natural Gas | 53.02 | 0 | 0.001028 | 0.05 |
| Biogas (Captured Methane) | 0 | 52.07 | 0.000841 | 0 |
| Gaseous Hydrogen from Natural Gas (2010) | 79 | | 0.000317 | 0.03 |
| Gaseous Hydrogen from Electrolysis (2010) | 270 | | 0.000317 | 0.09 |
| Fuel | Anthropogenic CO ₂ per Million BTU Input (kg) | Biogenic CO ₂ per Million BTU (kg) | High Heating Value (Million BTU Input per kWh) | Anthropogenic CO ₂ per kWh (kg) |
| U.S. Grid Average Electricity (2005) | 82.69 | Not Available | 0.00729 | 0.60 |

Sources: U.S. Environmental Protection Agency. "Mandatory Reporting of Greenhouse Gases." *Code of Federal Regulations*. Title 40, Part 98. Table C-1. October 30, 2009. **Hydrogen CO₂**: National Research Council, National Academy of Engineering, Committee on Alternatives and Strategies for Future Hydrogen Production and Use. *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs*. 2004. p. 201 (averaged value). **Hydrogen properties**: Oak Ridge National Laboratory. *Transportation Energy Data Book, Edition 28*. 2009. Tables B.1 and B.2. **Electricity**: U.S. Environmental Protection Agency. *eGRID 2007 Version 1.1*. 2008.

DIRECT AND INDIRECT EMISSIONS

When accounting for the GHG emissions from energy most current GHG reporting protocols track the direct emissions from combustion separately from any indirect emissions. Direct emissions for a transit agency (known as Scope 1 emissions) include CO₂e from burning natural gas for heat and the tailpipe CO₂e of a diesel transit bus. Indirect emissions over the lifecycle of a fuel, such as those caused by petroleum

extraction, refining, and transport (Scope 3 emissions), are analyzed separately, and reporting of such lifecycle impacts is optional under most reporting schemes, as the data continue to be quite scarce. Accordingly, lifecycle emissions are discussed separately in this report and are not part of the emissions factors in Table 5. However, it should be noted that the upstream lifecycle emissions of biofuels—the emissions associated with processes including growing the feedstock and producing the fuel—can be quite significant. The impacts of converting ecosystems that previously sequestered carbon to agricultural land can have an even greater impact on global carbon emissions. As a result, while most biofuels create GHG savings a few types actually result in a net increase of global GHGs over the lifecycle as compared to petroleum fuels.⁴⁸ Therefore, many organizations choose to consider lifecycle impacts when making fuel procurement decisions. For more information on the lifecycle emissions of biofuels see the Appendix.

GHG accounting norms treat the indirect emissions associated with electricity use—the emissions at the power plant—as a special case (Scope 2 emissions), and such emissions are required under many organizational GHG inventory reporting requirements. Therefore, in this analysis the indirect GHG emissions associated with electricity generation are analyzed alongside other transit fuel emissions.

Hydrogen presents a unique issue for this analysis, because it may be generated on-site or purchased from a supplier. If generated on-site the GHG emissions from the process (whether electricity, natural gas, or some other method) would be a significant part of a transit agency's emission's profile. Therefore, this analysis has included the GHG emissions from hydrogen production when comparing hydrogen to other transit fuels.

ANTHROPOGENIC AND BIOGENIC EMISSIONS

Another important distinction in GHG emissions analysis is the difference between biogenic sources of emissions (those occurring naturally) and anthropogenic emissions (those occurring because of human activity). When biofuels, such as biodiesel from soybeans, are combusted the resulting CO₂ emissions are considered biogenic.

To-date, biogenic CO₂ emissions have been treated separately from other GHGs under most reporting schemes, because the carbon released when combusting biofuels originated in the contemporary carbon cycle, and any changes in the stocks of biological carbon are tracked through agriculture, land use, and forestry GHG emissions accounting.

The reason for the differentiation between anthropogenic and biogenic emissions is that the combustion of fossil fuels releases carbon that has been stored in the earth for thousands of years, increasing the concentration of GHGs in the atmosphere, while the

combustion of plants releases carbon that was in the atmosphere in recent history and will be removed again if that plant is replaced with another. However, recent concerns about non-sustainably developed biofuels have some pushing for the CO₂ emissions of biofuels to be treated the same as CO₂ from fossil fuels, so the relative advantage of these fuels from a GHG perspective may change. This issue is discussed further in the section on biofuel and lifecycle emissions strategies in the Appendix. For the purposes of this analysis biogenic CO₂ is not included in GHG values unless specifically stated.

CH₄ AND N₂O EMISSIONS

The other two GHGs that result from the use of transportation fuels are CH₄ and N₂O. Unlike CO₂, emissions of these gases are not directly proportional to fuel use in the transportation sector. Emissions of these gases are affected by the emissions control technology on the vehicle and vehicle performance characteristics, so CH₄ and N₂O from transportation are usually calculated on a per vehicle mile basis, as shown in Table 6. The CH₄ and N₂O emissions from biofuels are considered anthropogenic under most GHG accounting schemes, as they would not have occurred but for the use of the plant or algae as transportation fuel.

Table 6. CH₄ and N₂O Emissions from Transit Vehicles

| | CH ₄ g per mile | N ₂ O g per mile |
|---|----------------------------|-----------------------------|
| Heavy Duty Diesel Bus | 0.0051 | 0.0048 |
| Methanol Bus | 0.066 | 0.175 |
| CNG Bus | 1.966 | 0.175 |
| Ethanol Bus | 0.197 | 0.175 |
| Biodiesel (BD20) | 0.005 | 0.005 |
| | CH ₄ g per kWh | N ₂ O g per kWh |
| U.S. Grid Average Electricity (2005) | 0.009 | 0.012 |

Source: U.S. Environmental Protection Agency. *Inventory Of U.S. Greenhouse Gas Emissions And Sinks: 1990 - 2008*. EPA 430-R-10-006. April 15, 2010. Tables A-99 and A-100. **Electricity**: U.S. Environmental Protection Agency. *eGRID 2007 Version 1.1*. 2008.

REGIONAL ELECTRICITY EMISSIONS

The characteristics of transportation fuels vary slightly by place and can change year-to-year or season-to-season. Some of these differences are policy driven, such as when fuels are required to be reformulated to reduce local air pollution. Other differences may be due to the natural variation in fuels sourced from different places on the earth. For the most part these variances are not large enough to impact the results of this research.

Electricity, however, can have an extremely wide range of emissions profiles depending on its generation sources. In 2005, the most recent year for which data are available, electricity used by those in California produced just 328 kilograms of CO₂ per Megawatt hour, while electricity provided to consumers in Kansas had an emissions rate over two times higher at 889 kilograms of CO₂ per Megawatt hour.⁴⁹ This regional electricity emissions variability can have a great impact on the emissions profile of transit agencies, especially those that choose to use electricity from the grid as a vehicle fuel. Additional complexity arises when one considers whether actions to reduce electricity use should assume an “average” rate of GHG savings per kWh or if the emissions rate of the non-baseload power sources (those most likely to be turned off if electricity demand goes down) should be used.

For the purposes of this research we have used an average electricity emissions rate for all of the U.S., which was 603 kilograms of CO₂ per Megawatt hour in 2005 (the most recent year for which data are available). Transit agencies that want to determine the average and non-baseload emissions associated with electricity in their area should refer to the U.S. Environmental Protection Agency’s (EPA) eGRID database, which provides emissions factors for electricity around the country. The electricity transmission and distribution grid is not neatly divided by state lines, so EPA uses a geography of “eGRID subregions” which provide a fair representation of the set of power plants ones electricity is likely come from.

HEAT CONTENT

The amount of heat energy in a given unit of fuel is known as its heat content. Heat content is typically measured in two ways: 1) The High Heating Value (HHV, also known as the Gross Calorific Value) measures all of the energy contained in a fuel; 2) The Low Heating Value (LHV, also known as the Net Calorific Value) subtracts out any energy used to transform water in the fuel to steam and reports only the net useful energy. Whichever value is used, it is important to use the same method across all fuels when making comparisons.

The U.S. EPA’s GHG reporting regulation and *Inventory of U.S. Greenhouse Gases and Sinks*, as well as U.S. Department of Energy, Energy Information Administration statistics all use HHV, so that is what is used in this study.^{50,51} However, one should note that many transportation alternative fuel data sources use the LHV, because the energy used to create steam is not put to useful work in today’s transportation technologies. So, one should check the heat content assumptions when comparing documents and data sources. The difference between the HHV and LHV will vary between and within fuels, but a rule of thumb is a 10% difference for natural gas and a 5% difference for petroleum products.⁵²

BASE CASE

In order to estimate the potential energy and GHG savings of transit strategies in 2030 and 2050 a point of comparison must be chosen. For this analysis “base cases” were developed using present day technology and use patterns. So, when a technology is found to create a 20% reduction in GHG emissions in 2030 that is a 20% reduction as compared to today’s vehicles. Separate base cases were created for buses, electric commuter rail, diesel commuter rail, heavy rail, light rail, and light duty vehicles. Base cases were chosen for the primary vehicle types and modes addressed by the set of GHG and energy use reduction strategies analyzed. A summary of the base cases is provided in Table 7 and the base case for each mode is discussed in greater detail below.

Each GHG and energy reduction strategy analyzed in this report is compared to the current-day base case that is relevant to that action. For example, hybrid electric buses in 2030 and 2050 are compared to a current-day 40-foot diesel bus; light rail vehicles with weight reduction in 2030 and 2050 are compared to today’s average light rail vehicles. The base case(s) for each strategy are identified in the detailed write-up on that strategy in the Appendix of this report.

Table 7. Transit Vehicle Base Case Energy and GHG Emissions Profiles

| Vehicle | Fuel (Units) | Annual Vehicle Miles Traveled | Vehicle Miles per Fuel Unit | Fuel use per vehicle mile (Fuel Units) | Energy Use per Seat Mile (BTUs) | CO ₂ e per Seat Mile | Average Occupancy Rate | CO ₂ e per passenger mile (kg) |
|------------------------|--------------------|-------------------------------|-----------------------------|--|---------------------------------|---------------------------------|------------------------|---|
| Diesel Bus | Diesel (Gallons) | 34,700 | 3.59 | 0.28 | 1,028 | 0.08 | 28% | 0.27 |
| Diesel Commuter Rail | Diesel (Gallons) | 62,480 | 1.71 | 0.59 | 709 | 0.05 | 30% | 0.17 |
| Electric Commuter Rail | Electricity (kWh) | 62,480 | 0.10 | 8.04 | 510 | 0.04 | 30% | 0.14 |
| Heavy Rail | Electricity (kWh) | 59,591 | 0.17 | 5.78 | 789 | 0.07 | 47% | 0.14 |
| Light Rail | Electricity (kWh) | 45,845 | 0.12 | 8.12 | 950 | 0.08 | 37% | 0.21 |
| Light Duty Vehicle | Gasoline (Gallons) | 11,432 | 20.50 | 0.05 | 1,220 | 0.09 | 32% | 0.27 |

Note: Light duty vehicle assumed at 5 seats

Sources: Transit vehicles from U.S. Department of Transportation, Federal Transit Administration. National Transit Database, RY 2008 Database. 2009. Light Duty Vehicle from FHWA. *Highway Statistics 2008*. Table VM-1. 2009

It can be difficult to determine the efficiency of transit vehicles by technology, because fuel use is reported to the National Transit Database (NTD) on a fleet-wide basis. A transit agency may have 100 CNG buses and 300 diesel buses, but only report one total passenger mileage value for the whole system, making it impossible to differentiate emissions per passenger mile rates between the two vehicle types. Therefore, an analysis of the NTD was performed and only fleets that used a single fuel were considered in developing the performance averages for the base case. This study uses 2008 vehicles and operations as the 2010 base case, because 2008 is the year for which the most recent data is available through the National Transit Database at the time of this analysis

Transit Bus

In 2008 the typical transit bus on the road was 7.5 years old, measured 40 feet long, sat an average of 38 passengers, and allowed another 22 passengers to stand. The most common transit bus ran on diesel fuel, had a fuel efficiency of 3.6 miles per gallon, and traveled 34,700 miles annually.⁵³ A diesel bus traveling 34,700 miles at 3.6 miles per gallon would use 9,672 gallons of fuel and emit 98 metric tons of CO₂e.

On average, transit buses had 10.5 passengers per vehicle, or a 28% occupancy rate.⁵⁴ So, while energy use was just 0.007 gallons per seat mile (1,028 BTUs), it was 0.026 gallons per passenger mile (3,673 BTUs). GHG emissions from diesel fuel combustion were 0.075 kg per seat mile and 0.27 kg CO₂e per passenger mile.

The diesel fuel in this report is assumed to have the characteristics of Number 1 Distillate, which according to the U.S. Department of Energy, Energy Information Administration can be used as either a diesel fuel or fuel oil and, “[I]s used in high-speed diesel engines generally operated under *frequent speed and load changes*, such as those in *city buses* and similar vehicles.”⁵⁵

The Federal Highway Administration reports that the average bus on the road in 2008 achieved a fuel economy of 6.4 mpg – a much higher fuel efficiency value than the base case used here.⁵⁶ However, this statistic includes all buses, including intercity buses, rather than just transit buses – FHWA reports 843,308 registered buses in this category in 2008,⁵⁷ while APTA reports 66,506 transit buses in 2008.⁵⁸ The start and stop driving pattern of transit buses contribute to their lower fuel economy relative to motor coaches and other buses. However, all energy savings figures presented in this report are given as percent improvements over the base case, so a transit agency can apply findings to their fleet if their average bus fuel economy is higher or lower than 3.6 mpg.

Commuter Rail

Commuter rail is a fixed guideway train that typically runs between a city and suburbs. Commuter rail in the U.S. generally uses either diesel fuel or electricity. For this analysis electricity and diesel commuter rail are profiled separately, as the emissions profiles of the two energy sources are quite different. As commuter rail trains can have a variable number of passenger cars, the energy and GHG base case is on a per passenger car basis. The average diesel commuter rail train had 4.8 passenger cars and the average electric commuter rail train had 3.9 passenger cars in 2008. Commuter rail vehicles were 18 years old on average in 2008 and had 115 seats with standing room for 69 additional passengers.

Diesel Commuter Rail

At 0.59 gallons of diesel per mile and 62,480 annual miles traveled⁵⁹ a typical electric commuter rail passenger car could use 36,636 gallons of diesel in a year, which would emit 376 metric tons of CO_{2e}.

Diesel commuter rail consumed 0.005 gallons per seat mile, which is equal to 709 BTUs, for an emissions rate of 0.052 kg CO_{2e} per seat mile. The average occupancy rate for commuter rail in 2008 was 30%, or 34.5 passengers per car.⁶⁰ Accordingly, per passenger mile energy use was 0.017 gallons (2,362 BTUs), resulting in emissions of 0.17 kg per passenger mile.

Electric Commuter Rail

At 8 kWh per mile and 62,480 annual miles traveled⁶¹ a typical electric commuter rail passenger car could use 502,211 kWh in a year, which would emit 302 metric tons of CO_{2e} at the U.S. average GHG emissions rate for electricity.

Commuter rail consumed 0.07 kWh per seat mile, which is equal to 510 BTUs of power generation input heat, for an emissions rate of 0.042 kg CO_{2e} per seat mile. The average occupancy rate for commuter rail in 2008 was 30%, or 34.5 passengers per car.⁶² Accordingly, per passenger mile energy use was 0.233 kWh (1,699 BTUs), resulting in emissions of 0.14 kg per passenger mile.

Heavy Rail

Heavy rail is a fixed guideway transit technology that uses rights of way that are separated from other vehicles. Heavy rail can operate with a variable number of passenger cars on a given train, so the base case uses the energy and emissions profile of heavy rail per passenger car.⁶³ The average heavy rail train had 7.1 passenger cars in 2008.

The average heavy rail vehicle in the U.S. in 2008 was 21 years old and ran on electricity. Heavy rail passenger cars have an average seating capacity for 53 and

standing capacity for 101. Heavy rail used 5.8 kWh of electricity per passenger car mile. Passenger cars traveled an average of 59,591 miles in 2008.⁶⁴ A vehicle traveling 59,591 miles at 5.8 kWh per mile uses 344,695 kWh of electricity. At U.S. average electricity GHG emissions rates that electricity usage results in 208 metric tons CO₂e.

Energy use per seat mile on heavy rail was 0.11 kWh, or 789 BTUs, and emitted 0.066 kg CO₂e. Heavy rail had a 47% occupancy rate, or 25 passengers per car, on average in 2008.⁶⁵ Energy use per passenger mile was 0.23 kWh, or 1,679 BTUs, and emitted 0.14 kg CO₂e.

Light Rail

Light rail is a fixed guideway transit type that may share a right of way and typically uses fewer passenger cars than heavy rail. The average light rail vehicle in 2008 was 17 years old and ran on electricity. Light rail can operate with one or more passenger car per train, so the light rail GHG and energy use base case is presented on a per passenger car basis. The average light rail train had 1.8 passenger cars in 2008. Passenger cars had an average seating capacity of 62 and standing capacity of 109. Light rail used 8.12 kWh per passenger car mile. Each passenger car traveled an average of 45,845 miles in 2008.⁶⁶ A light rail car traveling 45,845 miles at 8.1 kWh per mile uses 372,063 kWh of electricity in a year, which emits 224 metric tons CO₂e at U.S. average electricity emission rates.

Energy use per seat mile on light rail was 0.13 kWh, which is equal to 950 BTUs of power generation input heat and emitted 0.079 kg CO₂e. Light rail had a 37% occupancy rate, or 23 passengers per car, on average in 2008.⁶⁷ Energy use per passenger mile was 0.352 kWh, or 2,567 BTUs, and emitted 0.21 kg CO₂e.

Non-Revenue Vehicle Base Cases

Strategies that do not affect revenue vehicle emissions are compared to base cases appropriate for each strategy. For example, reduction in the use of high GWP gases compares the use of CO₂ as a replacement refrigeration chemical in air conditioners to today's use of HFCs. High efficiency non-revenue vehicles are compared to today's average light duty vehicles. The energy use of facilities with energy retrofits is compared to the average energy use for buildings today. The base case for each strategy is explained in the Appendix.

V. TRANSIT AGENCY GHG REDUCTIONS AND ENERGY SAVINGS IN 2030 AND 2050

As the vast majority of transit agency energy is used in vehicles, most of the strategies with large potential climate and energy savings involve vehicle technologies and alternate fuels. Operation and maintenance improvements will also play important roles in ensuring vehicles of any technology type are put to effective use and can meet their energy efficiency potential. All of the other sources of emissions in a transit agency's GHG inventory are much smaller than revenue vehicles, but actions to improve the efficiency of facilities and non-revenue vehicles, decrease the carbon intensity of employee travel, and consider the lifecycle impacts of construction and other activities are all part of a comprehensive portfolio of climate change mitigation activities for transit agencies.

As is described in detail in the scenarios below, a rail transit agency that takes aggressive climate action could reduce the GHG footprint of its fleet against today's levels 55% to 78% by 2030 and 81% to 94% in 2050 with a fleet of light-weight, efficient vehicles running on renewable energy. Bus transit agencies can also achieve significant savings with several different low-carbon fuel options – clean electricity, biofuels, and hydrogen produced using carbon capture and storage. Even using conventional fuels, improvements in vehicle technology and operations can create large energy and GHG savings for transit, as is shown in the hypothetical transit agency profiles in below.

The exact impact of efficiency improvements will vary across agencies and future technology projections are uncertain. Therefore, most of the energy and GHG savings presented in this analysis are presented as ranges. However, two hypothetical transit agency scenarios have been created combining the mid-points of strategy outcomes to demonstrate the scale of impact an agency-wide climate and energy efficiency action strategy can have.

