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Federal Transit Administration

TRANSIT GREENHOUSE GAS EMISSIONS MANAGEMENT COMPENDIUM

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Foreword

As major fleet operators and builders of extensive infrastructure systems, public transit agencies have an opportunity to demonstrate the benefits of a wide range of GHG emission reduction practices through both their day-to-day operations and through their capital investment programs.

The objective of this Compendium is to provide up-to-date information to transit operators, as well as regional transportation planners and decision–makers, on the sort of greenhouse gas (GHG) emissions reductions being reported, and on the sources of information available for making informed decisions about specific GHG reduction actions.

The Compendium provides a framework for identifying greenhouse gas (GHG) reduction opportunities, highlighting specific examples of effective GHG reduction practices. The GHG savings benefits of public transit are first described. GHG saving opportunities are then organized under four activity areas: 1. Agency Planning for System Expansions and Major Construction Projects; 2. Agency Fleet Procurement Practices; 3. Agency Fleet Operation and Maintenance Practices; and 4. Agency Support for Green Buildings and Green Workforce Practices.

The Compendium also includes a detailed GHG footprint for the Metropolitan Atlanta Rapid Transit Authority in Atlanta, Georgia. Data on MARTA's 2008 operations is used to demonstrate how transit agencies can use the data they collect to develop an annual GHG footprint. This footprint uses a three-scope emissions accounting system that is based on reporting recommendations made by the American Public Transportation Association.

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13. ABSTRACT : This Compendium provides a framework for identifying greenhouse gas (GHG) reduction opportunities while highlighting specific examples of effective GHG reduction practices. The GHG savings benefits of public transit are first described. GHG saving opportunities are then organized under four activity areas: Agency Planning for System Expansions and Major Construction Projects; Agency Fleet Procurement Practices; Agency Fleet Operation and Maintenance Practices; and Agency Support for Green Buildings and Green Workforce Practices. The Compendium includes a detailed GHG footprint for the Metropolitan Atlanta Rapid Transit Authority in Atlanta GA, demonstrating how agencies can use the data they collect to develop an annual GHG footprint. This footprint is based on reporting recommendations made by the American Public Transportation Association, using a three-scope emissions accounting system similar to the protocols developed by The Climate Registry and World Resources Institute.			
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List of Acronyms Use in this Report

AESS	Automatic engine stop/start controls
APTA	American Public Transportation Association
APU	Auxiliary power unit
BC	Black Carbon
CH_4	Methane
CO	Carbon Monoxide
CO_2e	Carbon dioxide equivalent
CNG	Compressed natural gas
DDHS	Diesel-driven heating systems
DGE	Diesel gallon equivalent
DOE	Department of Energy
DOT	Department of Transportation
EPA	Environmental Protection Agency
FTA	Federal Transit Administration
GGE	Gallon of gasoline equivalent
GHG	Greenhouse gas emissions
GWP	Global warming potential
HVAC	Heating, Ventilation and Air Conditioning
IPCC	Intergovernmental Panel on Global Climate Change
LCA	Life cycle analysis
LNG	Liquefied natural gas
LEED®	Leadership in Energy and Environmental Design (Certification)
MARTA	Metropolitan Atlanta Rapid Transit Authority
NO_x	Nitrogen oxides
N_2O	Nitrous oxide
NAS	National Academy of Sciences
GISS	National Aeronautics and Space Administration Goddard Institute for Space Studies
NREL	National Renewable Energy Laboratory
NTD	National Transit Database
O_3	Tropospheric Ozone
O&M	Operation and maintenance (Practices)
ORNL	Oak Ridge National Laboratory
PHEV	Plug-in hybrid electric vehicle
PV	Photovoltaic (cells, panels, systems)
TIGGER	Transit Investments for Greenhouse Gas and Energy Reduction (Grants)
TOD	Transit oriented development
TRB	Transportation Research Board

EXECUTIVE SUMMARY

Compendium Purpose and Organization

As vehicle fleet operators, and often as builders of extensive infrastructure systems, public transit agencies across the country are demonstrating the benefits of a wide range of greenhouse gas (GHG) emissions reduction practices, both through their day-to-day operations and through their capital investment programs. This Compendium provides a framework for identifying GHG reduction opportunities, while highlighting specific examples of effective GHG reduction practices. The objective of the Compendium is to provide up-to-date information to transit operators, as well as regional transportation planners and decision–makers, on the sort of GHG reductions being reported, and on sources of information available for making informed decisions about specific GHG reduction actions.[1]. GHG saving opportunities are organized in the Compendium under four activity areas:

1. Agency Planning for System Expansions and Major Construction Projects (Chapter 3)
2. Agency Fleet Procurement Practices (Chapter 4)
3. Agency Fleet Operation and Maintenance Practices (Chapter 5), and
4. Agency Support for Green Buildings and Green Workforce Practices (Chapter 6)

The Compendium also includes (Chapter 7) a detailed "GHG footprint" for a single transit agency, demonstrating how transit agencies can use the data they collect on energy consumption and combine it with data linking energy use to GHG emissions, to develop an annual GHG footprint. The footprint is based on data made available by the Metropolitan Atlanta Rapid Transit Authority (MARTA), one of the nation's largest public transit agencies, with extensive heavy rail, fixed route bus and paratransit services. The footprint follows closely the reporting recommendations made by the American Public Transportation Association (APTA) based on a Three-Scope emissions accounting system similar to the protocols developed by The Climate Registry and World Resources Institute. The results indicate that the regionwide GHG emissions reductions benefits from keeping transit riders out of their automobiles exceeds MARTA's current vehicle operating emissions from bus, rail and paratransit trips by between 2-to-1 and 3-to-1.

Before describing the many transit supply side actions covered by these four activity areas, such savings are placed in the context of transit's broader role in reducing GHG emissions by attracting automobile riders to leave their vehicles at home, and instead use alternative forms of more energy efficient and less polluting transportation such as bus, vanpool and rail transit. This includes the important role transit systems can play in encouraging more compact, and more travel efficient land development patterns.

From a transit agency's perspective, the ability to limit carbon dioxide and other GHG emissions, while maintaining high service frequency and ride quality, presents both a challenge and an opportunity: one tied closely to an agency's ability to reduce costly energy consumption in both vehicle fleet and fixed infrastructure operations. Supported by federal research and development

[1] The purpose of this report is not to propose GHG policies for the transit industry, nor does it recommend government actions to reduce emissions. Any products referenced in the report are meant to illustrate the types of actions possible, and are not an endorsement of any vendor specific product or service per se.

dollars, transit agencies have become important testbeds for developing more fuel efficient personal transportation technologies as well more energy efficient workplaces. The actions discussed in this Compendium draw on numerous studies reported in the literature. A web-based survey was also used to seek examples of successful and planned GHG reduction practices within transit agencies known to be pursuing innovative ways to reduce their energy bills and GHG emissions.

Summary of GHG Emissions Reduction Practices Discovered

The Compendium includes the following GHG reduction actions, reported in Chapters 3 through 6 respectively:

Planning for System Expansions & Major Construction Projects:

System Planning
Getting GHGs on the Agenda

Project Development
Putting GHG Impacts into the Assessment

Construction
Selecting Greener Construction Materials
Applying Energy Efficient Construction Equipment and Practices
Limiting Travel for Workers, Construction & Waste Materials

Transit agencies, along with State DOTs and MPOs are currently looking for ways to capture GHG emissions within the transportation planning and project selection process. This is starting to happen and is expected to become a common element as federal as well as regional climate change legislation evolves. With significant GHG emissions (and emissions reduction potentials) associated with large construction projects, there is currently a need to develop consistent measures of the full life-cycle emissions associated with capital investments in rail and highway system extensions. This includes the emissions resulting from the provision, application, transport, use, and disposal of construction materials such as concrete, asphalt and steel. While a good deal of information on the GHG emissions associated with construction processes is now becoming available (see Chapter 3), there is currently limited reporting on how to apply this to transit projects.

Vehicle Procurement Practices:

Selecting a Vehicle/Fuel Technology
Benefits of Electric, Electric-Hybrid, Biofuel, and Fuel Cell Buses
Emissions Reducing Railcar Technologies
Battery Supported Light Rail Systems
Hybrids for Paratransit, Non-Revenue, & Ferryboat Services

Successful GHG Emissions Reduction Technologies
Regenerative Braking
On-Board and Wayside Energy Storage Systems
Advanced Transmissions Technologies

Lightweight Materials
Smart Grid Technology
In-Wheel Electric Motors

The single biggest decision affecting a transit agency's production of GHG emissions is likely to be the selection of fleet vehicles, their energy efficiencies when in service and the types of fuel they use. Life cycle assessments of vehicle emissions indicate that hybrid-diesel buses have been very effective in reducing GHGs at reasonable cost, while biodiesel buses, electric powered buses and trolley –buses all offer significant GHG reductions, especially if the electricity driving them is from clean sources such as nuclear and hydro power. Gasoline hybrids are also popular purchases for non-revenue fleet vehicles.

Fleet Operation and Maintenance Practices:

Efficient Fleet Management Practices
Environmental Management Systems Certification
Uses of IVS/ITS Technology
Flexible/Deviated Fixed Route Services
Demand Responsive Real-Time Software
Vehicle-to-Passenger Load Matching
Route Restructuring
Reduced Vehicle Deadheading

Efficient Vehicle Operation
Driver Training
Idle Reduction Technologies & Protocols
Speed and Braking Controls
Low Rolling Resistance Tires

Vehicle Maintenance Practices
Real Time Maintenance Monitoring Technologies
Automated Fuel and Fluid Management Systems
Application of the latest Environmental Management Systems (EMS) techniques to vehicle fleet operation and maintenance practices is another way to reduce fuel consumption and GHG emissions. By making use of the latest in-vehicle monitoring and tracking technologies, transit agencies can gain benefits from reduced non-revenue vehicle miles to more efficient vehicle driving practices. A combination of idle shutoff technology and enforcement of idling protocols can offer significant fuel savings.

Green Building, Property, and Workforce Practices:

Sustainable Building Design, Construction and Operations
Green Building Codes and Standards
Integrated Design
Building Envelopes
More Efficient Energy Consuming Equipment

Renewable Energy Systems

Building Retrofits

Employee Travel Savings
Employee Rideshare/Flextime/Telecommuting & Bicycle Storage Programs

Public transit agencies have been at the forefront of green building practices over the past decade, introducing some of the earliest LEED® Certified buildings into a region. The energy consumed in heating, cooling, lighting, and operating on-site machinery can be a significant percentage of a transit agency's annual energy bill. The GHG emissions attributed to the MARTA's rail stations and yards, bus depots, offices, and other buildings in Chapter 7 represent roughly 30% of the agency's 2008 carbon footprint. While this percentage may vary a good deal across agencies, use of the latest building designs and operating technologies can prove cost effective as well as less polluting from an agency standpoint.

Most transit agencies appear to be interested in reducing greenhouse gas emissions from their operations, and as the case studies reported in this Compendium demonstrate, significant progress is being made. However, the quality of the empirical evidence currently available to help them do so is rather uneven. While the study managed to identify a wide range of actions that transit agencies have been using to reduce their GHG emissions, and in the process often lowering their energy bills, a consistent approach to selecting the best mix of these activities for a given situation and type of transit agency has yet to be developed. Still largely absent from the available empirical evidence is a comprehensive and standardized accounting of the costs associated with many GHG emissions reduction actions now available.

1. INTRODUCTION

1.1 Purpose and Organization of the Compendium

This Compendium describes both a framework and a set of in-practice examples for public transit agencies to consider when looking to reduce their energy consumption and greenhouse gas (GHG) emissions. In doing so, the Compendium provides the following information:

1. A framework for considering the many specific actions transit agencies can take to reduce their own GHG emissions (Chapter 1)

2. A concise statement of the important roles that public transit agencies play in reducing GHG Emissions (Chapter 2)

3. Example case studies, highlighting recent and current transit agency projects and practices that demonstrate and quantify ways to achieve significant GHG reductions (Chapters 3 through 6); and

4. A detailed "GHG footprint" for a single transit agency (the Metropolitan Atlanta Rapid Transit Authority in 2008), demonstrating how transit agencies can quantify their GHG emissions, and the nature of the data sources required to do so (Chapter 7).

As major fleet operators and builders of extensive infrastructure systems, public transit agencies have an opportunity to demonstrate the benefits of a wide range of GHG emission reduction practices, through both their day-to-day operations and their capital investment programs. Since the 1970 Clean Air Act, the nation's transit agencies have served as test beds for emissions reducing vehicle technologies. With the addition of GHGs to the list of emissions to be controlled for, transit agencies can similarly provide leadership in society's efforts to develop more environmentally benign transportation systems.

Information for the case studies reported in the Compendium is drawn from a number of sources: via a literature search; via analysis of the information contained in the National Transit Database; via a web-based survey and telephone follow-up with selected transit agencies. The Compendium has also benefitted from material contained in the American Public Transportation Association*'s Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit* (APTA, 2009), which offers additional case studies as well as additional technical details to support such practice.

The GHG footprinting chapter draws heavily on the latest ideas in life cycle analysis (LCA) in order to develop a comprehensive agency footprint, covering each of an agency's major GHG producing activities. A bibliography at the end of each chapter contains useful reference materials that readers may wish to pursue in search of greater details on a specific topic. The research project supporting development of this Compendium also produced a review of existing greenhouse gas emissions calculators available for use by transit agencies (Weigel et al, 2010).

The principal audience for the Compendium is transit system planners and both staff and board members in metropolitan planning organizations and state departments of transportation who want a single source of information on the sort of reductions in GHG emissions that are achievable, both currently and in the near future. Recognizing that the principal goals of a transit agency are to make public transit more accessible, more affordable, and ultimately more adoptable by the general public, the Compendium offers useful examples of how a transit agency might continue to do so, while at the same time limiting greenhouse gas emissions and certain aerosols produced by its services

In addition to providing benefits to society at large, successful carbon management practices can also bring immediate rewards to the transit agency itself. This includes help in marketing services to environmentally conscious riders, help in reducing the costs of purchased energy, and help in making the agency more attractive to federal grant programs (FTA 2009a,b). With both federal and many state governments considering limiting carbon emissions through such instruments as carbon 'cap and trade' programs, the more energy efficient a transit agency can become, the greater its chance of competing in the new carbon limited energy consumption marketplace.

Better GHG accounting can also prepare an agency for more effective participation in climate change registries, such as The Climate Registry, and U.S. EPA's Climate Leaders program, and for involvement in carbon trading schemes such as the Chicago Climate Exchange, and Climate Exchange Plc that are now starting to offer financial benefits for GHG emissions reductions. To get the most out of such schemes a transit agency will need to be able to measure GHG production from the acquisition and subsequent operation of all of its assets: its fuels, its vehicle fleets, and its built structures. Transit agencies can also play an important role here in setting a high standard for such reporting, one that can help an agency look for ways in which to cut GHGs, and ultimately benefit financially from the emissions it saves and the continually lowering costs of clean technologies it implements.

Finally, many of the actions for reducing GHGs described in the Compendium carry with them additional benefits to both a transit agency and society at large. The most obvious of these is energy cost savings, from which other benefits also accrue, notably reduced criteria pollutants, as well as a reduced dependence on imported oil (CFR, 2006). These benefits are usually addressed in the detailed studies found in the references supplied. An effort is made within the Compendium itself, however, to identify potential disbenefits and other barriers to the adopting specific GHG reducing actions.

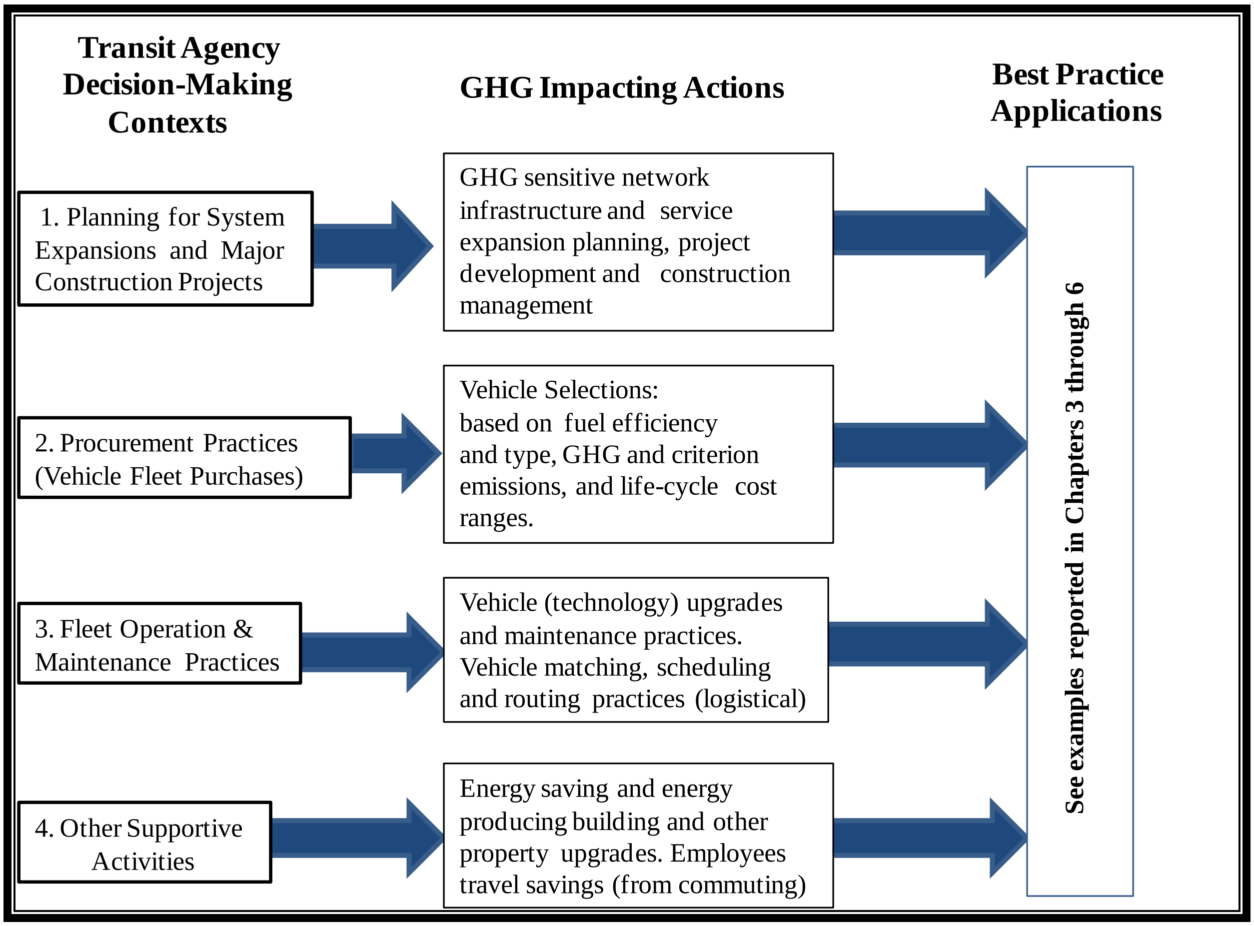
1.2 Emissions Reduction Framework: Key Activity Areas

GHG saving opportunities are organized in this Compendium under four activity areas:

Chapter 3: Agency Planning for System Expansions and Major Construction Projects
Chapter 4: Agency Fleet Procurement Practices
Chapter 5: Agency Fleet Operation and Maintenance Practices, and
Chapter 6: Green Building, Green Structures and Green Workforce Practices

Figure 1.1 provides a summary of the GHG measurement issues associated with each of these four areas, showing the linkages (from left to right) between agency planning and decision-making contexts, the GHG inventories they impact, example emissions reduction opportunities, and how these relate to the best practice case studies found within Chapters 3 through 6 of this Compendium.

Figure 1.1 Linking Decision-Making Contexts to GHG Reduction Opportunities and Best Practices



Planning for System Expansions and Major Construction Projects. A great deal can be accomplished if GHG emissions considerations are brought into an agency's strategic planning activities from the very start of the process, especially where the planning involves decisions about large monetary investments in new or improved infrastructure, vehicles, and levels of service. Significant capital investments in any of these activities may impact GHG emissions for years and possibly decades to come. They include the selection of new or significantly expanded guideways associated with both underground and above ground rail and bus projects, and may include new rail stations, new park-and-ride lots, new maintenance depots, garages and fuel storage facilities, offices, warehousing space and other buildings. System planning may also include the adoption of substantially revised bus transit system route plans.

Fleet Procurement Practices. A second area of opportunity addresses the embodied energy and GHG emissions associated with the production of different transit fleet vehicles (railcars, buses, vanpool vehicles, etc) as well as their more commonly reported end use, or *tailpipe,* emissions.

Fleet Operations and Maintenance Practices can also have a significant impact on energy usage and GHG emissions. Efficiencies can be obtained from a variety of practices. Briefly here, examples including driver training courses, better matching of vehicle size with temporally varying demands for service, properly inflating tires, and utilizing regenerative breaking systems.

Other Activities: Green Building, Green Properties, and Green Workforce Practices can all lower GHG emissions. Approximately 43 percent of U.S. carbon dioxide (CO2) emissions result from the energy services required by residential, commercial, and industrial buildings (EPA, 2006). The various buildings and other structures maintained and operated by transit agencies fall into this category. While transit vehicles account for the majority of energy used by a typical transit agency, buildings and other structures are also important consumers of energy. For example, of the 2.7 MMtCO2e emitted by the New York Metropolitan Transportation Authority (NYMTA) in 2007, 18% are attributed to electricity and heating in the agency's facilities, stations, and maintenance yards (Gallivan and Grant, 2010, Chapter 3). As derived in Chapter 7 of this Compendium, the GHG emissions attributed to Atlanta's MARTA system of rail transit stations and yards, bus depots, offices, and other structures represents an estimated 30% of the agency's 2008 carbon footprint, principally from electricity generation and consumption.

Since the late 1970s the United States has made remarkable progress in reducing the energy use and carbon intensity of its building stock and operations, with a 25 percent decline in energy use per square foot of commercial building space (Brown et al, 2005). This includes savings from retrofitting of energy efficient lighting fixtures and other green buildings practices associated with the adoption of the Leadership in Energy and Environmental Design (LEED®) certified activities. Retrofitting buildings with more energy efficient options includes periodic replacement with the latest lighting, heating and cooling system components. Renewable Energy (RE) installations can further increase the net efficiency of a building, and even be a source of offsetting revenue. Where new or significantly expanded stations, depots, garages and office buildings are concerned, data on current and emerging green building practices is available from a variety of sources, including assessments based on the U.S. Green Building Council's LEED™ certification of buildings.[2] Transit agencies can also help to reduce GHG emissions by supporting employer-based transportation demand management (TDM) strategies. Savings via reduced vehicle miles of travel can also come from flexible employee working programs, including telework, flex-time, and also rideshare programs.

Not directly related to these actions, but providing a context for the empirical values reported in subsequent chapters, Chapter 2 below provides a concise description of how shifts away from private automobile travel to public transit ridership help to reduce GHG emissions in some

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[2] See www.usgbc.org/leed/

significant ways. The Chapter also provides an introduction to the use of life cycle assessment (or LCA) as a tool for measuring and comparing the greenhouse gas emissions associated with the provision of both public transit and private automobile ridership.

1.3 Causes and Impacts of Global Climate Change

The large majority of climate scientists today believe that human activity in the form of greenhouse gas production is contributing significantly to a long-term warming of the planet.. These gases, most notably emissions of carbon dioxide (CO_2), but also significant amounts of non-CO2 GHGs and certain aerosols.[3] result from the rapid growth in fossil fuel-supported industrial production, itself fueled by rapid growth in world population and increasing levels of individual resource consumption (of food, health care, material possessions, travel, etc.) that have accompanied rising incomes in the more developed countries

Because of CO2's long "shelf-life" in the atmosphere and large anthropogenic production relative to many other short-lived GHGs, CO2 is the most important greenhouse gas over the long-term. However, the importance of non-CO2 GHGs should not be understated in that it is estimated that the combined impact of anthropogenic non-CO2 GHG emissions produced between 1750 and 2005 is considered to have caused a roughly equal amount of warming as anthropogenic emissions of CO2 caused during the same time period. If the effects of the anthropogenic emissions of black carbon over this time period are added to the impact of anthropogenic non-CO2 GHG emissions, the combined impact exceeds that of anthropogenic CO2 emissions (though CO2 is still is more important because of its generally longer shelf-life). If actions are not taken to limit GHG emissions, scientists at the Intergovernmental Panel on Global Climate Change (IPCC) anticipate global average surface temperature rises by the end of this century in the range 2.0 to 4.5 degrees Centigrade (3.6 to 5.2 degrees Fahrenheit) resulting from a doubling of Carbon Dioxide (equivalent) over pre-industrial levels (IPCC, 2007a). Such temperature changes bring with them considerable potential to disrupt current crop cycles and to affect economic activity in a variety of harmful ways, including loss of land and infrastructures to rising sea levels (Meyer, 2006), and increases in the frequencies of intense precipitation events, droughts, and hurricanes (IPCC, 2007b).

The Energy Information Administration (EIA)[4] and World Resources Institute (WRI)[5] estimate that almost 21% of worldwide GHGs are attributable to U.S. sources. Since 1980 total carbon emissions in the United States have increased by 0.8 percent each year. Even with the enactment of more stringent CAFE[6] , building, and appliance standards, total U.S. carbon emissions are projected to grow by another 7 percent between 2007 and 2030, making reductions all the more urgent if we are to avoid the worst effects of a warming planet (EIA, 2009a). Ongoing federally

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[3] Transit agencies may influence global climate through the emission of tropospheric ozone and black carbon. Because of their short atmospheric lifetime – which ranges from weeks to months -- and uncertainties about their global warming potential, these substances are currently not included in official emissions estimates (TRB, 2009).

[4] See http://www.eia.doe.gov/oiaf/1605/ggrpt/

[5] See http://cait.wri.org/ for access to the World Resources Institute's Climate Analysis Indicators Tool

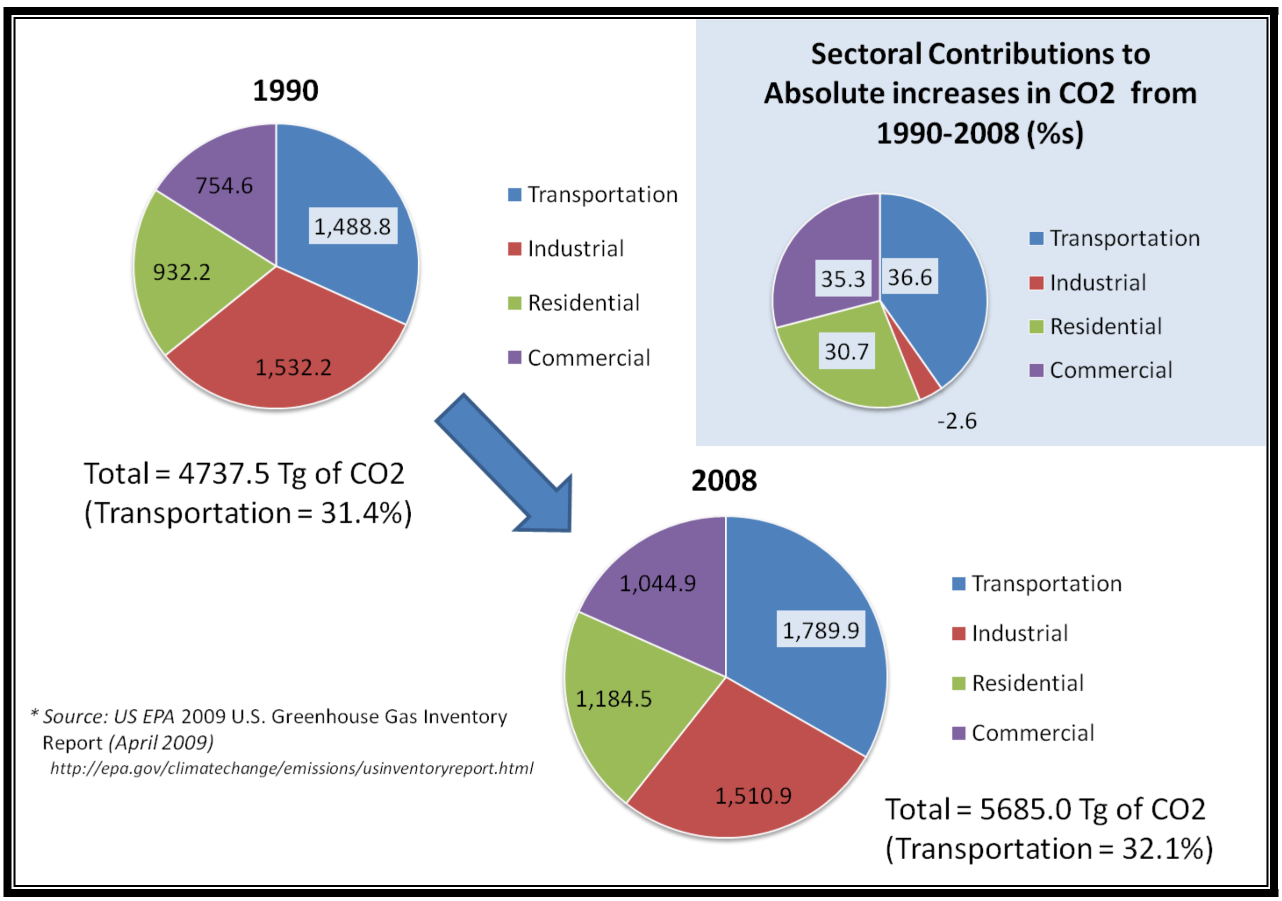
[6] Corporate Average Fuel Efficiency

mandated studies of the problem in the U.S. are seeking ways to mitigate future GHG emissions through a wide range of actions (NAS, 2009). Consistent with the recommendations for economy-wide actions coming out of recent U.S. National Academy of Sciences studies (NAS 1992, 2008, 2009), and the sort of responses the transportation sector might take to reduce our society's dependence on fossil fuels (TRB, 2009: Appendix B), the practices described in this report represent a subset of actions focused on reducing GHG emissions from public transit systems.

1.4 The U.S. Transportation Sector Emissions Profile

The transportation sector currently accounts for some 27 percent of the nation's annual end-use GHGs: with 95% of these emissions in the form of carbon dioxide (CO_2). This means that the U.S. transportation sector alone is responsible for almost 6% of worldwide GHG production. Transportation is also the fastest growing contributor to our economy's GHGs (see Figure 1.2), with expected improvements in the energy efficiency of vehicles forecast to be more than offset by anticipated growth in vehicle miles of travel (EIA, 2008, 2009b). Furthermore, the transportation sector in the United States is the largest contributor of the aerosol black carbon (BC), primarily through the use of diesel fuel. Aerosols are thought to have a net cooling effect on climate, but BC specifically is thought to have a warming effect.

Figure 1.2 Transportation End-Use Contributions to U.S. CO_2 Emissions 1990-2008



Although the percentages above are impressive, the particular constituents of the transportation-sector emissions profile cause even more warming relative to other economic sectors. New analysis shows that warming caused by the on-road transportation sector is enhanced by interactions between non-CO2 greenhouse gases and aerosols that can lead to the lengthening of the lifespan of methane (CH_4) already present in the atmosphere, contribute substantially to the warming caused by tropospheric ozone (O_3), and reduce the cooling properties of clouds, snow, and ice. NASA Goddard Institute for Space Studies modeling of climate change impacts has led to the conclusion that when using constant year 2000 GHG emissions levels, on-road transportation is and will be the most significant economic sector responsible for positive forcing (warming) in the short term (about 20 years out). By the end of the century, on-road transportation will still be the second most important anthropogenic perturbation on the climate, surpassed only by the power generation sector. Both of these sectors are represented in transit agency GHGs.

Additional examples of current public transit agency greenhouse gas savings practices can be found in *Current Practices in Greenhouse Gas Emissions Savings from Transit. TCRP Synthesis 84 (Gallivan and Grant, 2010).* http://www.trb.org/Publications/Blurbs/163614.aspx

The on-road transportation sector is the largest contributor of carbon monoxide (CO) emissions in the United States. Though methane emissions for the sector are small relative to other economic sectors, the indirect effect of CO on existing CH_4 in the atmosphere can have a substantial impact by extending CH_4's lifespan and consequently increasing its global warming potential (GWP). CO, along with Nitrogen Oxides (NOx) and non-methane volatile organic compounds (NMVOCs) from the sector, is also a precursor to the formation of $O_{3,}$ a greenhouse gas that causes atmospheric warming. Additionally, black carbon (BC) from the sector is an aerosol that can cause warming through effects on cloud properties and settlement on ice and snow cover. The on-road transportation sector is the largest contributor of black carbon aerosols in the United States.

In contrast, the power generation sector, which is currently ranked above transportation in terms of gross GHG emissions, presently has a much smaller net-warming impact than the on-road transportation sector due primarily to the negative forcing (cooling) effect of sulfate aerosol emissions. By the end of the century, this sector is projected to have a much stronger net-positive forcing due to the long shelf-life of CO2 emissions in the atmosphere that eventually overcompensates for the effect of negative forcings within this sector. Despite this, on-road transportation is still projected to be second in terms of warming by the end of the century, doubling its 2020 positive radiative forcing on the planet (Unger et al, 2010).

In addition to the GHGs and aerosols covered above, three additional classes of GHGs are associated with direct emissions from common leakages, such as leakages associated with building heating and cooling practices. These Perfluorocarbons (PFCs, with GWPs in the range 5,200 to 12,200), Hydrofluorocarbons (GWP range 124 to 12,800) and sulfur hexaflourides (SF_6, with GPWs in the range 16,300 to 22,800) are very effective absorbers of infrared radiation, so that even the leakage of small amounts of these gases contribute significantly to global warming. These are the sorts of emissions that need to be minimized, for example, through "green building" practices. It is common practice to use global warming potential (GWP) conversion factors to aggregate overall greenhouse gas emissions into what are called CO2 equivalents (CO2e) by including alongside CO2 the per-gram warming impact of non-CO2 gases in relative comparison to CO2. These typically include methane (CH4), with a per gram GWP 21 times that of CO2 over a 100-year period, and nitrous oxide (N2O) with a GWP 310 times that of carbon dioxide (IPCC, 2007). This methodology is employed in several of the example transit activities and case studies in this compendium. However, as noted previously, the indirect effect of transportation-specific non-CO2 greenhouse gas emissions, and the direct and indirect effect of black carbon have a substantial influence on the overall impact of the transportation sector emissions profile. While the CO2e methodology employed in this compendium is generally useful to translate overall GHG impact relative to CO2 alone, inclusion of transportation-specific indirect and precursor GHGs and direct and indirect aerosol effects in this methodology may be beneficial in future analyses.

Table 1.1 CO_2 Emissions per Gallon of Fuel or per Kilowatt-Hour of Electricity

Fuel Source:	CO_2 Emissions Rates:
Gasoline[1]	19.4 lbs /gallon (8.81 kilograms/gallon)
Diesel[1]	22.2 lbs/gallon (10.15 kilograms/gallon)
Ethanol[2]	12.6 lbs/gallon (5.7 kilograms/gallon)
CNG[1]	0.119 lbs/gallon (0.054 kilograms/gallon)
LNG[1]	9.83 lbs/gallon (4.46 kilograms/gallon)
Biodiesel[2]	21.2 lbs/gallon (9.6 kilograms/gallon)
Electricity[1,3]	Ranges from .272 to 2.28 lbs/kilowatt-hour (national average of 1.431 lbs/kWh)

Data Sources:

1. *EPA (2008) Climate Leaders Greenhouse Gas Inventory Protocol Core Module Guidance. Direct Emissions from Mobile Combustion Sources. U.S. Environmental Protection Agency, EPA430-K-08-004 Washington, D.C.* *www.epa.gov/stateply/documents/resources/mobilesource_guidance.pdf*

2. U.S. Department of Energy, Argonne National Laboratory *http://www.transportation.anl.gov/modeling_simulation/GREET/publications.html*

3. Brown and Logan (2008). *http://www.spp.gatech.edu/faculty/workingpapers.php* Tables B-8 and B-10

Notes: CNG =Compressed Natural Gas, LNG = Liquefied Natural Gas

1.5 Relating GHG Emissions to Energy Consumption

CO2e estimates produced in transportation planning studies and project assessments are usually obtained by tracking the amount of energy used to power different types of vehicles (i.e. rather than measuring atmospheric CO2e concentrations directly).[7] This means converting a gallon of fuel, or in the case of a mode powered by electricity, the number of kilowatt-hours (kWh) of electricity, into its CO2e. A number of readily accessible sources now provide conversion factors to help with this. However, it is important in using such sources to be aware of their underlying assumptions. Table 1.1 provides a set of CO_2 conversion factors for the most commonly reported alternative motor fuels used in transit vehicles. The figures represent typical average emissions rates, reported per gallon of liquid or gaseous fuel or per kilowatt-hour (kWh) of electricity, as reported in NAFA-EDF (2009).

The major determinant of how much CO_2e is associated with a kilowatt-hour (kWh) of electricity depends principally on the *fuel feedstock* used to produce this electricity, and notably coal, nuclear, or hydro-power. As a result, significant state by state differences exist. Utility generated electricity mainly from coal produced an upper value of over 2,000lbs of CO_2 per kWh in a number of coal dominated power production states,, while the States of Idaho and Washington but had values below 330 lbs/kWh in 2005, due to extensive use of hydro-electric power (Brown and Logan, 2008). For the purposes of this Compendium what matters most is our ability to compare the GHGs emitted across these different energy feedstocks (coal, petroleum, hydro, nuclear, solar and wind power) as well as across the different modes of transportation they enable, in a consistent manner.

1.6 GHG Emissions Calculations

While most transit agency decision-making contexts warrant evaluation of GHG emissions, the majority of transit agency GHG emissions arise from the energy and material processes supporting vehicle fleet propulsion. Therefore, vehicle and fuel procurement decisions involve considerable GHG emissions implications. Publicly available GHG emissions calculators fall under two main categories, each one reflecting different emerging needs of transit agencies for GHG reporting (Weigel et al, 2010):

1. Registry/inventory based calculators, most suitable for standardized voluntary reporting, carbon trading, and regulatory compliance.

2. Life cycle analysis (LCA) calculatorssuitable for demonstrating the benefits of transit over private automobile travel, or the advantages of one type of transit sub-mode or vehicle type over another.

Inventory-based calculators are generally consistent in their approach to GHG emissions quantification; however, their limited focus constrains their use for comprehensive GHG

[7] The direct measurement of CO2 is being done at thousands of sites around the world. In the U.S this includes the VULCAN project , see: http://www.purdue.edu/eas/carbon/vulcan/index.php

emissions estimation. LCA calculators represent a growing attention to the "upstream" and "downstream" GHG emissions associated with vehicle and fuel supply chains. With the passage of California's 2006 Global Warming Solutions Act (AB-32), the importance of more comprehensive LCA-based analyses is likely to increase, and to influence the way carbon registries accept reporting of GHG savings in the future. Both methods give most of their attention to the GHG (and energy) savings resulting from the use of alterative vehicle/fuel combinations that have immediate relevance to vehicle fleet and fuel procurement decisions. Federal data collection and reporting requirements, notably through the Federal Transit Administration's (FTA) National Transit Database (NTD), support the quantification of these actions by collecting fuel consumption, electricity use, and vehicle miles of travel data on a year by year basis.

The suitability and utility of a GHG emissions calculator depends upon the emissions reporting needs of the user. The inventory calculators that are based on a reporting protocol (APTA, 2009; EA 2009; ICLEI, 2009; The Climate Registry, 2009; WRI, 2009) follow what has become a standard "three-scope" division of emissions: direct emissions controlled by the agency (Scope 1), indirect emissions that occur outside of the agency (Scope 2), and "optional" emissions (Scope 3). With respect to revenue transit vehicle emissions, vehicle fuel combustion and refrigerant leaks fall under Scope 1, purchased electrical energy falls under Scope 2 (unless installing renewable energy onsite (e.g., solar or wind)), and upstream and downstream vehicle and fuel lifecycle emissions fall under Scope 3. The assumption of Scopes 2 and 3 is that these emissions would be accounted for as Scope 1 emissions by the organizations or entities that directly control them. GHG emissions avoidance due to a mode shift in favor of public transit, including congestion reduction and land use–related travel reduction benefits also come under Scope 3. The agency specific carbon footprint presented in Chapter 7 of this Compendium is based on this three scope approach as described in the American Public Transportation Association's "Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit" (APTA, 2009).

In addition to serving the requirements of emissions reporting, the calculator outputs should also support an internal evaluation of the emissions efficiency of fuel and vehicle procurement decisions. Such efficiency may be accounted for in terms of energy inputs (GHGs per gasoline gallon equivalent of fuel used), operational activity (GHGs per mile), or service output (GHGs per passenger-mile). An emission per passenger-mile based metric provides a widely applicable normalization that allows for comparison of GHG emissions efficiencies both across and within transportation modes.

While the integration of LCA and inventory/registry based GHG calculators evolves towards a common set of procedures, we have chosen in this Compendium to demonstrate the value of both approaches. In Chapter 3 we report on both the direct and indirect (largely "upstream") emissions savings associated with different fleet procurement options. Chapter 7 provides an example of how such indirect savings can be captured in the 3-Scope, inventory based protocol for GHG reporting proposed by APTA (2009).

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2. TRANSIT'S ROLE IN MITIGATING GLOBAL CLIMATE CHANGE

2.1 Introduction

Public transportation systems play an important role in reducing both the nation's energy consumption and its production of GHG emissions. Transit agencies have also been widening this GHG emissions gap between private automobile travel and public transit ridership by reducing their own GHG emissions. Significant GHG reductions can result from increasing transit ridership, whether considering the direct vehicle propulsion based emissions, or broader life-cycle assessments including vehicle, fuel, and infrastructure provision.

2.2 Riding Transit Can Reduce Vehicle-Combustion Related Emissions

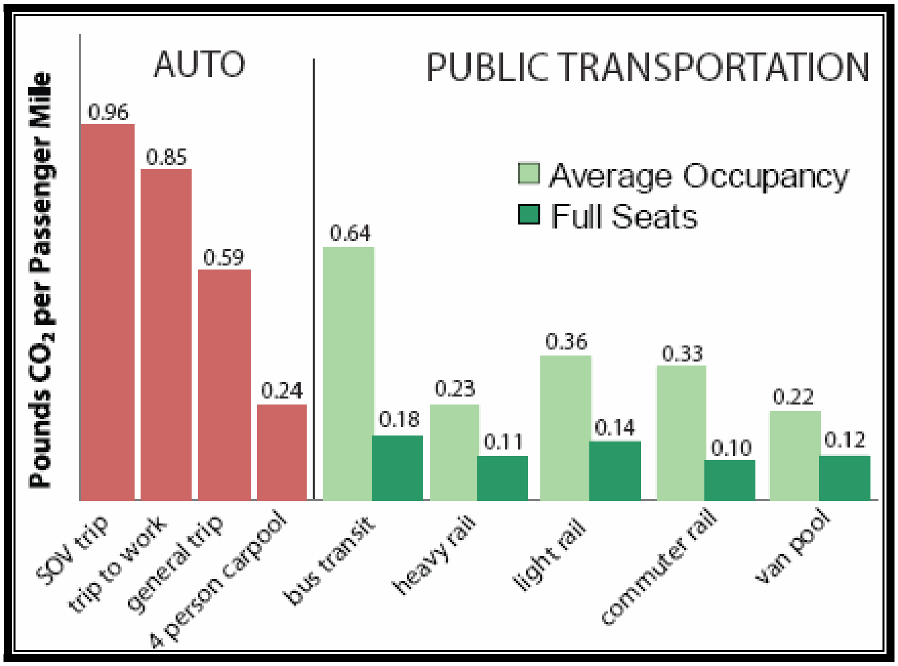
"Tailpipe" Emissions: While the average single occupant auto emits 0.96 pounds of CO_2 per passenger mile, the average public transit bus mile emitted only 0.64 pounds, while a (nationally averaged) bus with all seats taken would emit only 0.18 pounds per passenger mile. Similarly large, and potentially much larger savings are also possible from rail and vanpool services (see Figure 2.1).

Table 2.1 GHG Reductions Due to Public Transit: Recent Studies

Study	Findings - Annual Emissions Reductions
Hodges, 2010	While the average single occupant auto emits 0.96 pounds of CO2 per passenger mile, the average public transit bus mile emitted only 0.64 pounds per passenger mile in 2008, with a ridership weighted average over all public transit modes of 0.45 pound per passenger mile
Bailey, 2007; Bailey and Mokhtarian, 2008	Transit ridership saved more than 8.4 million metric tons of CO_2 in calendar year 2004
Southworth & Sonnenberg, 2007	Public transit systems operated in the nation's largest 100 metropolitan areas, when averaged over all mode/service types, produced less than 65% of the emissions of the equivalent number of private auto passenger miles on an annual basis

With travel by public transit modes accounting for less than 4% of all person miles of travel in the U.S (BTS, 2009), considerable additional potential to reduce nationwide GHG emissions resides in convincing Americans to travel less by low occupancy automobiles, pickup trucks and sport utility vehicles, in favor of higher occupancy public transit alternatives.

Figure 2.1 Estimated CO2 Emissions per Passenger Mile: Average and Full Vehicle Occupancies



Source: Hodges (2010)

Notes: The average number of passengers for private auto work trips = 1.14, and 1.63 for general trips.

Transit-Supportive Land Development Benefits: Public transit systems can also influence tripmaking, and therefore direct, vehicle-combustion based GHG emissions, through the land use arrangements they encourage and help to sustain. More compact and mixed land use arrangements can reduce direct, vehicle propulsion-based GHG emissions by reducing vehicle trip frequencies and trip lengths.

At the local level this effect can be felt through the siting of individual transit facilities. Such facilities have often been catalysts for a change in travel choices. To encourage downtown development the Chattanooga Area Regional Transit Authority (CARTA) developed peripheral parking garages with free shuttle service. By constructing parking facilities at either end of the business district the system intercepts commuters and visitors before they drive into the city center, reducing traffic problems. Free shuttle buses are financed through the garages' parking revenues. These buses depart from each garage every five minutes all day, every day, and pass within walking distance of most downtown destinations. The electric powered shuttles transport approximately one million riders each year, while also making shuttle-served property attractive to businesses (EPA, 2006).

A*t the regional or metropolitan level,* transit-oriented development (TOD) is one of the most effective strategies for linking land use and transit investment at specific sites. *TCRP Report 128: Effects of Transit-Oriented Development (TOD) on Housing, Parking, and Travel*, surveyed 17 housing projects that combined compact land use with transit access and found that these projects averaged 44 percent fewer vehicle trips per weekday than that estimated by the Institute for Transportation Engineers (ITE) manual for a typical housing development (Arrington and Cervero, 2008).

A 2008 study in Minneapolis-St-Paul found that comprehensive transit and smart growth policies will be essential to meeting Minnesota's goal to reduce GHG emissions 15% below 2005 levels by 2015. The study found that an extensive light rail transit (LRT) or bus rapid transit (BRT) network in the Twin Cities region might reduce statewide vehicle miles of travel by 2.2% in 2025. Improvements to the region's existing transit system could reduce statewide VMT by 0.3% (Boies et al, 2008).

In Portland, Oregon, studies of household location and travel behavior have indicated that transit service and mixed use development have had an important influence on reducing automobile trips, and even auto ownership. For example, neighborhoods with mixed use development and transit service had a 58% auto share for neighborhood trips and a VMT per capita of 9.8. This compared to a regional average of 87.3% auto share and a 21.8 VMT per capita. In Arlington County, Virginia, transit ridership in corridors served by regional rail service had 39% commute share by transit whereas the commute share outside the corridors was 17%. In the San Francisco Bay Area, the Bay Area Air Quality Management District approved guidelines in 2010 that gives cities and counties numerical pollution thresholds to use in deciding whether to require developers to conduct studies on ways to remove pollution during the land-use review process. Under the guidelines, developers planning projects expected to generate more than 1,100 metric tons of greenhouse gases a year — the amount from 55 typical new single-family houses — would have to conduct an environmental review on ways to reduce or offset pollution. To reduce their carbon footprint, developers could consider locating projects near bus and train stations, creating shuttles to transit centers, or installing solar energy panels on buildings and using energy-saving insulation.

Bailey et al (2008) found that the availability of a rail station within ¾ mile and a bus stop within ¼ mile of one's residence is associated with fewer miles driven: reducing aggregate, nationwide vehicular travel on the order 102.2 billion miles in 2004. This translates into an additional 3.4 billion gallons saved due to transit's secondary effects though more efficient urban form. At 8.9 Kg of CO_2 per gallon of gasoline this in turn translates into a reduction of 37 million metric tons of GHGs emitted in 2004 due to the presence and operation of the nation's public transit systems.[8]

Based on an analysis of household travel data sampled from many different urban areas, Bento et al (2005) estimate that a 10% reduction in distance to the nearest transit stop reduces annual average vehicle miles of travel by about one percent, while in the 26 cities with a rail system a 10% increase in rail route miles reduces annual vehicle miles of travel by 0.2%. They also found that a 10% increase in distance to the nearest transit stop raised the probability of owning one vehicle by about 3%; while greater rail supply reduced the likelihood of a vehicle purchase,

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[8] A number of other studies, including those reported in Davis and Hale (2007) and by APTA (2009), while correlative rather than causal, also find large *secondary* travel reduction multipliers associated with transit's interaction with urban form.

conditional on a city having a rail system to begin with. Brown et al (2008, 2009) show a similar association, with a positive correlation between rail transit mileage and lower carbon emissions per capita among the nation's 100 largest metropolitan areas. Chen et al (2008) found that higher job accessibility to work by public transit decreases the likelihood of households owning more cars in the New York metropolitan region, as well as deterring people from using the auto for home-based work tours: while longer distances to public transit at both home and work increased the propensity to use the automobile in home-based work tours. They also found that maximizing the transit-enabled job accessibility of all locations in such home-based tours helped to deter automobile use to some degree.

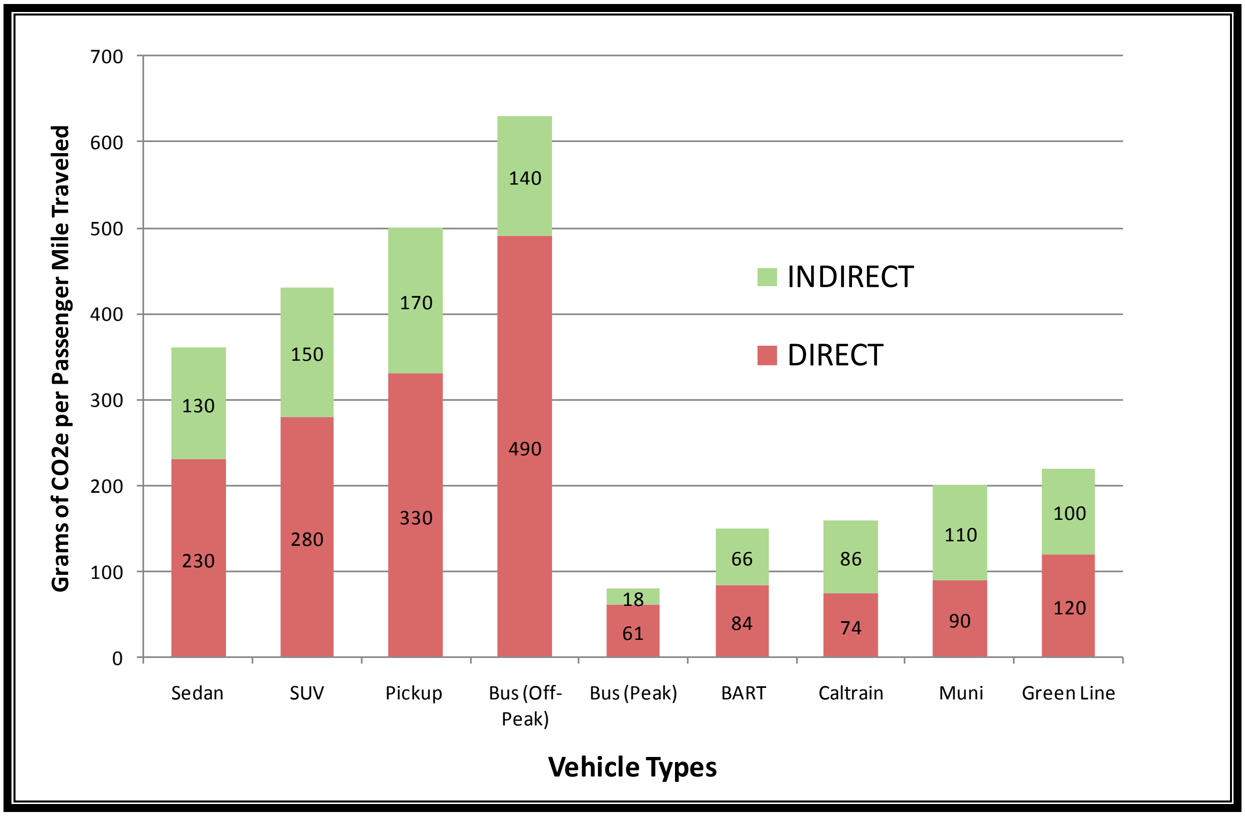
The recent *Report to Congress* (USDOT, 2010) describes a range of potential GHG reductions from land use strategies. Three studies were highlighted in the *Report to Congress* – the Urban Land Institute's *Growing Cooler* report (Ewing et al, 2008); the Urban Land Institute's *Moving Cooler* report (Cambridge Systematics, 2009); and the Transportation Research Board's *Special Report 298: Driving and the Built Environment* (TRB 2009). The *Report to Congress* took the middle estimate of the study ranges and adjusted them to the same baseline. This yielded a reduction of U.S. transportation GHG emissions of 1 to 4 percent in 2030 and 3 to 8 percent in 2050 for compact land use strategies. The TRB Special Report 298 *Driving and the Built Environment* (TRB 2009) concluded that "the literature suggests that doubling residential density across a metropolitan area might lower household VMT by about 5 to 12%, and perhaps as much as 25%, if coupled with higher employment concentrations, significant public transit improvements, mixed uses and other supportive demand management measures". All three reports concluded that transit, non-motorized improvements, and pricing would be most effective over the long term if they were implemented in combination with more compact and better integrated land use patterns that reduce overall trip lengths and make alternative modes viable as a means of travel for many trips.

2.3 Reduced Life Cycle Emissions

Direct, Upstream and Downstream Emissions: Before any fossil fuel is burned in a vehicle's engine, or electricity used for vehicle propulsion, a good deal of energy has already been expended, and GHGs produced in the manufacture and delivery of the fuel, the vehicle, the roadways and the many other built infrastructures that support these vehicle operations. The US Environmental Protection Agency (US EPA, 2006) refers to these emissions as either "upstream" emissions, produced during the processes of extraction (or in the case of biofuels, harvest), manufacture, assembly, and transport. In the case of transit systems this infrastructure includes rail tracks, stations, depots, bus shelters, park-and-ride structures and administrative offices owned or operated by the transit agency, as well as any dedicated (e.g. bus-only lane) roadways. There can also be *downstream emissions* associated with the processes involved in disposal or recycling of vehicles and their parts (e.g. tires), used oils and other spent lubricants, and with discarded building contents (e.g. old furniture, used light bulbs) and construction materials. These upstream and downstream emission are often grouped together and termed "indirect" emissions.