HYPOTHETICAL TRANSIT AGENCY PROFILES IN 2030 AND 2050

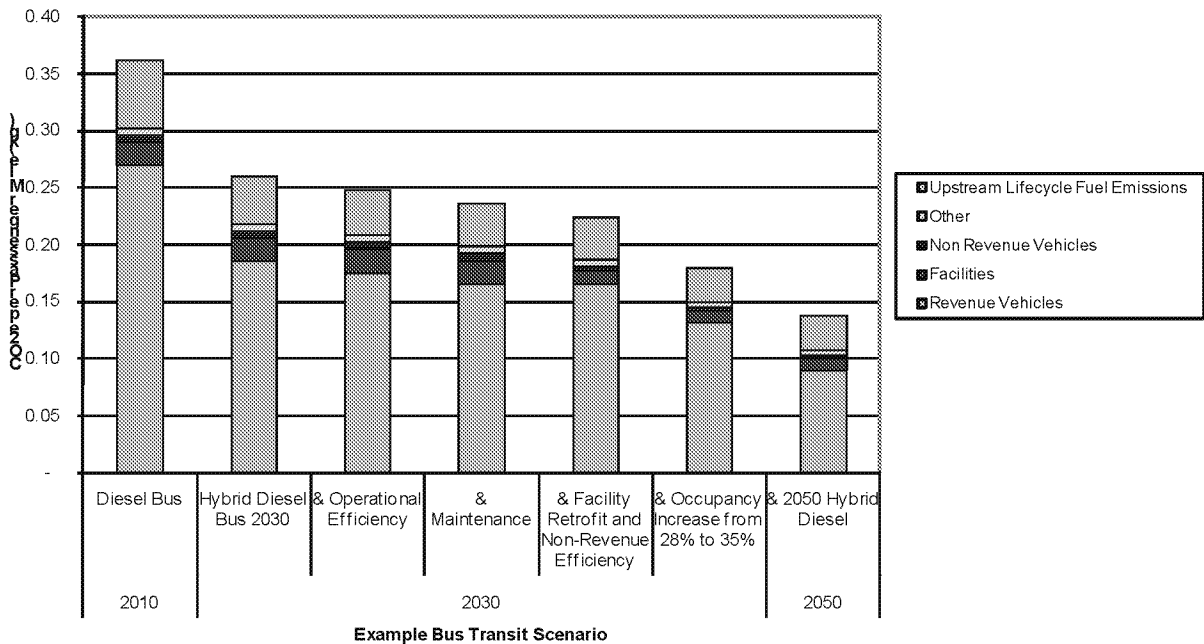
Figure 8 shows the potential GHG emissions per passenger mile in 2030 and 2050 of an example bus transit agency that adopts hybrid diesel technology while also gaining efficiency through operational and maintenance improvements. In this scenario, the fuel efficiency of the buses increases from 3.6 mpg in 2010 to an average 6.5 mpg in 2030 and 11.3 mpg in 2050.

This efficient diesel hybrid scenario assumes the transit agency makes improvements in facility and non-revenue vehicle energy efficiency, as well, to bring the total emissions inventory of the transit agency down from a hypothetical 0.37 kg CO₂e per passenger mile in 2010 to 0.23 kg CO₂e per passenger mile in 2030. These values include estimates of the upstream lifecycle GHG emissions associated with transit energy use. Other

lifecycle and indirect emissions sources that could be addressed by transit agency climate action, including employee commute and waste, are not included here, but are discussed further in the Appendix.

As the efficient diesel hybrid bus transit agency in this example makes efforts to increase vehicle occupancy from an average 28% to 35% it further drives down its emissions metrics to 0.18 kg CO_{2e} per passenger mile in 2030. Additional efficiency improvements in hybrid fleet technology by 2050 reduce overall emissions even further in this scenario resulting in 0.14 kg CO_{2e} per passenger mile by 2050, a 62% reduction from 2010 levels.

Figure 8. Hypothetical Efficient Bus Transit Agency GHG Emissions in 2030 and 2050

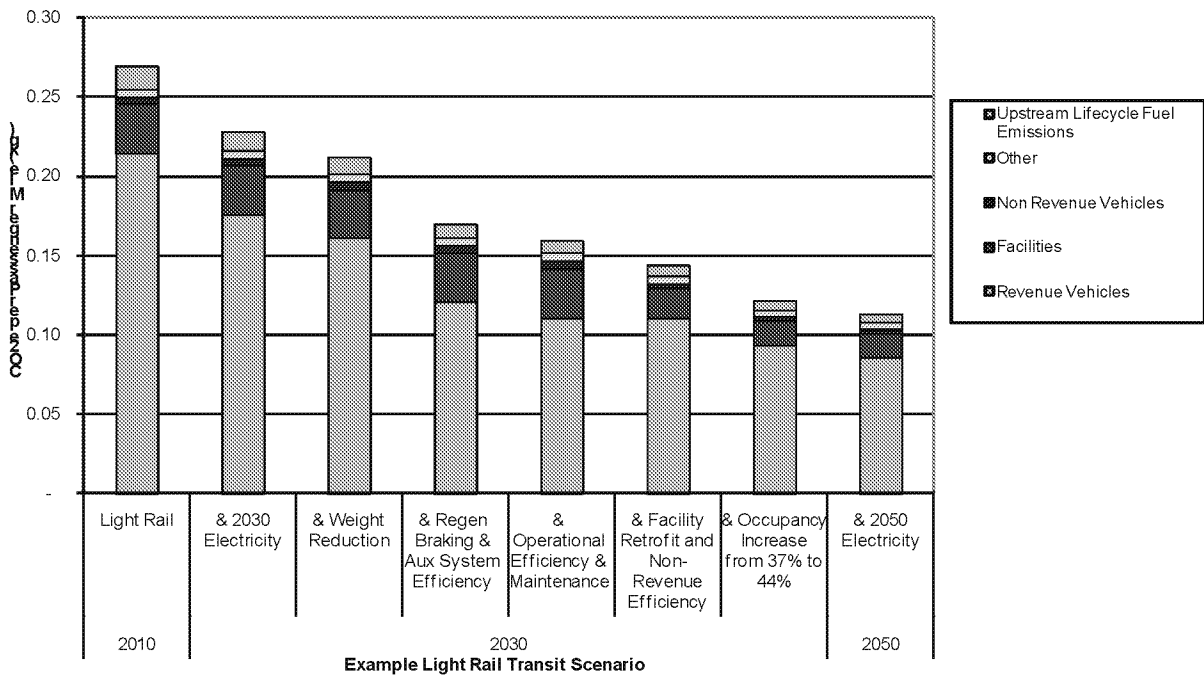


Transit agencies operating rail systems will benefit from a different set of technology and fuel improvements. Therefore a second hypothetical transit agency scenario has been created for a light rail transit system as is shown in Figure 9. In this light rail system grid electricity is used to power a light rail fleet that has become more efficient through weight reduction, regenerative braking, and improvements in auxiliary systems. Operational improvements and maintenance further enhance energy savings in this scenario and the result is a fleet of light rail vehicles that use just 4.9 kWh per vehicle mile in 2030 instead of today’s 8.1 kWh per vehicle mile.

Even using conservative projections for electricity GHG reductions from the *Annual Energy Outlook*, the emissions profile of the high efficiency light rail system in this example benefits from the gradual decarbonization of the U.S. electric supply by 2030

and 2050. The resulting emissions per passenger mile for the vehicles are 0.13 kg CO_{2e} in 2030 and 0.09 kg CO_{2e} in 2050. When the full hypothetical GHG inventory of the transit agency in this scenario is taken into account it has an emissions metric of 0.11 kg CO_{2e} per passenger mile in 2050. This value includes energy efficiency retrofits at transit agency facilities and fuel economy gains among non-revenue vehicles. This is a 58% reduction from 2010 emissions rates for this example transit agency. Substituting other electric rail modes in this example produces similar rates of emissions reductions, so while the emissions values will be different for commuter rail and heavy rail, the trend would look the same as the hypothetical light rail system in Figure 9, thus duplicate charts for those modes are not reproduced here.

Figure 9. Hypothetical Efficient Light Rail Transit Agency GHG Emissions in 2030 and 2050.



GHG SAVINGS BY STRATEGY

Figure 10 and Figure 11 show the potential GHG savings of each strategy analyzed in this report against its respective base case using the data and methods described in the Appendix. As discussed in the methods section of this report, the base cases are not equivalent for all strategies—for example, facility improvements are compared to a base case of building energy use, while fuel cell buses are compared to today’s diesel buses—but these charts are intended to give a sense of the scale of savings each strategy can achieve in the relevant part of a transit agency’s GHG footprint. The savings percentages shown should only be compared in terms of the relative effectiveness of a strategy in reducing GHG emissions in its own area. There is large potential to

significantly reduce the emissions of high GWP gases like air conditioner refrigerant by 2050, but these represent a very small share of transit agencies' overall emissions, and reducing emissions in this area will not address vehicle fuel emissions.

Some strategies show a wide range of potential savings. For some this represents true uncertainty about the potential effectiveness of a strategy in achieving emissions reductions. For other areas a wide range of savings arises because these general strategies encompass many different implementation and technology details. For example, the adoption of biofuels will have very different GHG implications if transit agencies use 20% biodiesel (as is common today) or adopt technologies that enable the use of 100% biodiesel. The range of biodiesel savings represents both of those options.

Transit agencies that operate electric buses will have different emissions depending on the carbon-intensity of the electrical grid in their region. The emissions for electric buses presented here are national average as a region-by-region analysis of electricity emissions is outside of the scope of this study. The Renewable Power strategy shows the emissions reduction potential of cleaner electricity generation than the grid average.

Figure 10. GHG Reductions of Transit Strategies 2030

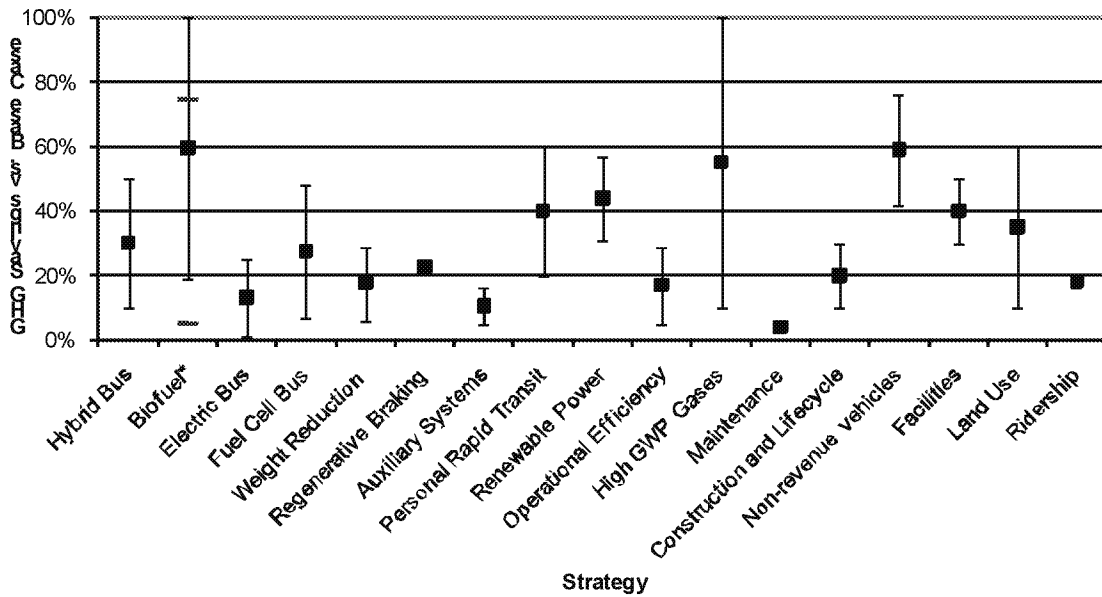
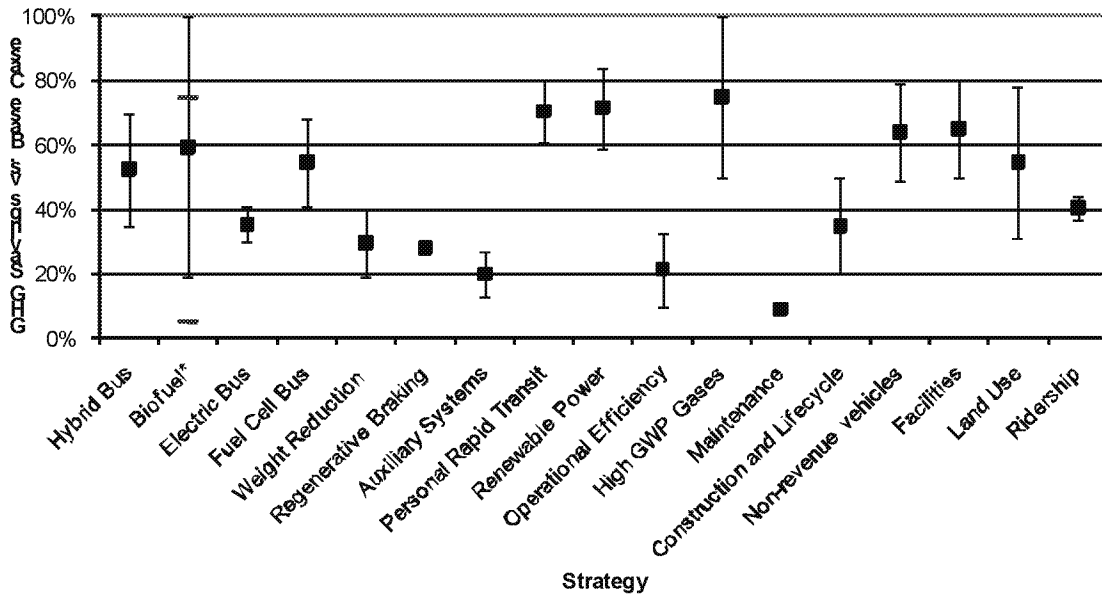


Figure 11. GHG Reductions of Transit Strategies 2050



*Note, in this study lifecycle emissions are analyzed separately from direct emissions and are discussed in the Construction and Lifecycle strategy. However, Biofuels have significant upstream lifecycle emissions which are often considered when making procurement decisions, so the range of lifecycle impacts of biodiesel are shown as red lines in Figure 10 and Figure 11 for comparison purposes. For more information see the Appendix.

GHG AND ENERGY SAVINGS SCENARIOS

In addition to analyzing specific energy use and GHG savings strategies individual, this report looks at scenarios where multiple strategies are undertaken together. The individual savings potentials of multiple strategies cannot simply be summed together to determine the impact of a combined portfolio of savings actions. When combining multiple strategies to determine their joint impact the following calculation was used:

$$\% \text{ Savings of Scenario} = (1 - [(1 - \% \text{ Savings of Strategy 1}) \times (1 - \% \text{ Savings of Strategy 2}) \dots])$$

For example, at the high end, hybrid buses are projected to achieve 50% fuel savings in 2030. This savings is combined with operational efficiency improvements (12%) and savings from maintenance (5%) using the formula above, resulting in an overall 58% fuel savings for this high efficiency hybrid bus scenario.

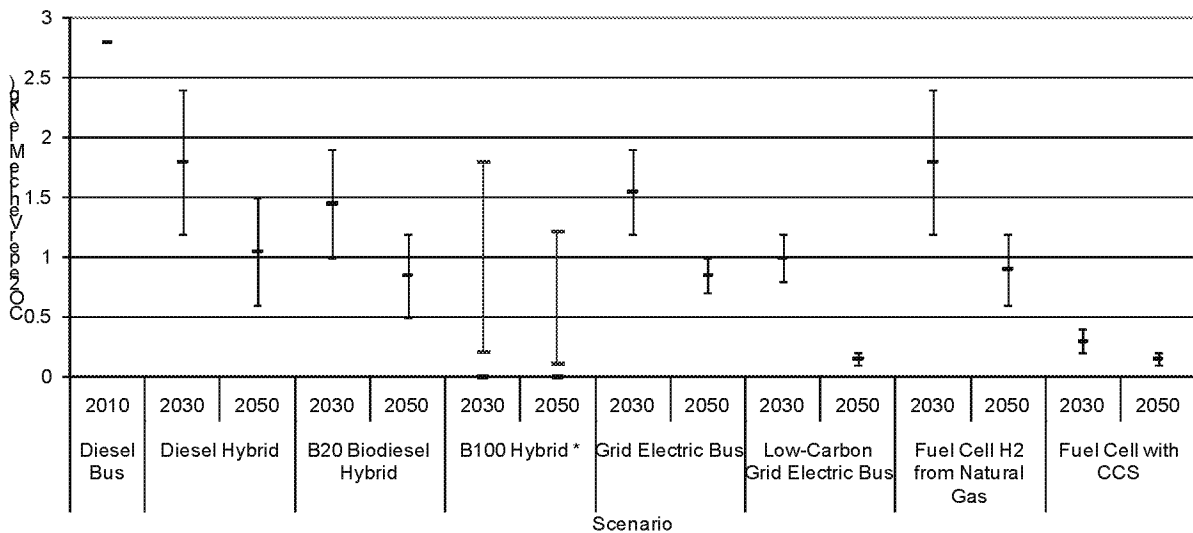
BUS SCENARIOS

Four main bus technologies were examined for this analysis: 1) Hybrid, 2) Biofuel, 3) Electric, and 4) Fuel Cell. In addition, light weight designs, operational efficiencies, and maintenance improvements are all modeled to create a set of future transit bus emissions and energy use scenarios. Figure 12 charts the potential GHG emissions per

vehicle mile for the bus scenarios in 2030 and 2050. Each scenario is discussed further below. All of the technology scenarios analyzed for buses achieve GHG emissions reductions against today’s diesel buses. GHG emissions per vehicle mile decrease by a minimum of 14% by 2030 and 46% by 2050 under the strategies profiled; emissions savings could be as high as 99%.

The lowest carbon bus option in these scenarios is B100 when considering only direct anthropogenic emissions (0.002 kg CO₂e direct emissions). The upstream lifecycle emissions of biodiesel can be significant, however, and these lifecycle emissions are shown in red in Figure 12 for comparison purposes. The two scenarios that include carbon capture and storage—low-carbon electricity and fuel cells with carbon capture and storage—are the next lowest emissions of the bus scenarios. Carbon capture and storage remains a costly and speculative technology at the time of this writing, so the scenarios that include carbon capture and storage should be considered less feasible than others that rely on proven technologies. Among technologies that are commercially available today, both hybrid diesel buses and electric buses achieve significant GHG savings in 2030 and 2050 when buses will have most likely gotten lighter and more efficient than today’s models.

Figure 12. GHG Emissions per Vehicle Mile by Bus Scenario in 2030 and 2050



* Note that B100 biodiesel has a direct anthropogenic emissions rate of 0.002 kg CO₂e per vehicle mile. Indirect lifecycle emissions for hybrid buses using B100 biodiesel from soy (higher emissions) or waste grease (lower emissions) are also shown in red for comparison purposes, because upstream lifecycle emissions are often a consideration in biofuel procurement decisions. More information can be found in the biodiesel and lifecycle sections of the Appendix.

HIGH EFFICIENCY HYBRID AND BIODIESEL HYBRID BUSES

Hybrid bus technology is examined with three fuel types for 2030 and 2050 – diesel, B20 (20% biodiesel, 80% standard diesel), and B100 (100% biodiesel). Projected hybrid bus technology improvements are combined with the Operational Efficiency and Maintenance strategies to achieve overall fuel efficiency of 4.3 to 8.6 mpg in 2030 and 6.7 to 16 mpg in 2050 (the use of biodiesel in the hybrid buses in these scenarios is assumed to cause no fuel efficiency penalty). The regenerative braking technology in hybrid diesel buses, along with other innovations, gives them a significant efficiency advantage over today's standard diesels which achieve just 3.6 miles per gallon on average. Additional benefits from a separate weight reduction strategy were not included in this scenario, as it was assumed that future projections of hybrid technology in the literature include weight reduction.

Diesel hybrid technology when combined with fuel savings from operation and maintenance improvement can achieve an emissions rate of 0.11 to 0.22 kg CO₂e per passenger mile by 2030 and 0.06 to 0.14 kg CO₂e per passenger mile by 2050. The use of biofuel reduces this by nearly 20% with B20 and 99% with B100. As is shown in Table 8, increasing passenger occupancy rates on the buses can bring these metrics down significantly.

Biodiesel has zero anthropogenic tailpipe CO₂ emissions, so use of B100 in this scenario creates a very small emissions metric of 0.002 kg CO₂e per vehicle mile when CH₄ and N₂O emissions are estimated. The lifecycle (upstream) emissions of B100 are presented here as a point of comparison. According to the U.S. EPA, soy-based biodiesel can have substantial GHG impacts on a global scale as land use is converted to agriculture to produce the fuel feedstock. Therefore, biodiesel is estimated to create a 22% lifecycle emissions benefit as compared to standard diesel when manufactured from soybeans. When created from waste grease it can result in an 80% emissions reduction.⁶⁸ More discussion of these issues can be found in the Appendix.