Figure 2.2 shows some of the results of a recent study by Chester and Horvath (2008). In all cases, for the systems they evaluated, well patronized public bus, light rail, and heavy rail transit services produce much lower upstream as well as lower direct emissions per passenger mile than does private automobile travel. It is also clear from this study, however, that ridership levels play a large role in transit's ability to reduce travel related GHGs. More riders means more fuel saved and fewer GHGs produced.

Figure 2.2 Direct (Vehicle Propulsion) and Indirect Emissions for Selected Passenger Modes*

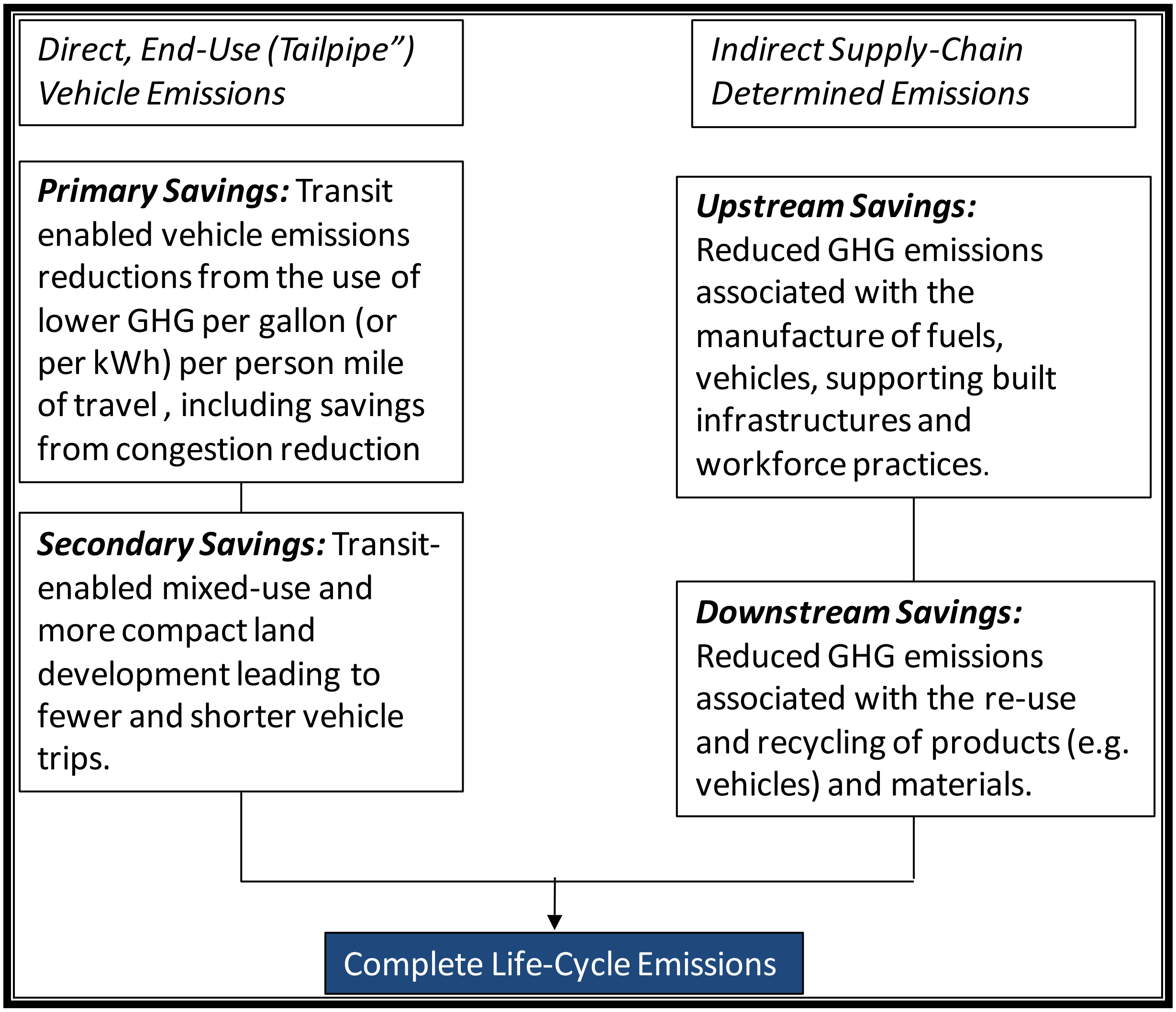


Source: Derived from Chester and Horvath (2008), Tables 33 and 76. Notes: BART = San Francisco (CA) Bay Area Rapid Transit, electrified heavy rail , Caltrain (CA) = diesel powered heavy rail; Muni = San Francisco (CA) electric light rail Municipal Railroad; Green Line = Boston (Mass) electric light rail Boston Green Line; Bus = 40-foot diesel powered urban transit bus. MJ = megajoule, g = gram, PMT = passenger miles of travel.

2.4 Summary of GHG Emissions Reduction Opportunities

Combining the direct plus indirect upstream and downstream emissions reduction possibilities described above produces the complete life-cycle assessment approach shown in Figure 2.3. Examples of both direct and indirect emissions reduction actions are found in this Compendium.

Figure 2.3 Greenhouse Gas Savings Opportunities from Public Transit



Source: Based on APTA (2009)

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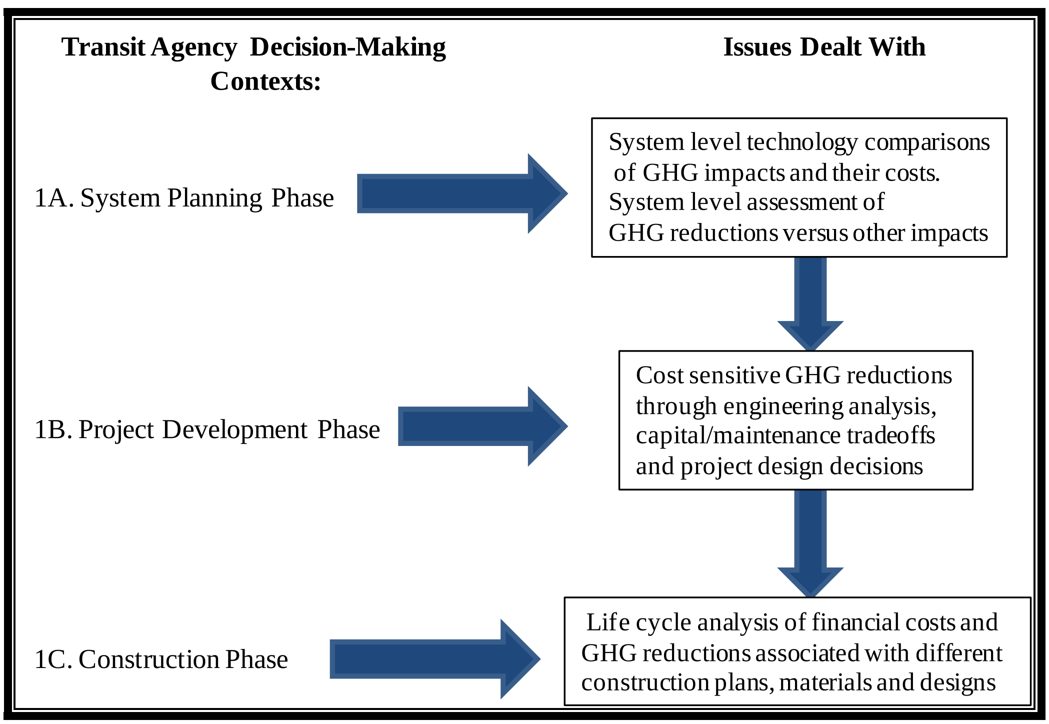
3. PLANNING FOR SYSTEM EXPANSIONS AND MAJOR CONSTRUCTION PROJECTS

3.1 Introduction

Any significant expansion of transit service within a region will produce significant GHG emissions (although, as demonstrated in Chapter 2, the net result may be to reduce emissions account if auto travel and its associated system expansion needs are taken into account). This is especially true if the expansion involves the preparation of new guideways associated with surface level, above ground, or underground rail projects. Some fixed route bus projects also may require improvements to sections of the highway network, as well as the construction of new park-and-ride lots, bus stations, maintenance depots, garages, fuel storage facilities, warehousing space and other buildings. GHG emissions associated with new building practices are covered in Chapter 6 of this Compendium. The focus here is on system level decision-making practices and the construction technologies they subsequently bring into play.

Three elements, or phases, of activity can be identified with system expansions and major transit agency construction projects (see Figure 3.1). All three phases can have a substantive impact on the GHG emissions profile of a transit agency.

Figure 3.1 System Planning, Project Development, and Construction Issues



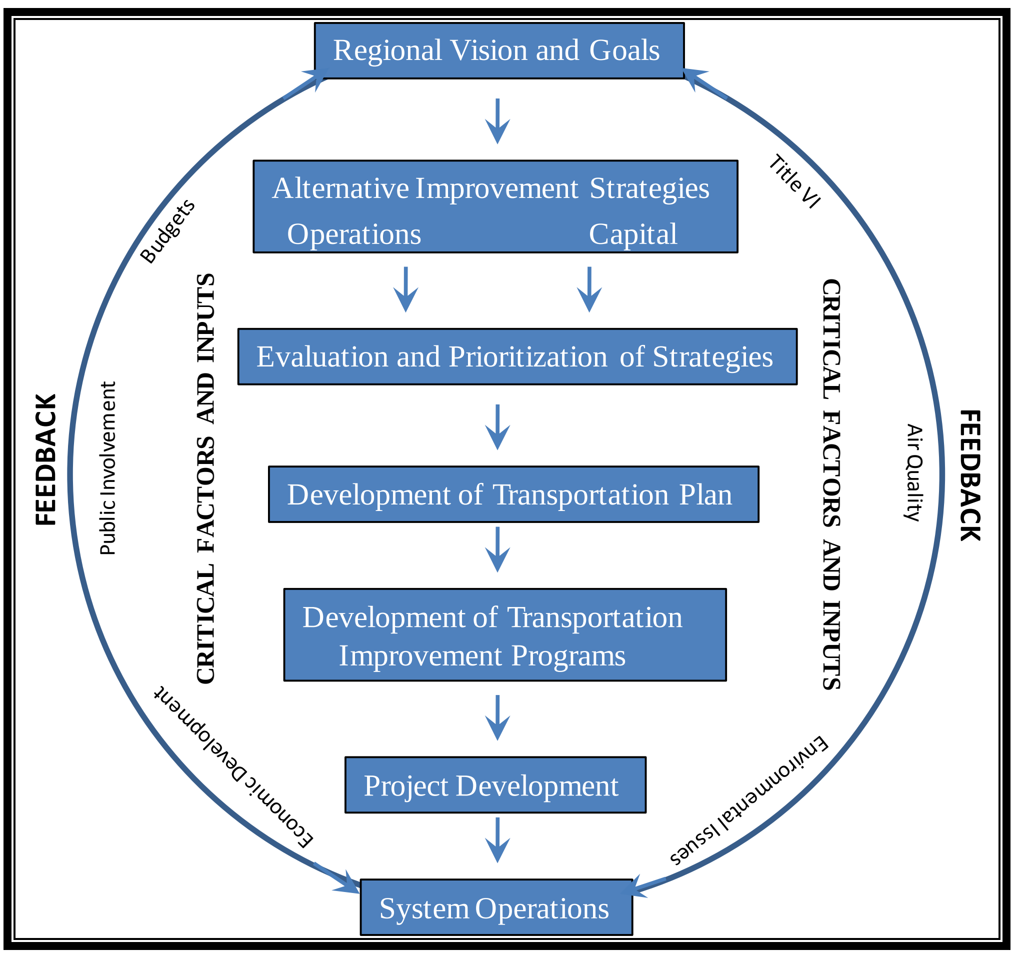
In considering each of these three phases in turn below, transit agency staff must become familiar with:

1. the role of GHG emissions assessment within the regional transportation planning process
2. appropriate measures of GHG emissions impacts within this process, on a project by project basis, and
3. the tools and methods available for quantifying project specific GHG emissions, including the indirect life-cycle emissions associated with projects involving construction of new transit guideways and other transit service supporting facilities.

3.2 Incorporating GHG Impacts Into System Planning

Transit agencies are important partners in the statewide and especially the metropolitan transportation planning process. It is during this process that important decisions are made concerning the future characteristics of the transportation system, such as what priority will be given to different modal investments, what policies and programs need to be in place to enhance system performance and where the funding will come from for prospective investments. Figure 3.2 shows the key steps in this planning process.

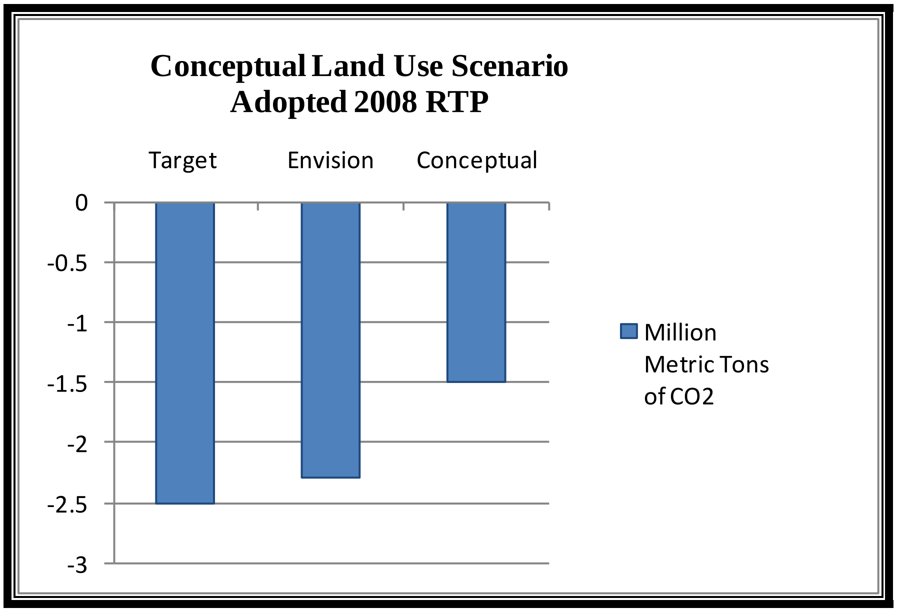
Figure 3.2 Steps in the Transportation Planning Process



Source: (FTA 2010a)(re-drawn)

Transit agencies need to participate in every step of this process, from determining a regional vision to monitoring system operations. Considering GHG emissions during the system planning process can be done in a variety of ways. Given the often "high level" nature of the planning process, such a consideration is at a very general level, for example, examining different land use scenarios and corresponding transportation system configurations to see how each relates to the region's goals and objectives.

Figure 3.3. Land Use/Transit Scenarios to Reduce GHG Emissions



Source: Fregonese Associates., 2009 *(re-drawn figure)*

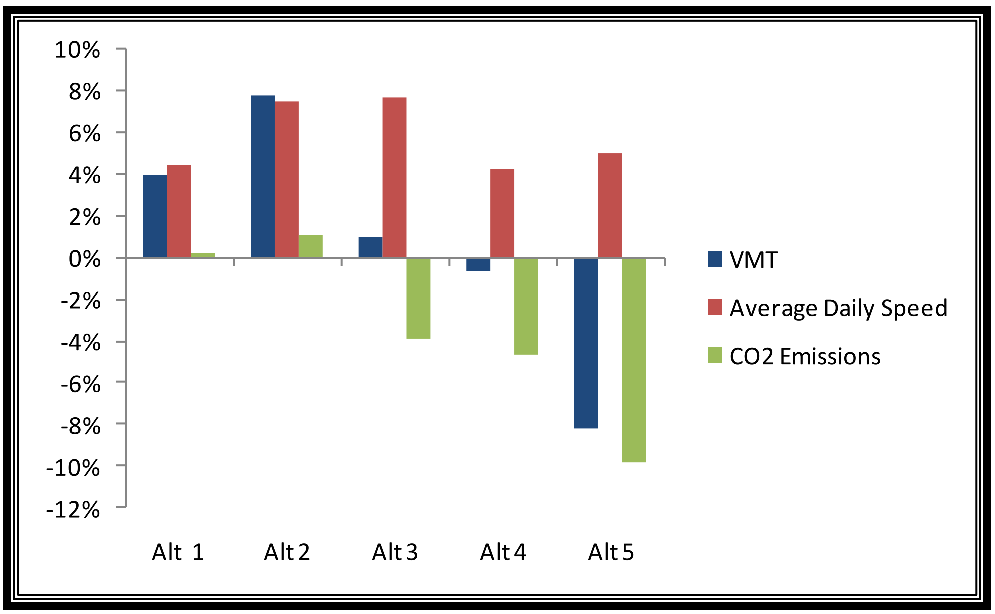
Figure 3.3 shows a common way of indicating the impact of scenarios on important planning factors, in this case, CO_2 emissions. This example comes from the Southern California Association of Governments (SCAG) representing the Los Angeles metropolitan area. This analysis was in response to state legislation that requires each Metropolitan Planning Organization (MPO) to develop a sustainable communities strategy (SCS) for reducing carbon emissions. Alternatively, if the GHG emissions reduction targets cannot be met through the SCS, an Alternative Planning Strategy (APS) may be developed showing how those targets would be achieved through alternative development patterns, infrastructure, or additional transportation measures or policies. In the case shown in Figure 3.3, new transportation investments would be needed especially in upgrading some major corridors with local bus transit to rapid service. [9]

As concern for climate change and GHG emissions grows, it seems likely that such concern will manifest itself in each step of the planning process (ICF International, 2008). For example, a

[9] Although the Envision scenario in Figure 3.3 showed a higher level of GHG emissions reduction, relative to the "conceptual" scenario, it did so by not meeting city and county forecasts of population and employment growth (Fregonese Associates, 2009).

regional vision and the corresponding goals statement could present minimizing pollutant emissions, including GHG emissions, as one of the important directions for the region's transportation system. Identifying different improvement strategies (step 2 in Figure 3.2) that are targeted at reducing GHG emissions then become part of the alternatives identification process. Such planning is usually undertaken by transit agencies when major system-level investment in transit is being considered, or when decisions need to be made on what transit technology (for example, heavy rail, light rail, bus rapid transit, etc.) should be adopted regionally, or in specific corridors. Systems and corridor-level planning are key steps in project development here, since it as at these points that the context is set for the selection of a project for implementation (FTA 2010b).

Figure 3.4 Assessing GHG Emissions in Different System Planning Scenarios, Puget Sound



Baseline
o Includes all planned and funded projects and programs
o Starting point for comparing other alternatives

Alternative 1
o Makes existing transportation system more efficient with traditional funding sources.
o Includes a High Occupancy Toll (HOT) lane systems

Alternative 2
o Closest to current long-range plan Funded form traditional sources
o Adds substantial roadway and transit capacity Includes a two-lane HOV system

Alternative 3
o Uses tolls to pay for most critical roadway improvements o Traditional funding for new transit, bicycle and pedestrian network improvements

Alternative 4
o Uses tolls to manage system and fund programs
o Improves roadway choke points, transit and non-motorized travel options

Alternative 5
o Largest expansion of high capacity transit, bus service, bicycle, and pedestrian facilities
o Funded by freeway and arterial tolls
o Uses traditional strategies plus tolling to reduce carbon emissions

Source: PSRC, 2010 *(re-drawn figure)*

A second example of a system-level planning approach, shown in Figure 3.4, also comes from Seattle, Washington. The Washington legislature has passed legislation setting statewide goals to reduce GHG emissions to 1990 levels by 2020, 25 percent below 1990 levels by 2035, and 50 percent below 1990 levels by 2050 (PSRC, 2010). According to the final environmental impact statement for the region's 2040 transportation plan, "the state has set benchmarks for reducing annual statewide per capita vehicle miles traveled (VMT). These benchmarks are to decrease annual statewide VMT per capita by 18 percent by 2020, 30 percent by 2035, and 50 percent by 2050. These reductions are from a forecasted statewide VMT baseline of 75 billion in 2020." As part of the metropolitan transportation plan update, each alternative was evaluated for GHG emissions as well as total and per capita VMT. A four-part Greenhouse Gas Strategy to reduce GHG emissions was included in the plan, focusing on land use, transportation choices, user fees, and technology strategies.

Table 3.1 CO2e Summary Emission Burden Assuming Current LRT Energy Profile and Carbon Free Electric Profile, Sound Transit

Mode	No Build 2030	2030 With ST2 Plan - Current Energy Profile	2030 With ST2 Plan - Carbon Free Energy Profile
Roadways			
Daily Auto VMT	99,398,539	98,536,539	98,536,539
Total Daily CO_2e (metric tons)	45,485	45,091	45,091
% Change from Baseline	-	-0.87%	-0.87%
Sound Transit Buses			
Daily Bus VMT	50,420	42,427	42,427
Total Daily CO2e (metric tons)	125	105	105
% Change from Baseline	-	-15.85%	-15.85%
Other Buses			
Daily Bus VMT	166,497	122,704	122,704
Total Daily CO2e (metric tons)	431	318	318
% Change from Baseline	-	-26.30%	-26.30%
LRT			
Daily LRT VMT	25,587	92,587	92,587
Total Daily CO2e (metric tons)	71	258	0
% Change from Baseline	-	261.86%	-
Commuter Rail			
Daily Commuter Rail VMT	7,956	10,063	10,063
Total Daily CO2e (metric tons)	54	68	68
% Change from Baseline	-	26.48%	26.48%
TOTAL (Roadways,LRT & Commuter Rail, Buses)			
Total Daily CO2e (metric tons)	46,166.60	45,850.20	45,581.90
Total Annual (metric tons)	14,080,813	13,981,261	13,902,480
% Change from No Build	-	-0.71%	-1.11%

***Source: Sound Transit, 2008** (re-drawn)*

Another systems level planning process focuses specifically on different transit system technologies and network configurations to be selected: for example, when a decision over whether heavy rail, light rail, bus rapid transit, etc. should be adopted regionally or in specific corridors. An example of this type of planning is also found in Seattle, where Sound Transit, the region's express bus and rail transit agency, was developing a regional transit investment strategy that was going to be placed before the voters in a region-wide referendum. Extensive planning was undertaken in numerous corridors, with a wide range of evaluation criteria and performance measures being considered.

Table 3.1 shows some of the results of the analysis that was included in the planning effort, in this case, focusing on GHG gas emissions and change in VMT. In 2030, the build alternative was predicted to reduce overall regional CO_2e emissions by approximately 326 metric tons daily, or 99,552 metric tons annually using current electric power fuel mix assumptions. Under a potential future scenario in which all electricity was generated using non-carbon emitting sources, the CO_2e emissions reduction is about 585 metric tons daily or 178,334 metric tons annually. To estimate the GHG impacts of the plan, transportation modeling estimates of VMT by mode and vehicle type (i.e. cars, LRT, buses, commuter rail) was converted into energy consumption. Then depending on the energy source, the energy consumption of the various modes was converted into CO_2 equivalents (CO_2e).

3.3 Considering GHG Emissions in Project Development

The need for a system improvement often leads to a project development process, which is a more detailed planning and engineering effort to provide the information needed to construct or implement a project. For projects that could have significant environmental impacts, project development also includes environmental analyses and studies that identify potential impacts and corresponding mitigation strategies. The degree of complexity and effort associated with project development will depend on the size of the project and the likely impacts. For example, minor improvements to bus bays or station access points still go through some form of project development effort, although nowhere near the level of effort as would be required for a new light rail line or bus rapid transit facility.

For projects that go through an environmental review process, GHG emissions could be considered in many different steps. Defining a scope for environmental review includes having all agencies potentially concerned with an environmental analysis agree upfront with the scope of the analysis effort. The scope includes the geographic boundaries, types of impacts, needed data, required methodologies and types of mitigation strategies that should be considered. The scoping process is not an analysis-focused process. In essence, it is a process of developing a consensus among the major stakeholders for a particular project that some set of environmental impacts, certain types of data, and proposed analysis methods should be used during the environmental review process. The role of GHG analysis in this stage is thus being identified by major stakeholders as one of the analyses that should be undertaken during the environmental review process.

Identifying a purpose and need for the project planning process is a legislatively required action that explains to the public and decision makers that the expenditure of funds is necessary and worthwhile and that priority for the project relative to other needed projects is warranted. The project purpose and need also drives the process for alternatives consideration, in-depth analysis, and ultimate selection. In this early stage of the environmental review process, it is not likely that formal analyses will be undertaken to show potential GHG impacts.

The next step encompasses effective alternatives analysis—identification of the project evaluation criteria, analysis of individual project alternatives, and selection of the preferred alternative. To the extent that the scoping process has identified GHG emissions as a critical impact factor, these steps will be the core technical process for analyzing potential GHG impacts. Similar to previous steps in statewide/regional and corridor transportation planning, the identification of project evaluation criteria will most likely borrow from national and other sources. For example, tons of GHG emissions or GHG emissions per traveler could be used as criteria for assessing differences among alternatives. The actual analysis of alternatives would use these criteria as a guide for producing the assessment information that will be used to identify a preferred alternative.

The most important decision points in project planning are the decisions that result in an adopted plan or in the projects that will be implemented. Thus, making sure that the prioritization criteria are consistent across the different levels of decisions is important. This is particularly true with GHG emissions-related projects. Often, the results of the planning process are not reflected in the actual projects that are programmed (in many cases, different groups do the planning and the programming, and the influence of federal funding programs can be critical in determining which projects are funded). If plans and policies identify GHG emission reduction strategies as important priorities for a state or region, but the programming process does not consider related criteria or the criteria are not given adequate consideration, it is not likely that the results of GHG analysis will have much influence on the types of investments that will occur in a jurisdiction.

For major capital transit projects, the Federal Transit Administration (FTA) has defined an alternatives analysis process that identifies the key steps in taking a project from concept to final design. The role of GHG analysis in this process is primarily one of assessing the GHG emissions associated with each alternative and the change in emissions relative to some base case. As one proceeds through this process, the level of specificity of the alternatives and of the final locally preferred alternative (LPA) becomes much greater. For example, FTA guidance states that the final definitions of the alternatives should consist of the plan and profile drawings, cross-section drawings for various line segments, conceptual drawing of stations and park/ride lots, and proposed specifications developed in a conceptual engineering effort (FTA, 2010c). Final service operating plans reflect the equilibration of transit service levels with travel demand. The definition of alternatives should include:

1. Headway assumptions
2. Peak hour peak direction volume (at peak load point);
3. Peak hour vehicle loadings;
4. Weekday vehicle miles and hours for each route; and
5. Adopted vehicle loading standards

Each of these could have a significant impact on ridership and ultimately on the GHG emissions associated with each alternative. For example, intelligent vehicle spacing technology for coordinating train station arrivals and departures, by monitoring and adapting running speeds, can help to optimize the use of energy captured by wayside regenerative braking systems that use ultracapacitors suited to rapid collection and discharge of electric power (see Chapter 4). In such cases the limited storage capability of many current wayside energy storage systems places a premium on train scheduling, allowing energy stored from braking to be used productively, notably to accelerate trains out of stations, rather than losing much of this energy to heat dissipation (avoiding unwanted line voltage build-up).

An example of project-level consideration of GHG emissions is found in the environmental analysis for the Columbia River Crossing project in Portland, Oregon (CRC, 2008). This is a bridge, transit and highway project whose purpose is to improve travel efficiency and safety in Interstate 5 traveling over the Columbia River in Portland, OR and Vancouver, WA. The project consists of a five-mile section that includes a new bridge crossing and numerous interchange improvements. The Draft Environmental Impact Statement (DEIS) for the project identified five alternatives for consideration: no build, replacement of the I-5 bridge along with bus rapid transit, replacement of the bridge along with light rail, a supplemental bridge along with bus rapid transit and a supplemental bridge along with light rail. The GHG emission analysis included both short-term construction related effects and long-term effects relating to the operations of both the highway and transit services for the project. For each mode and project phase, GHG emissions were estimated based on the energy consumed. For example, the estimated GHG emissions level for transit operations was based on the following equation:

$$EM = E \text{ x } EF \text{ x } CDE \tag{3.1}$$

where:

EM = Emissions of carbon dioxide (lbs. of CO_2)
E = Energy (fuel) consumed (gallons or kWh)
EF = Emission conversion factor by fuel type
CDE = Carbon dioxide equivalents factor (100/95) (CO_2 emissions are assumed to account for 95% of GHGs emitted by transportation).

For transit operations, the energy consumed was estimated using the following equation:

$$E = V \text{ x } L \text{ x } FCR \text{ x } CF \tag{3.2}$$

where:

E = Energy consumed (BTU)
V = Daily volume of light rail cars
L = Length of rail segment (miles)
FCR = Fuel consumption rate based on average operating speed (kWh/mile)
CF = Fuel conversion factor (BTU/KWh)

Table 3.2 shows the estimated impact of each alternative on CO_2e emissions. The replacement crossing with associated highway improvements, a toll on I-5, and light rail or bus rapid transit (Alternative 2 or 3) would reduce CO_2e emissions by about 2 or 3 percent compared to the No-

Build Alternative. This reduction is due to fewer auto trips over the river, more people riding on public transit, and reduced traffic congestion which also improves fuel efficiency. Alternatives 4 and 5 were estimated to increase CO_2e emissions relative to the No-Build alternative, primarily because they include aggressive increases in the frequency of light rail or bus rapid transit and other bus routes without realizing proportional decreases in auto travel.

Table 3.2 CO_2 Emissions Analysis for Columbia River Crossing

Full Alternatives Summary of Daily Energy Use and CO2 Emissions

Alternative	Energy Consumed (mBtu)	Electricity Consumed (mBtu)	Gasoline consumed (gal)	Bio/Diesel Consumed (gal)	CO_2e Emissions (tons)
Existing	4,014.4	77,355.3	8,343.0	19,585.2	342.5
Alternative 1 (No-Build)	5,384.2	152,628.0	10,661.0	25,536.6	463.3
Alternative 2 (Repalcement, BRT)	5,248.1	152,628.0	9,598.0	25,520.9	452.3
Alternative 3 (Replacement, LRT)	5,242.3	162,063.3	9,598.0	25,231.8	452.4
Alternative 4 (Supplemental, BRT)	5,729.2	160,645.6	9,622.0	28,790.3	493.7
Alternative 5 (Supplemental, LRT)	5,687.1	172,053.3	9,622.0	28,172.0	490.7

Source: (CRC, 2008, re-drawn)

The DEIS identified several strategies that should be considered to mitigate the impact of project-related GHG emissions, including:

1. Implement programs that further encourage use of public transit
2. Promote compact and transit-oriented development that encourages walking
3. Provide safe and well-lighted sidewalks to encourage walking
4. Provide safe and more accessible connections to paths for bicyclists and pedestrians
5. Offer ride-share and commute choice programs
6. Construct with materials and build systems that meet efficiency standards for equipment and lighting design
7. Recycle building materials, such as concrete, from project
8. Use sustainable energy to provide electricity for lighting and other operational demands
9. Plant vegetation to absorb or offset carbon emissions
10. Promote fuel-efficiency improvements, such as a low carbon fuel standard
11. Promote diesel engine emission reduction
12. Consider clean energy certificates or other carbon offsets for energy used

This project is a good example of how construction-related emissions can be considered as part of a study. The DEIS also focused attention on the potential impacts of a changing climate on the project alternatives, an issue of particular concern given the crossing of a river.

3.4 GHG Accounting in the Construction Phase

"Given the importance of a life-cycle approach to GHG emissions analysis, there is uncertainty regarding the need to estimate emissions resulting from transportation system construction and

maintenance, as opposed to system use. Methods to estimate construction GHG emissions are poorly developed." (ICF International, 2008)

The above quote is taken from a recent review of state DOT and MPO efforts to include 'climate change' concerns into the transportation planning process. The same uncertainly currently affects transit agency planning agencies. To date, transit agencies have focused on estimating the GHG emissions associated with the *use* of their transportation vehicles and supporting facilities. However, agencies are now also starting to consider quantifying the emissions associated with construction as well as maintenance of these facilities. Including an estimate for GHG emissions for construction in a planning or project development study is one step towards a more complete life cycle analysis approach to the study. Doing so can also identify opportunities for significant cost savings associated with reduced materials acquisition, energy consumption, and materials disposal costs.

Capital projects typically lead to construction activities that produce significant GHG emissions, as a consequence of raw materials conversion (e.g. from limestone to cement), structural manufacture and installation, and transportation of materials, workers, and waste to/from construction sites. Much of this activity is out-sourced to private contractors; while a few of the larger transit agencies may also carry out some construction projects using in-house resources. A recent review of GHG reducing construction practices for the US Environmental Protection Agency concluded that:

"Although a comprehensive construction- related life cycle emissions inventory has not been conducted, there clearly are opportunities to reduce emissions by recycling and/or reusing materials, improving shipping methods, and/or selecting different materials". (EPA, 2009a)

Transit agencies can take actions under three broad GHG reducing strategies (Gallivan and Grant, 2010:

1. Use of alternative, including recycled construction materials
2. Use of more energy efficient construction equipment, and
3. Reduction of emissions associated with transporting workers and materials to, from, and within construction sites.

While transit agencies cannot regulate the activities of their contractors as easily as they can their own employees, they can pay attention to the following opportunities when developing support contracts, to try to ensure that the most effective GHG reducing construction practices are being applied. Cost savings are possible where GHG reductions are the result of lower energy costs, or reductions in the volume of materials purchased.

Alternative Construction Materials: Depending on the type of capital construction project, (e.g. rail line or bus lane system expansion, a great deal of concrete, steel, asphalt, wood, or industrial composites may be used. There is currently no widely accepted procedure for estimating the GHG emissions from the use of such materials in transit or non-transit projects. With this in mind, the following information should be seen as a general guide to the sort of GHG emissions involved in construction projects.

The life-cycle GHG (CO_2e) emissions associated with four different rail transit and one high speed rail system[10] were estimated by Chester and Horvath (2008), including the emissions associated with the built infrastructure required to support these systems. The values shown below are drawn from their summary of the energy and GHG emissions factors, under the heading "track and power delivery":

Construction sector GHG emissions are often grouped into three broad categories of activities: fossil fuel combustion to produce heat to run equipment, purchased electricity, and non-combustion activities, including production of GHGs from reactions such the CO2 released during lime production (EPA, 2009a, Schokker, 2010). Concrete production is a major GHG emitter (see Table 3.3), due largely to the direct creation of CO_2 emissions in the production of cement.[11] About half of the CO_2 used to produce cement comes from burning coal or other fossil fuels, and the rest comes from the conversion of limestone to lime. Efforts to reduce the GHG emissions associated with this process include improving manufacturing plant efficiency, and measures such as burning waste tires instead of coal to reduce the GHG emissions from combustion. A third trend is towards the use of high-strength, 9000 psi concrete columns in place of 4000 psi concrete, leading to the use of less material overall. A fourth widely used tactic to reduce the carbon content of a cubic yard of concrete is to replace cement with materials such as fly ash, slag cement, and silica fume (Schokker, 2010).

Table 3.3 Example GHG Emissions Estimates from the Creation of Rail Infrastructure Materials

Type of Retrofit	Total Cost	$ Savings/Yr.	Payback Yr.
Lighting Retrofits	$ 1,350,000	$ 313,190	4.3
Lighting Controls	$ 436,900	$ 104,084	4.2
Roof Replacement	$ 428,000	$ 75,088	5.7
Overhead Doors	$ 42,100	$ 7,550	5.6
Total	$ 2,257,000	$ 499,912	4.5

Source: Chester and Horvath (2008) Extracted from Table 64 – "Fundamental Environmental Factors for Rail Modes"

Reuse and recycling of materials is an important area for GHG reductions. In the U.S. there are established secondary markets for the reuse of asphalt, concrete, steel, and certain other metals (EPA, 2009b). For example, two-thirds of recovered asphalt is re-used for new asphalt hot

[10] San Francisco's BART and Caltrain Heavy Rail Transit and its Muni and Boston 's Green Line Light Rail Transit systems, and a proposed California High Speed Train line.

[11] Concrete is a mixture of cement, coarse and fine aggregates (i.e. rock and sand) and water, with cement made typically from limestone and clay.

mixes, and one-third is recycled as sub-base material for paved roads (EPA, 2009a). At its major expansion project worksites, New York's MTA recycles some 80% of worksite debris, either as recycled waste or reused construction materials, diverting thousands of tons of traditionally landfill-bound construction waste for recycling (MTA, 2010). For a light rail project, TriMet in Portland, Oregon installed some 6,000 plastic ties made of recycled automobile gas tanks, using recycled plastic bollards, reusing existing road-base concrete, and using recycled asphalt and concrete for road base materials, and providing cost savings to the agency in the process. At the New York MTA railroad ties made of a composite of recycled plastic, waste tires, waste fiberglass, and structural mineral fillers are being introduced (MTA, 2009).

Energy Efficient Construction Equipment and Practices: The US EPA's study of the potential for reducing GHG emissions in the construction sector identifies, and provides example calculations for a number of promising practices (EPA, 2009a):

1. Use alternative fuels/technologies in non-revenue vehicles: e.g. use of biodiesel
2. Implement and enforce no-idling policies on gasoline and diesel powered trucks and other on site vehicles:
3. Establish regular equipment maintenance policies: e.g. proper tires inflation and wheel alignments in non-revenue vehicles can reduce fuel consumption for a small truck by 3- 4 %. Proper forklift maintenance can also save on propane fuel.
4. Consider alternatives to diesel generators: including dual-fuel generators using a mix of natural gas or propane and diesel, using non –fossil fuel generated electricity, or using solar panels in offices to reduce the need to run the generators.
5. Fuel savings from proper sizing of vehicles to haulage tasks, and
6. Training in support of proper vehicle operating practices: e.g. two stage slope excavation in a stair fashion, instead of dragging a bucket from bottom to top in one motion uses 8% less fuel. For example, having an excavator's boom swivel 30 degrees to dump its load instead of 90 degrees could reduce fuel use by 3%.

Transportation of Workers, Construction Materials, and Waste: The distances that workers, construction materials, and also waste materials have to travel to get to and from a construction site make a significant contribution to GHG emissions: varying a good deal between 5% to 85% of the total emissions generated in the process of assembling on site structures (Cole, 1999). Therefore the acquisition of locally provided materials can be a significant benefit. So too can the proximity of landfills or other waste disposal sites. Recycling of materials, as opposed to disposal in landfills can also be a profitable option.

Sources of GHG Emissions Estimates Associated with Construction Projects: APTA's (2009) protocol for reporting transit agency GHG emissions suggests using the following default associated with the consumption of construction materials for steel, cement and asphalt used in a reporting year:

Table 3.4 Example Construction Materials Emissions Factors

Material	Default Emission Factor ($MT\ CO_2e$/MT of material)
Steel	1.06
Cement	0.99
Asphalt	0.03

Source: APTA, 2009

However, for the purposes of estimating potential GHG reductions a more detailed set of computations is required. This presents something of a challenge currently. There are no consistent and widely accepted guidelines for estimating emissions from road or rail construction projects for use in either National Environmental Policy Act (NEPA) analysis, or for State Implementation Plan (SIP) and conformity development. There are, however, a number of software tools available for assessing the GHGs associated with construction projects. The National Institute of Standards and Technology's (NIST) BEES[12] software provide full life cycle estimates of the emissions resulting from raw material acquisition, manufacture, transportation, installation, use, and waste management, while EPA's Waste Reduction Model (WaRM)[13] provide emissions calculations associated with alternative waste management practices.

The Sacramento Metropolitan Air Quality Management District has also developed a Road Construction Emissions Model that computes CO_2 emissions produced from construction vehicles and equipment (SMAQMD, 2010).[14] This detailed spreadsheet model estimates CO_2, CO, NOx, and BC emissions from a wide variety of construction activities and also both on-highway and off-highway vehicle/equipment types. These activities include, but are not limited to, grubbing/land clearing, grading/excavation, drainage/utilities/sub-grade work, transport of materials, and paving. The equipment and activity emissions are aggregated into a bottom-up estimate of a construction project's emissions per day, per construction phase, and per the entire construction period. The model has been used to calculate construction emissions for transit projects, such as the Sacramento Regional Transit District's (RT) Downtown/Natomas/Airport Corridor light rail transit project. Construction of the one mile project was estimated to emit 587 tons of CO_2. By reducing private automobile travel, the light rail project is estimated to reduce operational GHG emissions by 20 tons per year[15]. Thus, the emissions produced during the construction of the project are estimated to be offset or "payed-back" by operational emissions savings.

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[12] http://www.bfrl.nist.gov/oae/software/bees/
[13] http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_home.html
[14] http://ww.airquality.org/ceqa/RoadConstructionModelVer6.3-2.xls.
[15] http://www.sacrt.com/dna/pdfs/MOS-1DEIR/Chapter%205%20-%20Environmental%20Analysis.pdf

The CHANGER[16] software developed for the International Raid Federation (Zammataro, 2010) also enables a detailed environmental analysis of the total amount of greenhouse gas emissions released in the course of a road construction project. It accommodates a wide range of different user needs, from gross 'pre-project phase' estimations through to comprehensive end-project assessment. The pre-construction module takes into account:

1. Clearing and piling: based on the ground surface area cleared per unit of road surface, an estimation can be generated for both machine use and fuel consumption.
2. Cut exports and fill imports transport to and from the road site

The pavement module takes into account:

1. On-site impacts: electricity and fuel consumption on the construction site as identified and evaluated.
2. Pavement construction materials: this section encompasses unbound materials, hydraulically bound materials, bituminous bound materials, metals, rubber and plastic, etc., from which the user can easily select the materials required for construction of the different layers of the given pavement.
3. Materials transport including the transport of aggregates, bituminous materials, cement, concrete, and emulsions either directly to the road site or first to a mixing plant, then from the plants to the road
4. Construction machines: total consumption of fuel is determined on the basis of the working hours of the machinery and characteristics and efficiency of the material used.

Tthe URBEMIS software[17], created for the South Coast Air Quality Management District (Jones and Stokes Associates, 2007) for the purpose of estimating a range of emissions from land use development projects, also contains useful information. It breaks construction emissions into the following seven project 'phases': Demolition, Mass Site Grading, Fine Site Grading, Trenching, Building Construction, Asphalt, and Coating (Paints). This software also includes the ability to account for transporting materials to and from a construction site.

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[16] CHANGER is a licensed software, priced (October 2010 on-line info) at 2,000 Euros for IRF members, an 4,000 Euros for non-members: (http://www.irfghg.org/.

[17] http://www.urbemis.com/

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4. VEHICLE PROCUREMENT PRACTICES

4.1 Introduction

This chapter is used to summarize the opportunities offered to reduce an agency's GHG emissions, as well as reduce its fuel consumption bill, based on transitioning to more energy efficient and less polluting vehicle technologies. Procurement of vehicles is a major transit agency expense that has implications for fuel costs and greenhouse gas emissions for many years to come. Fleet procurements are therefore one of the principal means of reducing an agency's GHG footprint. The typical lifetime for a transit bus, when used in cost-benefit analyses for example, is twelve years. Similarly, more than sixty percent of all heavy railcars, more than half of all commuter railcars, and over one third of all light railcars were over 15 years old in 2008.[18] Some locomotives have remained in active use for more than 30 years.

4.2 Selecting a GHG Reducing Vehicle/Fuel Technology

The ability to reduce an agency's fuel bill and at the same time reduce GHG emissions is only one in a number of considerations constraining vehicle choice. Final selection, whether of a single vehicle, or a fleet of vehicles (perhaps incorporating more than one type, or size, of vehicle) will depend on a number of variables, including:

1. available capital versus operating budgets, and how these square with vehicle purchase costs and with vehicle life-cycle operating and maintenance costs;
2. types of routes operated: notably route lengths and stop-go frequency;
3. nature of sunk investments, such as existing rail track;
4. availability of rights of way for system expansions;
5. revenue generating potential: based on ridership levels and vehicle load factors;
6. life-cycle GHG emissions production; and
7. criteria emissions production, and the ability to comply with federal and regional air quality regulations

Recognizing that specific financial, physical and also regulatory constraints will constrain most new vehicle purchase decisions, the following sections highlight recent and emerging vehicle technologies that are demonstrating significant in-service GHG reductions on a per vehicle-mile as well as per passenger-mile basis. The principal focus is on bus and railcar technologies, which together cover the vast majority of transit rides today. Direct comparisons between bus and rail transit options are not the subject of this chapter.

4.3 Successful and Emerging GHG Emissions Reduction Technologies

Over the past decade or so, a number fuel saving technologies have been introduced successfully into both bus and rail transit vehicles. a number of these technologies work synergistically, with

[18] FTA's National Transit Database. Table 25.

net GHG reductions and associated fuel savings dependent on how well they are integrated into in-service operations. Knowledge of these technologies, including a vehicle's make/model/version, technical specification, and amount of in-service experience are all important considerations when selecting cost effective as well as clean bus or railcar options.

Regenerative Braking: Regenerative braking technology converts a vehicle's kinetic energy into a form of potential (stored) energy that, instead of being dissipated as heat, can be used to power the vehicle. As a vehicle's brakes are applied the electric motor becomes an electric generator. The generation of electricity results in a resistive torque that slows the vehicle. In a regenerative braking system, the electricity generated from braking can be stored chemically (as in a battery), mechanically (as in a flywheel) or electrostatically (as in an ultracapacitor). The technology is being used today in transit and trolley buses as well as in heavy and light rail transit systems. The regenerative braking technology being used by the Metropolitan Transit Authority 's heavy rail system in the New York is estimated to supply between 7.5% and 22.5% of the energy and associated GHG reductions(MTA, 2009).

On-Board and Wayside Energy Storage Systems: Today about sixty percent of U.S. rail transit systems use regenerative braking to capture and re-use energy (Holmes, 2008). Two forms of energy capture are in use: on-board and wayside. In the case of rail wayside systems, the energy storage system is set up to redirect the regenerated braking energy to a *third rail* which runs parallel to the two rails used to support the train, and where it can then be used to power nearby trains, notably when a train is accelerating out of a station. These wayside energy storage solutions uses energy storage devices such as ultracapacitors and flywheels, located at intervals along a rail track, as part of a system-wide power conversion and distribution system. A train decelerating into a station sends the energy captured through regenerative braking to a nearby wayside storage devices which then a nearby accelerating train. Tackoen (2010) provides a description of many of the latest energy recovery storage technologies in use and in use today, with examples from Europe, Asia and the United States. In the U.S. this includes a $5.2 million pilot project to use carbon fiber flywheel technology on a 2·4 megawatt lineside (wayside) system, by MTA's Long Island Rail Road (LIRR) in New York. This technology has had success in storing energy regenerated during braking, for re-use when commuter trains accelerate, helping to lower energy consumption as well as reduce the peak power demand. A $4.5 million 2009 TIGGER grant from the FTA the Los Angeles County MTA will also use flywheel technology to capture regenerative braking energy with the installation of a wayside energy storage substation (or WESS) at the Westlake high-speed heavy rail passenger station.

Ultracapacitors are electrical energy storage devices that have the ability to recover and store some of a vehicle's kinetic energy through regenerative braking, by combining battery and capacitor forms of energy storage technology. Using a porous material such a carbon immersed in an electrolyte solution, they are able to store a large amount of energy (a high capacitance). By also storing the energy as a separation of charge (as capacitors do) they are capable of releasing this stored energy very quickly when needed. On-board ultracapacitors have been shown to work well if transit buses make frequent stops per mile, operate at low speeds, and are able to take advantage of the high charge and discharge rates associated with frequent starts and stops

(Lammert, 2008). In Shanghai, China, an ultracapacitor electric bus network using 400 roadside charging points plus a number of larger vehicle charging stations is under development.[19]

Ultracapacitors are excellent rapid charging /recharging devices, but have limited energy storage capabilities when compared to the most modern batteries. New rail transit technology in Sapporo, Japan is testing Nickel Metal-Hydride (NiMH) batteries that are expected to complete more than 1.4 million life cycles, and offer a useful life of roughly 15 years: versus a lithium ion type of battery that currently offers about half as many life cycles. In addition, these new batteries also appear to suffer very little “memory effect”: a condition whereby a battery loses its maximum energy capacity over time due to repeated recharging following a partial after partial discharge. The batteries are also relatively easy to disassemble and recycle, having no welding connections, and no lead, mercury or cadmium to dispose of. Termed Battery Power Stations, or BPSs, track-side batteries can be used to store some of the energy from regenerative braking that is often lost in current rail transit systems (by limiting line voltage drop). BPSs also allow an increase in the minimum distance required between recharging substations, fewer substations are required to operate the system. In November 2007, Kawasaki tested its BPS on the Tanimachi line of the Osaka mass transit system in Japan, with electricity energy consumption decreased by 20 percent in the test area.

Smart Grid Technology: Making the most of wayside energy storage systems depends upon the ability to not only capture but also store, and then quickly release the energy when as well as where it is most needed. solution for the release and allocation of energy here is “smart grid” technology[20]. This technology utilizes software to allocate electric energy from the local grid on a moment by moment basis, possibly using flywheel or ultracapacitor technologies, improved nickel- metal-hydride or lithium-ion batteries to store an electrical charge long enough to be made best use of (Holmes, 2008). A challenge for rail transit systems is to find a way to successfully store and later re-use, either locally or elsewhere in the rail system, as much of the energy captured from regenerative braking systems as possible. If sufficient energy storage capability can be achieved significant benefits may also one day accrue to local power utility companies which may then be able to buy back electricity from the local transit agency. Tackoen (2010) briefly references the idea of “reversible substations” which can put electricity obtained from braking back onto the electric Grid.

Successful storage solutions will allow transit agencies to use lower cost off-peak electricity to run trains, as well as protecting the transit system from potentially damaging voltage sags that can damage the electronic equipment used in railcars.

Advanced Transmissions Technologies (Bus, Van, Non-Revenue Vehicles): A move to 8-speed automatic transmissions, along with friction reduction and improved gear shift logic is estimated to reduce fuel consumption in transit buses between 1% and 4% (TRB, 2010, Table 6-12). “Intelligent transmissions” are now also finding their way into the latest buses. These

[19] http://www.technologyreview.com/energy/23754/

[20] As called for in the Energy Independence and Security Act (EISA) of December 2007, Title XIII, Section 1305. See http://www.nist.gov/smartgrid/

transmissions are linked to control software systems that offer intelligent acceleration-dependent gear shifting points that adapt to topography, vehicle acceleration, axle transmission ratio and load conditions to minimize fuel expenditure. The number of gearshifts may be reduced by as much as 50 percent, producing better fuel consumption in the lower speed ranges thanks to the partly mechanical power transmission, as well as a diminished thermal load on the engine cooling circuit using the power-split principle. Shift-free driving also leads to higher driving comfort and less engine maintenance, while a typical oil change interval is also extended, possibly dramatically (LMS International, 2009) when compared to a typical oil drain interval every 6,000 miles for a conventional diesel transit bus (Schiavone, 2010)[21] . Intelligent transmissions are now appearing in buses around the world, with one major manufacturer of intelligent transmissions reporting estimates of fuel savings from a combination of an economical transmission and intelligent terrain-dependent transmission control at up to 19% over conventional transmissions in a 40 foot bus.[22]

Lightweight Materials: In addition to emission reductions through alternative fuel use, further reductions are possible through the use of ultra high strength stainless steel, composites, and carbon fibers in vehicle bodies and chassis (EERE, 2005). Based on experience in Houston, TX, a 10% reduction in fuel consumption appears to be possible (TRB, 2003). Recent advances in lightweight materials technology begun under the US Department of Energy's Freedomcar & Vehicle Technologies Program are now moving into the commercialization stage, with a 50% reduction in the mass of the basic bus body, through the use of a chassis consisting of ultra high strength stainless steel. By making the platform lighter, the size and mass of other bus components, including the suspension, wheels, brakes, and propulsion system can also be reduced. This not only reduces the initial and maintenance costs of a bus, but the new low-floor ultra lightweight buses have room for 45 passengers, about 5 more passengers than can fit in a standard low-floor bus. The major enablers of this extra space are the absence of a mechanical drive train and the smaller wheels. A cost savings of 15%–20% over the standard bus body is anticipated, while fuel efficiency is projected to rise to as high as 13 mpg - about three times that of current 40 seat buses.

A 2009 study by TIAX for the National Academies (TRB, 2010, page 143) estimated fuel savings of 2% - 3% are feasible in a 2015-2020 timeframe, and also estimated the costs of getting these reductions at between $2 and 4$ per pound up to the first 800 lbs, rising to 8$ to 10$ per pound in the 1,600-2,800 lb range. This applies to a representative 40 foot, 40,000 gross vehicle weight transit bus with an average fuel consumption of 31 gallons of diesel per 100 miles (or 3.22 mpg).

In a recent study of a wide range of sustainable transit practices by the Metropolitan Transit Authority of the State of New York (MTA, 2009), a set of 10% , 15% and 25% energy savings scenarios are developed, using technology that has a reasonable chance of near-term availability.

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[21] While some newer engines with more advanced emissions controls, especially those with exhaust gas recirculation, require more frequent oil change intervals at 3,000 miles (Schiavone, 2010, page 13). However, the of an oil drain interval as large as every 24,000 miles has been posited for hybrid diesels (Chandler, K. andWalkowicz, K., 2006, page 7)

[22] http://www.zf.com/corporate/en/products/innovations/ecolife/topodyn/topodyn.html

Based on either retrofitting or purchasing new railcars for the region's heavy rail system, CO_2 reductions were estimated for a number of different technology adoption and performance scenarios associated with a) regenerative energy systems and b) the use of lightweight materials in railcars construction/operation. The regenerative techniques here "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". The weight reduction techniques include " elimination of redundant components, substituting lighter materials such as aluminum for steel, and design optimization to enable identical structural performance with reduced weight" (MTA 2009, page 23).