Table 8. High Efficiency Hybrid and Biodiesel Hybrid Buses 2030 and 2050

| Performance Metric | 2010 Diesel Bus | Diesel Hybrid | | B20 Biodiesel Hybrid | | B100 Hybrid Lifecycle Emissions | |
|--|-----------------|---------------|--------------|----------------------|--------------|---------------------------------|--------------|
| | | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| CO _{2e} per Vehicle Mile (kg) | 2.8 | 1.2 to 2.4 | 0.6 to 1.5 | 1.0 to 1.9 | 0.5 to 1.2 | 0.2 to 1.8 | 0.1 to 1.2 |
| CO _{2e} per Passenger Mile at 28% Occupancy(kg) | 0.27 | 0.11 to 0.22 | 0.06 to 0.14 | 0.09 to 0.18 | 0.05 to 0.12 | 0.02 to 0.17 | 0.01 to 0.11 |
| CO _{2e} per Passenger Mile at 35% Occupancy in 2030 and 50% Occupancy in 2050 | Not applicable | 0.09 to 0.18 | 0.03 to 0.08 | 0.07 to 0.14 | 0.03 to 0.06 | 0.02 to 0.14 | 0.01 to 0.02 |
| Vehicle Miles per Gallon | 3.6 | 4.3 to 8.6 | 6.7 to 16 | 4.3 to 8.6 | 6.7 to 16 | 4.3 to 8.6 | 6.7 to 16 |

Strategies included: Hybrid Bus, Biofuel, Operational Efficiency, and Maintenance. Note B100 tailpipe emissions are 0.002 kg CO_{2e} per vehicle mile. Indirect lifecycle emissions including emissions from global land use change due to biofuel production shown in red.

HIGH EFFICIENCY ELECTRIC BUSES

A scenario of high efficiency electric buses is presented in Table 9. The strategies included in this scenario are Bus Electrification, Weight Reduction, Regenerative Braking, Operational Efficiency, and Maintenance. By combining these strategies a transit agency could have a bus fleet that emits just 0.11 to 0.18 kg CO_{2e} per passenger mile by 2030 and 0.07 to 0.09 kg CO_{2e} per passenger mile by 2050. The energy source in this scenario is grid-connected electricity assuming electricity emissions rates as forecasted by the U.S. Department of Energy, Energy Information Administration to 2030 and extrapolated out to 2050.⁶⁹ While electricity emissions decrease in this scenario (from 0.61 kg per kWh today to 0.49 kg per kWh in 2050) this forecast does not include any federal GHG reduction policies for electricity.

Table 9. High Efficiency Electric Buses 2030 and 2050

| Performance Metric | Diesel Bus | Grid Electricity | | Low-Carbon Grid Electricity | |
|--|----------------|------------------|--------------|-----------------------------|--------------|
| | 2010 | 2030 | 2050 | 2030 | 2050 |
| CO ₂ e per Vehicle Mile (kg) | 2.8 | 1.2 to 1.9 | 0.7 to 1.0 | 0.08 to 1.2 | 0.1 to 0.2 |
| CO ₂ e per Passenger Mile at 28% Occupancy (kg) | 0.27 | 0.11 to 0.18 | 0.07 to 0.09 | 0.07 to 0.11 | 0.01 to 0.02 |
| CO ₂ e per Passenger Mile at 35% Occupancy in 2030 and 50% Occupancy in 2050 (kg) | Not applicable | 0.09 to 0.14 | 0.04 to 0.05 | 0.06 to 0.09 | .007 to 0.01 |
| Vehicle Miles per Gallon Diesel Equivalents | 3.6 | 5.3 to 8.4 | 9.8 to 13.6 | 5.3 to 8.4 | 9.8 to 13.6 |
| CO ₂ e per kWh (kg) | Not applicable | 0.52 | 0.49 | 0.34 | 0.10 |
| Strategies Included: Electric Bus, Weight Reduction, Regenerative Braking, Operational Efficiency, Maintenance | | | | | |

An alternate scenario of “Low-Carbon Grid Electricity” is also presented. In this scenario the Electric Power Research Institute’s most aggressive forecast for an electricity grid that includes carbon capture and storage, renewable power, and other advanced technologies is used to present a high-GHG-savings case.⁷⁰ More information about the specifics of these assumptions can be found in the Appendix. If the U.S. electricity grid evolves to become a very low-carbon energy source, a transit agency that uses this low-carbon electricity could have a bus fleet that emits just 0.07 to 0.11 kg per passenger mile in 2030 and 0.01 to 0.02 kg per passenger mile in 2050.

Efforts to increase occupancy would not reduce the emissions profiles of the buses in this scenario, but it would improve the GHG per passenger mile metric. Therefore, an additional point of analysis is presented in Table 9 that shows the potential GHG per passenger mile if bus occupancy were to be increased to 35% by 2030 and 50% by 2050. Given that today’s average bus occupancy is 28% an increase to 50% would require aggressive action streamline operations, use Intelligent Transportation Systems, promote land use changes that enable more households to use transit and more, but as this analysis shows the result would be significantly greater system efficiency. If increased occupancy comes from increasing ridership through mode shift from personal vehicle travel, this strategy would have additional benefits to the community in terms of the lower vehicle emissions of riders and overall lower emissions as on-road congestion decreases.

HIGH EFFICIENCY FUEL CELL BUSES

Fuel cell buses using hydrogen as fuel are examined along with Weight Reduction, Operational Efficiency, and Maintenance in this high efficiency fuel cell scenario. Table 10 shows the potential GHG metrics for buses in this scenario – at today’s occupancy rates buses could achieve 0.11 to 0.23 kg CO₂e per passenger mile by 2030 and 0.05 to 0.11 kg CO₂e per passenger mile by 2050 using hydrogen produced from natural gas. If the CO₂ emissions that result from hydrogen production can be addressed through carbon capture and storage the GHG emissions profile of fuel cell buses could be significantly improved. As with the other scenarios, when occupancy improvements are taken into account the GHG per passenger mile metrics for buses can be reduced even further.

Table 10. High Efficiency Fuel Cell Buses 2030 and 2050

| Performance Metric | 2010 Diesel Bus | Hydrogen from Natural Gas | | Hydrogen with Carbon Capture and Storage | |
|---|-----------------|---------------------------|--------------|--|---------------|
| | | 2030 | 2050 | 2030 | 2050 |
| CO ₂ e per Vehicle Mile (kg) | 2.8 | 1.2 to 2.4 | 0.6 to 1.2 | 0.2 to 0.4 | 0.1 to 0.2 |
| CO ₂ e per Passenger Mile at 28% Occupancy(kg) | 0.27 | 0.11 to 0.23 | 0.05 to 0.11 | 0.02 to 0.04 | 0.01 to 0.02 |
| CO ₂ e per Passenger Mile at 35% Occupancy in 2030 and 50% Occupancy in 2050 | Not applicable | 0.05 to 0.20 | 0.02 to 0.05 | 0.01 to 0.03 | 0.003 to 0.01 |
| Strategies included: Fuel Cell Bus, Weight Reduction, Operational Efficiency, Maintenance | | | | | |

RAIL SCENARIOS

The most promising vehicle technology solutions to improve energy efficiency among rail transit are regenerative braking, reducing vehicle weight, and decreasing the energy use of auxiliary systems. These strategies, combined with operations efficiency and maintenance improvements, greatly decrease the energy use and GHG emissions of rail vehicles in 2030 and 2050.

Figure 13 charts the GHG emissions per passenger car miles of four types of high efficiency rail – electric commuter rail, diesel commuter rail, heavy rail and light rail under projection scenarios for 2030 and 2050. In general, the savings achieved by rail efficiency strategies are expected to be proportional to their current energy use patterns. However, the gradually decarbonization of the electric grid benefits the electric modes.

The three high efficient electric rail modes are also modeled with a renewable power strategy. This strategy assumes on-site renewable power generation by transit agencies or purchases of renewable power account for 20% to 50% of electricity use in 2030 and 50% to 80% of renewable electricity use in 2050. If a transit agency were to use 100% renewable power the emissions profile for its electrically powered vehicles would fall to 0, but most transit agencies will likely continue to draw some power from the regional electric grid.

Figure 13. GHG Emissions per Passenger Car by Rail Scenario in 2030 and 2050

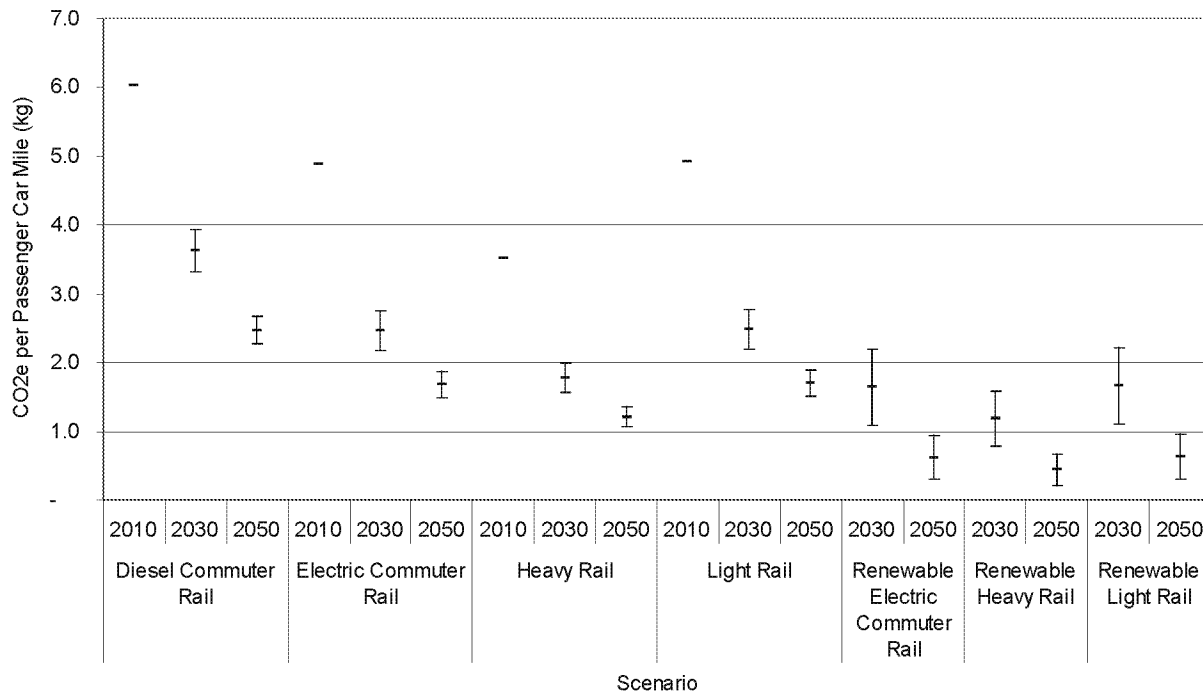
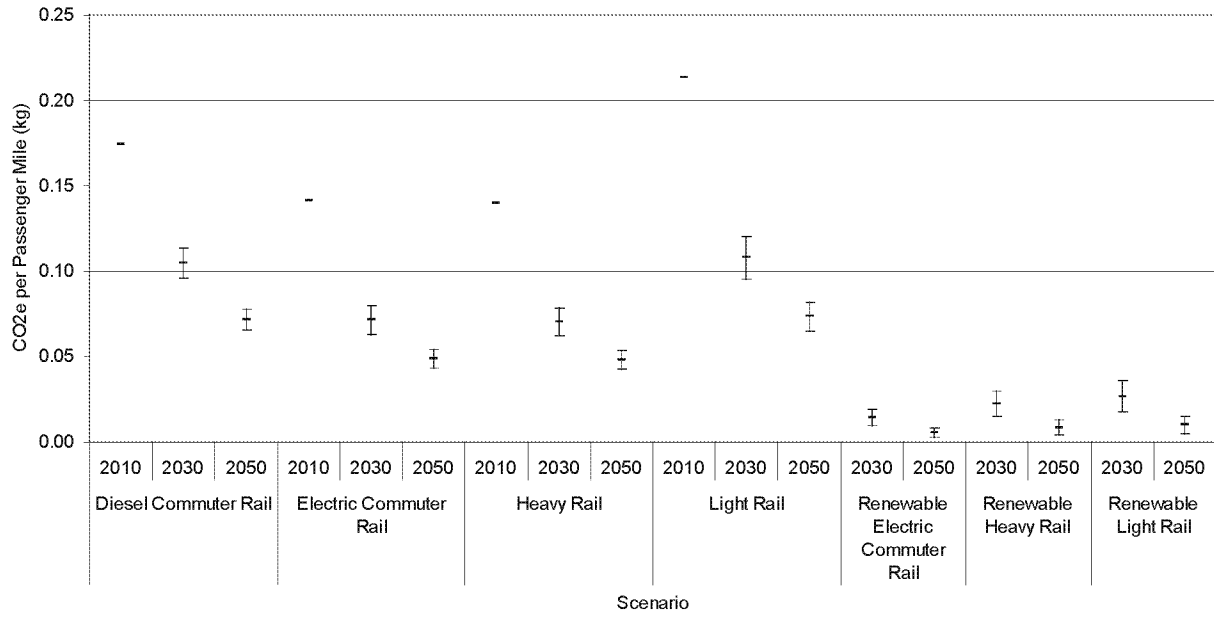


Figure 14 charts the same rail scenarios as Figure 13, but shows them on a per passenger mile basis. Even accounting for the variations in passenger occupancy between rail types, the general trend persists. The GHG emissions per passenger mile of all rail modes decrease by 2030 and are even lower by 2050 as transit agencies reap efficiency gains from Intelligent Transportation Systems and maintenance innovations as well as lighter weight vehicles that demand less energy and regenerate braking energy that is currently lost as heat.

Figure 14. GHG Emissions per Passenger Mile by Rail Scenario in 2030 and 2050



The GHG metrics for the high efficiency rail scenarios are documented in Table 11. These lightweight rail vehicles with regenerative braking and efficient auxiliary systems use less electricity than today’s average vehicles. The GHG emissions from electric rail transit decrease even further as the electricity used to propel the vehicles gets less carbon-intensive.

Table 11. High Efficiency Rail 2030 and 2050

| Performance Metric | Diesel Commuter Rail | | | Electric Commuter Rail | | |
|--|----------------------|--------------|---------------|------------------------|--------------|---------------|
| | 2010 | 2030 | 2050 | 2010 | 2030 | 2050 |
| CO ₂ e per Passenger Car Mile (kg) | 6.0 | 3.3 to 3.9 | 2.3 to 2.7 | 4.9 | 2.2 to 2.7 | 1.5 to 1.9 |
| CO ₂ e per Passenger Mile at Today's Occupancy(kg) | 0.17 | 0.10 to 0.11 | 0.07 to 0.08 | 0.14 | 0.06 to 0.08 | 0.04 to 0.05 |
| CO ₂ e per Passenger Mile at High Occupancy in 2030 and 2050 (kg) | Not applicable | 0.08 to 0.10 | 0.04 to 0.05 | Not applicable | 0.05 to 0.07 | 0.03 to 0.03 |
| Renewable Power CO ₂ e per Passenger Car Mile(kg) | Not applicable | | | | 0.01 to 0.02 | 0.003 to 0.01 |
| Performance Metric | Heavy Rail | | | Light Rail | | |
| | 2010 | 2030 | 2050 | 2010 | 2030 | 2050 |
| CO ₂ e per Passenger Car Mile (kg) | 3.5 | 1.6 to 2.0 | 1.1 to 1.3 | 4.9 | 2.2. to 2.8 | 1.5 to 1.9 |
| CO ₂ e per Passenger Mile at Today's Occupancy (kg) | 0.14 | 0.06 to 0.08 | 0.04 to 0.05 | 0.21 | 0.10 to 0.12 | 0.06 to 0.08 |
| CO ₂ e per Passenger Mile at High Occupancy in 2030 and 2050 (kg) | Not applicable | 0.08 to 0.11 | 0.04 to 0.05 | Not applicable | 0.10 to 0.13 | 0.05 to 0.06 |
| Renewable Power CO ₂ e per Passenger Car Mile(kg) | Not applicable | 0.01 to 0.03 | 0.004 to 0.01 | Not applicable | 0.02 to 0.04 | 0.005 to 0.02 |
| Strategies included: Weight Reduction, Regenerative Braking, Auxiliary Systems Efficiency, Operational Efficiency and Maintenance | | | | | | |

FACILITIES

Facilities are the next biggest source of energy use and emissions after the revenue vehicle fleet for most transit agencies. Energy efficient retrofits today are achieving savings of 30% and more, so it is quite possible that an agency could achieve cost effective energy reductions at their facilities in 2030 and 2050 of this amount or more. Table 12 demonstrates the energy and GHG savings potential for a single commercial building under four retrofit scenarios. Every building is different, and transit agencies have a wide variety of facility types with quite different energy use profiles, but this scenario is intended to give a sense of the scale of GHG and energy savings possible.

Table 12. Facility Energy Efficiency 2030 and 2050

| Year | Energy Efficiency Savings | Electricity Use (kWh) | Natural Gas Use (Standard Cubic Feet) | CO ₂ e per building (kg) | Electricity Saved (kWh) | Natural Gas Saved (Standard Cubic Feet) | CO ₂ e Saved Per Building (kg) |
|------|---------------------------|-----------------------|---------------------------------------|-------------------------------------|-------------------------|---|---|
| 2010 | 0% | 191,624 | 403,765 | 116,151 | Not applicable | Not applicable | Not applicable |
| 2030 | 30% | 134,137 | 282,635 | 95,479 | 57,487 | 121,129 | 40,920 |
| 2030 | 50% | 95,812 | 201,882 | 68,199 | 95,812 | 201,882 | 68,199 |
| 2050 | 50% | 95,812 | 201,882 | 68,199 | 95,812 | 201,882 | 68,199 |
| 2050 | 80% | 38,325 | 80,753 | 27,280 | 153,299 | 323,012 | 109,119 |

OTHER STRATEGIES

The other strategies analyzed in this report each address smaller parts of a transit agency’s GHG inventory. While none of these strategies will have as big an impact on a transit agency’s energy use and emissions as the strategies affecting revenue vehicle operations do, action in these areas may be part of an effort to comprehensively address transit agency GHG emissions organization-wide. Each of these strategies is discussed further in the Appendix.

Reductions in emissions of high global warming potential gases, such as those used in vehicle air conditioning through the use of substitutes for the high impact GHGs that are in use today can cut emissions up to 100% in this area.

Non-revenue fleet emissions will likely benefit from increases in fuel efficiency of light duty vehicles through 2050. Emissions this area could be reduced 42% to 58% by purchasing high-efficiency vehicles. Additional emissions reductions can be achieved through the use of alternative fuels and efforts to reduce non-revenue vehicle use. As employers, transit agencies can impact emissions of employee commute and employee business travel by promoting commute alternatives and using new technologies to avoid unnecessary business travel.

Reductions in the indirect lifecycle emissions of transit operations including the GHG emissions from construction can be addressed through procurement guidelines that favor low-carbon materials and supply chains. The availability of information on the lifecycle GHG footprint of products is likely to grow in coming years, which will make efforts to understand and reduce emissions associated with procurement easier.

Finally, as has been discussed earlier in this report, the influence transit agencies influence have on travel behavior extends beyond transit riders and more broadly into the communities transit agencies serve. By promoting transit oriented development and other efficient land use strategies a transit agency can enable emissions reductions and

increase its ridership base. Household travel GHG savings as great as 78% are possible in location efficient neighborhoods.⁷¹

VI. CONCLUSIONS

Transit agencies play an important role in the effort to address global climate change by providing transportation alternatives and supporting land use patterns that reduce vehicle travel. Transit's role as a GHG reduction strategy has come into stronger focus in recent years as corporations and governments incorporate transit ridership in their climate action plans. At the same time, transit agencies have GHG footprints of their own and reducing organizational emissions can sometimes seem at odds with efforts to lower community emissions by expanding service. Yet, a new generation of transit vehicles with energy efficiency and low-carbon fuels are making it possible for transit agencies to substantially cut fuel use and GHG emissions. As a result, transit agencies will continue to offer low-carbon transportation alternatives in the communities they serve in the decades to come.

By 2030 transit agencies will have a fleet of vehicles that are lighter and use less fuel to provide the same level of service. For example, a 2010 Transportation Research Board report forecasts that urban buses can reduce fuel consumption 30% by the years 2013-2015 and 25% by 2015-2020.⁷² If these efficiency improvement trends were to continue, a range of 35% to 70% fuel savings for hybrid buses could be achieved by 2050. Agencies that move away from conventional diesel and electric fuels to lower-carbon energy sources have the potential to reduce their GHG footprint even further. Even without cutting-edge vehicle technology improvements, transit agencies have the potential to reduce fuel use and cut emissions by optimizing fleet maintenance and operations.

Vehicle fuel use makes up the bulk of a transit agency's GHG emissions profile, but all actions that contribute to transit agency service, including facilities, construction, and employee travel can achieve emissions reductions into 2030 and 2050. As transit agencies move to GHG efficiency metrics that take the whole organizational footprint into account, rather than just vehicle fuel use, reducing the GHG emissions of these other aspects of agency operations will improve agency performance. As a result, the transit agencies of 2030 and 2050 could provide transportation options that help communities reduce their contributions to global climate change far below today's levels.

This study greatly benefitted from the research that is being done to test and document the performance of new transit technologies out in the field. As transit agencies adopt new technologies and operational improvements, tracking and sharing performance will help expand the information available and increase the rate of change, making it easier and faster for transit to become more fuel efficient and reduce emissions.

Performance measurement can help fine tune operations internally, as well, and ensure that new technologies are performing as planned. Clear documentation of the actions a transit agency is taking to improve energy efficiency and reduce GHG emissions can also be very helpful in communicating with the public.

As more transit agencies inventory their GHG emissions and develop sustainability plans it will help benchmark performance and provide insight into technologies and operations that can help all transit providers reduce emissions and energy use. Not all of the factors that affect a transit system's emissions profile are under its control; transit operators may be able to learn from each other's emissions profiles to understand areas where others have overcome external barriers to energy and GHG reduction.

We are in an age of energy efficiency innovation, and transit agencies can help drive progress by including energy and GHG standards in its procurement. Improvements in transit technologies and operations do not just reduce the GHG footprint of a given transit agency, but can have ripple effects throughout a community as performance and ridership increases and households make use of the affordable transportation alternatives in their neighborhoods.

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APPENDIX: GHG AND ENERGY USE REDUCTION STRATEGY PORTFOLIO

I. INTRODUCTION

Part 1 of this document presented the research, methods, and results of an analysis of transit GHG emissions and energy use in 2030 and 2050. Part 2 presents each of the specific transit GHG and energy reduction strategies in detail. Each strategy begins with an overview of its GHG and energy savings potential in table format, followed by a description of the strategy and details on the GHG and energy profile of the technology in 2030 and 2050. Each strategy is compared to a relevant current-day base case. For example, hybrid electric buses are compared to a current-day 40-foot diesel bus.

Savings estimates in this section estimated for each strategy individually and should not be presumed to be completely additive—the emissions savings from using biofuels will overlap with any emissions savings created by reducing deadhead bus mileage if those strategies are implemented together. The savings scenarios in Part 1 eliminated any double counting before summing up the impacts of more than one strategy.

The strategies analyzed in Part 2 of this document are as follows:

Vehicles and Fuels

1. **Hybrid Vehicles:** Vehicles that operate on two or more fuels
2. **Biofuel:** Fuel derived from plants or algae
3. **Electric Buses:** Vehicles that run on stored or grid-supplied electricity
4. **Fuel Cell Buses:** Vehicles that use fuel cells for propulsion, especially hydrogen fuel cells
5. **Weight Reduction and Right-Size Vehicles:** Lighter weight buses and trains, as well as vehicles of all types sized to meet demand
6. **Regenerative Braking:** Capture and use of energy usually lost as heat during braking
7. **Auxiliary Systems Efficiency:** Reducing the demand of non-propulsion energy uses, such as air conditioning
8. **Personal Rapid Transit:** Fixed guideway transit with 2 or 4 person cars
9. **Renewable Power:** Low-carbon electricity for transit vehicles or facilities

Operations and Maintenance

10. **Operational Efficiency:** Changes in the ways vehicles are operated, such as routing or acceleration
11. **High Global Warming Potential (GWP) Gases:** Chemicals used in systems, such as air conditioners, that have global warming impact many times that of carbon dioxide
12. **Maintenance:** Upkeep of vehicles and systems to ensure maximum possible efficiency

Other

13. **Construction and Lifecycle Impacts:** Transit system construction projects and the upstream emissions associated with transit activity
14. **Non-Revenue Vehicles, Employee Commute, and Employee Travel:** Vehicles that are not part of the transit revenue service fleet
15. **Facilities:** Transit system buildings including stations, offices, and maintenance facilities
16. **Land Use:** Community location efficiency to increase transit ridership and reduce vehicle use
17. **Ridership and Occupancy:** Improving transit emissions per passenger mile by increasing transit vehicle occupancy

II. DETAILED GHG AND ENERGY USE REDUCTION STRATEGIES

1. HYBRID VEHICLES

Summary

Table 13. Hybrid Vehicle GHG Emissions and Energy Use Profile

| | Diesel Bus | Hybrid Bus | |
|--|----------------|--------------|--------------|
| | 2010 | 2030 | 2050 |
| GHG Reduction vs. Diesel Bus | Not applicable | 10% to 50% | 35% to 70% |
| GHG Reduction with B100 Biodiesel | Not applicable | 99.9% | 99.9% |
| Fuel Use Per Vehicle Mile (Gallons) | 0.28 | 0.14 to 0.25 | 0.08 to 0.18 |
| Vehicle Miles per Gallon | 3.6 | 4.0 to 7.2 | 5.5 to 12.0 |
| GHG Emissions (kg CO ₂ e) per Vehicle Mile | 2.8 | 1.4 to 2.6 | 0.9 to 1.8 |
| GHG Emissions (kg CO ₂ e) per Passenger Mile at 28% Occupancy | 0.27 | 0.13 to 0.25 | 0.09 to 0.17 |

Description

A hybrid vehicle is any vehicle that moves using at least two types of energy – hybrid electric diesel buses use both diesel and electric power to move the vehicle. The most common type of hybrid transit vehicle today is a hybrid electric transit bus. Other fuels that have been combined with electric drive technology to create hybrid buses include natural gas and biodiesel. Hybrid vehicles typically incorporate regenerative braking that allows the vehicle is to capture energy that would be otherwise wasted from braking and store it for electric use.⁷³

Hybrid buses are among the fastest growing new technologies in the transit fleet. The 2008 National Transit Database reports 676 hybrid diesel vehicles and 43 hybrid gasoline vehicles. The 2010 American Public Transit Association estimates hybrid and electric vehicles may be as much as 4.9% of the transit bus fleet, up from 0.1% in 2001.⁷⁴ The share of hybrid buses in the fleet is growing as hybrid buses are 35% of the new buses ordered by transit agencies.⁷⁵

Transit buses are extremely well suited to hybrid technologies. The stop and start nature of transit bus service allows a transit bus to take full advantage of the energy

captured regenerative braking to power the vehicle.⁷⁶ Buses may gain extra efficiency by using series, rather than parallel, hybrids where the internal combustion engine is allowed to operate at its range of maximum performance at all times.⁷⁷ Hybrid transit vehicles currently cost in the range of \$200,000 more than conventional diesel buses and have higher battery replacement and maintenance costs, but are valued for their lower fuel cost, decreased urban air pollutant emissions, and GHG emissions savings.⁷⁸

Transit buses may also use plug-in hybrid electric technology to charge batteries at night and enable auxiliary systems to be used during maintenance. However, the electricity consumed while the vehicle is plugged into the grid should be considered when evaluating the fuel efficiency and GHG emissions profile of the vehicle. For more about the GHG emissions of grid-connected electric vehicles see the Electric Bus strategy in this Appendix.

Ferry boats may also be strong candidates for hybrid technology. The vast majority of ferries operated by transit agencies today are diesel powered. A private ferry company in the San Francisco Bay has introduced a hybrid ferry that uses photovoltaic cells and wind to charge a battery system for electric power, while the vehicle also runs on diesel.⁷⁹

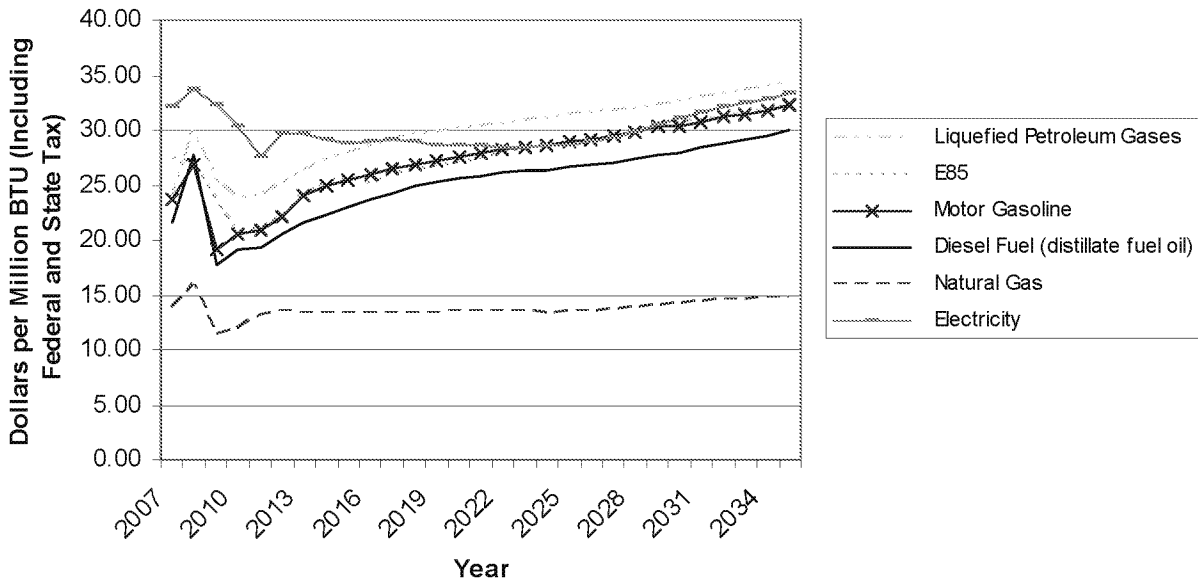
Advances in gasoline hybrid technology for personal vehicles are likely to benefit demand response, paratransit, vanpool, and non revenue vehicles that are a growing share of transit fleets around the country. Demand response transit is a large and growing aspect of transit agency service. The demand response fleet is quite diverse, ranging from 4 person passenger cars to 20 seat shuttle buses and up to 40 foot buses.⁸⁰ Expected advances in fuel efficiency for cars and light duty trucks will benefit transit agencies operating small vehicles, as hybrid technologies become more efficient.

Fuel price plays a significant role in transit technology decisions. Natural gas gained popularity among transit bus fuels over the past two decades, due to the lower local air pollution impact of such fuels as compared to conventional diesel and the competitive price of natural gas as compared to other fuels. Compressed natural gas, liquefied natural gas and blends fueled 2.8% of the bus fleet in 1996, and grew to 18.5% of the bus fleet in 2008. In 2009, however, the share of buses fueled by natural gas dipped to 18.3% as transit agencies looked more to electricity and hybrid vehicles.⁸¹

As is shown in Figure 15, long term forecasts from the US Department of Energy's *Annual Energy Outlook* show natural gas prices remaining lower than other transportation fuels on a per-BTU basis, with natural gas prices staying relatively flat from 2008-2035 while most other fuels see increases over that period.⁸² This pricing trend could serve as a counterbalance to other factors that are moving current transit fuel decisions away from natural gas today. However, the model used in the *Annual Energy Outlook* only

includes impacts from existing policies; if federal climate legislation were enacted, the relative prices of carbon-intensive fuels could change significantly by 2035.

Figure 15. Transportation Energy Prices 2007 to 2035 (2008 Dollars)



Source: U.S. Department of Energy, Energy Information Administration. Annual Energy Outlook 2010. Report #:DOE/EIA-0383(2010). May 11, 2010. <http://www.eia.doe.gov/oiaf/aeo/index.html>

Analysis

A study of hybrid diesel buses in New York found savings ranging from 29% to 38% over the average diesel 2.33 miles per gallon.⁸³ The Washington Metropolitan Area Transit Agency (WMATA) reports average fuel economy of 3.93 miles per gallon in their hybrid buses, which is 9.5% higher than the diesel average.⁸⁴ Table 13 summarizes the GHG and fuel savings projected with hybrid buses in 2030 and 2050. As with all transit vehicles, the fuel efficiency of hybrid buses will vary with operating conditions. Areas where buses have many stops or hills may see the greatest improvement in fuel economy from hybrids as the vehicles make the most out of regenerative braking.

Hybrid bus performance will likely improve as energy storage technology advances. Potential additional benefits from weight reduction are discussed further in the weight reduction strategy in this Appendix. The April 2010 U.S. Department of Transportation Report to Congress, *Transportation's Role in Reducing U.S. Greenhouse Gas Emissions*, estimated that hybrid transit buses could achieve 10%-50% GHG emissions savings over conventional diesel buses by 2030.⁸⁵ A 2010 Transportation Research Board report,

Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles, forecasts that urban buses can reduce fuel consumption 30% by the years 2013-2015 and 25% by 2015-2020.⁸⁶ Extrapolating these estimates out, a range of 35% to 70% fuel savings was estimated for hybrid buses in 2050 as is shown in Table 13.

While natural gas has been a popular fuel in the past few decades because of its low cost and reduced local air quality effects, its GHG emissions are significant. However, 18.3% of transit buses in the *APTA Public Transportation Vehicle Database* use natural gas and many transit agencies have the infrastructure for fueling with natural gas.⁸⁷ One manufacturer, Innovative Solutions for Energy (ISE) estimates that compressed natural gas (CNG) hybrid buses will achieve 40% greater fuel efficiency than standard CNG buses.⁸⁸ Natural gas has a lower energy density than diesel, so CNG buses tend to get lower fuel economy than diesel on a per diesel gallon basis, but the fuel economy improvements of hybridization combined with the lower carbon-intensity of CNG could result in savings of 35% versus standard diesel buses.⁸⁹ CNG can also be blended with hydrogen, which if produced renewably, could reduce emissions 7% to 10%.⁹⁰

Table 14. Hybrid Bus Fuel Efficiency Assumptions

| | 2010 Diesel Bus | 2030 Hybrid | | 2050 Hybrid | |
|-----------------------|-----------------|-------------|------|-------------|------|
| | | Low | High | Low | High |
| Fuel Savings | Not applicable | 10% | 50% | 35% | 70% |
| Fuel Efficiency (mpg) | 3.6 | 4.0 | 7.2 | 5.5 | 12.0 |

Diesel electric hybrid vehicles use standard diesel fuel with its emissions of 10.18 kg CO₂ per gallon. CH₄ and N₂O emissions from hybrid electric transit vehicles have not been extensively studied, but are presumed to be in the range of that of conventional diesel buses at 0.005 grams per mile. Transit agencies can further reduce the anthropogenic emissions profile of hybrid vehicle by using biofuels, which are documented further in the biofuel strategy in this Appendix.

2. BIOFUEL

Summary

Table 15. Biofuel GHG Emissions and Energy Profile

| | Diesel Bus | Biofuel Bus 2030 and 2050 | |
|---|----------------|---------------------------|-------|
| | 2010 | B20 | B100 |
| GHG Reduction vs. Diesel Bus | Not applicable | 19 to 20% | 99.9% |
| Fuel Use Per Vehicle Mile (gallons) | 0.28 | 0.28 | 0.30 |
| Vehicle Miles per Gallon of Diesel Equivalent | 3.6 | 3.5 to 3.6 | 3.3 |
| Direct Tailpipe GHG Emissions (kg CO ₂ e) per Vehicle Mile | 2.8 | 2.3 | 0.002 |
| Direct Tailpipe GHG Emissions (kg CO ₂ e) per Passenger Mile at 28% Occupancy | 0.27 | 0.22 | 0 |
| <p>Note direct tailpipe emissions shown here. Biofuels have significant upstream lifecycle emissions—from 24% to 95% of diesel tailpipe emissions depending on the source of the biofuel. Direct emissions are analyzed separately from upstream emissions in this report, because transit agencies must track them separately under most reporting schemes. For more information see the Construction and Lifecycle strategy in this Appendix.</p> | | | |

Description

Biodiesel is the primary biofuel in use for heavy duty transit vehicles today; 6.4% of the transit buses in the *APTA Public Transportation Vehicle Database* used biodiesel in 2009.⁹¹ Biodiesel can be blended with diesel and used in standard diesel engines in proportions up to 20% (known as B20) or used as a stand alone fuel (B100). Biodiesel is generated from waste oils, vegetable oils, and animal fats. Recent strides have been made in generating biodiesel from algae.⁹²

Biodiesel has energy security attributes as it can be domestically produced rather than imported. Biodiesel has slightly higher emissions of nitrogen oxides (10%), but substantially lower emissions of other local air quality pollutants—particulate matter, hydrocarbons and carbon monoxide than standard diesel.⁹³

At this time, biodiesel carries a cost premium to standard diesel. The Clean Cities program’s April 2010 Alternative Fuel Price Report shows an average U.S. biodiesel

price of \$3.57 per gallon as compared to \$3.02 per gallon for diesel – an 18% premium.⁹⁴ But, given that biodiesel has a slightly lower energy density than diesel, the price differential per BTU is even greater with biodiesel priced 27% higher per BTU.

Biodiesel demand has grown substantially over recent years and prices may decline with economies of scale, although feedstock constraints will impact this market. The National Biodiesel Board reports that U.S. biodiesel production reached 700 million gallons in 2008⁹⁵ with production capacity at 2.69 billion gallons.⁹⁶

Two constraints of biodiesel are that it does not perform as well as standard diesel in cold weather and it can degrade some of the rubber and plastic that is part of standard diesel vehicles.⁹⁷

Analysis

Table 15 summarizes the GHG and fuel savings projected with biofuel buses in 2030 and 2050. Biodiesel has a slightly lower energy density than diesel (128,000 vs. 139,000 BTUs per gallon), so the fuel efficiency of a vehicle using biodiesel is expected to be slightly lower as well. A 2008 NREL study of B20 biodiesel buses in St. Louis found that the buses achieved 1.7% lower fuel economy than comparative diesel vehicles.⁹⁸ A 2006 study in Denver found equivalent fuel economy between biodiesel and diesel buses.⁹⁹ NREL has not studied the impacts of B100 on fuel economy in transit buses in real world situations, but based on the energy density of the fuel, one could expect fuel economy to be 8% lower.

The U.S. Department of Energy, Energy Information Administration's *Annual Energy Outlook* forecasts energy use to 2035 and assumes fuel economy among diesel buses will remain flat.¹⁰⁰ This flat fuel economy assumption is used in this biofuel strategy as well. Biofuels may be combined with other technology improvements such as lightweight vehicles or hybrid vehicles to result in a more efficient vehicle, but those strategies are analyzed separately.

Biodiesel as B100 has zero anthropogenic tailpipe CO₂ emissions. Sustainably produced biodiesel is a renewable fuel. The direct CO₂ emissions from biodiesel are considered biogenic rather than anthropogenic – the carbon in biodiesel is part of the existing carbon cycle and is taken back out of the atmosphere when the source of the biodiesel is renewed, such as when another crop is grown – so biodiesel vehicles contribute less to global climate change than standard diesel vehicles. Nevertheless, combustion of biodiesel does create emissions at the tailpipe. The direct biogenic emissions of biodiesel are 9.5 kg CO₂ per gallon (10.3 kg CO₂ per gallon diesel equivalent).¹⁰¹ Under most GHG reporting schemes today the biogenic CO₂ associated with biofuel use is reported separately and not included in a GHG inventory total; however there is ongoing

discussion in the field as to the best way to account for tailpipe CO₂ emissions from biofuels and the standards may change over time.

The CH₄ and N₂O emissions from biodiesel use are considered anthropogenic, so the GHG emissions of biodiesel transit vehicles are not 0, but the emissions of these gases are very small compared to CO₂ emissions—U.S. EPA report transit buses using B20 emit 0.005 grams per mile of CH₄ and N₂O.¹⁰² Assuming similar emissions for B100 vehicles, the CO₂e emissions for a vehicle are 57 kg per year.