The vehicle weight reduction scenarios assume a roughly 2,000 lb weight reduction per railcar, producing a 2.5% savings in electricity generation in each case, suggesting a similar reduction in CO_2e emissions. The following is a list of the weight reducing actions described in the report (MTA, 2009, page 24: see report for technical details, estimated energy saving impacts of specific actions, and assumptions used):

1. Composite instead of plymetal panel flooring
2. Giga cell battery with alternative battery box
3. Utilize oilless compressor concepts
4. Corrugated wheels / lightweight wheels
5. Utilize single draft gear (tube style) link bar
6. One free axle on 1 non-motorized truck replacing OSMES*
7. Gear unit with lowest weight
8. Lightweight floor pans
9. Eliminate OSMES*, brackets and equipment
10. Eliminate flip up seats
11. Eliminate secondary center collision posts
12. Trip cock linkage weight reduction
13. Eliminate 1 of 2 coupler adapters on NMTs units
14. Reduce weight of coupler guides on type 1 truck
15. Reduce heater grill weight
16. Reduce advertisement card clips weight

*OSMES refers to an optical speed and position measurement system

In-Wheel Electric Motors: In the Netherlands a new kind of hybrid-electric bus is now being road tested, one that uses in-wheel electric motors to improve efficiency. The bus is a series hybrid: a diesel generator charges a battery, which in turn supplies electricity for two motors, one in each rear wheel. Thanks largely to its in-wheel motors, the bus can travel twice as far as a conventional bus on a gallon of diesel. As with other hybrid buses, the in-wheel design saves fuel by capturing energy from braking, using it to generate electricity that can be employed for acceleration. The in-wheel motors also offer additional savings by eliminating the need for a transmission, differential, and related mechanical parts, while reducing overall vehicle weight.[23] This is a technology that transit agencies in the U.S. may wish to monitor over the next year or two.

[23] See http://www.e-traction.com/news.htm

4.4 Transit Bus Fleet Options

The Changing Composition of the Current US Transit Bus Fleet: Public transit agencies around the country, and around the world, have introduced a variety of more energy efficient and/or alternatively fueled buses into service over the past two decades. This has lead to significant reductions in criteria pollutants, including non-CO_2 GHGs and aerosols such as carbon monoxide, nitrogen oxide, ozone and particulate matter (which contains black carbon), as well as increased fuel efficiencies and lower greenhouse gas (GHG) emissions. Further improvements are expected in the coming decades. A 2010 National Academy of Sciences study (TRB, 2010) reports possible technology-driven fuel economy improvements for conventional diesel buses in the range of 9% to 14% between 2015 and 2020 [24] Significant GHG reductions associated with new vehicle procurements are also being achieved through selection of alternative fuel (AF), hybrid electric (HE), or combined AF-HE vehicles. For example, the 2010 TRB study suggests that hybrid power trains could lower the fuel consumption of buses that stop frequently by as much 35%. Complimenting these "greener" fuel/engine technologies, additional energy and GHG reductions can also be obtained from the use of lightweight materials in vehicle construction, as well as from more aerodynamic vehicle designs, and by using a variety of devices to provide inexpensive auxiliary (sometimes also called "hotel") power for air-conditioning and other means of ensuring customer comfort.

Alternative & Emerging Bus Technologies

Diesel Buses (Conventional)

Diesel Hybrid-Electric (HE) Buses

Biodiesel HE Buses

CNG HE Buses

Gasoline HE Buses

LPG HE Buses

Plug-in Diesel HE Buses

Biodiesel Fuel Blend Buses

CNG and LNG Fueled Buses

Electric Battery-Powered Buses

Hydrogen Fuel Cell (FC) Buses

Hydrogen FC HE Buses

Table 4.1 shows the recent trend in buses built or on order in 2008. The majority of buses currently in use in the United States are petro-diesels, but by 2008 hybrid-electric (HE), compressed and liquefied natural gas (CNG and LNG), and biodiesel fueled buses accounted for 28% of all transit bus fuel consumption (APTA, 2010, Table 15). A number of additional bus technologies are also in the early stages of in-service testing, in most instances as part of a

[24] The results of this study have also influenced a proposed new US DOT/US EPA rule-making leading to new heavy duty vehicle, including bus, fuel economy regulations and standards. See http://www.epa.gov/oms/climate/regulations.htm#prez

single or small number of vehicles taking part in a federally subsidized technology demonstration project, notably hydrogen fuel cell and hydrogen-hybrid electric buses.

The majority of the hybrid buses in service in the United States today use a petro-diesel engine combined with an electric motor and batteries. However, CNG-hybrids, biodiesel-hybrids, and hydrogen fuel cell hybrids are also candidates for significant net energy and GHG savings. A few transit agencies are also operating buses, including trolley buses, that draw power from the nation's electricity grid. These include pure electric vehicles (EVs) as well as a small number of smaller seating capacity plug-in hybrid electric vehicles (PHEV).

Table 4.1 Recent Trends in Transit Bus Orders by Fuel Type

Bus (Fuel) Type	# Buses Built in 2008	%	# Buses Ordered	%
Conventional Diesel	1,508	47.7%	559	23.7%
Diesel & Electric Battery	579	18.3%	781	33.1%
CNG	670	21.2%	488	20.7%
Biodiesel	279	8.8%	304	12.9%
CNG & Diesel	18	0.6%	150	6.4%
Gasoline	50	1.6%	25	1.1%
CNG & Gasoline	23	0.7%	0	0.0%
Gasoline & Electric	21	0.7%	37	1.6%
Hydrogen	14	0.4%	16	0.7%
Total	**3,162**	100.0%	**2,360**	100.0%

Diesel-Electric Hybrid Buses: A number of both in-service studies of the fuel savings and GHG reductions associated with shifting to diesel-electric hybrid buses have been carried out. Between 12% and 35% reductions n per vehicle mile GHG emissions were obtained (see inset). As a result, diesel-electric hybrids have become a very popular technology for fixed route bus procurements over the past decade. Fourteen of the forty-three TIGGER[25] projects funded by the federal government in 2009 include purchases of DHE fleet vehicles. Buses are available in various sizes, including 40-foot and 60-foot articulated versions, as well as smaller capacity models. The latest electric hybrids, as well as all-electric powered buses and trolleys (and electrified rail systems also, see below) now obtain additional GHG reductions through the use of regenerative braking technology, which can capture and re-use up to 25 percent of the kinetic energy lost by a decelerating vehicle (TRB, 2003). Plug-in, Grid powered diesel-electric hybrids are also in development and in-the-field testing (Advanced Energy, 2003).

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3 See http://www.fta.dot.gov/index_9440_9326.html

Seattle, Washington**:** Table 4.2 shows the estimated GHG emissions associated with in-service diesel and diesel-electric hybrid bus use by King County Metro Transit, after converting CH_4 and N_2O emission to their CO_2 equivalents. On a per mile basis, the hybrid buses achieved a 21.1% reduction in GHG emissions relative to the diesel buses.[26] The 'Metro has 235 hybrid buses (nearly one-quarter of its bus fleet), 213 of which are 60 ft articulated hybrid buses.

Table 4.2 GHG Emissions Savings

	Diesel Bus	Hybrid Bus
CO_2 (kg)	1,420,959	1,157,648
N_2O (g)	1,683	1,738
CH_{-4} (g)	1,788	1,846
CO_2e (tonnes)	1,421.51	1,158.21
CO_2e (grams/mile)	4,055	3,199
CO_2e (grams/mi. % reduction)	--	21.10%

Source: ***Chandler and Walkowicz, 2006***

A National Renewable Energy Laboratory assessment of vehicle performance compared the emissions generated by 10 model year 2004 New Flyer DE60LF diesel-electric hybrid buses against 10 model year 2004 New Flyer D60LF diesel buses. Both bus types are based on the same vehicle platform and provide the same service capacity,and over a 12 month period between April 1, 2005 and March 31, 2006, the hybrid and diesel buses logged similar average monthly miles of service. Table 4.3 summarizes the specifications, costs, and laboratory based fuel use performance data. The maintenance costs accounts for all maintenance activities during the evaluation period. It is important to note that the maintenance costs do not account for major repair and overhaul activities that are known to occur during the bus life cycles, such as engine rebuilds, transmission rebuilds, and battery replacement (for the hybrids). The evaluation of the buses included a measurement of the CO_2 emissions rate on a dynamometer test designed to replicate a Metro Transit duty cycle.

New York City operates the largest hybrid diesel- electric bus fleet in the world, totaling over 1,700 vehicles in 2009.[27] Two studies by the National Renewable Energy Laboratory in Golden,

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[26] Notice that for this estimate, the N_2O and CH_4 emissions were higher for the hybrid bus than for the diesel bus .Currently there is no per mile emission factor available for N_2O and CH_4 emissions from hybrid buses, so the conventional per mile emission factors were applied to the higher mileage of the hybrid buses, resulting in conservative estimates.

[27] http://www.mta.info/nyct/facts/ffenvironment.htm

Colorado (Barnitt and Chandler, 2006; Barnitt, 2008) provide compelling evidence for the fuel savings benefits of these vehicles. First, ten Orion VII (model year 2002) hybrid-diesel electric 40-foot buses (with a capacity of 38 Seated, 32 standing) operating out of two NYC bus depots were evaluated over the course of a 12-month period, from October 2004 to September 2005. Buses out of these depots travel at average speeds around 6.3 - 6.5 mph and make frequent stops.

Table 4.3 King County Metro Hybrid Bus Evaluation Data

	Diesel Bus	Hybrid Bus
Number of Buses	10	10
Manufacturer and Model	New Flyer DE60LF	New Flyer D60LF
Model Year	2004	2004
Seats	58	58
Purchase Cost (per bus)	$445,000	$645,000
Maintenance Cost ($/mile)[1]	0.462	0.444
Total Mileage (maint. cost est.)	353,785	371,458
Total Mileage (fuel est.)	350,567	362,049
Fuel Cost ($/mile)	0.791	0.624
Fuel Consumption (gallons)	139,996	114,054
Fuel Type	B5	ULSD
Fuel Economy (avg. mpg)	2.5	3.17
Lab Test CO_2 (grams/mile)[2]	3,446	2,614

Source: Chandler and Walkowicz, 2006 *[1] The maintenance costs do not account for major repair and overhaul activities that are known to occur during the bus life cycles, such as engine rebuilds, transmission rebuilds, and (for the hybrids) battery replacement. [2.] Both bus types are based on the same vehicle platform and provide the same service capacity. Table 4.3 summarizes the results. The evaluation of the buses included measurement of* CO_2 *emissions based on a dynamometer test designed to replicate a Metro Transit duty cycle.*

The 2006 evaluation found these series[28] diesel-hybrid buses achieved an average of 3.19 miles per diesel equivalent gallon, giving a 37% higher fuel economy than the (1994 and 1999 model

[28]See http://www.eesi.org/files/eesi_hybrid_bus_032007.pdf , for example, for a brief description of series vs. parallel hybrid electric vehicle propulsion systems.

year) diesel buses being run on the same city routes; and an 88% improvement over 2002 model year CNG buses also tested. The hybrid-electric buses also had a 23% lower cost per mile than these CNG buses, due almost entirely to the difference in fuel economy. Based on the calculation procedure used for the King County Metro buses, the MTA hybrid buses produced only 3,182 g/mile of CO_2e, equivalent to a per mile GHG savings of 26.9% and 25.3% respectively over MTA's diesel and CNG buses, respectively. A subsequent study by Babbitt (2008), based on a February 2006 to January 2007 in service evaluation of a more recent (Gen II) hybrid bus technology purchased by NYC Transit. While fuel economy was slightly lower than the Gen I hybrids, this was attributed by the manufacturer to greater use of air conditioning in the Gen II bus tests, An additional improvement for the newest set of hybrid-electric buses is a reported to be a lithium-ion energy storage system, replacing the Gen I and Gen II lead acid battery technology.

Denver, Colorado: Since 2005 the Denver Regional Transportation District (RTD) has purchased over 270 forty-foot low-floor diesel buses, including nine hybrid electric buses. Over a 12 month, post 2008 recording period the hybrid buses achieved a 15.6% fuel economy improvement over the convention diesel buses, when both models were equipped with the same energy saving intelligent transmission shifting technology. This intelligent acceleration-dependent gearshift technology adapts vehicle performance to topography, vehicle acceleration, axle transmission ratio and load conditions, reducing the need for gearshifts and giving a reported 5% to 10% fuel savings (RTD, 2010). Less maintenance is also anticipated, with a typical oil change interval.

Edmonton, Alberta: A one year in–use performance based life cycle comparison of four alternative bus technologies in the city of Edmonton, Canada yielded similar fuel economy and CO_2e savings results. The two model year 2006 hybrid electric diesel bus models tested yielded GHG savings the 12% to 20% range, when compared with a year 2007 model clean diesel bus (Checkel, 2008). The fourth option tested, an electric trolley bus (drawing electrical power from an overhead wire, but using motor controls and an on-board emergency battery that allows it to travel at reduced speeds off the trolley wires for several miles, in order to bypass traffic accidents and blockages) yielded comparable CO_2e emissions to the clean diesel bus, depending on local versus regional electricity fuel feedstock mix:

	Clean Diesel	Hyrbid 1*	Hybrid 2*	New Trolley**
Kg CO_2e /mile	3.16	2.78	2.54	2.93 to 3.11

Notes: * 2006 model year hybrid buses; ** includes use of a 20% backup diesel fleet in case of power outages. These tests were run under trolley bus corridor conditions that involved more stops, more traffic, lower average speed and lower annual mileage than most transit fleet averages.

This Edmonton report is also useful for its comparisons of different bus purchase and life cycle operating costs, as well as some attempt at a sensitivity analysis of these costs and the various bus emissions produced.

Biodiesel Powered Buses: Many transit agencies now use biodiesel in their buses. Biodiesel offers a number of potential benefits. In terms of greenhouse gas emissions, the CO_2 absorbed by the plants grown to produce the biofuels feedstock can also help to offset the carbon emissions generated when biofuel is burned in the vehicle. Biodiesel also has the benefit of being a domestically produced renewable fuel. Most production at present comes from soybeans, but transit agencies are also running vehicles on canola oil, tallow, and recycled cooking oils. A 1998 life cycle analysis study by the National Renewable Energy Laboratory (Sheehan, et al, 1998) concluded that biodiesel produced from soybean oil reduces net emissions of CO_2 by over 78% compared to petroleum based diesel, while B20 (20% biofuel, 89% petro-diesel) can reduce CO_2 emissions from urban buses by around 15.7%. Both EPA and DOE studies produce similar findings (DOE, 2005). From a health effects perspective, significant reductions in tailpipe emissions of carbon monoxide, hydrocarbons, and particulate matter are have also been reported, and biodiesel also appears to improve the performance of diesel particulate filters, which are now standard equipment on new diesel powered vehicles (Krahl et al, 2003).[29]

Schiavone (2007) provides a recent review of biodiesel use in the nation's transit fleets, including two agency specific case studies (the Central Ohio Transit Authority (COTA) and the Roaring Fork Transportation Authority in Aspen, Colorado) that offer insights into the costs of adopting biodiesel and the pros and cons of different biodiesel blends. Eighteen transit agencies are identified, ten of which use biodiesel blends including from 2% to 20% biofuel, seven using a 20% (B20) blend, and one (COTA) using blends from 20% to 90 % (B20 to B90).

Electric Powered Trolley Buses: Trolley buses are rubber-tired vehicles with electric motors powered by electricity from overhead wires. The trolley buses connect to the wire via a "trolley" pole on the roof that is topped by an insulated shoe. In North America, the cities of Seattle, San Francisco, Boston, Philadelphia, and Dayton in the U.S. and Vancouver in Canada, operate electric trolley systems. Many other trolley systems operate in Europe. The GHG savings associated with trolley service are tied closely to the energy feedstock used to produce the electricity. If this energy comes from hydroelectric, nuclear, wind or solar power, a complete life cycle analysis of these energy production and distribution systems shows very little end use GHG emissions, and one to two orders of magnitude fewer GHG emissions per kilowatt hour than fossil fuel (coal, gas, oil) based power plants (Spadaro, 2000, WNA, 2009). However, even with the use of fossil fuel-based electricity sources, research has shown that GHG emissions can still be substantially lower than gasoline or diesel powered vehicles (Unger et al, 2009).

With over 330, 60 foot articulated and 40 foot standard trolley buses serving 16 different routes, San Francisco in California has the largest trolley-bus fleet in North America. Along with its streetcars and the cable motors for the cable cars, the city's trolleys get their electric power from the city's hydroelectric Hetch Hetchy Water & Power Project. The city of Seattle in Washington State operated 159 trolley buses, over 14 different city routes, with some 19.7 million boardings in 2009. The power is delivered to these vehicles from 40 Metro substations scattered across the city. Each substation houses electrical equipment that converts the incoming 26,000-volt AC (alternating current) power into the 700-volt DC (direct current) *power used by the trolleys.[30] The converted electricity is fed into the overhead wires via conduits that travel underneath Seattle streets and then the poles that support the overhead system. Seattle Metro purchases the electricity to power these trolleys from Seattle City Light, which reports deriving almost 98% of

[29] http://www.epa.gov/otaq/diesel/retrofit-tips.htm#standards
[30] http://metro.kingcounty.gov/up/projects/trolleyevaluation.html

its electricity from very low GHG producing hydropower (88.8%), nuclear, and wind energy sources (Seattle City Light, 2009).

4.5 Life-Cycle Cost Comparison Issues for Alternative Bus Technologies

The decision to purchase an alternative transit bus technology will be heavily influenced by both the up-front capital investment (i.e. the vehicle procurement cost) as well as the full life-cycle cost of purchasing, operating, and maintaining the vehicles. The following sections provide some background information on both of these issues.

When considering the results of comparative bus technology studies, it is important to understand that a number of different aspects of bus technology, as well as environmental conditions, can impact fuel consumption and related emissions rates. From a climate change perspective, since absolute reductions in GHG emissions is the ultimate goal, this is not a problem. Realistically, however, comparative life cycle-based purchase, operation and maintenance costs need to be compared across vehicle types to determine the GHG reductions obtained per dollar spent. Financial constraints may warrant considering a slightly more polluting vehicle on an overall life cycle cost plus life cycle emissions basis.

Example Bus Procurement Costs: According to American Public Transportation Association's 2009 Public Transportation Vehicle Database (APTA, June 2009), the average price paid to the manufacturer for a standard 40 foot diesel bus in 2008 and 2009 (3,031 vehicles available nationwide) was $427,721; and for a 60 foot articulated bus (338 vehicles available nationwide) it was $820,719. Table 4.4 shows the average cost paid to the manufacturer for all 2008 and 2009 conventional diesels, hybrid electric diesels (= diesel battery hybrids), CNG, gasoline and hydrogen electric hybrids and biodiesels, as well as reported prices for buses on order in 2010 and 2011.

Based on Table 4.4 below, the capital costs of acquiring either a hybrid diesel electric bus in 2008 through 2011 is just over 47% higher, on the average, than the cost of acquiring a conventional diesel, and after adjusting for average number of seats per bus Biodiesels cost 17% more on average, and CNG buses 23% more on average than conventional diesels based on currently reported payments to the bus manufacturers. Articulated, 60 foot hybrid diesel electric buses were 17.5% more expensive to acquire than conventional articulated diesels. These costs can often be reduced, however, through governmental programs that are intended to give these technologies a competitive edge.

Recognizing that transit agencies are faced with an "uncertain mix of volatile energy prices, emerging bus technologies, and pending climate change regulation", Peet et al (2010) have developed a prototype model for transit operators that examines the fuel type, consumption, and emissions of an existing transit fleet mix. Using the fleet characteristics of the Chicago Transit Authority (CTA), the spreadsheet-based method provides information for an evaluation of alternative fleet mixes, based on user-modified inputs of operating, capital and regulatory costs, illustrating the sensitivity to various inputs for both short-term fleet allocation and long-term fleet procurement practices. The model is being developed to help a transit agency estimate the potential operating costs and emissions of new bus procurements "through a life-cycle comparison of conventional), maturing and emerging hybrid and electric vehicle technologies, under varying scenarios".

Table 4.4 2008-2011 Bus Procurement Costs by Vehicle/Fuel Types

Bus (Fuel) Type	Procurement Period[1]	# Orders[2]	# Buses	Average Cost/Bus	Average # Seats/Bus
DF = Diesel Fuel (Conventional)	2008-11 (O)	98	1193	356,583	37.1
	2008-9	89	1057	356,030	37.2
DF = Diesel Fuel (Conv.), Articulated	2008-11 (O)	4	81	690,409	57.3
	2008-9	2	27	672,266	51.2
DB = Diesel & Electric Battery	2008-11 (O)	12	528	560,778	39.6
	2008-9	8	281	541,723	40.3
BD = Biodiesel	2008-10 (O)	28	316	407,484	36.2
	2008-9	26	295	395,084	36.6
HY = Hydrogen	2008-10 (O)	3	15	598,874	38.7
	2008-9	1	12	617,596	36
CN = Compressed Natural Gas	2008-11 (O)	20	797	470,288	39.7
	2008-9	17	771	473,929	39.8
GB = Gasoline & Electric Battery	2008-9	2	40	564,961	38.0
CB = CNG & Electric Battery	2008-9	1	3	1,300,000	40.0
DB = Diesel & Electric Battery, Articulated	2008-11 (O)	7	277	793,126	56.0
	2008-9	6	219	795,013	55.7
HY = Hydrogen, Articulated	2008-10 (O)	2	15	895,700	60.0
	2008-9	1	13	873,000	60.0

Source: based on data reported in APTA (2009). [1] 2008-9 refers to buses purchased or on order in 2008 and 2009. 2008-10 (O) or 2008 -11 (O) refers to buses purchased in 2008 and 2009, and on order for delivery in 2009, 2010 or 2011; [2] = number of separately reported purchases (can be 1 or a large number of buses per order). Not all active or on-order bus procurements reported in the APTA database have a reported purchase price, The .# buses refers to those purchased or on order that did report a purchase cost.

Comparable Bus Life Cycle Costs: While alternatively fuelled hybrid-electric, biodiesel and CNG buses are currently more expensive to acquire than conventional diesels, they can still be an attractive choice for bus fleet managers since they provide substantial fuel cost savings, while showing comparable maintenance costs.

Clark et al (2009) provide a detailed capital plus variable life cycle costing study of hybrid 40 foot and 60 foot buses, drawing comparisons with pre-2007 and more recent conventional diesel, CNG, and also gasoline-electric hybrid vehicles. Based on data from test sites in four cities (New York, NY; Seattle, WA; Long Beach, CA, and Washington, D.C.), the study found that a diesel-electric hybrid bus purchase was more expensive than the purchase of conventional diesel or natural gas buses, but the hybrid electric bus offers superior fuel efficiency, particularly at low speeds.

A "Well-to-Wheels" Analysis computes the energy and emissions resulting from primary energy source extraction through vehicle operation. This includes the fuel production and delivery process, ending with the fuel used at the pump. It also captured the energy and emissions required to manufacture and deliver the vehicle itself. See http://greet.es.anl.gov/ for example .

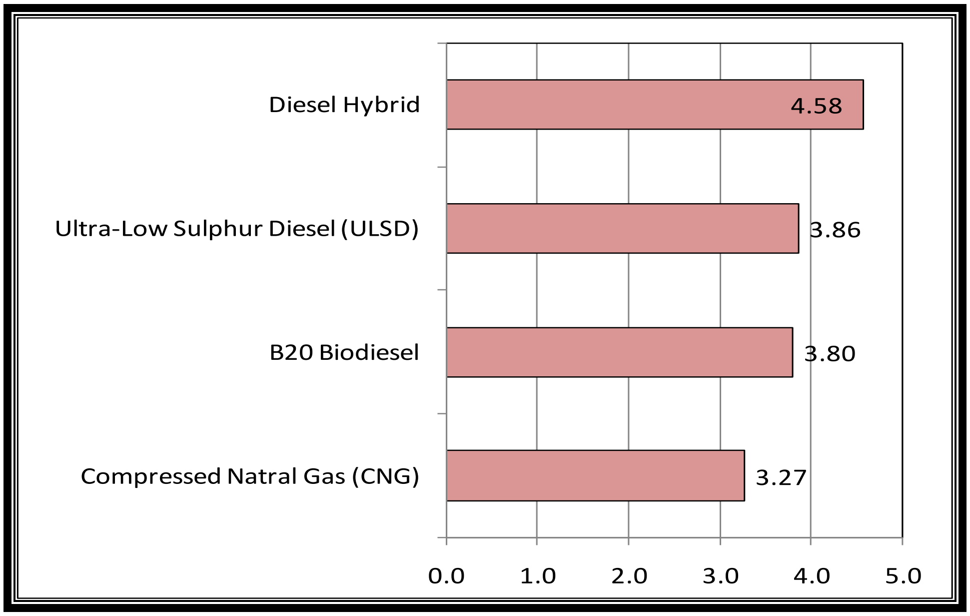
Drawing from the report's executive summary, life cycle cost (LCC) was found to be affected substantially by several cost factors, such as purchase incentives, fuel price, bus operation speed and mileage, battery technology, and bus lifespan. Diesel buses with a conventional drivetrain were usually found to be the least expensive technology, in comparison with diesel-electric hybrid and CNG buses—especially during intermediate- and high-speed operation, and despite the growing complexity of diesel engine technology. Diesel-electric buses are impacted by high purchase cost and battery replacement cost, but become attractive for their fuel savings when operated at slow speed or over longer life mileage. *Fuel efficiencies for the in- service buses tested ranged 1.71 to 3.74 miles per diesel equivalent gallon, suggesting significant GHG savings potential if the right bus can be matched to the right service conditions*.

Assuming that bus mileage and fuel consumption, per mile maintenance costs and fuel costs remain constant, and no interest is charged/earned on bus procurement, operation, and maintenance cash flows, *the fuel cost savings of the diesel-electric hybrid bus nearly offset its higher purchase cost in at the end of the bus lifetime (payback period of 12.3 years).* The FTA may also cover up to 80% of the purchase price of a standard diesel bus under its various grant programs[31], while its discretionary 5308 Clean Fuels Grant Program[32] may cover up to 90% of the net incremental costs to comply with the Clean Air Act. These grants can significantly reduce the purchase cost differential.

Gasoline-electric hybrid buses were found to cost around 5% to 10% more than diesel-electric hybrids overall, and to offer a good alternative to diesel for situations in which a hybrid system is desired to achieve fuel efficiency but criteria emissions restrictions might prohibit pre-2010 diesel engine operation. The LCC of CNG buses was usually found to fall between those of conventional diesel and diesel-electric hybrids. It was also noted that to be competitive "the purchase scale for CNG buses should be large (over 50 buses) to offset capital infrastructure costs), unless these costs will not be borne by the bus operator, are reduced by some infrastructure incentives, or CNG infrastructure is already in place".

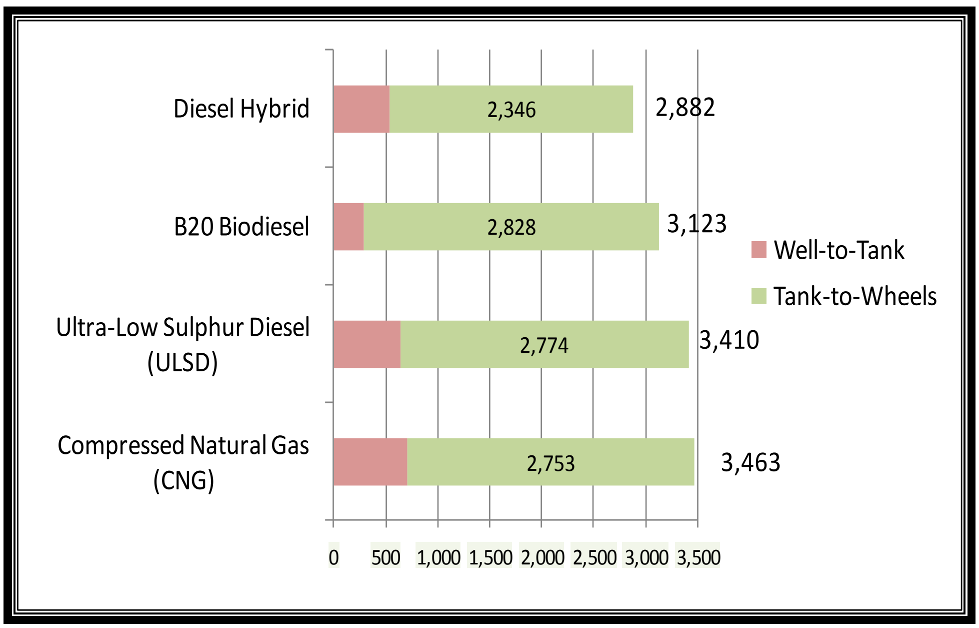
Figure 4.1 MPG estimates for Four Types of Bus
at National Annual Average Speed*

[31] http://www.fta.dot.gov/grants_financing.html
[32] http://www.fta.dot.gov/funding/grants/grants_financing_3560.html



Source: See Clark et al (2007) *12.72 mph. All buses are 40-foot, low floor designs.*

Figure 4.2 Well-to-Wheels CO_2e Emissions in Grams/Mile for Four Bus Types*



Source: Clark et al (2007) **Emissions averaged Over a 12 Year Vehicle Life: 2007- 2019*
GHG emissions include carbon dioxide and methane, derived using Argonne National Laboratory's GREET model .See: http://greet.es.anl.gov/

A 2007 LCC analysis by the University of West Virginia, based on data collected from a number previous studies, suggests significant GHG reductions possible from operating diesel-hybrid buses. Based on a 12 year vehicle operating life, a "Well-to-Wheels" analysis found significant fuel economy savings potential (Figure 4.1), as well as significant GHG reduction possibilities on a grams per vehicle mile basis: on the order of 18% better than the ultra low sulfur diesel bus they used for comparison (Figure 4.2).