Over their lifecycle, biofuels contribute emissions through production, refining, transportation and more. This is discussed further in the lifecycle and construction strategy in this Appendix. On a lifecycle basis, the U.S. EPA finds that biodiesel reduces GHG emissions by 80% as compared to diesel when produced from waste greases. When biodiesel is produced from soybeans its lifecycle emissions are just 22% lower than petroleum diesel over a 100 year analysis when the land use impacts of additional agriculture are taken into account.¹⁰³ Algal biofuel has gained research attention recently, because not only does algae absorb CO₂ as it grows, but there is a potential CO₂ from major sources such as power plants to be injected into algae production environments to facilitate growth and promote GHG capture.¹⁰⁴

3. ELECTRIC BUSES

Summary

Table 16. Electric Bus GHG Emissions and Energy Profile

| | Diesel Bus | Electric Bus | |
|--|----------------|----------------|----------------|
| | 2010 | 2030 | 2050 |
| GHG Reduction vs. Diesel Bus | Not Applicable | 1% to 26% | 30% to 42% |
| GHG Reduction with Low-Carbon Electricity | Not Applicable | 30% to 52% | 51% to 88% |
| Fuel Use Per Vehicle Mile | 0.28 gallons | 4.0 to 5.4 kWh | 3.4 to 4.0 kWh |
| Vehicle Miles per Gallon of Diesel Equivalent | 3.6 | 3.6 to 4.7 | 4.7 to 5.7 |
| GHG Emissions (kg CO ₂ e) per Vehicle Mile | 2.8 | 2.1 to 2.8 | 1.7 to 2.0 |
| GHG Emissions (kg CO ₂ e) per Passenger Mile at 28% Occupancy | 0.27 | 0.20 to 0.27 | 0.16 to 0.19 |
| GHG Emissions (kg CO ₂ e) per Passenger Mile at 28% Occupancy with Low Carbon Electricity | Not Applicable | 0.13 to 0.19 | 0.03 to 0.13 |

Description

The electric bus strategy focuses on grid-powered electric vehicles. These include both battery electric buses and electric trolley buses.

Electric Trolley Bus

Electric trolley buses are rubber tired buses that operate on city streets and are powered by electricity that comes from overhead wires. San Francisco has the largest fleet of electric trolley buses with 331 of the 611 electric trolley buses in the U.S. as reported in the 2008 National Transit Database.¹⁰⁵ Electric vehicles have no direct tailpipe emissions, which has local air pollution benefits. But the climate change impact of electric vehicles through the power plant emissions associated with the electricity consumed is significant.

Electric trolley buses require substantial capital investment for the required electrical infrastructure. Also, communities may raise aesthetic issues about overhead wires, and the trolley bus poles that connect the bus to the overhead wires occasionally come off, requiring the driver to reconnect them. However, San Francisco has found the electric

trolley buses are quieter, perform better on hills, require less maintenance, and last longer than motor buses.¹⁰⁶ Electric trolley buses have a useful life of 18 years, as compared to 12 years for motor buses.¹⁰⁷

Improvements in electric trolley bus technology, such as the addition of auxiliary power units that enable operating off line for short distances make them more reliable and flexible. Auxiliary batteries can be powered by regenerative braking to improve the efficiency of trolley buses.

Battery Electric Vehicle

Today's batteries remain quite large and heavy. Issues of range limits, charging time, and battery life have been among the barriers to use of battery electric transit vehicles. Battery electric buses tend to be shorter and have less seating capacity than a standard diesel buses. The 2008 National Transit Database shows nine transit agencies in the U.S. operate 74 battery electric vehicles.¹⁰⁸ Battery electric buses are not widely available today.¹⁰⁹ But, with improvements in battery storage, plug in electric buses may become feasible for more communities.

Technology Developments

Other electrification technologies are being explored for buses including inductive charging, systems embedded along the roadway or at stops.¹¹⁰¹¹¹ These have the potential to eliminate the need for overhead wires and could bring greater efficiencies as well.

Ultracapacitors, which have less storage capacity but much faster charging times, are beginning to be used in buses. In Shanghai, the electric buses with ultracapacitors charge for a few minutes using overhead wires at selected stops – rather than using the continuous overhead wires along the entire route required by standard electric trolley buses – and have a range of 3 miles with the air conditioning on or 5 miles without.¹¹²

Analysis

As the electricity grid gets cleaner and bus technology improves the average grid-powered electric bus could reduce GHGs up to 26% in 2030 as compared to today's diesel buses. By 2050, electric buses could reduce emissions by 30 to 42% over today's diesel buses.

According to energy use data in the National Transit Database, electric trolley buses get approximately the same fuel efficiency on a per-BTU or Diesel Gallon Equivalent basis as diesel buses today. The average electric trolley bus uses 5.4 kWh per mile, while diesel buses get 3.6 miles per gallon.¹¹³ The energy used to produce electricity will be different at each power plant and changes over time, as it depends on the technology

and fuel used to generate power, but U.S. EPA’s eGRID database reports 7,293 BTUs of primary energy consumed to produce one kWh on average in the U.S.¹¹⁴ (When used, electricity provides a standard 3,412 BTUs of energy, so the power plant input rate represents 47% efficiency.) Diesel fuel has a high heating value of 139,000 BTU per gallon.¹¹⁵ So, an electric bus uses 39,020 BTUs per mile while a diesel bus uses 38,515 BTUs per mile.

A range of fuel efficiency for electric buses was estimated as is shown in Table 17. At the low end, electric buses in 2030 were assumed to have the same fuel efficiency as electric trolley buses as reported in the NTD in 2008. Higher estimates of 25% fuel efficiency improvement in 2030 and 37% in 2050 was created with a linear projection of fuel efficiency improvements based on historical data in the NTD.

Table 17. Electric Bus Fuel Efficiency Assumptions

| | 2008 | 2030 | | 2050 | |
|-----------------|------------------|----------------|-----------------|-----------------|-----------------|
| | | Low | High | Low | High |
| Fuel Efficiency | 5.4 kWh per mile | No improvement | 25% improvement | 25% improvement | 37% improvement |

The GHG emissions associated with an electric bus are directly related to the carbon-intensity of the electricity that powers it. An electric trolley bus that uses today’s grid average electricity has 14% higher emissions per vehicle mile than a diesel bus (but 10% lower emissions per seat mile). In California, where electricity is nearly half as carbon-intensive as the national average, an average electric trolley bus has 38% fewer GHG emissions per mile than a diesel bus.

The emissions associated with electrification will be dependent on the carbon intensity of the U.S. electrical generation infrastructure through 2030 and 2050. Electricity emissions for 2030 and 2050 were estimated based on the U.S. Department of Energy’s Annual Energy Outlook (AEO). The AEO states, “Federal and State energy policies recently enacted will stimulate increased use of renewable technologies and efficiency improvements in the future, slowing the growth of energy-related CO₂ emissions through 2035.”¹¹⁶ Specifically, Figure 16 shows that as power generating plants become more efficient and switch to less carbon-intensive fuels, GHG emissions associated with electricity use are forecasted to decrease 14% to 0.52 kg CO₂ per kWh in 2030 from 0.61 kg CO₂ per kWh in 2005.¹¹⁷

Because the AEO forecast only extends to 2035, the 2050 emissions rate was extrapolated at the same rate of growth to 0.49 kg CO₂ per kWh. Emissions of CH₄ and N₂O were estimated to decrease from today’s rates in proportion to CO₂; these gases are

such a small share of electricity GHG emissions that they do not significantly impact results.

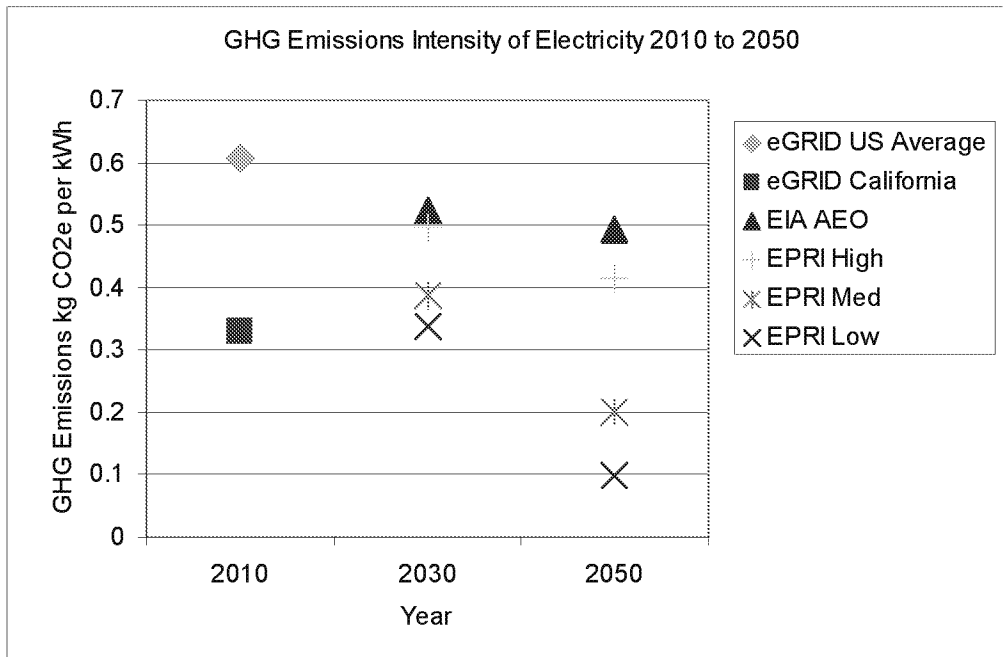
The AEO report estimates the impacts of currently enacted policies in its forecasts, so the 2030 and 2050 emissions rates do not assume any national cap on GHG emissions from power generation facilities. Under the AEO reference forecast renewable energy represents 5.5% of electricity generation in 2007 and 8.5% in 2030. The AEO report analyzes several other future scenarios, of which the high economic growth case has the largest share of renewable electricity at 9.3% in 2030.¹¹⁸ Transit agencies may choose to augment the share of renewable power through direct renewable generation or renewable power purchases, which is discussed in Strategy 9 of this report.

The AEO forecasts, while widely used, are considered fairly conservative by some because they only forecast the impacts of policies that have already been enacted, rather than speculating on future policy changes. The Electric Power Research Institute (EPRI), a utility funded research organization, created several forecasts of electricity emissions for a 2007 study on plug-in electric hybrid vehicles that include some prospective policies that affect electricity generation.¹¹⁹ These forecasts are discussed here for comparison purposes and are shown as “low carbon electricity” in

Table 9, Figure 12, and Table 16, but are not used elsewhere in this study.

EPRI creates three scenarios for electricity in 2050 with varying levels of carbon pricing, renewable power, nuclear power, power plant efficiency and carbon capture and storage. The most aggressive of these scenarios assumes that existing fossil fuel plants can be retrofitted to capture and store CO₂ emissions and has an average emissions rate of 0.097 kg CO₂ per kWh, which is just 20% of the emissions in the 2050 projection based on the AEO forecast.¹²⁰ Emissions rates for electricity in 2030 were interpolated from the EPRI scenarios and are shown in Figure 16. If electricity generation were to follow the EPRI forecast, electric buses could produce 30% to 52% fewer GHGs than today's diesel buses by 2030. In 2050 bus emissions could be 51% to 88% lower than today.

Figure 16. GHG Emissions Intensity of Electricity 2010 to 2050



Note that the EIA AEO values are used for the main analysis in this report.

4. FUEL CELL BUSES

Summary

Table 18. Fuel Cell Bus GHG Emissions and Energy Profile

| | Diesel Bus | Fuel Cell Bus | |
|--|----------------|--|--|
| | 2010 | 2030 | 2050 |
| GHG Reduction vs. Diesel Bus | Not applicable | 7% to 48% | 41% to 68% |
| GHG Reduction with Carbon Capture | Not applicable | Up to 94% | Up to 94% |
| Fuel Use Per Vehicle Mile | 0.28 gallons | 0.16 to 0.21 kg H2 and 0.31 to 0.42 kWh | 0.10 to 0.16 kg H2 and 0.20 to 0.31 kWh |
| Vehicle Miles per Gallon of Diesel Equivalent | 3.6 | 4.6 to 6.3 | 6.2 to 9.7 |
| GHG Emissions (kg CO ₂ e) per Vehicle Mile | 2.8 | 1.5 to 2.6 | 0.9 to 1.7 |
| GHG Emissions (kg CO ₂ e) per Passenger Mile at 28% Occupancy | 0.27 | 0.14 to 0.25 | 0.09 to 0.16 |

Description

Fuel cells use an electrochemical reaction to take in fuel and create electricity. Hydrogen fuel cell transit buses are attractive in many cities because they have no direct tailpipe emissions other than water. Hydrogen production—most commonly from natural gas—has significant indirect emissions associated with it, so fuel cells are not an emissions-free technology. However, fuel cells are more efficient than today’s internal combustion engines, so on balance a fuel cell bus can be more efficient than a diesel bus.¹²¹ AC Transit in California is working to develop alternative hydrogen manufacturing processes using solar power and landfill gas that would reduce the net GHG impact of their fuel cell buses even further.¹²²

The National Renewable Energy Laboratory has been conducting extensive testing and evaluation of fuel cell buses since 2000.¹²³ Fuel cell fuel efficiency, measured in terms of gallons of diesel equivalent, was found to be 28% higher than standard diesel buses at Connecticut Transit¹²⁴ and 48% higher at AC Transit (22% and 43% including nightly electric battery charging) on a High Heating Value basis.¹²⁵ In both these studies the fuel cell buses have hybrid electric propulsion systems. A similar study of a non-hybrid electric fuel cell buses with no regenerative braking in San Jose, California found fuel efficiencies to be 19% lower than the diesel buses tested.¹²⁶

Analysis

Table 18 summarizes the GHG and fuel savings projected with fuel cell buses in 2030 and 2050. The most common type of fuel cell bus requires hydrogen fuel. Currently, most hydrogen is manufactured using a natural gas process that releases CO₂, one of the primary GHGs, as a byproduct at a rate of 9.22 to 12.1 kg CO₂ per kg hydrogen. With technology improvements a National Academy of Engineering study estimates that emissions from hydrogen production could be reduced to 8.75 to 10.3 kg CO₂ per kg hydrogen in the future. As with electricity generation, efforts to sequester the carbon generated from hydrogen production are being explored and the National Academy of Engineering study estimates emissions of 1.3 to 1.53 kg CO₂ per kg hydrogen are possible in the future with carbon sequestration.¹²⁷ In this scenario it is assumed that the fuel cell buses are plugged in at night, so a small amount of electricity is used as well as the hydrogen.

Electrolysis of water is another hydrogen production method that is being pursued for transportation purposes. Electrolysis uses electricity to split water into hydrogen and oxygen. This method is less efficient than reformation of natural gas, but has greater potential as a distributed energy source with small scale production units connected to existing electric and water infrastructure.¹²⁸ Unlike the methods that reform natural gas or other fuels, electrolysis does not emit any GHGs directly from the hydrogen production process. However, the indirect emissions associated with electricity generation must be considered when examining the climate change impacts of this technology. Today's technologies require 53 to 70 kWh of electricity per kg of hydrogen produced, which equates to 32 to 42 kg CO₂ per kg hydrogen at the 2005 U.S. average emissions rate for power generation.¹²⁹ Potential efficiency improvements in this hydrogen generation processes could lower the energy requirements to 46 kWh per kg hydrogen – a 13% improvement over the higher efficiency systems today.¹³⁰

For the 2030 analysis presented here the National Renewable Energy Laboratory fuel cell bus efficiencies, as adjusted for nighttime plug-in electric use, of 22% and 43% lower energy use than standard diesel buses were used in combination with 2010 hydrogen production emissions of 9.2 to 12.1 kg CO₂e per kg fuel.^{131,132} The 2050 analysis assumes that fuel efficiency will increase 1% per year from 2030 to 2050 and that the National Academy of Engineering forecast of 8.75 to 10.3 kg CO₂ per kg hydrogen is met.¹³³

5. WEIGHT REDUCTION AND RIGHT-SIZE VEHICLES

Summary

Table 19. Lightweight Vehicle GHG Emissions and Energy Profile

| | Diesel Bus | | Diesel with Weight Reduction | |
|---|---------------------------------------|---|---|--|
| | 2010 | 2030 | 2050 | |
| GHG Reduction vs. Diesel Bus | No Reduction | 6% to 13% | 19% to 22% | |
| Fuel Use Per Vehicle Mile (Gallons) | 0.28 | 0.24 to 0.26 | 0.22 to 0.23 | |
| Vehicle Miles per Gallon | 3.6 | 3.8 to 4.1 | 4.4 to 4.6 | |
| GHG Emissions (kg CO₂e) per Vehicle Mile | 2.8 | 2.5 to 2.7 | 2.2 to 2.3 | |
| GHG Emissions (kg CO₂e) per Passenger Mile at 28% Occupancy | 0.27 | 0.23 to 0.25 | 0.21 to 0.22 | |
| | Rail | | Rail with Weight Reduction | |
| | 2010 | 2030 | 2050 | |
| GHG Reduction vs. Base Case Rail | No Reduction | 19% to 29% electric or 6% to 13% diesel | 30% to 37% electric or 19% to 23% diesel | |
| Fuel Use Per Passenger Car Mile | 5.8 to 8.1 kWh or 0.59 gallons diesel | 5.0 to 7.6 kWh or 0.51 to 0.54 gallons diesel | 4.5 to 6.6 kWh or 0.45 to 0.48 gallons diesel | |
| GHG Emissions (kg CO₂e) per Passenger Car Mile | 3.5 to 6.0 | 2.5 to 5.6 | 2.2 to 4.9 | |
| GHG Emissions (kg CO₂e) per Passenger Mile | 0.14 to 0.21 | 0.10 to 0.17 | 0.09 to 0.15 | |

Description

Transit vehicles are among the heaviest vehicles in operation. Light rail vehicles can weigh over 100,000 pounds.¹³⁴ At around 28,500 pounds without passengers (curb weight), the standard diesel bus’s bulk contributes substantially to its relatively low fuel economy.¹³⁵ Transit vehicles must preserve safety and reliability foremost, and historically this has been at odds with the fuel economy and emissions reductions gains possible through many vehicle weight reduction designs.

New vehicle technologies often weigh even more than current designs, as buses must accommodate more equipment, additional batteries for energy storage, and larger fuel tanks. Hybrid buses in New York weigh over 3,000 lbs more than a diesel bus.¹³⁶ A fuel cell bus in a recent Connecticut Transit demonstration weighs 36,000 lbs empty, yet holds fewer passengers than a diesel bus of similar size.¹³⁷

Typically, technology gets smaller and lighter as it goes through multiple iterations. But many of the additions to transit vehicles in recent years to improve accessibility and comfort, such as bicycle racks and wheelchair lifts, have added to vehicle weight. This additional weight is cited as one reason for the declining fuel economy of buses.¹³⁸ Transit bus and rail energy use both increased 0.4% per vehicle mile annually on average from 1970 to 2007.¹³⁹

Analysis

Table 19 shows the energy and GHG savings results of an analysis of vehicle weight reductions for transit vehicles in 2030 and 2050. The 2010 Transportation Research Board report *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles* estimates that urban transit buses can achieve fuel reduction of 3% by 2015 and 6.25% by 2020.¹⁴⁰ While not a weight reduction strategy, the report also estimates the potential benefits of low rolling resistance tires and tire pressure monitoring at 1.5%.¹⁴¹ The 2020 value of 6.25% fuel reduction is used as the low end of the range for this strategy in 2030. The high end of the fuel savings for 2030, 12.75%, and the low end of the range of savings in 2050, 18.8%, are extrapolated from the trends in the Transportation Research Board Study.

Fisher Coachworks is developing a hybrid bus design that is expected to weigh 19,800 lbs—30% less than diesel bus and 33% compared to today's hybrid vehicles. The Fisher Coachworks GTB-40 uses lightweight "Niconic 30" steel and redesigns the body of the bus to use less material. The bus is expected to get 10 miles per gallon, but much of this fuel efficiency improvement is due to the hybrid electric propulsion and other system improvements, rather than the vehicle weight reduction alone.¹⁴² The 30% weight reduction of this vehicle is used as the basis for the analysis of potential GHG reductions from vehicle weight reduction in 2050 combined with the Transportation Research Board estimate that up to 7.5% improvement in fuel economy can be achieved per 10% reduction in vehicle weight.¹⁴³

New York MTA's Smart Fleet program has worked extensively on weight reduction issues for their heavy rail system using innovative ideas from staff that know the fleet best.¹⁴⁴ Over the entire subway system NY MTA estimate 2.5% energy savings are possible from weight reductions of 1,440 lbs for retrofits of current vehicles and up to 3,203 lbs for vehicles with new lightweight designs.¹⁴⁵

Transit agencies can also increase the efficiency of their fleet by ensuring that they use the right size vehicle at any given time. Smaller vehicles with higher fuel economy can be used on routes with light ridership and during off-peak times; larger vehicles, such as double-decker buses, may take the place of two buses during peak times. Transit rail systems already do this by adjusting the number of passenger cars on a train. Other

modes find benefit from “right-sizing” as well, in a survey of transit agency use of 30 foot and smaller buses, 50% cited “matching capacity to demand” as a top reason for purchasing small buses.¹⁴⁶ Improvements in information systems will make it easier for transit agencies to dynamically track ridership and analyze use patterns to make fine grain adjustments to the on-road vehicle fleet without diminishing service. The primary constraints on this type of efficiency strategy will be the capital investment required to use different vehicles at different times. Vehicle storage capacity might be another barrier to adoption by some transit agencies.

6. REGENERATIVE BRAKING

Summary

Table 20. Regenerative Braking GHG Emissions and Energy Profile

| | Diesel Bus | Diesel Bus with Regenerative Braking | |
|---|---------------------------------------|---------------------------------------|--------------------------------|
| | 2010 | 2030 | 2050 |
| GHG Reduction vs. Diesel Bus | No Reduction | 22.5% | 28% |
| Fuel Use Per Vehicle Mile (Gallons) | 0.28 | 0.22 | 0.20 |
| Vehicle Miles per Gallon | 3.6 | 4.6 | 5.0 |
| GHG Emissions (kg CO₂e) per Vehicle Mile | 2.8 | 2.2 | 2.0 |
| GHG Emissions (kg CO₂e) per Passenger Mile at 28% Occupancy | 0.27 | 0.21 | 0.19 |
| | Electric Rail | Rail with Regenerative Braking | |
| | 2010 | 2030 | 2050 |
| GHG Reduction vs. Base Case Rail | No Reduction | 33% electric or 22.5% diesel | 42% electric or 28% diesel |
| Fuel Use Per Passenger Car Mile | 5.8 to 8.1 kWh or 0.59 gallons diesel | 4.5 to 6.3 kWh or 0.45 gallons diesel | 4.2 to 5.8 kWh or 0.42 gallons |
| GHG Emissions (kg CO₂e) per Passenger Car Mile | 3.5 to 6.0 | 2.4 to 4.7 | 2.0 to 4.3 |
| GHG Emissions (kg CO₂e) per Passenger Mile | 0.14 to 0.21 | 0.09 to 0.14 | 0.08 to 0.13 |

Description

Regenerative braking has been incorporated into transit vehicles at an increasing rate in recent years, a trend that is likely to continue. Transit vehicle travel patterns make them ideal candidates for regenerative braking, because the technology allows the capture of some of the energy that was historically lost as heat in the stop-and-start travel pattern of a transit vehicle.

The energy captured by regenerative braking must be stored or transferred to an electricity system, and a vehicle needs to be able to draw electric power to use the saved energy. Rail systems and electric trolley buses can be retrofit to accommodate regenerative braking or the technology can be incorporated in new vehicles – transit agencies in San Francisco, New York, Phoenix, and Portland have all explored it for

these applications.^{147,148} But for most transit buses it is typically only available as part of a package in new alternative technology vehicles. One of the major sources of energy savings in hybrid transit buses is in the use of regenerative braking. Notably, of the fuel cell buses evaluated by the National Renewable Energy Laboratory, only those with hybridization and regenerative braking saw energy efficiency improvements over standard buses.¹⁴⁹

Improvements in energy storage technology have made it possible to capture and use regenerative braking energy, but further improvements are needed for this technology to meet its full potential. Flywheels, batteries, and ultracapacitors are all being used by transit systems to increase energy storage. In transit rail systems with dense traffic the energy captured by regenerative braking can be fed to other trains through the third rail, limiting the need for storage, but wayside storage is an area for further research and innovation.¹⁵⁰

Analysis

Table 20 presents the energy and GHG savings projected from the use of regenerative braking in transit vehicles in 2030 and 2050. In New York, the subway fleet is being converted to all alternating current (AC) to enable use of regenerating braking across the system and tracks are being redesigned to make the most out of regenerative braking. New York MTA's Sustainability Plan models regenerative braking system wide and states, "Regenerative techniques include on-board and trackside energy storage, operational enhancements such as start/stop synchronization, and software modifications allowing train cars to better use regenerated energy." MTA models the energy savings potential for fleetwide regenerative braking with on-board energy storage using technology available in the "near-term" and estimates savings of 22.5%.¹⁵¹

MTA's anticipated savings value was used to estimate 2030 GHG and energy reductions from this strategy as is shown in Table 20. Applied to a typical transit bus, this would increase fuel economy from 3.6 mpg to 4.7 mpg and GHG emissions would fall 22.5%. Heavy rail energy use would fall from 5.8 kWh per passenger car mile to 4.5 kWh per passenger car mile. However, due to the projected decreased carbon intensity of electricity in 2030, the GHG emissions of rail fall even more than energy use—33% lower than the 2010 base case. Commuter rail and light rail energy use would fall proportionately. As with all of the electrical strategies in this analysis, the electricity emissions impacts are calculated using emissions factors based on the U.S. Department of Energy's *Annual Energy Outlook*.¹⁵² For more information about the electricity emissions assumptions used in 2030 and 2050 see Strategy 3, Electric Bus.

An analysis of the BART heavy rail system estimated that a retrofit with ultracapacitors to enable regenerative braking could result in 28% electricity savings. System-wide the

reduced electricity use would save \$8.7 million per year, resulting in a 11 year simple payback on the \$95 million project cost¹⁵³ BART's estimated savings of 28% were used to model the 2050 GHG and energy reductions from this strategy. This brings the fuel economy for buses up to 5.0 mpg and heavy rail energy use decreases to 4.2 kWh per mile. Bus GHG emissions fall 28% while rail emissions fall 42% against the 2010 base case due to the increased savings from cleaner electricity nationwide.

7. AUXILIARY SYSTEMS EFFICIENCY

Summary

Table 21. Efficient Auxiliary Systems GHG Emissions and Energy Profile

| | Diesel Bus | Diesel Bus with Auxiliary Efficiency | |
|---|-----------------------------------|---|---|
| | 2010 | 2030 | 2050 |
| GHG Reduction vs. Diesel Bus | No Reduction | 5% | 12.5% |
| Fuel Use Per Vehicle Mile (Gallons) | 0.28 | 0.27 | 0.24 |
| Vehicle Miles per Gallon | 3.6 | 3.8 | 4.1 |
| GHG Emissions (kg CO₂e) per Vehicle Mile | 2.8 | 2.7 | 2.5 |
| GHG Emissions (kg CO₂e) per Passenger Mile at 28% Occupancy | 0.27 | 0.26 | 0.24 |
| | Electric Rail | Electric Rail with Auxiliary Efficiency | |
| | 2010 | 2030 | 2050 |
| GHG Reduction vs. Base Case Rail | No Reduction | 16% electric 3% diesel | 26% to 27% electric 8% to 10% diesel |
| Fuel Use Per Passenger Car Mile | 5.8 to 8.1 kWh or 0.59 gallons | 5.6 to 7.9 kWh or 0.57 gallons | 5.3 to 7.4 kWh or 0.53 to 0.54 gallons |
| GHG Emissions (kg CO₂e) per Passenger Car Mile | 3.5 to 6.1 | 3.0 to 5.9 | 2.6 to 5.5 |
| GHG Emissions (kg CO₂e) per Passenger Mile | 0.14 to 0.21 | 0.12 to 0.18 | 0.10 to 0.16 |

Description

Over time transit vehicles have added more auxiliary systems for reasons such as passenger comfort, safety, and accessibility. Heating, air conditioning, power steering, lighting, electronic signage, wheelchair lifts are all examples of systems on transit vehicles that use power for reasons other than to move the vehicle. Other auxiliary systems, such as fans and compressors are essential to vehicle operation, but could be made more efficient. The addition of auxiliary systems is one reason why transit bus efficiency has not improved over time.

The energy use of auxiliary systems can be improved new energy efficient equipment and operational changes. Additionally, at least one pilot project is using alternative energy to power auxiliary systems – a private transportation company in San Francisco

is testing the use of solar power to charge batteries to run air conditioning and wireless internet services for passenger comfort while still complying with California's anti-idling rules¹⁵⁴

Analysis

Bus

Table 21 summarizes the GHG and fuel savings projected with auxiliary system efficiency in 2030 and 2050. Auxiliary systems can be redesigned to use less energy. The Tri-County Metropolitan Transportation District of Oregon (TriMet) pioneered a diesel bus retrofit program that replaced the hydraulic engine cooling fan with a set of electric fans that help maintain engine operating efficiency while using less energy – a 5% improvement in fuel economy – cutting out hydraulic fluid, and lowering maintenance costs.¹⁵⁵ 2030 savings are estimated based on this 5% level of efficiency achievement and a 5% GHG reduction is achieved.

A transit bus with the air conditioning on can use 25% of its energy for auxiliary loads.¹⁵⁶ Efforts to limit the energy used by climate control systems can include heating and air conditioning efficiency, window treatments, solar reflective paint, and insulating materials. The 21st Century Truck Partnership set a goal of reducing auxiliary system energy use by 50%.¹⁵⁷ Based on these values, a 12.5% energy use reduction is analyzed for buses in 2050 and GHG emissions are proportional to these energy savings.

Rail

An analysis of energy use in the Bay Area Rapid Transit (BART) heavy rail system suggested a set of heating, ventilation, and air conditioning (HVAC) retrofits that would save 2.3% of vehicle electricity use. Actions included changes in air intake, high efficiency HVAC units, and variable frequency drives for fans. The report also recommends adjusting the temperature settings in passenger cars to reduce heating and cooling needs.¹⁵⁸

Energy efficient lighting is becoming more standard in new vehicles, but it is also possible to retrofit older vehicles with more efficient lights. Estimated savings for BART from replacement of fluorescent lights with more efficient models and use of daylight sensors are 0.33% of vehicle electricity use.¹⁵⁹

2030 auxiliary efficiency improvements were estimated at 2.6% based on the HVAC and lighting improvements at BART. This efficiency improvement when paired with the systematic decrease in GHGs from electricity across the U.S. in 2030 results in 16% GHG savings against the 2010 base case. As with all of the electrical strategies in this analysis, the electricity emissions impacts are calculated using emissions factors based on the

U.S. Department of Energy's *Annual Energy Outlook*.¹⁶⁰For more information about the electricity emissions assumptions used in 2030 and 2050 see Strategy 3, Electric Bus.

BART estimates that 16.5% to 20% of rail energy use goes to auxiliary systems. The 2050 analysis for rail assumes a 50% reduction of that total auxiliary system use, which is in line with the bus auxiliary energy savings goal. Again, the reduced GHG emissions factor for electricity in 2050 increases the savings from this strategy to 26% to 27% against the 2010 base case.

8. PERSONAL RAPID TRANSIT

Summary

Table 22. Personal Rapid Transit Emissions and Energy Profile

| | Light Rail Passenger Car | Personal Rapid Transit | |
|--|--------------------------|------------------------|--------------|
| | 2010 | 2030 | 2050 |
| GHG Reduction vs. Light Rail per passenger mile | No reduction | 20% to 60% | 61% to 81% |
| Seats | 62 | 2 or 4 | 2 or 4 |
| Fuel Use Per Seat Mile (kWh) | 0.13 | 0.13 | 0.07 |
| GHG Emissions (kg CO₂e) per Seat Mile | 0.08 | 0.07 | 0.03 |
| Average Occupancy Rate | 37% | 40% to 80% | 40% to 80% |
| GHG Emissions (kg CO₂e) per Passenger Mile | 0.27 | 0.09 to 0.17 | 0.04 to 0.08 |

Description

Personal rapid transit (PRT) is a set of automated, on-demand transportation technologies that have been in development for the past half-century.¹⁶¹ Current designs for PRT include small 2-4 person vehicles on fixed guideways that make extensive use of intelligent transportation systems technology to allow riders to make non-stop trips from origin to destination.¹⁶² At this time the energy use profile of such systems is unknown, but there is the potential for the systems to achieve very high efficiency on a per passenger basis if the on-demand technology enables much higher occupancy rates than today’s scheduled transit routes.

Conceivably, PRT could one day be a replacement for some current demand response transit systems. Demand response is a transit mode that uses cars, vans, and buses and picks up passengers upon request. Demand response may be used to increase accessibility for riders with special needs or in areas underserved by fixed route transit.

Demand response is the fastest growing part of transit agency fleets, yet the low occupancy rates of demand response vehicles make them particularly inefficient on a per passenger mile basis. In 2008, demand response systems in the U.S. had just 12% occupancy on average, which led to an emissions rate of 1.4 kg per passenger mile.¹⁶³

Since demand response is typically offered to promote equitable mobility, rather than to reduce vehicle travel, emissions rates have been less of a focus.

Analysis

Table 22 summarizes the GHG and fuel savings projected with personal rapid transit in 2030 and 2050. PRT remains a largely conceptual transit technology, so energy use data for this analysis were based on today's light rail trains. The average light rail vehicle today uses 0.13 kWh per seat mile. PRT in 2030 is assumed to achieve the same efficiency, but PRT vehicles are assumed to have just 2 or 4 seats. Passengers per vehicle were estimated to match today's average of 1.6 for personal vehicles, resulting in 40% or 80% occupancy rates depending on the seats per vehicle.

Unlike in other vehicle analysis in this report, the base case vehicle in this strategy is much larger and has a far greater passenger capacity – it would take 39 PRT vehicles to carry the same number of passengers as a single light rail car given the occupancy assumptions here. Therefore, GHG savings are compared on a per passenger mile basis. Including the emission reduction benefit from the lower-carbon electricity supply in the U.S. in 2030 PRT results in a 20% to 60% saving per passenger mile as compared to today's light rail. As with all of the electrical strategies in this analysis, the electricity emissions impacts are calculated using emissions factors based on the U.S. Department of Energy's *Annual Energy Outlook*.¹⁶⁴ For more information about the electricity emissions assumptions used in 2030 and 2050 see Strategy 3, Electric Bus.

In 2050 PRT is assumed to achieve an average energy use per seat mile of today's most efficient light rail system – the New Orleans Regional Transit Authority used just 0.067 kWh of electricity per seat mile in 2008.¹⁶⁵ Again, PRT cars are assumed to have 2 or 4 seats with 1.6 passengers per vehicle for occupancy rates of 40% and 80%. A 60% to 81% savings per passenger mile is found in 2050, which one again includes a cleaner grid-average electricity supply than is available today.

9. RENEWABLE ELECTRICITY

Summary

Table 23. Renewable Power Emissions Profile

| | U.S. Grid Average Electricity (2005) | 2030 | | 2050 | |
|--|--------------------------------------|------|------|------|------|
| | | Low | High | Low | High |
| Grid Electricity Consumption Replaced with Renewable Power | None | 20% | 50% | 50% | 80% |
| GHG Savings vs. 2005 Grid Average Electricity | None | 31% | 57% | 59% | 84% |
| CO_{2e} per kWh (kg) | 0.61 | 0.42 | 0.26 | 0.25 | 0.10 |
| Note that GHG savings against 2005 emissions rates are higher than the share of grid electricity replaced with renewables because the grid electricity is forecasted to get cleaner over time as well. | | | | | |

Description

For transit agencies that rely on electricity to power revenue vehicles, the use of electricity with a lower GHG emissions rate can be one of the most successful ways to reduce the overall GHG footprint of the transit system. As is discussed in the electric bus strategy, the average electricity supplied over the grid in the U.S. is forecasted to get slightly less carbon-intensive in the coming decades, and may have substantially fewer GHG emissions if nationwide GHG regulations are imposed. However, a transit agency may want to supply its own clean electricity or contract with a renewable supplier rather than wait to see how these nationwide trends pan out. The impact of renewable power generation on a transit agency’s emissions profile will vary depending on the grid electricity being offset. This strategy assumes a reduction in use of grid-average U.S. electricity in 2030 and 2050.

Transit agency facilities provide many opportunities to generate electricity with on-site renewable power sources. Partnerships with local electric utility companies may be possible to defray the capital costs of grid-connected renewable installations.¹⁶⁶ Coney Island’s Stillwell Avenue Terminal Train Shed in New York has an 80,000 square foot roof made of thin-film photovoltaic cells that produce 240,000 kWh of electricity per year.¹⁶⁷ In total, NY MTA generates 1.4 million kWh of electricity on-site through photovoltaics and a hydrogen fuel cell.¹⁶⁸

Photovoltaic panels can be used to power lighting and signage at signals, stations, bus stops, and more. Photovoltaic arrays at maintenance facilities and vehicle yards can be used to plug in vehicles during cleaning, maintenance, and start-up to avoid idling while providing a canopy to shade vehicles during mid-day off-peak service. Photovoltaics can also be placed on the roofs of transit agency offices. Solar thermal energy systems can be used to heat water for use at transit facilities. Transit agencies operating hydrogen fuel cell buses can use renewables to produce hydrogen.¹⁶⁹

Geothermal heat is another renewable energy source that agencies may choose to make use of to replace the use of natural gas, fuel oil or electricity for heating. Geothermal is not completely emissions-free, but it has a substantially lower GHG profile than other heat sources. Several transit agencies are beginning to install wind turbines to generate electricity and tidal power is another potential clean energy source that some transit agencies may be able to take advantage of in their region.

Aside from installing on-site renewables, transit agencies can reduce the emissions impact of their electricity use by contracting for renewable power. However, agencies should be aware that under the reporting protocols of most GHG programs today an agency can only report that it has zero GHG emissions from its electricity use if it is acquiring electricity from an off-grid source, such as a photovoltaic array it has directly wired into its facilities.

If an agency is using electricity from the grid but purchasing renewable energy credits (RECS), “green tags”, a green power product from a utility, or otherwise contracting for renewable power that is supplied over the regional transmission and distribution grid most reporting systems will require one to report the emissions of that grid electricity use using grid average emissions factors and simply make note of the renewable purchases. The logic behind this is that when one is using electricity from the regional transmission and distribution grid those electrons are drawn from the regional power pool – which includes all electric generators in the region – rather than from a specific power plant. The emissions factors for the grid region simply calculate the total emissions from all power sources divided by the total electricity generated, so any renewable power in that pool is contributing to make all of the electricity consumed slightly cleaner.

These accounting rules may change over time. Indeed, the electric power industry is beginning to document emissions rates certified by third parties that may be adopted for use by certain reporting schemes. But in the near-term agencies looking to reduce their carbon footprint should be aware that purchasing grid-connected renewable power may not result in “zero carbon” electricity from a GHG accounting standpoint. Even with on-site renewables the renewable energy crediting systems and GHG accounting rules can be quite complex. At AC Transit the environmental benefits of PV

installations on-site have been contracted to others, so the agency doesn't get to account any emissions reduction benefit from them.¹⁷⁰

Analysis

Table 23 shows the GHG impacts of several levels of renewable power purchases or generation. The blended emissions factors that result from purchase or generation of 20% and 50% renewables combined with grid average electricity are presented for 2030—and are slightly higher than the savings from the renewable purchase alone because grid electricity in 2030 is expected to be cleaner than today's. In 2050 the renewable shares analyzed are 50% and 80%, and again the grid average electricity share of such a portfolio is cleaner than today's electricity. The New York Metropolitan Transit Agency has set a goal of using 80% renewable electricity by 2050.¹⁷¹ It is possible for a transit agency to completely eliminate its electricity GHG footprint through the use of 100% renewable power, but given that transit agencies are likely to remain connected to the electricity grid it is assume that they will continue to draw some grid electricity through 2050 even in the most ambitious renewable power scenario.