4.6 Rail Transit Vehicles

Recent U.S. Railcar Procurements: Both heavy and light rail public transit systems in the United States are powered by electricity drawn from the nation's Electric Grid. In 2008, some 11,377 heavy rail transit (HRT) and 1,969 light rail transit (LRT) vehicles were available for service nationwide, powered by 3,897.7 and 720.9 million kilowatt hours of Grid supplied electricity respectively (APTA, 2010). Self-powered commuter railcars consumed a further million kilowatt hours of electricity in 2008, while commuter locomotives consumed and additional million gallons of diesel fuel. The electric power supply for these vehicles is provided either by overhead lines (catenaries) or by contact rails. GHG reductions are obtainable from either the use of 'cleaner' (i.e. lower carbon emitting) electricity, from more fuel efficient diesels, or from a move to lower carbon fuels.

The costs of procuring, operating, and maintaining rail transit vehicles varies considerably by type of transit mode (commuter, heavy or light rail) and by individual vehicle capacities, as well as by the nature, including the frequency of services offered. Within an rail sub-mode similar challenges exist in selecting the most suitable technology. Table 4.5 below shows the average procurement costs (paid to the manufacturer) based on APTA (2009) reporting of recent and pending procurements, through 2011.

Table 4.5 Recent Railcar Procurement Costs

Transit Mode	Fuel Type	Procurement Period[1]	# Orders[2]	# Rail Cars	Average $ Cost per Railcar	Average # Seats per Railcar
Heavy Rail	Electricity	2010-11	12	1313	1,684,698	43.2
Light Rail	Electricity	2008-10	6	184	4,209,374	75.0
Commuter Rail	Electricity	2009-11	9	514	2,218,185	106.7
Commuter Rail	Unpowered	2008-10	25	480	2,196,952	135.2

Source: based on data reported in APTA (2009) *[1] 2008-9 refers to railcars purchased or on order in 2008 and 2009. 2010 and 2011 refers to railcars on order. [2] = number of separately reported purchase orders (can be 1 or a large number of railcars per order). Not all active or on-order railcar procurements reported in the APTA database have a reported purchase price.# Rail Cars refers to those purchased or on order that did report a purchase cost.*

The unpowered railcars shown in Table 4.5 require a locomotive. The average cost of a diesel fueled commuter rail locomotive, based on some 38 vehicles purchased in 2008 and 2009 was just under $2.6 million dollars (APTA, 2009). Some 62 electrically powered commuter rail locomotives are also reported to be on order for 2010-11, at an average procurement cost of just under $9.2 million dollars.

The carbon emissions associated with Grid-powered trains are heavily dependent on the energy feedstock used in vehicle propulsion. With just over half of all U.S. electricity generated from coal, most transit agencies must draw at least some of their electric power from coal-based power plants. However, even with the use of fossil fuel-based electricity sources, research has shown that such a GHG emissions profile is still a substantial improvement over non-electricity powered vehicles (gasoline/diesel) and their associated GHG emissions profile (Unger et al, 2009). Where nuclear or hydro-electric sources of power are involved, or additional power can be obtained from renewable sources such as solar collectors and wind turbines, significant GHG emissions reductions are possible on a life cycle basis. A number of transit systems today also draw on Grid electricity produced from natural gas, which is typically a source of lower life cycle emissions than either coal or petroleum based fuels.

Heavy Rail Systems: A number of advances in rail transit vehicle technology offer energy and associated GHG savings. BASE Energy, Inc. (2007) provide a detailed description of seven of these technologies and how they computed the potential for electricity savings associated with their use in the Bay Area Rapid Transit (BART) heavy rail system in San Francisco, California (see Table 4.6).

Table 4.6 BART Rail Car Energy Efficient Technologies Study

Technology	Energy Savings	CO2e Reduction Potentials[1]
	kWh/car-year	***metric tons /car-year***
Ultracapacitors for regenerative breaking energy storage	123,989	83.1
Permanent magnet motors for car propulsion[2]	45,063	30.2
Variable frequency drives on HVAC supply fans	4,196	2.8
Optimized outside air intake into cars	2,184	1.5
Higher efficiency HVAC units	1,242	0.8
Daylight controls on flourescent lamps	1,194	0.8
High efficiency lighting	1,170	0.8
Total	179,038	120.0

Source: Based on BASE Energy, Inc. (2007) *Table ES-2B* [1]*Estimates computed by Compendium authors.*
[2]*Refers to replacing existing Induction Motors and Direct Current Motors.*

The GHG reductions shown were computed by the authors of this Compendium, and are based on an average US electricity mix (of coal, nuclear, hydro-power, etc) of 670 grams of CO_2e per kilowatt hour (Samaras and Meisterling, 2008), including an average of 54 grams of CO_2e from "upstream" extraction, processing, and transport of fuels prior to generation. A similar table for potential energy savings associated with retrofitting the seven technologies shown to existing railcars is also provided by the BASE Energy study, to which is also added significant energy savings from directing cooler air to the inlet of the railcar condenser heat exchangers. The study identifies total energy saving technologies that could potentially save an estimated 43% of BART total railcar electrical usage, with a projected cost savings of over $13 million per year

Other U.S. transit agencies with large railcar fleets, such as Chicago's CTA, the New York MTA, and MARTA in Atlanta are also making use of ultra capacitors (Burke, 2000; BASE, Inc, 2007) to store the energy captured from regenerative breaking technology, using the braking action to feeds energy that would otherwise be lost as heat when the train stops. The energy being recovered from regenerative braking systems is being passed via a third rail or catenary to power other, nearby trains. A portion of this kinetic energy can be reused to power vehicles auxiliaries, such as lighting and air conditioning, but most of it is being returned to the network.

Battery Supported Light Rail Systems: Light rail transit (LRT) systems are currently undergoing significant changes that are starting to demonstrate significant energy and associated GHG emissions reductions (Siu, 2007; Fujimoto, 2008; Barrow, 2009). LRT systems have historically drawn their power from an overhead catenary, with a number of ground based power sources introduced into practice over the past decade in cities such as Bordeaux, France and Manheim, Germany (solving the safety issues associated with the potential electrocution of pedestrians by using a variety of technologies that draw electric current only when the LRT vehicle is passing over the line). Each of these systems can now make extensive use of regenerative braking technology linked to ultracapacitors for rapid energy. In cities such as Nice in France, Lisbon in Portugal and Sapporo in Japan, these energy capture technologies are now linked to advances in nickel-metal hydride (NiMH) batteries, allowing light rail vehicles store more of the energy they get from regenerative braking and as a result to operate for long stretches without the need to draw on either a ground based or overhead catenary power supply. This also means eliminating the "upstream" energy and GHG emissions associated with the provision as well as upkeep of these structures. And it allows the possibility of taking more direct or more attractive routes that may also increase ridership, especially through historic or other tourist areas where overhead wires are discouraged or not allowed. In Sapporo, Japan, Kawasaki report that a 3-car, 3-bogie articulated 28 seat, 60 passenger Swimo tram, can now use a NiMH battery for traction power on sections up to six miles when overhead catenary power is not available, storing power from regenerative braking and requiring only 5 minutes to recharge the battery, the time it takes to turn the vehicle around at terminals (Kawasaki, 2008). LRT vehicle suppliers such as Alstom, Bombadier, CAF, and Siemens are reporting battery recharging times as low as a few seconds. Just how many GHG emissions are avoided depends a good deal on the upstream electricity source . In Alberta, Canada, Calgary's CTrain fleet is powered with very low GHG producing electricity, generated by 12 large windmills (wind turbines) located in southern Alberta.

4.7 Paratransit Fleets, Non-Revenue Vehicles, and Ferryboat Services

A number of transit agencies have procured ***hybrid gasoline-electric vehicles*** for use in their paratransit/demand responsive services, and/or as part of their non-revenue vehicle fleet. Using a TIGGER grant, 31 paratransit buses in seven transit agencies across the Illinois will be replaced with hybrid gasoline-electric buses to help reduce greenhouse gas emissions and energy consumption in that state. The vehicles are expected to reduce fuel consumption by a total of 100,000 gallons, and reduce GHGs by a total of 871 metric tons annually. The vehicle will turn the engine off to prevent emissions from idling and use regenerative braking technology to save additional energy. Rabbittransit in York county, Pennsylvania is introducing 10 hybrid gasoline-electric buses into its paratransit fleet as part of a pilot project. These vehicles are believed to offer a 32% reduction in greenhouse gas emissions, due to a 40% improvement in miles per gallon over a conventional gasoline vehicle of the same capacity, with all-electric operation of the vehicle at low speeds and an anticipated 75% reduction in fuel consumption during idling. The Valley Transportation Authority Santa Clara, California operates the largest fleet of hybrid-electric paratransit vehicles in the country. The agency estimates that it cut its annual GHG emissions by 385 metric tons by replacing it gasoline powered vehicles with a fleet of 60 hybrid gasoline-electric sedans and a non-revenue fleet of 10 hybrid gasoline-electric SUVs. Paratransit fuel economy is reported to have increased from around 15 mpg to around 45 mpg as a result. Fleet expansion to 106 hybrids is underway.

Transit agencies are also turning to hybrid gasoline-electric vehicles for use in day-to-day non-revenue service activities, including vehicles used by transit police. For example, the Maryland Transit Authority's police force use a variety of energy-efficient vehicles, including three electrically-powered patrol scooters, bicycles, a gasoline-electric hybrid sedan, and two sedans and six SUVs that can be powered with ethanol. Similarly, the Chicago Transit Authority's non-revenue fleet includes gasoline-electric hybrid SUVs, sedans, and pickup trucks; as well as vehicles that can run on E-85 fuel, a blend of 85 percent ethanol and 15 percent gasoline, and vehicles that run on compressed natural gas.

The Broward County, Florida Mass Transit Department is operating a ***hybrid diesel-electric ferryboat service***. Of the eight ferryboat services reported in the FTA's National Transit Database, seven use diesel-powered craft, while the New York City DOT operates ferry boats run on biodiesel as well as petro-diesel. Washington State DOT is experimenting with 5%, 10% and 20% blends (B5, B10, B20) of biodiesel, mixed with ultra-low sulfur petro-diesel fuels, as part of a Biodiesel Research and Demonstration Project. Three different vessels are used, with the biodiesel produced from canola oil, soybean oil, restaurant oil and tallow (unused beef fat left over from the rendering process).

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5. FLEET OPERATION AND MAINTENANCE PRACTICES

5.1 Introduction

Transit agencies engage in a wide range of operation and maintenance (O&M) practices on a daily and periodic basis, and nearly all of these practices affect the efficient use of fuels/energy, which in turn affects agency GHG emissions. This chapter provides insights and guidance on strategies for reducing agency GHG emissions through periodic operations and maintenance (O&M) activities. This includes practices focused on maximizing productive service output per unit of energy, and on practices that minimize energy losses. Such practices reduce vehicular GHG emissions by improving the day-to-day energy efficiency of agency owned or leased revenue generating transit fleet vehicles, as well as non-revenue vehicles such as those used in right-of-way maintenance and security activities.

5.2 A Wide Variety of O&M Activities Can Reduce GHG Emissions

Strategies for reducing GHG emissions can be arranged into three general categories:

1. fleet management/logistics
2. vehicle operations, and
3. vehicle and (rail) track maintenance.

Many of these strategies are listed in Table 5.1, each associated with one or more mechanisms for GHG reduction, using either a technological, or a protocol fix, or sometimes a combination of both. For example, actions to save energy by reducing vehicle idling include both a technological fix in the form of automatic engine idle stop-start shut off systems, and a protocol-based fix in the form of a fleet wide mandatory idle reduction directive. Similarly, energy savings from smoother vehicle motion, involving less acceleration and stop-go movements can be captured through one or more combinations of preemptive transit vehicle signal control (fleet logistics), the use of on-board adaptive vehicle braking/cruise control/ traction control/ power management technology (vehicle operation), and driver training in support of efficient “eco-driving” practices (vehicle operation). These practices can be further supported by energy efficient tire inflation practices, and possibly low tire pressure warning technology (while also providing a more comfortable ride for patrons).

The ability to combine GHG reduction mechanisms in this manner can lead to a greater payoff, in both emission and financial terms. This in turn requires coordination of such actions within an agency. While both the operations activities and maintenance practices of transit agencies are both closely tied to the provision of mobility services, they are often administered and influenced by distinct groups of personnel within a transit agency. Operational activities are conducted by service planners, dispatchers, vehicle operators, and others who have unique responsibilities and skills for the efficient delivery of mobility services. Maintenance activities are separately conducted by specialists such as mechanics, electricians, and service attendants. Since the work of maintenance personnel impacts the efficiency of vehicle and fixed guideway operations, interdepartmental coordination of O&M activities can enhance complementary outcomes.

Table 5.1 GHG Reducing O&M Practices

Mode	Strategy/Objective	GHG Reduction Mechanism
	Fleet Management/Logistics	
Bus, Van	Better matching of vehicle capacity with passenger	Fleet management software
Bus, Van	More efficient (passenger miles/ vehicle mile) route structures	Fleet management software
Bus	More efficient vehicle positioning to reduce deadheading	Automatic vehicle location (AVL) & real time computer aided dispatch (CAD)
Bus, Van	"Flex"/deviated fixed route scheduling	Automatic vehicle location (AVL) & real time computer aided dispatch (CAD)
Van	More efficient vehicle dispatching	Dynamic CAD
Bus, Van, Light Rail	Smoother, more efficient vehicle movement	Transit signal priority/preemption
Non-Revenue Fleet	Vehicle patrolling, surveillance and road call reductions	Automatic vehicle location (AVL) & real time computer aided dispatch (CAD)
All	Less energy lost in idling	Mandatory idle reduction policies
	Vehicle Operation	
Bus, Van, Rail	Less energy lost in idling	Auto stop-start idle shut-off system
Bus, Rail	Less energy lost when vehicles standing	Switching auxiliary power off when vehicles in yard
Bus, Rail	Less energy lost in non-propulsive uses	Use of auxiliary power units for "hotel" energy sourcing of air-conditioning, lighting, and other non-propulsive functions (bus)
Rail	Less energy lost in non-propulsive uses	Tier II head end power (HEP) units for "hotel" energy sourcing
Bus, Van	Smoother, more efficient vehicle movement	Adaptive vehicle braking/ cruise control/ traction control/ power
Rail	Less energy lost in vehicle air conditioning	Variable speed fans
Rail	Less energy lost in vehicle warm-ups	Use of auxiliary power units
Bus	Less energy wasted in transmission losses	Optimal transmission shifting program
Rail	Less energy wasted in transmission losses	Transmission retarders
Bus, Van, Non-Revenue	Smoother, more efficient vehicle movement	Driver training/"Eco -driving"
	Vehicle Maintenance	
All	Less polluting lubrication	Use of synthetic lubricants
Rail	Less polluting rail track maintenance	Biodegradable, non-petroleum based grease
All	Efficient operation/fewer repairs/replacements	Maintenance monitoring technologies
All	Extended vehicle life	Scheduled engine & drivetrain tune-ups
Bus, Van, Non-Revenue	Smoother, more efficient vehicle movement	Correct tire inflation

5.3 Efficient Fleet Management Practices

The reduction of greenhouse gases per se may not be the major reason behind a transit agency's decision to restructure ridership services, but it does tend to correlate well with reductions in fuel consumption on a per passenger or passenger mile served. And, given a reduction in fleet size requirements for a given level of ridership served, with a reduction in the "upstream" emissions associated with vehicle manufacture.

Environmental Management Systems (EMS) Certification: A number of transit agencies have incorporated GHG emissions reduction actions into Environmental Management Systems, or EMS plans. An EMS is a set of processes and practices that enables an organization such as a public transit agency to both track and reduce its environmental impacts while increasing its operating efficiency. In 2003 the FTA began the promotion of, and offered some financial support for, EMS training and certification according to ISO (International Organization for Standardization) 14001 Standards. These standards are adapted to transit agency use, employing a toolbox of management techniques oriented towards minimizing harm to the environment.[33] This program entered its third round in June of 2010.[34] The EMS being developed by the Los Angeles County Metropolitan Transportation Authority is especially interesting here because of its stated use as climate change management tool (Metro, 2010). In Seattle, Sound Transit has developed an annual Sustainability Progress Report based on its ISO 14001 derived EMS practices, with climate change mitigation strategies listed as one of five major thrust areas (along with Green Building and Design, Environmentally Preferable Purchasing, Waste Prevention and Recycling, and Energy Efficiency: see Sound Transit, 2010).

Uses of IVS/ITS Technology: Many of the improvements in O&M practices used by transit agencies over the past two decades have involved use of the latest electronic communications technology, usually in conjunction with the introduction of computer software and hardware platforms geared to optimizing the use of fleet vehicles. This includes a variety of technologies often grouped under the label Intelligent Vehicle System (IVS) or Intelligent Transportation System (ITS) technologies, and when applied at the system-wide or agency-wide level to large vehicle fleets, as IVS/ITS architectures.[35] In particular, many of the nation's public transit agencies now benefit from the deployment of GPS assisted automatic vehicle location (AVL) devices, coupled with computer aided dispatch (CAD) systems**.** When applied in combination, AVL and CAD provide up-to-date information on vehicle locations to assist vehicle dispatchers in matching demand to supply: as well as informing travelers of the status of current services via station message signs. A review of AVL use in bus transit operations, by Parker (2008), identifies maintenance as well as operational benefits, while putting capital investment costs for deployed systems in the range of $10,000 to $20,000 per instrumented vehicle as a general rule of thumb.[36]

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[33] http://www.fta.dot.gov/planning/environment/planning_environment_227.html

[34] Access to information on EMS participation, and to a number of agency specific EMS experiences from Round 2 of this program can be found at: http://www.fta.dot.gov/planning/environment/planning_environment_227.html.

[35] "Transit Management" deployment statistics for U.S. metropolitan areas through 2007 can be found at the US DOT's ITS Deployment Statistics site: http://www.itsoverview.its.dot.gov/TM.asp

[36] Using the following regression formula as a rough approximation of expected capital costs for any given project: Contract Award = Fleet Size*$17 577 + $2,506,759 ($R2 = 0.677$), based on 27 contract awards dating from 2001 to 2007 in the United States and Canada: and best suited for fleets having less than 750 vehicles.

At its best, IVS technology integrates both on-board vehicle and wayside systems. “For example, IVS applications could ultimately reduce bus fuel consumption, maintenance costs, and running time variation by (Hwang et al, page 232):

1. Determining the vehicle’s expected time of arrival at an upcoming intersection (taking into account past history, current speed, traffic levels, and active stop requests);
2. Communicating with the wayside traffic signal controller to request priority handling at a particular intersection;
3. Determining in advance what signal will actually be displayed at the time the vehicle is expected to arrive; and
4. Informing the operator whether it would be advisable to maintain speed or decelerate for an expected stop signal.”

Flexible/Deviated Fixed Route Services: In a variation on traditional demand responsive or paratransit application, the use of **“**Flex” or “Deviated Fixed Route” service options allows otherwise fixed route buses or vanpools to deviate from their usual, pre-scheduled route, on order to pick up or drop off one or more riders at an otherwise out-of-route location. Once the pick up or drop off is made, the vehicle returns to, and resumes its usual route. Where the deviation leads to a higher passenger-mile per gallon of fuel consumed, the service is reducing overall travel GHGs. If the out-of-route passengers also pay a full fare or subscription for the service, revenue dollars per vehicle mile of service may also result. The down side is the potential for delay to other riders, and possible loss of patronage as a result. Software programs exist to help transit agencies optimize this sort of flexible service provision.

As more operators equip their smaller buses and vanpool vehicles with various forms of ITS communication and location tracking technologies, shorter lead times may be required in order to determine which out-of-route trip requests to meet, allowing these flexible routing and scheduling systems to become more energy efficient in the future. For example, the Utah Transit Authority began operating three new community “flex” routes in May of 2010. The routes bring new all-day service to areas that previously had no service or had only morning/evening commuter buses. The new routes offer a regularly scheduled route through the community but have the ability to deviate up to 3/4 mile off of the regular fixed route for just $1 more than standard fare. Customers can call to schedule a deviation up to two hours prior to the trip. The new routes operate using a smaller shuttle-style van, which is less expensive to operate than a full-size bus, but still has room to carry the potential number of riders on the routes.

In Fitchburg, Massachusetts, the Montachusetts Area Regional Transit merged conventional paratransit with a full-fare subscription service that delivered an operating cost reduction of 60% with no impact on quality of service. Next day rideshare services appear to be especially popular for transporting young children to schools, as well as for federal welfare, Head Start, disabled, and special needs riders, where conventional fixed-route transit typically involves multiple transfers or extended walking distances (Hwang et al, 2006). Potts et al (2010) found that 194 out of 501 transit agencies responding to their survey currently used some form of flexible/deviated route transit service. They provide a number of case study examples, and guidelines on where such services may apply in rural, small urban and larger urban environments. A detailed analysis of miles reduced, fuel saved and emissions avoided per passenger served has still to be provided for such services, given a suitable regional ridership demand profile. However, cost savings reported indicate some promise, given a suitable ridership demand profile and service area geography.For example, the Potomac and Rappahannock Transportation Commission (PRTC) operates OmniLink, a route-deviation system blended with fixed-route characteristics to provide transit services for all area residents without operating a separate ADA paratransit system. PRTC estimates a 25% to 50% cost savings by operating this one service versus two separate (fixed, demand-responsive) services.

Demand Responsive Real-Time Software: The Toledo Area Regional Transit Authority (TARTA) of Ohio uses a demand response software solution that enables passengers to quickly gain access to, and request paratransit information via a touchtone telephone. With flexible 24 hours a day, seven day a week automated system access, passengers are able to set up call-back reminders that promote punctuality and reduce missed trips. TARTA's service for riders with special needs is called TARPS (Toledo Area Regional Paratransit Service) and covers all of Toledo, Sylvania, Maumee, Rossford, Perrysburg, Ottawa Hills, Waterville and Spencer and Sylvania Townships. The paratransit software is designed to reduce driver wait times and no shows, as well as prevent same day cancellations. Using interactive voice response (IVR) confirmation, callback and cancel modules, the software enables clients to review trip bookings through a computerized voice system to confirm accuracy, while the callback module also provides passengers with automatic reminders of upcoming trips.[37] The benefits of such a system is the ability to reduce emissions from vehicle miles of travel lost to no-shows, as well as to reduce vehicle idling while waiting for customers to board an arrived vehicle.

Vehicle-to-Passenger Load Matching: By going with the smaller buses on routes that are not currently operating at capacity, a transit agency might save on the vehicle's purchase price as well operating costs as through significantly reduced fuel consumption. However, heavier-duty 40 foot buses tend to have a longer operating life, on the order of 350,000 miles, versus 150,000 to 200,000 miles for a lighter-duty (e.g. 20 foot) bus. In considering these options, the Lawrence transit agency in Kansas City selected a mix of bus sizes, supplementing a small fleet including 40 foot and 30 foot fixed route buses with the procurement of six shorter, 20 foot buses (at an estimated cost of $480,000).

Route Restructuring: Changes in the spatial distribution of household populations sometimes warrant a restructuring of fixed bus routes in order to provide short distance access to a larger number of potential riders. A higher ratio of seat miles to vehicle miles can also be achieved through more the application of route optimization software tools based on the "traveling salesman" principle of making the largest number of pickups per vehicle mile. Some significant fuel reduction gains may be possible. For example, the Port Authority of Allegheny County,

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[37] http://www.encyclopedia.com/doc/1G1-209031445.html

when surveyed, reported that "Current route restructuring (phased 4/2010 - 3/2012) will reduce non-revenue mileage by 28%." Many other examples are provided in the FTA sponsored series of reports included in TCRP 95: *Traveler Response to Transportation System Changes Handbook.* The handbook also provides suggestions for how to approach route restructuring issues, and case studies demonstrating the impacts on ridership levels and service levels from bus, rail, and demand-responsive route restructuring actions.[38] The challenge, of course, is to reduce vehicle operating costs, including energy costs, while retaining, and where possible increase, ridership on the new routes. This is not a simple task, and has been the subject of numerous technical papers. The textbook by Ceder (2007) provides a comprehensive treatment of many of the practical as well as scientific aspects of matching transit services to the pattern of ridership demands, and to issues associated with the efficient design of fleet resources as well as route structures.

Reduced Vehicle Deadheading: Moving buses around empty is to be avoided if possible, but is often required in order to position the vehicles for their next round of service. This repositioning is often termed 'deadheading". This includes the reduction of non-revenue, deadheading miles associated with empty vehicle pre-positioning and return to garage, or to the miles involved in moving from one fixed route to another over the course of a day. Sound Transit in the state of Washington implemented a mid-day bus storage program so that its' express buses coming from Pierce County are stored close to the central business district in Seattle between the morning and afternoon commutes, rather than driving back and forth empty. This is estimated to have saved some 95,000 gallons of diesel fuel (approximately 965 metric tonnes of CO_2), in 2008, without changing the amount of service provided.

5.4 Efficient Vehicle Operation

The efficient operation of individual vehicles within the transit fleet has also benefitted from recent advances in electronic communication-enabled IVS technology. Hwang et al (2006) identify the following IVS technologies as having energy savings, and hence GHG reduction, potential, either individually or in combinations:

1. Global Positioning System (GPS)-based route guidance and navigation
2. Communications-Based Train Control (CBTC)
3. Digital onboard Vehicle Area Networks (VAN) and Trainline networks
4. Short-range wireless communications
5. Mobile Data Terminals (MDT)
6. Multiplexed electrical systems
7. Adaptive braking
8. Adaptive traction control

[38] Chapter 10, "Bus Routing and Coverage,"broadens the coverage of conventional bus operations, as does Chapter 4 for express bus services, and Chapters 7 and 8 for urban rail systems. All aspects of demand
responsive and ADA (Americans with Disabilities Act) services are covered in Chapter
6; this includes matters of "scheduling" (dispatching) and service quantity.

9. Adaptive cruise control
10. Adaptive power management
11. Infrared vision enhancement
12. “Heads Up” Displays (HUD)
13. Wheel/tire temperature and air pressure monitoring
14. Precision steering and docking
15. Onboard Supervisory Control and Data Acquisition (SCADA)
16. Short-range Radio Direction and Ranging (RADAR) proximity sensing
17. Short-range ultrasonic proximity sensing
18. Machine vision
19. Interactive electronic defect card.