10. OPERATIONAL EFFICIENCY

Summary

Table 24. Operational Efficiency Energy and GHG Profile

| | Diesel Bus | Diesel Bus with Operational Efficiency | |
|---|---------------------------------------|---|---|
| | 2010 | 2030 | 2050 |
| GHG Reduction vs. Diesel Bus | No Reduction | 5% to 12% | 10% to 17% |
| Fuel Use Per Vehicle Mile (Gallons) | 0.28 | 0.24 to 0.26 | 0.23 to 0.25 |
| Vehicle Miles per Gallon | 3.6 | 3.8 to 4.1 | 4.0 to 4.3 |
| GHG Emissions (kg CO₂e) per Vehicle Mile | 2.8 | 2.5 to 2.7 | 2.4 to 2.6 |
| GHG Emissions (kg CO₂e) per Passenger Mile at 28% Occupancy | 0.27 | 0.24 to 0.26 | 0.22 to 0.24 |
| | Rail | Rail with Operational Efficiency | |
| | 2010 | 2030 | 2050 |
| GHG Reduction vs. Base Case Rail | No Reduction | 18% to 29% electric or 5% to 12% diesel | 22% to 33% electric or 10% to 17% diesel |
| Fuel Use Per Passenger Car Mile | 5.8 to 8.1 kWh or 0.59 gallons diesel | 5.1 to 7.7 kWh or 0.52 to 0.56 gallons diesel | 4.8 to 7.3 kWh or 0.49 to 0.53 gallons diesel |
| GHG Emissions (kg CO₂e) per Passenger Car Mile | 3.5 to 6.0 | 2.5 to 5.7 | 2.4 to 5.4 |
| GHG Emissions (kg CO₂e) per Passenger Mile | 0.14 to 0.21 | 0.10 to 0.18 | 0.09 to 0.17 |

Description

Operational efficiencies create many opportunities decrease transit fuel use and GHG emissions without making major vehicle technology changes. Even a fleet with the most efficient technology available needs to be operated efficiently to achieve expected energy and GHG savings. Incorporating operational staff into the climate action planning process can aid in the development to operational efficiency strategies. Additionally, operational staffs that understand the larger climate and energy saving goals can facilitate implementation climate action strategies out in the field.¹⁷²

Major operational changes, such as the implementation of bus rapid transit can produce marked GHG reductions.¹⁷³ Operational improvements that decrease wait times and travel speeds can also increase ridership while improving system efficiencies.¹⁷⁴ Real time vehicle monitoring systems can help identify performance problems and allow more detailed metrics and analysis that can be used to refine vehicle use.¹⁷⁵

Smart cards are being used on more and more transit systems. Transit agencies in Chicago and San Francisco have partnered with car sharing programs to allow riders to use the same smart card to access both transit and car share vehicles, allowing the car share vehicles to serve as a “last mile” solution and extend the reach of transit. In San Francisco smart cards are also being integrated with parking payment systems.¹⁷⁶ Over time it is expected that the fine-grain data on passenger travel patterns that Intelligent Transportation Systems enable will enable service innovations that lead to even more efficiency gains.

Not all of the things that affect transit operations are under agency control. For strategies such as traffic signal timing to decrease transit vehicle travel time transit agencies often must work with the transportation planning agencies in their communities.¹⁷⁷

Analysis

Table 24 shows the results of analysis of projected operation efficiency opportunities for bus and rail in 2030 and 2050. Specific operations improvements were not analyzed separately. Rather, a rate of energy savings is estimated based on an assumed package of operational improvements that will likely include Intelligent Transportation Systems, routing innovations, the use of smart cards to speed up boarding and fare payment, acceleration controls, and more.

Reducing rapid deceleration and braking can save as much as 5% of fuel use in heavy duty vehicles in the city, so this is used as the lower estimated savings rate in 2030.¹⁷⁸ Route optimization has been found to reduce heavy duty fleet vehicle fuel use by 8-10% by reducing travel distances, avoiding congestion, and consolidating trips.¹⁷⁹ While transit vehicles with fixed routes cannot optimize their travel routes the way other heavy duty vehicles can, route planning should take vehicle efficiency into consideration. Stop consolidation is one way that some bus systems have found to increase efficiency through routing. The New York Metropolitan Transportation Authority found that controlling the acceleration and speed of its subway vehicles saved 12% of energy use per subway car mile, and this is used as a basis for the higher estimated savings in 2030.¹⁸⁰

Some operational efficiency improvements, such as idling reduction, can be among the most cost effective GHG strategies, because they provide GHG and energy savings with no investment.¹⁸¹ A lifecycle analysis of transit systems found that idling can account for over 30% of the CO₂ emissions of vehicle operation.¹⁸² Given this and other potential avenues of operational savings it is assumed that transit systems can achieve an additional 5 percentage points of savings with operational improvements from 2030 to 2050, for a savings range of 10% to 17%.

11. HIGH GWP GASES

Summary

Table 25. GHG Profile of High Global Warming Potential Gases

| Use | Example Gas | Global Warming Potential | 2030 Savings | 2050 Savings |
|---------------------------|-----------------|--------------------------|----------------|--------------|
| Vehicle Air Conditioning | HFC-134a | 1,300 | 99.7% to 99.9% | 100 |
| Building Air Conditioning | HFC-134a | 1,300 | 30% to 50% | 50% to 90% |
| Refrigerators | HFC-134a | 1,300 | 99.7% to 100% | 100 |
| Fire Suppressant | HFC-227ea | 2,900 | 99.7% to 100% | 100 |
| Electrical Equipment | SF ₆ | 23,900 | 10% | 100.00% |
| Vehicle Maintenance | HFC-134a | 1,300 | 100% | 100% |
| Summary | | | 10% to 100% | 50% to 100% |

Description

The Kyoto Protocol designated six types of GHGs that have become the primary focus for most climate change programs. The majority of transit agency emissions come from fossil fuel combustion which causes emissions of CO₂, CH₄, and N₂O. The other three types of GHGs addressed by the Kyoto Protocol are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆). SF₆ is a dense gas valued for its stability and is used as an insulator in electrical systems. Transit agencies that own or operate electrical infrastructure are likely responsible for some SF₆, which is used in relatively small quantities but has a potent climate change impact— one kg of SF₆ has the same global warming impact of as much as 23,900 kg of CO₂.

The impact of a GHG relative to CO₂ is known as its global warming potential (GWP). When summing up a set of different GHGs, each is first multiplied by its GWP to normalize it by its climate change impact, the total of the gases is then labeled carbon dioxide equivalent (CO₂e).

HFCs and PFCs are the other types of high global warming potential gases that transit agencies will have in their emissions inventory. Many HFCs and PFCs were adopted for use as a transitional technology to enable the phase-out of chemicals in refrigeration system and other areas that were harming the ozone layer. As the ozone depleting substances were removed, HFCs and PFCs took their place, and their use has been growing ever since.

Transit agencies are likely to use HFCs in vehicle and building air conditioning, fire suppression systems, and refrigerators. HFCs from air conditioning in buses in the U.S. emitted 1 million metric tons of CO₂e in 2008, which was 8% of the total emissions emitted by buses that year. Because of the increased use of HFCs to replace ozone depleting substances, HFC emissions in buses grew 35,629% from 1990 to 2008.¹⁸³

Analysis

Table 25 shows the GHG reductions that may be possible in 2030 and 2050 by replacing high GWP gases with other materials. Transit agencies can reduce the GHG impacts of its HFC use by inventorying sources, making repairs to leaks, improving any processes that may result in HFC emissions, and working toward adoption of low-GWP substitutes. A study of utility companies found SF₆ leak rates in the range of 9% to 11%.¹⁸⁴ The U.S. Environmental Protection Agency (EPA) reports CO₂ and HFO-1234yf may be available as possible substitutes for HFCs in bus and train air conditioning systems by 2020., which could reduce the GHG impact of these systems by 99.7 to 99.9%.¹⁸⁵ For building air conditioners, Microchannel Heat Exchangers are available today and could reduce emissions 35 to 50%, while low global warming potential blended compounds may be available after 2020 that could reduce emissions 50-90% according to EPA.¹⁸⁶ Water, inert gases, and fluorinated ketone are all available today as fire suppressants that would reduce GHGs 99.97 to 100%, with other substitutes anticipated after 2020.¹⁸⁷ By 2015-2020 refrigerators using hydrocarbons, CO₂ or HFOs may be available that would reduce GHG emissions by 99.7 to 100%.¹⁸⁸

In its 2008 GHG emission inventory, BART notes that it has been using an aerosol that emits HFC-134a in maintenance to remove chewing gum from passenger cars. The report notes, "The resulting HFC emissions from the use of freeze mist were estimated to be 2029.56 metric tons of CO₂ equivalent. Interestingly, while this only accounts for 2.3% of the total emissions of this GHG inventory, it is equivalent to over half (51.6%) of the emissions from all non-revenue vehicle fuel use in 2007."¹⁸⁹

12. MAINTENANCE

Summary

Table 26. Maintenance Energy and GHG Profile

| | Diesel Bus | | Diesel Bus with Maintenance Improvement | |
|--|---------------------------------------|---|--|--|
| | 2010 | 2030 | 2050 | |
| GHG Reduction vs. Diesel Bus | No Reduction | 3% to 5% | 8% to 10% | |
| Fuel Use Per Vehicle Mile (Gallons) | 0.28 | 0.26 to 0.27 | 0.25 to 0.26 | |
| Vehicle Miles per Gallon | 3.6 | 3.7 to 3.8 | 3.9 to 4.0 | |
| GHG Emissions (kg CO ₂ e) per Vehicle Mile | 2.8 | 2.7 to 2.8 | 2.6 | |
| GHG Emissions (kg CO ₂ e) per Passenger Mile at 28% Occupancy | 0.27 | 0.26 | 0.24 to 0.25 | |
| | Rail | | Rail with Maintenance Improvement | |
| | 2010 | 2030 | 2050 | |
| GHG Reduction vs. Base Case Rail | No Reduction | 16% to 18% electric or 3% to 5% diesel | 25% to 27% electric or 8% to 10% diesel | |
| Fuel Use Per Passenger Car Mile | 5.8 to 8.1 kWh or 0.59 gallons diesel | 5.5 to 7.9 kWh or 0.56 to 0.57 gallons diesel | 5.2 to 7.5 kWh or 0.53 to 0.54 gallons diesel | |
| GHG Emissions (kg CO ₂ e) per Passenger Car Mile | 3.5 to 6.0 | 2.9 to 5.8 | 2.6 to 5.5 | |
| GHG Emissions (kg CO ₂ e) per Passenger Mile | 0.14 to 0.21 | 0.11 to 0.18 | 0.10 to 0.16 | |

Description

Without proper maintenance vehicle efficiency can degrade substantially. According to the U.S. Department of Energy, “Every decrease in pressure by 1 pound per square inch for four tires can decrease fuel economy by 0.3%. Some fleets use nitrogen inflation, tire pressure monitoring systems, and other technologies to maintain optimum tire pressure.”¹⁹⁰ Engine tuning, wheel alignment, and even using the proper motor oil can provide slight improvements to efficiency that can add up across a fleet.¹⁹¹

In many ways, advancing maintenance practices to ensure peak performance of the vehicle fleet may be the most cost effective GHG mitigation action a transit agency can take.¹⁹² Allowing deferred maintenance to build up on a transit system can negate the climate actions an agency is taking.¹⁹³

New vehicle technologies or retrofits can put additional burdens on maintenance staff as they have to learn new systems, or manage the parts and maintenance multiple

different vehicle types. There are likely to be new maintenance issues that arise with every new technology, and every new vehicle model will require specific spare parts.¹⁹⁴ So GHG strategies with maintenance implications are more likely to succeed if a strong maintenance record can be demonstrated. Moreover, maintenance staff members understand the transit technologies inside out, so engaging them in the climate action planning can enable innovation.¹⁹⁵

Analysis

Table 26 shows potential energy and GHG emissions savings in 2030 and 2050 from maintenance. In 2030 it is assumed that savings from maintenance occur through improvements equivalent to maintaining tire pressure and alignment. The 2050 strategy assumes a system-wide innovative maintenance program that improves vehicle performance above business as usual. Tri-Met in Portland has been able to increase gas mileage in buses by 7.5% through maintenance improvements such as optimizing shifting efficiency, using tire pressure monitors, and performing front end alignments.¹⁹⁶

13. CONSTRUCTION AND LIFECYCLE IMPACTS

Summary

Table 27. Fuel Lifecycle GHG Profile

| Vehicle | Upstream Lifecycle Emissions Rate | Upstream CO ₂ e Emissions per Vehicle Mile (kg) | Total Lifecycle CO ₂ e Emissions per Vehicle Mile (kg) | Upstream CO ₂ e Reduction with Fuel Savings | | | |
|--------------------------------------|-----------------------------------|--|---|--|--------------------|--------------------|--------------------|
| | | | | 10% Fuel Reduction | 30% Fuel Reduction | 20% Fuel Reduction | 50% Fuel Reduction |
| | 2010 | 2010 | 2010 | 2030 | | 2050 | |
| Diesel Bus | 22% | 0.62 | 3.1 | 0.06 | 0.19 | 0.12 | 0.31 |
| Soy Based B100 Biodiesel Bus | 78% of diesel emissions | 2.70 | 2.7 | 0.27 | 0.81 | 0.54 | 1.35 |
| Waste Grease B100 Biodiesel Bus | 20% of diesel emissions | 0.69 | 0.69 | 0.07 | 0.21 | 0.14 | 0.35 |
| Diesel Commuter Rail Passenger Car | 22% | 1.32 | 7.3 | 0.13 | 0.40 | 0.26 | 0.66 |
| Electric Commuter Rail Passenger Car | 6% | 0.29 | 5.2 | 0.03 | 0.09 | 0.06 | 0.15 |
| Heavy Rail Passenger Car | 6% | 0.21 | 3.7 | 0.02 | 0.06 | 0.04 | 0.11 |
| Light Rail Passenger Car | 40% | 0.30 | 5.2 | 0.03 | 0.09 | 0.06 | 0.15 |

Description

Much of this report has focused on the direct emissions impact of transit agency operations. The upstream and downstream GHG impacts of transit agencies, though often smaller in scale than direct agency emissions, are much broader in scope. Lifecycle emissions include the emissions associated with all of the energy used to extract, refine, and transport vehicle fuels. Lifecycle emissions also include the emissions associated with the manufacture and disposal of transit vehicles. Construction and maintenance of transit facilities and infrastructure can also be a major source of system lifecycle emissions.

One estimate by Chester and Horvath finds that vehicle operation for Newark's Light Rail system accounted for just 24% of lifecycle transportation emissions. The same study finds that vehicle operations of an average urban transit bus accounted for 71% of lifecycle emissions. Rail systems in New York, San Francisco and Chicago were also estimated with vehicle operation emissions accounting for 34% to 57% of the system lifecycle total. The station and track infrastructure required for rail systems are a large part of why vehicle operations in these systems are a smaller share of the lifecycle total as compared to bus systems.¹⁹⁷

Lifecycle emissions, though not usually required to be reported under most GHG programs, are an area of increasing interest to many organizations that want to fully account for their GHG impacts. Organizations are beginning to work to determine the emissions of suppliers and contractors to be able to use their buying power to promote low materials and products with low GHG footprints. Though efforts have been made on a material-by-material basis to document lifecycle GHG impacts, the Greenhouse Gas Protocol Initiative is providing a first ever comprehensive method to enable organizations to measure and track lifecycle emissions.¹⁹⁸

As transit agency vehicles become more efficient and use less fuel the total lifecycle GHG impact of that fuel will fall as well. But transit agencies can further reduce the lifecycle impacts of fuel use through procurement efforts that measure and reduce the lifecycle emissions impacts of fuel sources through the supply chain. It is becoming increasingly possible for transit agencies to understand the GHG impact of the entire supply chain of a given purchase, from office paper to capital equipment as manufacturers and suppliers work to document their GHG footprints. Local sourcing of materials is one way to cut down on the lifecycle GHG impact of goods, and using local, low-carbon goods and manufacturers helps build the U.S. green economy.¹⁹⁹

Analysis

Table 26 shows the potential upstream GHG savings per vehicle mile of transit vehicles with reduced fuel use. The lifecycle GHG impacts of electricity use include the emissions associated with the generation of electricity that is then lost during transmission and distribution, and extraction, refining and transport of generation fuel. Transmission and distribution losses represented approximately 6% of electricity use in 2008, but can be higher in some areas.²⁰⁰

The lifecycle or "Well-to-Wheel" emissions of transportation fuels are an area of intense analysis and uncertainty as efforts are made to ensure alternatives to petroleum use create real benefits to global climate change mitigation considering impacts over their entire supply chain and beyond. U.S. EPA estimates the lifecycle GHG impacts of diesel fuel to be 22% of the direct GHG emissions from vehicle use²⁰¹ Therefore, when one kg

of CO₂e is emitted from a diesel vehicle another 0.22 kg of CO₂e have been emitted to extract, refine, transport, and supply that diesel fuel to the vehicle.

On a lifecycle basis, U.S. EPA finds that soy-based biodiesel reduces GHG emissions 22% over a 100 year analysis period when used in place of diesel fuel. While biodiesel has low anthropogenic tailpipe emissions, large scale adoption of soy-based biofuels would result in the conversion of ecosystems around the world that currently sequester carbon into the agricultural production of soybeans resulting in significant GHG emissions. Biodiesel made from waste grease would not have this impact on land use, so it is found to reduce lifecycle GHG emissions 80% against diesel. Ethanol ranges in emissions impact from a 13% increase in lifecycle emissions for corn derived ethanol with coal used in processing to a 128% reduction in lifecycle emissions against gasoline for switchgrass ethanol.²⁰²

Many of the materials used in building and maintaining transit systems have significant lifecycle GHG impacts. Data on lifecycle GHG of materials, manufacturing, and products is becoming increasingly available as suppliers and purchasers both seek to reduce the GHG footprint of goods. The process of making cement includes heating calcium carbonate in a kiln to transform it into lime, a chemical reaction that emits approximately 0.5 kg of CO₂ for every kg of cement created.²⁰³ The energy used in the process, such as to heat the kiln, adds another 0.6 kg CO₂ emissions to the lifecycle impact of a kg of cement.²⁰⁴

One model shows lifecycle emissions for virgin steel production at 5.2 kg CO₂ per kg material.²⁰⁵ Aluminum, which has a very energy intensive production process, has an emission profile of 11.66 kg CO₂e per kg material for virgin wrought aluminum and 9.72 kg CO₂e for virgin cast aluminum.²⁰⁶ Using recycled materials can reduce the lifecycle footprint of a project substantially; the lifecycle CO₂ emissions of recycled aluminum and steel are estimated at just 26-42% of the virgin metal.²⁰⁷ Tri-met in Portland is making use of recycled plastic railroad ties and bollards, which have lower lifecycle carbon intensity than steel.²⁰⁸

The full GHG impact of a transit construction project—such as a light rail route addition—is only beginning to be understood, but is likely to be a large source of emissions.²⁰⁹ Because organizational GHG inventories are generally done on an annual basis, and transit construction projects happen intermittently, the GHG impacts of infrastructure development may not be part of a transit agency's GHG baseline. As a result, when construction projects do take place they will have a big impact on an agency's emissions inventory. Efforts to reduce the carbon-intensity of the operation, from the planning phase forward, can mitigate the impact of the project's emissions on the agency's GHG profile. Construction standards, like those offered by the U.S. Green Building Council's Leadership in Energy and Environmental and Design (LEED)

program, can help an agency plan and implement a construction project with a lower GHG impact.²¹⁰

Lifecycle emissions also include end-of-life emissions. When materials such as paper are sent to the landfill they produce GHG emissions as they decompose. Reducing and recycling waste can cut the downstream lifecycle emissions of a transit agency. Proper disposal of items containing high GWP gases, such as refrigerators, to ensure the gases are captured and reused can reduce the end-of-life emissions footprint such items.