Driver Training (Bus, Van): Driving behavior has a strong effect on fuel use, and U.S., European, and Japanese studies have indicated that fuel economy improvements on the order of 5 to 10 percent can be obtained if drivers are aware of the effects of their driving style on efficiency and adjust their driving accordingly (ECCJ 2003, ECMT/IEA 2005). “Eco-driving” is a term that is becoming popular when referring to the use of non-aggressive driving techniques such as shifting up as soon as possible, maintaining a steady speed, anticipating traffic flow and decelerating smoothly. According to GTZ (2005), efficient driving techniques achieved through a combination of vehicle fuel, speed and acceleration monitoring, and driver training can reduce fuel consumption by 5% to 10%, and sometimes by a good deal more, depending on starting conditions. In Edmonton, Canada, the “Fuel Sense” program instructs drivers to operate vehicles for maximum fuel efficiency while considering operational needs. Participating drivers learn techniques such as reducing idling time and planning more efficient routes. A computerized fuel dispensing system measures the fuel usage of individual drivers at regular intervals. Data for some 800 trained municipal bus operators averaged a 12% fuel efficiency gain with overall GHG savings to date put at around 10% (Transport Canada, 2010). The addition of real-time fuel economy indicators on vehicle dashboards is also a useful method worth exploring.

Idling Reduction (Bus and Van): Vehicle engine idling is a major source of GHG emissions from both revenue and non-revenue activities, and from both highway and rail transit vehicles. Referring back to Table 5.1, emissions from idling are influenced by a variety of operating characteristics. These include time spent stopped in congested traffic and/or at signalized intersections, stopping for passenger boarding/alighting and fare purchase, engine operation solely for the provision of passenger comfort and security, freeze protection and warm-up of the engine and ancillary systems, cleaning of the vehicle interior (“hotel” loads), and even stationary surveillance of transit property from transit police cruisers.

Agencies can therefore benefit from a coordinated effort at idling reduction across the various departments and personnel that either have an impact on the way vehicles are operated or on the practices of their vehicle operators and maintenance staff. For example, many recent orders for diesel buses include the provision of automatic engine stop/start technology; however, the use of these technologies may not be compatible with ancillary computer systems (such as bus stop announcing systems or emergency road call systems), or they may not be compatible with the provision of comfortable interior conditions demanded by operators or passengers. Best practice therefore suggests an assessment of idling practices prior to vehicle procurement as well as during vehicle operations.

__Example Bus Idling Reduction Case Study:__ **Chicago Transit Authority (CTA).** Researchers at the University of Illinois at Chicago have helped the CTA investigate strategies for mitigating excessive idling of diesel transit buses (Ziring and Sriraj, 2010). With respect to bus technologies, the CTA has utilized automatic shutdown/start-up systems to shutdown diesel bus engines left in idle. For the CTA, all New Flyer and Optima buses are delivered with 15 minute automatic shutdown systems, and NABI and NOVA buses are delivered with 30 minute systems. No shutdown devices are installed on buses manufactured before 2000. Each of the alternative idle reduction strategies shown in Table 5.2 could provide emission reduction benefits for as long as the life of the vehicle.

Table 5.2 Direct Bus Energy and GHG Emissions for Entire Fleet

Strategy	Diesel Consumption (gallons)	CO2 Emissions (tons)	Fuel/CO2 Reduction (%)
Baseline	40,865,010.00	453,601.61	--
Auxiliary power unit (APU)	35,636,009.55	395,559.71	12.80%
Battery-powered AC/diesel-fired heater	34,060,146.40	378,067.63	16.65%
Automatic Shutdown/Start-up	33,701,995.68	374,092.15	17.53%

Source: See Ziring & Sriraj, 2010

Table 5.3 Financial Costs and Savings per Bus

Strategy	Capital Cost	Operating/ Maintenance Cost	Annual Savings	Payback (years)
Auxiliary power unit (APU)	$8,000	$400	$12,396 - $14,719	0.5 – 0.6
Battery-powered AC/diesel-fired heater	$7,500	$400	$13,769 - $14,719	0.5
Automatic Shutdown/Start-up	$1,200	$0	$11,740 - $14,380	0.1
Direct power connection	$2,100	$0	$3,407	0.6

Source: See Ziring & Sriraj, 2010

Not only do bus idling reduction strategies provide direct fuel, financial, and GHG emissions savings, they can also help to reduce engine wear-and-tear which affects the frequency of oil changes and overhauls, as well as fuel economy. Bus idling reductions can also help to reduce criteria air pollutants in areas where buses idle (notably locations adjacent to bus garages, bus terminals, and special events bus parking). However, the feasibility of both automatic and driver initiated shutdowns are limited by concerns of start-up reliability, interior comfort, and disruptions to on-board computer systems (estimated at one hour per day of idling between maintenance tasks at the pilot garage).

In 2004 the CTA issued a General Bulletin aimed at curtailing unnecessary idling of buses. The bulletin states that bus operators must shut off engine on layovers of more than 5 minutes, except in extremely cold or hot weather, and must also shut off the engine immediately when their bus is staged at an event, except in extremely cold or hot weather. However, Ziring and Sriraj (2010), who interviews 58 different bus operators (10% of operators at a specific CTA bus garage), identified two significant opportunities for reducing fuel/energy losses due to idling, which they term storage idling and service idling:

Storage idling occurs at bus garages and terminals when repairers, servicers and operators start a bus's engine earlier than necessary and neglect to shut off a bus's engine when the bus is not required to be on, or unnecessarily restart a bus's engine immediately after the bus's automatic shutdown timer has turned the bus off." Such idling may be greatest at outdoor bus garages where low ambient temperatures conditions necessitate extensive idling.

Service idling is non-discretionary idling which occurs while a bus is in the field but not engaged in transporting passenger: notably idling while standing in lace at special events, and idling on layovers. These buses may idle their engines for the duration of these events to maintain comfortable cabin temperatures. Idling for long periods of time could also occur on layovers, which occur when bus operators wait for shift relief, wait to pull onto their route in the opposite direction, or stop for a personal break. The authors note that "While storage idling reaches its highest levels during winter months when bus warm-up times are longer, service idling occurs consistently year-round".

Idle reduction programs are now being applied in a number of transit agencies around the country. When surveyed in April, 2010, the Port Authority of Allegheny County reported "Idling practices (were) altered 3 years ago in conjunction with County ordinance. (This resulted in a) 12% reduction in idle time." In responding to the same survey, The Utah Transportation Authority (UTA) reported that "No idling of buses saves around $1 million per year". The City of Calgary, in Canada's Alberta province has a no-idling policy which states that:

"City Transit vehicles will not be parked with engine operating for more than 5 minutes unless it is essential for performance work. Exceptions are during an initial engine warm-up period in weather below-10 Celsius and during periods of extreme cold weather below-10 Celsius. When engines must be left operating, for any reason, the operator will remain with the unit."

Similar anti-idling laws exist elsewhere, and the number of locally and regionally imposed anti-idling laws is on the rise (Gaines and Levinson, 2009a). In New York, for example, a statewide idling law sets a similar limit of 5 minutes for trucks and buses, unless the temperature is below 25 degrees Fahrenheit. Many of these laws are targeted principally at trucks, but the technologies for reducing idling by providing more energy efficient means of heating both passenger spaces and engine blocks, as wall as providing air conditioning are generally applicable to heavy duty diesel buses also. Idling has also become an issue with school and tour buses and the emissions they release (Gaines and Levinson, 2009b). As a result, more effective idle reduction technologies may be on the horizon. For example, Intercity Transit, which operates in Thurston county, Washington implemented a bus pre-heater program in 2009 that it expects will reduce its fuel costs by $30,000 to $50,000 per year.[39]

Speed and Braking Controls (Bus): A vehicle retarder, when actuated, provides an auxiliary and independent braking system for absorbing a portion of the kinetic energy of a decelerating bus. By sharing braking with the service brake system, the retarder results in cooler brakes and significantly increased lining life (Boktor, 1983). Intercity Transit, WA recently (May, 2010) completed a retarder application test that it projects will save the agency $60,000 to $80,000 per year in fuel costs when implemented in its bus fleet. The retarder action occurs when the brake is applied, rather than when the throttle is disengaged (i.e. when the throttle is relaxed to the idle or throttle off position, causing the engine and transmission to slow the vehicle, instead of using the brakes and transmission). As a result, it is expected that brake replacement costs may increase, but both dollar savings and fuel/emission reductions will be significant.[25] Safety issues must remain paramount in making such changes, of course.

Low Rolling Resistance Tires (Buses, Vans, Non-Revenue Vehicles): Transit buses are unlikely to adopt wide based single tires, however, although low rolling resistance and next generation dual tires are expected to offer fuel consumption savings over current tires on the order of 0.8% to 2% (TRB, 2010, Table 6-11).

Idling Reduction (Rail): The purchase of idle reduction technology in rail transit operations is also paying dividends in terms of energy as well as emissions savings. When used in diesel fueled commuter locomotives it can offer significant GHG emissions reduction where long duration in-station idling has been the norm. A number of technologies can be retrofitted to existing diesel powered locomotives for the purpose, including (Gaines, 2003):

1. Automatic engine stop-start controls (AESS)
2. On-board auxiliary power units (APU)
3. Electric Grid powered plug-in units
4. Diesel-driven heating systems (DDHS)

In some instances AESS systems that shut of the engine after a set idle time can cut idling times in half, using sensors to monitor the locomotive's water temperature, brake pressure and battery charge (e.g. engine stays on below 40^{o}F or water temperature drops below 100^{o}F: so that fuel savings tend to be greater in southern locations in the U.S.).

APUs provide an alternative, more efficient energy source to the locomotive's diesel engine for carrying out a number of tasks not associated with propulsion when a train is at a station. APUs are used to carry out such functions as lighting, heating and circulating the coolant and oil, charging batteries, and powering cab heaters. Use of APU technology in diesel locomotives recently acquired by the Maryland Area Rail Commuter (MARC) service are expected to reduce

[39] http://www.intercitytransit.com/newsandinfo/meetings/Documents/May%205%202010%20Packet.pdf

fuel consumption by around 3O%, in part from APU enabled reductions in locomotive idling. An option here is use Electric Grid-powered plug-in power units. Over 2,000 of these units have already been installed on commuter trains in the U.S., as well as on short line, regional, and Class 1 locomotives. As a fourth option, DDHS systems can also be used to charge batteries and power in-cab heaters. These systems make use of waste heat produced by variable engine operating speeds, to efficiently heat water and oil and maintain brake pressure. Operating independently of other locomotive systems, small, two cylinder, water cooled diesel engines, coupled with a water circulation pump and an alternator can pump heated coolant through a locomotive's engine, compressor, expansion tank, oil cooler and cab heater to keep the entire locomotive's water system warm during shutdowns. According to one manufacturer, these units r consumes less than a half gallon of fuel per hour during engine shutdown, compared with the 3 to 5 gallons per hour that idling locomotives typically use. [40]

Sound Transit in Washington State installed an auto start-stop system on all commuter rail locomotives in 2009. This automatically shuts down the locomotive's engine when its idling for long periods of time and automatically starts the engine when necessary. This is estimated to reduce engine idling by about 34 percent, and to cut over 1.8 million pounds of carbon dioxide emissions per year.

In late 2007 New Jersey Transit it announced plans to end locomotive idling when temperatures rose above 40°F and then expanded the no-idling policy to when temperatures dropped to 0°F. Since then, more than 100 diesel locomotives have been retrofitted with new starters, block heaters, and batteries. In addition, new wayside power stations have been installed in rail yards so that maintenance can continue on the locomotives even when the engines are turned off. The agency expects to save $835,000 a year in fuel costs and reduce emissions by 2,269 tons of carbon dioxide, as well as 26 tons of nitrogen oxides, and one-half ton of particulates, by having made these improvements.

Speed and Braking Controls (Rail): In 1996, New York City Transit began its *Subway Car Shunting Elimination Program*, one of its most successful energy conservation projects. By modulating the acceleration rate and limiting the top speed of the 5,800-car subway fleet, the agency reduces energy use per subway car mile by 12 percent and saves 240 million-kilowatt hours of electricity annually (MTA, 2010).

The New York MTA is also deriving energy savings by laying "humped tracks" as part of its Second Avenue Subway project. By adjusting track inclines at stations, it is possible to use gravity to reduce the energy trains expend in braking and acceleration, shaving kilowatts off each train arrival. Similarly, minute calibrations of the turn radius in tracks can minimize energy loss in braking (MTA, 2010, page 22).

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[40] http://www.hotstart.com/hotstart-introduces-low-cost-diesel-powered-heating-system-for-locomotives/

5.5 Adoption of Advanced Vehicle Maintenance Practices

Schiavone (2010), reviewing the latest preventative maintenance (PM) practices by U.S. public transit agencies, reports a wide variety of computer-based programs being used to schedule their PM intervals, with these same programs also being used to guide and track PM activities (i.e., follow-up repairs, parts, costs, etc.) over time by most agencies reporting. The more capable PM programs were found to be part of "a larger Management Information System (MIS) that tracks and helps manage many maintenance-related activities, including repairs, costs, parts inventory and purchasing, fuel and lubricant dispensing, vehicle history files, vehicle availability, timekeeping, payroll, account payable, facilities maintenance, and others".

Regular vehicle maintenance has long been known to pay feul saving dividends. For example, TriMet in Portland Oregon reports that its maintenance crews boosted gas mileage on buses an extra 0.32 miles per gallon in 2005, by adjusting transmissions, front-end alignments and steering control arms, and maintaining a set tire pressure, saving an estimated half a million gallons of diesel fuel that year.[41]

Real-Time Maintenance Monitoring Technologies allow for automatic collection and reporting of vehicle condition and maintenance record. This includes the ability to monitor a vehicle's engine performance, its fuel, lubricants, and antifreeze levels, the pressure in its tires or temperature of its wheels, and the conditions in the vehicle operator's cab as well as in passenger compartments. Properly inflated tires on vans and transit agency automobiles (e.g. transit police cars) can reduce fuel consumption by more than 3% according to the US Department of Energy, with under-inflated tires lowering gas mileage by 0.3 percent for every 1 psi drop in pressure of all four tires [42]. According to GTZ (2005), bus tire pressures that are between 15% and 20% too low can increase fuel consumption between 5% and 8%. The use of tire monitors is estimated to save on the order of 0.25% of a representative 40 foot transit bus's fuel, at a capital cost of around $900 (TRB, 2010, Table 6-11).

Automated Fluid Management Systems: King County Metro Transit in Seattle, WA, uses an automated fuel and fluid management system, that allows it to quickly identify and fix oil leaks, eliminate fuel discrepancies and leakages, and assess MPG changes to gauge whether or not vehicles need maintenance. Fuel station pumps can recognize a specific vehicle by number and use an automated shut-off system for recording and dispensing fuel that prevents at-the-tank overflows (and prevents fuel from being stolen, also).[43]

5.6 References

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6. GREEN BUILDING, GREEN PROPERTY, AND GREEN WORKFORCE PRACTICES

6.1 Introduction

Public transit agencies have been among the leaders in a number of cities in adopting low energy, low GHG "green" building practices. In further support of such actions, in July of 2009, and at the direction of the US Congress, the FTA released its Transit Green Building Action Plan (FTA, 2009). The Plan reviews ways that green building practices can conserve resources, as well as lower construction, operations, and maintenance expenditures through the efficient use of energy, water, building materials and land. This includes the construction of new transit facilities, as well as the refurbishment of existing facilities. In addition, FTA's Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) program provided funding for 9 solar installations, 2 wind installations, and 2 geothermal installations, reflecting the potential of transit properties to generate clean energy. The focus of this present chapter is on the energy and related greenhouse gas emission reductions obtainable from such practices. Also covered briefly in this chapter are ways for transit agencies to offer low GHG commute opportunities to their own employees.

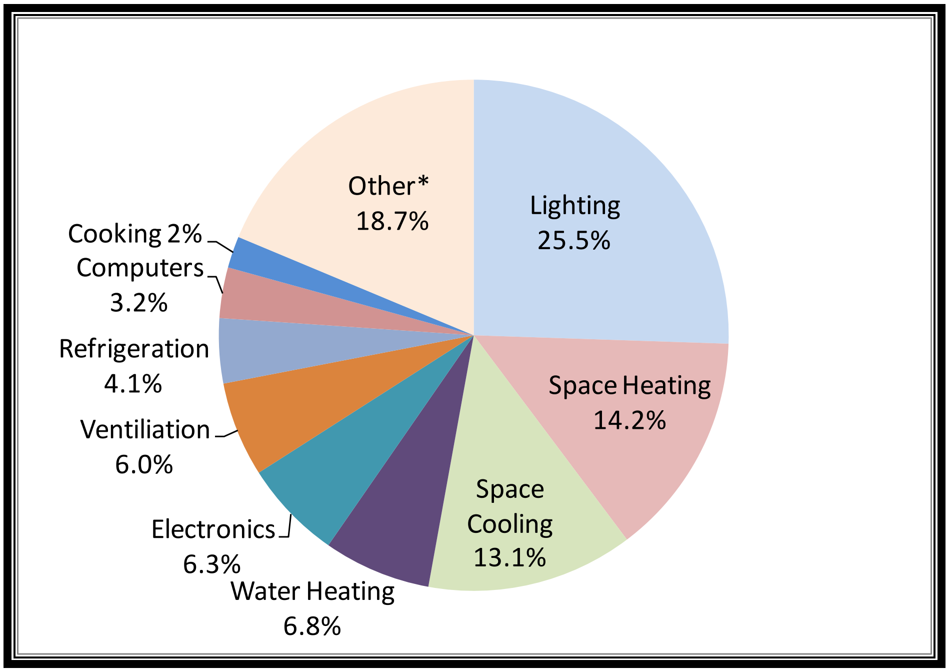
6.2 Significant GHG Reduction Opportunities Exist in Building Design, Construction and Operations

The design, construction, and operations of buildings each offer significant opportunities to reduce energy consumption and GHG emissions. In the United States, buildings account for 38% of direct domestic CO_2 emissions (NETL, 2009). U.S. buildings are responsible for 40% of domestic energy consumption (ASHRAE, 2009), while commercial buildings account for 18% of total domestic energy consumed (DOE, 2009). By 2020, the reduction in energy use as a result of energy efficiency practices could result in the abatement of 1.1 gigatons of greenhouse gas emissions annually. This reduction in GHG emissions is the equivalent of taking the entire U.S. fleet of passenger vehicles and light trucks off the roads. Incorporating high performance energy efficiency measures into commercial and public buildings accounts for 25% of this potential reduction in GHG emissions (McKinsey, 2009).

Energy use in large commercial and industrial buildings is generally dominated by HVAC and lighting loads. Figure 6.1 shows the breakdown of energy by end-use in commercial buildings. The actual breakdown of energy end-use depends on the type and function of a building, its occupancy, and the climate where the building is located. While many energy efficiency strategies in buildings, such as the use of natural daylighting, may require minimal or no upfront cost, often energy efficiency measures require upfront investment in return for savings that accrue over the lifetime of the solutions (McKinsey, 2009).

Transit agencies can play an integral role in working towards building energy efficiency by adopting green building practices in their many and varied facilities, such as transit guideways, stations, offices, garages, fuel storage depots, maintenance facilities, and the many other built structures that support transit services on a daily basis. The design and construction of high-performance, energy efficient buildings, as well as retrofitting existing buildings to be more energy efficient, can be a source of significant environmental opportunity, as well as operational cost savings, for transit agencies.

Figure 6.1 Commercial Buildings Percent Energy by End-Use



Source: DOE, 2008.
*Other * includes 1 quad of energy (5.5%) that is a statistical adjustment by the Energy Information Administration to reconcile two divergent data sources.*

Chapter 7 of this Compendium provides a good example of this. The GHG emissions attributed to the Metropolitan Atlanta Rapid Transit Agency's rail stations and yards, bus depots, offices, and other buildings represents roughly 30% of MARTA's 2008 carbon footprint (some 88,750 metric tons of CO_2e out of a total of 292,240 metric tons, principally from electricity generation and consumption.

Green building practices that have been demonstrated by transit agencies to significantly reduce GHG emissions can be grouped under the following headings:

1. Green building codes and standards
2. Integrated design
3. Building envelopes
4. Energy consuming equipment
5. Renewable energy systems
6. Building retrofits

The rest of this chapter describes such practices, puts them in context, and identifies successful practices that transit agencies should consider for reducing their GHG emissions. Most of these practices should have general applicability across transit agencies.

Adopting Green Building Codes and Standards: It is the responsibility of states or local jurisdictions to enforce building and energy code, while the responsibility to comply with the building energy code falls on developers, designers, and contractors. There are two primary baseline building energy codes that may be adopted by states and local jurisdictions:

1. the International Energy Conservation Code® (IECC) developed under the auspices of the International Code Council (ICC), and
2. the ANSI/ASHRAE/IESNA Standard 90.1 Energy Standard for Buildings except Low-Rise Residential Buildings developed under the auspices of the American Society of Heating, Refrigerating and Air Conditioning Engineers.

These codes and standards are maintained and updated by their respective organizations per a well defined revision process (DOE, 2010). Many jurisdictions across the country are also adopting more rigorous green building and energy efficiency codes. As of August 2009, there were over 300 such programs adopted by states and jurisdictions nationwide. Some jurisdictions are opting to either mandate these programs or are offering incentives to those who voluntarily comply (DOE, 2010). The State of California has even adopted a statewide mandatory green building code called CALGREEN scheduled to become effective on January 1, 2011 (BSC, 2010). CALGREEN will mandate that every new building constructed in California reduce water consumption by 20 percent, divert 50 percent of construction waste from landfills, install low pollutant-emitting materials, and requires increased energy efficiency. The California Air Resources Board estimates that these mandatory provisions will reduce greenhouse gas emissions in CO2 equivalent, by 3 million metric tons in 2020 (State of CA, 2010).

One of the most widely accepted green building certification programs, promulgated by the non-profit organization the United States Green Building Council (USGBC), is the Leadership in Energy and Environmental Design (LEED®) Green Building Rating System™. LEED® certification provides an independent, third-party verification that a building project is environmentally responsible (USGBC, 2010a). Specific LEED® rating systems and certification programs are tailored for new construction as well as for existing buildings. The LEED® rating system is a multi-tiered system that includes Certification, Silver, Gold, and Platinum rating, with Platinum being the highest rating. The LEED® standard has been applied to transit facilities such as the Corona Maintenance Facility in Queens, New York among others throughout the country. Some transit authority commissions are recommending that in the future, all applicable transit building projects seek LEED® certification. (MTA, 2009a) A number of public transit agencies in cities such as Charlottesville VA, Knoxville TN, and Toronto in Canada have already taken "the lead on LEED" to become the first LEED™ certified buildings in their respective cities. APTA's (2009) Transit Sustainability Guidelines directs analysts to the Green Building Initiative's (GBI) guidance and assessment program[44] and to the International Initiative for a Sustainable Build Environment's (IISBE) SBTool 07 toolkit for assessing the sustainability of traditional buildings.[45]

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[44] http://www.thegbi.org/green-globes-tools/
[45] http://www.iisbe.org/iisbe/sbc2k8/sbc2k8-dwn.htm

The GBI's Green Globes® system offers an online assessment protocol, rating system as well as guidance for green building design, operation and management. The system is used in Canada and in the USA. The Green Globes® assessment and rating system can be applied to new buildings as well as to existing buildings. Also, the system includes portfolio management capability that allows owners and developers with multiple properties to assess and compare the buildings in their portfolio. The Green Globes® system provides a recognizable certification that is achieved by undergoing third-party verification by trained regional verifiers (Green Globes, 2010).

The U.S. Environmental Protection Agency's (EPA) ENERGY STAR program for buildings allows many types of existing buildings to be rated on energy performance on a scale of 1-100 relative to similar buildings nationwide using EPA's Portfolio Manager. Buildings rating 75 or greater may qualify for the ENERGY STAR. Portfolio Manager allows you to track and assess energy and water consumption within individual buildings as well as across an entire building portfolio. Energy consumption and cost data are entered into a Portfolio Manager account to benchmark building energy performance, assess energy management goals over time, and identify strategic opportunities for savings and recognition opportunities. The ENERGY STAR program also offers the Target Finder building design rating system. Target Finder is a free online tool that informs and encourages the design of more energy efficient buildings. Building project designs that meet the Target Finder performance score threshold are eligible for "Designed to Earn the ENERGY STAR" certification. (EPA, 2010a).

Example LEED® Case Study: **The Corona Maintenance Shop in Queens New York** received a LEED® Certified rating by the U.S Green Building Council. The maintenance shop, which opened in December 2006 was the first LEED® Certified transit facility in the country. The facility incorporates several green building strategies including fuel cell technology, 100 KW photovoltaic array system, extensive use of daylighting, and rainwater collection. The 200 kW fuel cell unit mounted on the rooftop, is an electrochemical energy device that generates electricity to power motors, lights, and building equipment by converting hydrogen and oxygen into electricity. The building's use of natural lighting reduces the demand for electric lighting. Daylight enters the building through side windows and skylights. Windows with Low-e (low emissivity) coatings allow the transmission of visible light into the building interior while blocking radiant heat. Rainwater is harvested by the facility to wash subway cars. The facility is estimated to be 36% more energy efficient than is required by New York State energy code (MTA, 2010).

The total project cost for the Corona Maintenance Shop was $167 M. The added cost associated with the green components and LEED® Certification was $5.1 M (3% of total project cost), and the added cost associated with the energy reducing green components was $3.425 M (2% of total project cost). The expected yearly energy cost savings is $396,523. Therefore it is anticipated that in approximately 9 years the project will break even and realize net cost savings.

Integrated Design: The integrated design process relies on the exchange of information between all the stakeholders across the life cycle of the project, from defining the need for a building, through planning, design, construction, building occupancy, and operations. This approach is a deviation from the typical planning and design process, which entails specialists working in their respective specialties usually somewhat isolated from each other.

The integrated design process involves communication among the designers to ensure that all of the building systems are designed in concert with one another. Furthermore, integrated building design is most effective when key issues are identified early in the planning and design process.

A design charrette, a focused and collaborative brainstorming session, is a very useful activity to hold at the beginning of a project to encourage the exchange of ideas and information and allow truly integrated design solutions to take shape (NIBH, 2008).

In order to benefit from high performance, green strategies, the major components of a building including ***the building envelope, the heating, ventilation and air conditioning (HVAC) system, and the lighting systems,*** should be designed in an integrated manner that permits synergistic benefits to be realized. By using the integrated design approach, significant savings in both energy and cost may be achieved. For example, high performance building envelope and lighting design strategies could significantly reduce HVAC system requirements (NIBH, 2008).

Building Envelopes: The interface between the interior of a building and the outdoor environment is referred to as the building envelope or is sometimes referred to as the skin of the building. The envelope provides protection from the elements and controls the transmission of heat, moisture, and sunlight in order to maintain comfort for the building occupants. The transfer of energy through the building envelope occurs through surfaces such as the roof, walls, floors, doors, windows, as well as by air infiltration/leakage. To achieve high performance of a building envelope, materials must be specified to ensure enhanced insulating properties and moisture controls.