14. NON-REVENUE VEHICLES, EMPLOYEE COMMUTE, AND EMPLOYEE TRAVEL

Summary

Table 28. Light Duty Vehicle Energy and GHG Profile

| | Light Duty Vehicle | New Light Duty Vehicle | | Commercial Light Duty Vehicle | New Commercial Light Duty Vehicle | |
|---|--------------------|------------------------|-------|-------------------------------|-----------------------------------|-------|
| | 2010 | 2030 | 2050 | 2010 | 2030 | 2050 |
| GHG Reduction vs. Current Vehicle | No Reduction | 42% | 52% | No Reduction | 49% | 58% |
| GHG Reduction with Reduced Use | No Reduction | 54% | 76% | No Reduction | 59% | 79% |
| Fuel Use Per Vehicle Mile (Gallons) | 0.05 | 0.03 | 0.02 | 0.07 | 0.04 | 0.03 |
| Vehicle Miles per Gallon | 20.5 | 35.6 | 43.2 | 14.3 | 28 | 34 |
| GHG Emissions (kg CO₂e) per Vehicle Mile | 0.43 | 0.25 | 0.20 | 0.62 | 0.32 | 0.26 |
| GHG Emissions (kg CO₂e) per Passenger Mile at 1.6 Occupants | 0.27 | 0.16 | 0.13 | 0.38 | 0.20 | 0.16 |
| Vehicle Mile Reduction | No Reduction | 20% | 50% | No Reduction | 20% | 50% |
| Annual GHG Emissions (kg) | 4,896 | 2,269 | 1,170 | 6,736 | 2,760 | 1,423 |

Description

The non-revenue portion of transit agency vehicle fleets is an important area for efficiency improvements. As with revenue vehicles, transit agencies are required to report the GHG emissions of vehicles they own or operate under most of today’s GHG reporting schemes. Cars and light trucks in the non-revenue fleet can benefit from the substantial improvements in vehicle efficiency that are coming onto market. In addition transit agencies can choose to evaluate the uses of its non-revenue fleet and determine if travel could be reduced through trip consolidation or employees riding revenue vehicles.

Some businesses and government agencies are moving to replacing their fleets with car sharing programs. Car share programs allow individuals to rent a car by the hour in urban areas. By switching to a car share program for business vehicle use organizations are able to limit employee vehicle use to that which is really necessary. Outsourcing fleet management is another benefit of car sharing to most organizations, but that is less

of an issue for transit agencies that are already managing and maintaining a large fleet of vehicles.²¹¹

Transit agencies give everyone in the community transportation options for their journey to work. This provides a major benefit to employers, especially as more and more companies are taking measure of their GHG footprint. Most GHG reporting systems do not require companies to consider employee commute emissions, as employee personal vehicles are not directly owned or operated by the company, but tabulating employee commute emissions is often recommended because employers have many ways to influence the commute behaviors of their staff. Transit agencies are no different than other companies in this respect. While transit agency staffs know more than anyone else about the available transit options in their community, they may not be acting on that knowledge. The San Francisco Municipal Transit Agency surveys staff about their commute and has commute challenges to promote low-carbon commuting, such as through transit ridership, bicycling walking, and carpooling.²¹²

Employee business travel is another source of emissions that is recommended, but not required, to be tracked by most GHG reporting systems. Accounting for emissions from employee travel can help identify places for cost efficiencies as well as energy savings. Technology advances have greatly improved our ability to gather and share information from our office, but flying and driving to meetings is still the norm. Web-based participation is increasingly being offered for meetings and public hearings, and improvements in video conferencing technology progress transit agencies may make this type of communication a truly viable substitute for much business travel.

Analysis

Table 28 shows the GHG emissions and energy use associated with the average light duty travel today and estimated potential savings with new vehicles and reduced vehicle travel in 2030 and 2050. The 2030 values are based on U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook* (AEO) fuel economy forecasts and the 2050 values are extrapolated from AEO trends.²¹³ Non-revenue vehicles can benefit from the technology improvements that are likely to occur in the light duty vehicle sector into 2030 and 2050. As hybridization, electrification and fuel cells advance, transit agency maintenance vehicles, forklifts, and other parts of the non-revenue fleet can make use of these technologies to cut GHG emissions.

15. FACILITIES

Summary

Table 29. Facility Efficiency Energy and GHG Profile

| Year | Average Commercial Building | Efficient Facility | | | |
|---|-----------------------------|--------------------|---------|---------|---------|
| | 2010 | 2030 | 2030 | 2050 | 2050 |
| Savings | 0% | 30% | 50% | 50% | 80% |
| Electricity Use (kWh) | 191,624 | 134,137 | 95,812 | 95,812 | 38,325 |
| Natural Gas Use (Standard Cubic Feet) | 403,765 | 282,635 | 201,882 | 201,882 | 80,753 |
| CO ₂ e per building (kg) | 116,151 | 95,479 | 68,199 | 68,199 | 27,280 |
| Electricity Saved (kWh) | Not applicable | 57,487 | 95,812 | 95,812 | 153,299 |
| Natural Gas Saved (Standard Cubic Feet) | Not applicable | 121,129 | 201,882 | 201,882 | 323,012 |
| CO ₂ e Saved Per Building (kg) | Not applicable | 40,920 | 68,199 | 68,199 | 109,119 |

Description

Transit agencies typically operate a wide variety of facilities from offices and customer service centers to bus stops and maintenance yards. While the energy use and associated GHG emissions of transit agency facilities typically pale in comparison to that used by transit vehicles, facilities provide many opportunities for cost-effective efficiency improvements. Energy service contracts or partnerships with energy utilities can address the upfront cost of facility retrofits, allowing the cost to be paid for over time with energy bill savings. This was done successfully in New York to retrofit subway tunnel lighting and climate control equipment.²¹⁴

The average commercial building in the U.S. is 14, 000 square feet and uses 1,253 million BTUs of energy each year, or 89,800 BTU per square foot. These values are averages and vary by the building use, location, climate, age and other characteristics – an average warehouse uses just 45,200 BTUs per square foot, while an office uses more than twice that at an average of 92,900 BTUs per square foot.²¹⁵

There are no national statistics on the energy use at transit agency facilities, but some agencies have documented facility energy use as part of GHG inventories. The Alameda Contra Costa Transit District in California (AC Transit) reports 10.97 million kWh in electricity use and 372,000 therms of natural gas use in 2006, or 74,630 million BTUs

total. A small share of this natural gas was used to generate hydrogen for its fuel cell buses. This electricity and natural gas use was 6.5% of the agency's GHG emissions (93.5% was diesel and gasoline used for the vehicle fleet).²¹⁶ Every transit agency will be different—California's relatively mild climate, means lower winter heating needs for occupied buildings, for example. Transit agencies that operate climate controlled and lighted stations can expect facilities to be a larger share of overall energy use and emissions than those with mainly bus shelters.

Analysis

Table 29 demonstrates potential energy and emissions savings from facility energy efficiency efforts on an average commercial building in the U.S. Energy efficiency retrofits can help existing buildings cut energy use, increase comfort, and reduce facility operating costs. Using today's technologies commercial buildings are achieving savings of 30% and more with cost effective retrofit measures.²¹⁷ A high profile commercial retrofit, New York's Empire State Building, is achieving 38% energy reduction, and studies conducted while planning the retrofit found savings as high as 55% possible.²¹⁸ Not all of the retrofit measures needed to get to that level of savings were cost effective at this time, but according to the U.S. Department of Energy, by 2050 cost effective savings in the range of 50 to 80% may be feasible.²¹⁹ New facilities provide additional opportunities for energy savings against business as usual as building materials, orientation, and systems can be designed from the ground up to achieve efficient energy use.

The largest energy use in commercial buildings is for temperature control. Heating, cooling and ventilation (HVAC) make up 52% of energy use in commercial buildings, followed by lighting at 20%.²²⁰ Other uses include water heating, refrigeration, cooking, computers, and office equipment.

As the largest source of energy use and emissions HVAC is also the biggest potential source of saving for buildings. The need for heating and cooling can be reduced through increased insulation, better sealing the building envelope, improved windows, and climate sensors and controls. The performance of HVAC systems can also be greatly improved through retrofit or replacement and ongoing maintenance. Some retrofit steps are specific to transit agency facilities, for example AC Transit credits the installation of high-speed rollup doors at some facilities with at least a portion of the 40,000 therm drop in natural gas use between 2004 and 2005 at one facility as the new doors are closed more often in the winter.²²¹ This strategy could have even greater impact in a region with greater winter heating and summer cooling needs.

As the second source of largest source of energy use, lighting provides opportunities for fast and cost effective improvements. Newer fluorescent and LED lighting uses just a fraction of past models, especially when combined with lighting designs that focus light

on the areas that need it. Increasing the amount of daylight in a building not only reduces lighting needs, but can make for a more environment for workers and customers. The renovation of Coney Island's Stillwell Avenue Terminal Train Shed in New York included use of some transparent photovoltaic panels, so that during daylight hours indoor lighting is only required 2% of the time.²²² Occupancy sensors and timers can cut costs by making sure lighting is only on when needed.

Turning off equipment when not in use and upgrading to more efficient models will reduce electricity use as well. Refrigerators and vending machine may not seem like big sources of energy use in the context of an entire transit agency, but modern Energy Star models use half the electricity of previous models.²²³

Elevators and escalators are large energy users in transit stations and offices. The energy use of this equipment will depend on its design, size, and use, but average elevator can use 7,400 kWh per year and an average escalator can use 20,500 kWh per year. Retrofit options such as demand response systems and motor efficiency options can reduce energy use by up to 40%.²²⁴

The energy use of water heating equipment can be decreased with simple measures such as turning down the thermostat and adding insulation. Facility retrofits to achieve energy efficiency can also be used as an opportunity for water efficiency improvements. Solar water heaters are also being used by some transit agencies to cut the energy use of water heating.

16. LAND USE

Summary

Table 30. Land Use Efficiency Energy and GHG Profile

| | Light Duty Vehicle | Transit Oriented Household Vehicle | |
|---|--------------------------|---------------------------------------|----------------|
| | 2010 | 2030 | 2050 |
| GHG Reduction vs. Average Light Duty Vehicle Use | No Reduction | 10% to 60% | 31% to 78% |
| Vehicle Miles Traveled | 11,432 | 4,573 to 10,289 | 2,515 to 7,888 |
| Fuel Use Per Vehicle Mile (Gallons) | 0.05 | 0.05 | 0.05 |
| Vehicle Miles per Gallon | 20.5 | 20.5 | 20.5 |
| Annual GHG Emissions per Vehicle (kg) | 4,909 | 1,965 to 4,422 | 1,081 to 3,390 |

Description

Recent research has shown that transit can impact travel behavior in a neighborhood even among those who are not riding transit. A February 2008 report from ICF International found, “[A] significant correlation between transit availability and reduced automobile travel, independent of transit use. Transit reduces U.S. travel by an estimated 102.2 billion vehicle miles traveled (VMT) each year.”²²⁵

The Center for Neighborhood Technology’s (CNT) 2010 report, *Pennywise Pound Fuelish: New Measures of Housing + Transportation Affordability*, finds that,

“[L]ocation-efficient neighborhoods – compact, mixed use communities with a balance of housing, jobs, and stores and easy access to transit – have lower transportation costs because they enable residents to meet daily needs with fewer cars, the single biggest transportation cost factor for most households.”

CNT’s analysis shows that transit ridership increases with housing density – a doubling of housing density from 10 households per acre to 20 results in the share of commuters using transit doubling from 15% to 30%. Auto ownership, vehicle travel, and household transportation costs decrease as household density increases, as well.²²⁶

As land owners and major community stakeholders, transit agencies can work with the communities they serve to promote location efficient land uses. San Francisco has targeted new development in transit corridors to help meet its GHG reduction goals through transit ridership, and is working to promote multimodal solutions with street redesigns and signal timing. Bicycle parking car share car parking near transit are also enabling multimodal trips that link to transit.²²⁷

Analysis

Table 30 shows the potential energy and GHG reduction possible in 2030 and 2050 with reduction in VMT per personal vehicle. In 2010 CNT study for the Center for Transit Oriented Development (CTOD) it was found that households living within a half-mile of transit stations in the most location efficient areas of Chicago produced 78% less CO₂e than the average household in the region. This value is used as the high end of potential savings for this strategy in 2050. The next most location efficient areas showed emissions savings of 60% below the region, and this value is used as the high end of the range of what a transit agency could achieve with this strategy by 2030. Households living near transit in moderately location-efficient areas had 10% to 31% lower transportation GHG emissions than average households. These values are used as the low ends of the ranges for this strategy in 2030 and 2050. The only Chicago-area households near that transit had transportation GHG emissions higher than the regional average were those that lived in the least location efficient areas—neighborhoods with low residential density, large blocks, far from employment centers.²²⁸

Modeling the projected growth in the Chicago region to 2030, CNT finds that household transportation emissions can be as much as 28% below business as usual if growth is directed into the neighborhoods surrounding fixed-guideway transit stops. The potential savings increases to 36% if households move to the densest transit-oriented neighborhoods at a greater rate.²²⁹

17. RIDERSHIP AND OCCUPANCY

Summary

Table 31. Occupancy Increases and GHG Emissions by Mode

| | 2010 | | 2030 | | 2050 | |
|-------------------------------|------------------------|---|------------------------|---|------------------------|---|
| | Average Occupancy Rate | CO ₂ e per Passenger Mile (kg) | Average Occupancy Rate | CO ₂ e per Passenger Mile (kg) | Average Occupancy Rate | CO ₂ e per Passenger Mile (kg) |
| Transit Bus | 28% | 0.27 | 35% | 0.22 | 50% | 0.15 |
| Electric Commuter Rail | 30% | 0.14 | 37% | 0.11 | 52% | 0.10 |
| Heavy Rail | 47% | 0.14 | 54% | 0.12 | 52% | 0.08 |
| Light Rail | 37% | 0.21 | 44% | 0.18 | 69% | 0.10 |

Description

One of the primary metrics of transit vehicle climate change impact is CO₂e per passenger mile. The exact same transit vehicle can have two completely different values under this measure depending on the occupancy of the vehicle. Therefore, increasing ridership on existing transit vehicles can improve a transit agency’s overall efficiency.

Strategies to increase ridership have been well documented in the literature. New technologies such as travel planning software and real-time arrival information are making it easier for travelers to use the public transit system, which can increase ridership.²³⁰

The occupancy of transit vehicles varies greatly by time of day and day of the week. The morning and evening rush hours are the times of peak occupancy on weekdays, and an activity like a sporting event can produce full capacity crowds on transit for an evening. Transit agencies need to plan to accommodate such peak events, but the off-peak periods are when efforts to improve occupancy can have the most impact. By creating a steady demand for transit during mid-day, night time, and on weekends transit agencies can improve operational efficiency while meeting the service needs of the community.²³¹

Occupancy is calculated by dividing the number of passengers by the seats on a vehicle and does not include standing room. So, a completely full transit bus with all seats full and standing room at full capacity would have an occupancy rate of 160%. Heavy rail could have a maximum occupancy of 290%.

Analysis

Table 31 shows the potential GHG per passenger mile improvements that can be made by increasing transit vehicle occupancy in 2030 and 2050. GHG emissions per passenger mile in this strategy are calculated based on base case vehicle emissions per seat mile divided by the 2030 and 2050 occupancy rates for each mode.

The occupancy increases in this strategy are feasible, but substantial. The occupancy rates analyzed for 2030 and 2050 were selected as described below:

- This strategy assumes that occupancy rates can be increased on all modes 7 percentage points by 2030 and 22 percentage points by 2050. On a 38 seat diesel bus an increase from 28% occupancy to 50% requires the addition of 8 passengers per vehicle. The 2050 targets for commuter rail, heavy rail, and light rail require the average addition of 25, 12, and 14 passengers per passenger car respectively.
- A 50% occupancy rate on transit buses is higher than any public transit agency is achieving today. The highest occupancy achieved among the 50 largest bus systems in the U.S. is 58% at Academy Lines in New Jersey,²³² which is a privately owned commuter service that offers many routes that only operate at peak times when ridership and occupancy rates are greatest.²³³ MTA New York City Transit achieved a bus occupancy rate of 41% in 2008.²³⁴ Internationally, there may be systems achieving higher occupancy rates, but for this analysis of occupancy only data from the *National Transit Database* were used to enable apples-to-apples comparisons.
- The 52% commuter rail occupancy rate analyzed for 2050 matches that of the highest achieved in 2008 by the Central Puget Sound Regional Transit Authority (Sound Transit) in Washington.²³⁵
- Only one heavy rail system had higher occupancy in 2008 than the 69% rate analyzed for 2050; the New Jersey PATH achieved 94% occupancy, followed by the Los Angeles Metro at 64%.²³⁶
- Similarly, only one light rail system had higher occupancy in 2008 than the 59% rate analyzed for 2050. The Massachusetts Bay Transportation Authority (MBTA) had the highest occupancy of any light rail system at 73%. The next highest occupancy rate for light rail was 47%, which was achieved by both Metro Transit in Minnesota and the Metropolitan Transit Authority of Harris County, Houston, Texas (Metro).²³⁷

Occupancy increases improve the energy and GHG emissions per passenger mile of the transit system, but increasing the occupancy rate of vehicles does not reduce the GHG

emissions of transit agency operations. In fact, additional riders may cause slight increases in energy use, as the additional weight requires more fuel to move the vehicle. Adding 10 riders to a typical diesel bus could increase the bus weight by 5% over the vehicle weight at average occupancy levels. Additional riders may also increase stopping and loading times for transit vehicles. The additional fuel use caused by increasing vehicle loads is not accounted for here, but is quite small. The marginal GHG emissions per mile of an additional passenger are very close to zero.

For each new transit rider that switches from personal vehicle use GHG emissions are avoided in the community. The amount of personal vehicle emissions displaced by transit will vary based on factors such as the trip length transit replaces, the type of vehicle that would have been used, and the occupancy rate of personal vehicles. Moreover, some new transit trips may displace zero emissions activities such as walking or biking or may induce travel that would not have happened otherwise. Given all of these variables, it is recommended that a transit agency use a model specific to their system to determine the GHG avoided by transit in their region. The APTA *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit* suggests a default mode shift factor of 0.44 personal vehicle miles avoided per transit passenger mile, which can give a general sense of the scale of GHG savings.²³⁸

At the 2008 average of 20.5 miles per gallon for on-road passenger cars and light trucks, a personal vehicle emits 0.43 kg CO_{2e} per mile. Multiplying this by the mode shift factor results in 0.19 kg CO_{2e} avoided per passenger mile of transit ridership, as is shown in Table 32. The U.S. Department of Energy, Energy Information Administration’s *Annual Energy Outlook (AEO)* projects on-road fuel economy of 28 mpg in 2030,²³⁹ which is 0.31 kg CO_{2e} per mile and 0.14 kg CO_{2e} avoided per passenger mile of transit ridership. Extrapolating out the AEO projection to 2050 results in 36 mpg, or 0.25 kg CO_{2e} per mile which would make the emissions reduction from mode shift 0.11 kg CO_{2e} per passenger mile. Compared to the marginal GHG emissions of nearly zero for additional ridership through occupancy increases, this decrease in emissions in the community is sizeable.

Table 32. Emissions Avoided from Mode Shift

| | 2008 | 2030 | 2050 |
|---|------|------|------|
| On-Road Average Personal Vehicle Fuel Economy (mpg) | 20.5 | 28 | 36 |
| CO_{2e} Emissions per Mile (kg) | 0.43 | 0.32 | 0.25 |
| Mode Shift Factor | 0.44 | 0.44 | 0.44 |
| CO_{2e} Emissions Avoided per Passenger Mile of Transit Ridership (kg) | 0.19 | 0.14 | 0.11 |

The APTA GHG recommended practice also provides a method for calculating the GHG reduction in the community due to reduced congestion from transit ridership. This calculation has not been performed here because congestion forecasts for 2030 and 2050 are not available, but based on the APTA method and 2007 data from the Texas Transportation Institute, this benefit could be as much as 0.03 kg per passenger mile.²⁴⁰ The potential GHG reductions from land use changes are not calculated here, as increased ridership without transit expansion may not necessarily lead to additional land use changes.

If transit agencies expand service to increase ridership without increasing occupancy rates GHG emissions will be decreased in the region through mode shift, congestion reduction, and other factors, but the GHG inventory of the transit agency will increase as additional vehicle fuel is used. The U.S. Department of Transportation's 2010 Report to Congress, *Transportation's Role in Reducing U.S. GHG Emissions*, cites estimates that ridership expansion of 2.4% to 4.6% per year could create 6 to 18 million metric tons CO_{2e} in emissions reductions by 2030 and 9 to 32 million metric tons CO_{2e} by 2050. Ridership increase in these scenarios occurs through expansion of transit systems, increased frequency of existing transit, fare reductions, and improved travel times.²⁴¹

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