A building's roof is a large surface-area that is exposed to year-round direct sunlight. Light colored reflective roof products, also referred to as Cool Roofs, work by reflecting most of the sun's energy back into the atmosphere thereby keeping a building cooler and reducing air conditioning bills. Many reflective roof products are ENERGY STAR® labeled roof products which help save money by reducing energy use. The ENERGY STAR® website provides a Roofing Comparison Calculator intended to roughly estimate the savings a reflective roof can offer to a typical building and aid in the decision whether to choose a reflective roof (EPA, 2010a). Reflective roofs have been shown to reduce cooling energy savings up to 20 and 30 percent with a simple payback period of one to two years. Considering that roof surfaces are replaced on regular, albeit long intervals, installations of reflective roofs are relevant for both new buildings as well as for retrofits of existing buildings (Brown *et al*, 2005).

Green roofs are vegetated roofs that incorporate a high quality water proofing and root repellant system, a drainage system, filter cloth, a lightweight growing medium and plants. The two types of green roofs are intensive systems, which incorporate deeper root systems and larger plants, and extensive systems, with up to six inches of soil and which employ shallow root systems and smaller plants. Green roofs provide additional insulating value to the roof system and reduce solar heat gain of a roof, resulting in potential savings on energy heating and cooling costs. In addition, green roofs provide increased storm water retention. They also help reduce the heat island effect, which is the phenomenon that occurs when built up areas are hotter than nearby rural areas as a result of paved and dark surfaces. Finally, green roofs can be an amenity for building occupants in the form of accessible green space and roof gardens.

High performance wall designs minimize heat loss by reducing the amount of framing used and by optimizing the use of insulated materials. Generally these designs provide continuous exterior wall insulation as a thermal barrier with excellent thickness to performance ratio and air tightness. Examples of high performance wall systems include structural insulated panels (SIPs), insulated concrete forms (ICFs), and even straw bail design in dryer climates. Also with conventional wall designs, minor modifications can significantly reduce energy losses. For example, polyurethane bearing blocks have twice the insulating capability of wood and can be used to thermally isolate steel walls from foundations and from steel attic beams (Brown *et al*, 2005).

While improved wall system designs generally apply to new construction, insulated sheathing is available for wall retrofits but often requires modifications to window jambs and doorframes. Another strategy is to take advantage of modern insulating fabrics that can be hung from or applied to interior wall surfaces. The reflective properties of such materials can also be engineered to provide greater human comfort at reduced (winter) or elevated (summer) indoor temperatures, further increasing the energy savings (Brown *et al*, 2005).

Ventilation vs. moisture control: The two goals of minimizing energy use while also controlling moisture levels inside the building are often at odds. For example, while increasing the use of natural ventilation or use of an economizer may decrease energy consumption, if not implemented properly these strategies can potentially increase the amount of moisture in the form of water vapor that is brought into the building. In order to avoid this barrier to more efficient design and ensure proper control of humidity, designers must employ building science, expert planning and design, and the proper use of building materials in different climates. Furthermore, it should be noted that there is always a tradeoff between ventilation rates and energy consumption, especially in non-economizer mode in which outdoor air is conditioned.
This tradeoff between ensuring adequate ventilation and minimizing energy consumed by conditioning outdoor air, is especially relevant where ventilation rates are determined by occupant actuated exhaust ventilators.

The use of thermal storage in a building structure, also referred to as thermal mass, is an effective strategy to reduce energy consumption, especially in climates where daily temperature swings require both heating and cooling in the same 24-hour period. Materials with significant mass and with high heat capacity such as stone, adobe, brick, concrete, and ceramic have long been used as thermal storage. In addition, lighter-weight thermal storage materials and phase change materials (PCMs), including water, salts, and organic polymers, can be used for thermal storage (Brown *et al*, 2005).

Windows can improve the thermal performance of buildings by minimizing heat loss in heating-dominated climates and by minimizing solar heat gain in cooling-dominated climates. High performance fenestration technologies include improved framing materials, low-emissivity (low-E) and solar control coatings, low-conductance gas fills, improved thermal breaks and edge spacers, and better edge sealing techniques. These technologies may be used independently or in combination, but should be selected with consideration of climate zone in order to achieve optimal performance (EPA, 2000). Other GHG reducing technologies include:

Lower U-factor widows have a higher insulating value and experiences lower thermal heat transfer through the window. The window industry measures the energy efficiency of their products in terms of the rate of heat transfer through a product. The lower the U-factor, the lower the amount of heat loss, and the better a product is at insulating a building. A window with a lower solar heat gain coefficient (SHGC) experiences lower transmittance of solar energy as solar radiation that is allowed to pass through. Also, windows with low emissivity coatings on the interior side, are designed to reduce the flow of infrared energy from the building to the environment. Low-E coatings on the exterior side are designed to reject infrared energy from the sun, thus reducing air-conditioning loads. Also, the design of the window frame influences thermal performance of fenestration systems.

Electrochromic windows, also called smart glass, offer dynamic control and can change the light transmittance, transparency, or shading of windows in response to environmental signals such as sunlight, temperature or an electrical control. For instance these windows can reflect infrared energy away during the summer but transmit this energy into the building during the heating season. Estimated HVAC energy savings for office buildings in arid climates using electrochromic windows range from 30 to 40 percent (Brown *et al*, 2005).

Passive solar window design is also a cost effective and important strategy to control solar heat gain. In heating-dominated climates, major glazing surfaces should face south to collect solar heat in the winter when the sun is low in the sky. During the summer, when the sun's trajectory is high overhead, overhangs or other shading devices (e.g., awnings) block the solar radiation from entering the building and prevent excessive heat gain. In cooling-dominated climates, the optimal glazing strategy is preferential use of north-facing windows and generously shaded south-facing windows (EPA, 2010c).

Energy Consuming Equipment: Energy-consuming equipment in buildings include systems such as heating, ventilation, and air conditioning (HVAC) equipment, water heating equipment, and lighting equipment. In most commercial buildings, HVAC equipment accounts for over 30% of energy use in commercial building, lighting equipment accounts for over 25% of energy use, and water heating accounts for approximately 7% of energy use. Plug loads, including computers, electronics, and other appliances generally account for approximately 13.6% of energy used in commercial buildings (DOE, 2008). It is important to note that energy consumed by interior lighting and appliances adds to the cooling load of a building, so improvements in the efficiency of lighting and appliances can achieve additional energy savings for cooling systems. The energy use breakdown for transit agency facilities is somewhat different to commercial buildings. For transit agencies the proportion of energy consumed by lighting equipment is likely much greater, especially for transit stations and certainly for stations without climate controls. One case study of a transit agency, referenced later in this report, puts energy consumption of lighting systems at 45% of the total energy use.

Plug loads are energy consuming appliances and electronics such as computers, vending machines, message boards, and other appliances. There are many opportunities to reduce energy usage by managing plug loads, such as by ***purchasing ENERGY STAR rated equipment***, setting computer monitors to energy management mode, removing light bulbs from vending machines, and turning task lighting off when not in use. Long Island Bus in Ney York has completed the installation of a high-efficiency 1 megawatt sodium sulfur battery energy storage system at their Mitchell Field facility. The battery charged at night when electricity demand and utility rates are low and then used during the day to power compressors for fueling the Long Island Bus fleet of compressed natural gas buses. (MTA, 2009b).

HVAC Systems: The use of high performance HVAC equipment can result in energy savings between 10%-40%. Utilizing high-performance HVAC equipment along with whole building design can result in significant energy savings. Typically, a 30% reduction in annual energy costs is achievable with a simple payback period of about three to five years, and if the payback threshold is extended to seven years, the savings can be about 40% (NIBH, 2009). There are many manufacturers and various system designs for HVAC equipment, however the fundamentals of good design should be applied in all cases. When designing HVAC systems, all aspects of the building should be considered simultaneously in a whole building perspective. For example, the building envelope design must consider its effect on cooling loads and daylighting. In this way, an energy-efficient building envelope, coupled with a state-of-the-art lighting system, optimal use of natural daylight, and efficient, properly-sized HVAC equipment will cost less to purchase and operate than systems that are selected in isolation from each other (NIBH, 2009).

HVAC systems should be sized properly and safety factors for load calculations used reasonably to ensure efficient operation. Oversized equipment is less efficient in operation and costs more than properly sized equipment. Designers should not assume a simultaneous worst-case scenario for all load components (occupancy, lighting, shading devices, weather) and then apply the highest safety factors for sizing. Furthermore, since HVAC systems are sized to meet design heating and cooling peak conditions that historically occur only 1% to 2.5% of the time, designers should consider part-load performance of the equipment when selecting equipment. In addition, it is important to commission the HVAC systems as they do not always work as expected. Commissioning involves testing the HVAC systems under all aspects of operation (NIBH, 2009).

Ventilation systems use a great deal of energy and can be expensive to run. New York City Transit uses ***Heat Recovery Units (HRU)*** in many projects to reduce a building's ventilation energy load. When it is cold outside, the HRU recovers heat from outgoing air by using a heat exchanger to preheat fresh incoming air, which the HRU system distributes throughout the building. The roof of the Grand Avenue Bus Depot and Central Maintenance Facility in Maspeth, Queens has 34 ventilation and heating units. The facility's heat recovery application runs warms air exhausts past the cold winter air that the ventilation system must constantly bring in because of bus fumes and exhausts. These heat conductors warm the fresh air enough to save approximately 48 percent in heating energy costs (MTA, 2010).

<u>Example HVAC Case Study</u>: **Denver Regional Transportation District, East Metro** In May 2009, a technical feasibility audit was conducted by East Metro to determine the technical scope and preliminary budget for replacing the outdated components of the current heating system and to estimate the projected annual savings in natural gas consumption with the new system and advanced controls (RTD, 2009).

The existing heating system at East Metro accounts for over 74% of the facility's total annual energy consumption. The current system includes three Cleaver Brooks model CB200-600, 15-psi steam boilers. The boilers are each 30 years old and run on natural gas with fuel oil back up. These boiler units consume over 66,000 MMBtu of natural gas annually. The boilers average runtime is 4,800 hours per year and average two cycles per hour. The nitrogen oxide (NOx) levels at high fire are 60 ppm, and the units operate at approximately an 82% efficiency rate.

Table 6.1 East Metro Heating Upgrades and Respective Savings

System Detail	Value
System installed cost	$770,000
Projected annual energy savings	19,341 MMBtu/yr
Projected annual GHG savings (CO_2e)	1,032 tonnes/yr
Projected annual savings ($7/MMBtu)	$135,390
Percentage of facility's annual natural gas consumption saved	29%
Percentage of facility's annual total energy saved	22%
Potential lifetime energy savings	386,829 MMBtu
Potential lifetime GHG savings (CO_2e)	20,640 tonnes
Potential lifetime savings ($7/MMBtu)	$2,707,800
Initial TIGGER investment/lifetime energy savings	$2/MMBtu

East Metro will replace the three existing Cleaver Brooks boilers with three CBLE200-600, 15-psi, 20-ppm NOx boilers with Advanced Hawk Integrated Control Systems. The advanced control system will operate the boilers based on load demand as opposed to the current control system which is based on outside temperature. The systems are expected to yield overall efficiencies over 90%.

The updated heating system is expected to save 19,341 MMBtu/yr in natural gas consumption resulting in operational savings of over $135,000/yr at $7/MMBtu. Based on default emission factors for stationary combustion in commercial natural gas boilers (53.06 kg CO_2/MMBtu, 0.9 kg CH_4/MMBtu, and 0.9 kg N_2O/MMBtu), 1,032 tonnes of CO_2 will be avoided annually. As shown in Table 1, these savings would yield a 29% reduction in natural gas energy consumption and a 22% reduction in the annual energy consumption of the East Metro facility.

Water Heating: On average water heaters account for 6.8% of commercial energy end-use (DOE, 2008). Some technical improvements in water heating include heat pump water heaters, water heating dehumidifiers, and heating water with waste heat (Brown *et al*, 2005). Other technological innovations include solar water heaters, gas condensing water heaters, and tankless (or instantaneous) water heaters (Brown *et al*, 2005). Another effective strategy to decrease water heating energy is to reduce pipe runs by moving the water heater tank closer to the points of use and insulating hot water pipes, thereby reducing thermal losses in hot water pipes.

Lighting Systems: Lighting accounts for a significant portion of energy consumption in commercial buildings, and energy-efficient lighting technologies as well as use of natural daylight should be employed wherever possible. An energy efficient lighting strategy considers lighting technologies such as lamps, luminaires, ballasts, lighting controls, and use of natural daylight. Based on a sensitivity analysis of light rail transit station O&M practices in Europe (MALTESE, 2000), underground station lighting costs were found to be significant, and as much as more than twenty times higher than for a comparable surface station. In underground stations lighting also accounted for a higher percentage of operating energy used, as much as 63% versus 46% for surface stations.

Lamps, commonly called light bulbs, are selected for specific commercial applications based on their performance characteristics such as Color Rendering Index (CRI), Correlated Color Temperature (CCT), and Efficacy. At 70-100 lumens/watt, fluorescent lamps are among the lamps with the highest efficacy or energy efficiency. Use of fluorescent T10 or T8 lamps, offers advantages over T12 lamps in energy efficiency. Compact fluorescent lamps (CFLs) are small-diameter fluorescent lamps that are folded for compactness. CFLs last up to 10 times longer than incandescent lamps and use about one-fourth the energy and produce 90 percent less heat. High-intensity discharge (HID) lamps produce a large quantity of light in a small package. These lamps are typically used when high levels of light are required over large areas and when energy efficiency and/or long life are desired. Low-pressure sodium lamps produce up to 180 lumens/watt and have the highest efficacy of all commercially available lighting sources. Light-emitting diodes (LEDs), achieving efficacies up to 100 lm/w, have great potential as energy-efficient lighting for commercial building use (DOE, 2010a).

One example of an advanced, energy-saving technology in lighting that has achieved strong market acceptance is the electronic ballast. (DOE, 2008). Traditionally, fluorescent lights, which is the predominant lighting type in commercial buildings used magnetic ballasts. Replacing magnetic ballasts with electronic ballasts can result in as much as a 10 to 15 percent increase in lighting energy efficiency, as well as enable other energy saving features such as dimming and remote control (DOE, 2010a).

Another way to conserve energy in buildings is to install energy-efficient exit signs and parking lot luminaires. The most efficient light source technology for exit signs is light-emitting diodes (LED) which have a higher first-cost than incandescent signs, but will save money in the long-run. The most commonly used parking lot luminaires are energy-efficient, high-intensity discharge lamps or low-pressure sodium lamps, however the most efficient light source technology for outdoor use is outdoor photovoltaic lighting. In addition, task lighting can result in significant energy savings and improved visibility for workers (DOE, 2010a).

Natural Daylight: Daylighting can offer significant energy savings by offsetting a portion of the electric lighting load. An added benefit is the reduction in cooling capacity resulting from lowering a significant component of internal heat gains caused by electric lighting. Daylighting also improves occupant satisfaction and comfort (DOE, 2010a).

Use of high reflectance surfaces will allow the daylight to be reflected into and around the room and will reduce extreme brightness contrast. The ceiling is the most important interior light-reflecting surface, and high reflectance paints and ceiling tiles are now available with .90 or higher reflectance values. Tilting the ceiling plane toward the daylight source will increase the daylight that is reflected into the space. Light shelves are horizontal light-reflecting overhangs placed above eye-level with a transom window placed above. Light shelves are most effective on southern orientations to improve daylight penetration, create shading near the window, and to reduce window glare (DOE, 2010a).

Toplighting may be used beneficially in large single level floor areas and the top floors of multi-story buildings. Toplighting strategies include skylights, clerestories, monitors, and sawtooth roofs. High performance skylight designs incorporate reflectors or prismatic lenses to reduce the peak daylight and heat gain while increasing early and late afternoon daylight contributions. Lightpipes make use of high reflectance ducts which channel the light from a skylight down to a diffusing lens in the room. Clerestory windows make use of vertical glazing located high on an interior wall allowing daylight to reflect deep into an interior space. South-facing clerestories should be shaded from direct sunlight by a properly designed horizontal overhang (DOE, 2010a).

Lighting Controls help conserve energy and make a lighting system more flexible. A building designed for daylighting should incorporate photosensors to automatically adjust the light output by dimming the electrical lighting system based on detected daylight illuminance. Dimming the lights in response to natural daylight lowers the electric power demand and also reduces the thermal load on a building's cooling system. Occupancy sensors are used to turn lights on and off based on the detection of motion within a space. Clock switches or timers control lighting based on a preset schedule. Centralized building controls or building automation systems can be used to automatically turn on and off, or dim electric lights around a building (DOE, 2010a).

Example Lighting Case Study: **MTA Lighting Retrofits.** The Metropolitan Transportation Authority (MTA) in New York City replaced 1,700 lightbulbs with energy efficient compact florescent light bulbs. Of these 1,700 light bulbs, 700 were switched from 60W to 15W CFLs and 1,000 were changed from 100W to 20W CFLs. The CFLs require annual replacement while the previous bulbs required monthly replacement. The annual cost of the original bulbs was $10,200 per year while the annual cost of the CFLs is $11,050 per year. However, the cost savings from the CFLs from the annual cost of purchasing electricity is nearly $147,000 per year resulting in essentially an immediate payback period. This lighting retrofit reduces the annual electricity consumption by nearly 980,000 kilowatt-hours (MTA, 2009b). Based on U.S. EPA eGRID emission rates for the NYCW subregion (815.45 lbs CO_2/MWh, 36.02 lbs CH_4/GWh, and 5.46 lbs N_2O/GWh), the yearly savings in annual energy consumption equates to annual GHG emissions savings of approximately 362.5 tonnes of CO_2e.

For MTA's first completed LED conversion, MTA replaced all 262 mercury vapor fixtures on its Verrazono Narrows Bridge necklace lighting with energy saving, cost efficient light emitting diode (LED) fixtures. An LED light uses 30 watts of power to provide the equivalent light of a traditional 100 watt mercury vapor fixture. The LEDs also have a life span of up to seven years versus a three year life span for mercury vapor fixtures, resulting in lower maintenance costs of LEDs and substantially fewer roadway closures for light changing work. The retrofit will reduce the electrical power consumption for the necklace lighting by 73%. MTA is hoping to change out all of the necklace lighting at other crossings over the next few years (MTA, 2010).[46]

Energy management systems (EMS) and control systems incorporate a variety of devices and systems ranging from simple time clocks that control HVAC or lighting systems to centralized, computer-based building automation systems (BAS) that monitor, control, and optimize building systems and energy use. The BAS's main functions are to keep the building climate within a specified range, provide lighting based on an occupancy schedule, and monitor system performance and device failures.

The BAS can reduce building energy and maintenance costs when compared to a non-controlled building. A properly configured BAS-based system automatically controls building systems for cost effective and efficient use of energy. In addition, the BAS can provide energy information in clear, compelling formats, directly to the building operators and those best equipped to translate it into value.

Converged, integrated network solutions may be of particular value to transit agencies that oversee a portfolio of facilities. An integrated network system allows for a higher level of connectivity among a variety of products and building systems as well as among large portfolios of facilities. This integration can result in benefits such as cost reductions, process improvements in facility automation, monitoring, and management, and more efficient portfolio management. Converging building control and utility data into a shared network enables optimum management of facilities by connecting various silo systems and applications. The goal of the converged BAS is to create an open, integrated infrastructure that supports real-time control systems, enterprise

[46] The Bay Area Rapid Transportation, or BART system in (San Francisco, CA is also testing energy-saving, light-emitting diode (LED) lights.

applications, and information flow (King, 2009).

Many subway systems in Europe and in Asia employ the use of platform edge doors also called platform screen doors. Now the Metropolitan Transportation Authority (MTA) plans to use platform screen doors in the Second Avenue subway in New York City (Neuman, 2007). The doors, set into a wall of glass or metal, would create a floor-to-ceiling barrier, sealing off the track and tunnel area from the platforms, much like those in use in this country in many airport shuttle train systems.

There are several advantages to platform edge doors including improving climate control within the station, reducing the risk of accidents, and even preventing suicides. The doors would result in substantial energy savings from the station cooling systems. With open platforms, the air from the tunnels can mix with the air in the stations. With doors on the platform edge, the air from the tunnels would be at least partly blocked and the cooling system could operate more efficiently. Train systems that use platform edge doors also incorporate a computerized system to operate trains enabling trains to stop at exactly the same spot every time and line up properly with the platform doors. The MTA has a long term plan to develop a computerized system for New York subways, but in the mean time, doors would have to be designed to operate with trains controlled by human drivers.

NYC Transit is also introducing escalators that slow down and use "sleep mode" when not in use. A sensor recognizes a customer's approach, and the escalator gradually increases its speed. It is estimated that each "green" escalator in the New York subway system can save 17,122 kilowatts of power a day, a yearly savings of $1,883 per escalator. Since certain parts of green escalators may last between 11 percent and 33 percent longer than traditional escalators, they are expected to save maintenance and repair costs over time."[47]

Third rail systems, located either alongside or between the rails of a transit vehicle, act as a conductor of electricity, providing power to heavy rail and light rail cars. The MTA in New York has installed wireless equipment for the remote control of electric resistance heaters on the third-rail systems that provide power to its subways. Rather than leave the heaters on throughout the winter, the remote-control feature helps to minimize electricity use when the weather is warm enough that switching devices will not break down due to cold weather.

Renewable Energy Systems: At present, using renewable energy systems to provide a portion of a facility's or vehicle fleet's power requirements is usually more cost effective after most other energy efficiency strategies are exhausted. If energy efficiency strategies are available, generally the payback period of such strategies such as lighting retrofits, insulation upgrades, and refurbishing or replacing mechanical equipment is much faster than the payback on solar photovoltaic (PV) arrays and wind power generation projects. However, renewable energy installations have the potential to produce energy beyond the equivalent aggregate energy

[47] http://www.mta.info/nyct/facts/ffenvironment.htm#green_build

reductions such energy efficiency strategies are capable of, and the cost of renewable energy installations have declined markedly in recent years, with further cost declines forecasted against increasing costs of fossil fuel-based energy. When designing facilities it is always important to incorporate as many energy efficiency and energy conserving strategies as is cost effective, so that planned renewable energy components of design offset a larger portion of the total energy requirement.

In contrast to the situation for legacy fuels like petroleum, renewable energies are experiencing an explosion in growth due to dramatic reductions in cost and increasing support from most governments. In 2009, over 50% of new power capacity added in the United States came from renewable energy sources. The Obama Administration has strongly supported efforts to place the U.S. in a more competitive position in this market, while China, Germany, Spain have experienced unprecedented growth. The trends are so strong in parts of Europe that several EU countries are already on track to meet or exceed their 2020 targets for percentage of renewable energy consumption. Positioning public transportation to take advantage of a transition to these burgeoning markets supports long-term sustainability of the industry in addition to the potential for large GHG reductions. Conversely, the continued use of legacy fuels by the transit industry over the long-term could jeopardize its economic viability by burdening it with a less desirable energy cost-curve compared to that of renewable energy. Conveying the economic advantage of these new fuels over legacy fuels to transit agency decision-makers could help more seriously foster a vested interest on their part, while markedly improving transit’s GHG emissions profile.

While almost every area of the country can take advantage of renewable energy technologies, some technologies are better suited for particular areas than others. Assessing the resources of a region, state, city, or neighborhood is critical to renewable energy planning and siting. In addition to solar and wind energy for example, technologies to effectively tap geothermal energy resources depend on the amount of heat available at various depths from the surface (NREL, 2010).

Solar Photovoltaic (PV) systems are made from semiconducting materials that convert sunlight into electricity without producing air pollution or GHG emissions during operation. Grid-connected systems supply surplus power to the utility and take from the utility grid when the building system’s power supply is low. Building-integrated photovoltaic (BIPV) systems produce electricity and serve as construction materials at the same time, replacing traditional building components including curtain walls, skylights, atrium roofs, awnings, roof tiles and shingles, and windows. Almost all locations in the United States have enough sunlight for PV systems, with varying degrees of efficiency, and these arrays can be easily sited on roofs, integrated into building components, or placed above parking lots. (Brown *et al*, 2005).

Public transit agencies have been leaders in the construction of solar powered buildings. In April 2009 t**he Los Angeles County Metropolitan Transportation Authority (Metro) opened its Support Services Center** in downtown Los Angeles, the agency’s central maintenance facility for buses. The facility contains some 6,720 individual solar panels which generate 1,200 kilowatts of renewable, emission-free power. Along with other energy-efficient improvements, the project is expected to cut by 50% the facility's annual $1.1 million energy bill which is also expected to reduce the agency’s carbon emissions by more than 3,700 metric tons. In 2010

Greater Bridgeport Transit in Connecticut installed the first of a series of solar-powered bus stops. The lighting systems for these stops are powered by a solar battery which builds up electricity throughout the day through a solar cell mounted on top of the shelter. In Atlanta, Georgia a 2009 FTA TIGGER grant is being used to install energy-efficient solar panels at the Laredo Bus Maintenance Facility in Decatur, GA The project will provide for shade structures with integrated, grid-tied photovoltaic (PV) cells. The steel-and-concrete structures will cover 220 bus parking stalls, and will include translucent panels to filter sunlight. The facility's canopies will be equipped with light-emitting diodes (LEDs) to provide lighting for safety and maintenance activities at night. It is anticipated that the PV panels will generate electricity equivalent to the facility's annual electricity consumption.

In June of 2010 the Metropolitan Transportation Authority (MTA) began operating a rooftop-mounted solar thermal array consisting of 48 solar panels that heats hot water to wash subway cars at New York City Transit's Coney Island Overhaul Shop and Maintenance Facility. Installation of the array cost $550,000, but the agency's power bill is expected to be reduce by $94,000 a year, while avoiding 86 tons of carbon dioxide emissions a year associated with electricity use (RT&S, 2010). Miami-Dade Transit is utilizing solar-powered lighting in its over 900 bus shelters.

Wind power has also been increasing in economic feasibility. For coastal transit agencies, offshore wind power could play a greater role in increasing the percentage of power obtained from green power sources. For example, MTA is considering joining forces in a consortium with New York Power Authority (NYPA), Long Island Power Authority (LIPA), New York City, the suburban counties, and other parties to develop offshore wind sources along the coastlines. The scale of clean energy potential and the high efficiency of offshore wind farming, could be transformational for the MTA and how it meets its energy requirements. Furthermore, Renewable Energy Certificates (RECs) which can be sold separately from the underlying physical electricity associated with the renewable-based generation source, could be a potentially viable financing vehicle. (MTA, 2009b). Aside from offshore wind, onsite renewable generation from wind energy is gaining in popularity and has the added advantage of avoiding congested transmission lines. GO Transit in Toronto has installed an EW50 wind turbine at its Lisgar Station. The turbine can produce some 50 kilowatts of power in winds of (25.3 mph, and is expected to generate about 80% of the station's power, based on projections (GO Transit, 2009)

<u>Example Renewable Energy Case Study</u>: Greater Lafayette Public Transportation Corporation Wind Energy. The Greater Lafayette Public Transportation Corporation (GLPTC) plans to reduce its electrical energy usage by investing in onsite equipment to harness a renewable source of energy generated by wind power. Due to zoning restrictions requiring that the distance between the base and any adjacent property line exceed the height of the shaft, GLPTC has elected to purchase systems that are mounted on the roof of its administrative and maintenance facilities. The unit will be on pivoting mounts allowing it to turn directly into the prevailing winds to maximize energy captured. The energy produced by the system will be connected directly to 3 phase power. The system is expected to have a minimum lifespan of 30 years (GLPTC, 2009)

GLPTC will use the energy produced by the wind turbine to provide electricity to its facilities. Any additional energy needed to operate the facilities will be purchased from the existing energy provider, Duke Energy. In the case that the wind turbine produces more energy than what is demanded by GLPTC at any given time, the excess energy will be sold back to Duke Energy. The GLPTC garage, maintenance facility, and administration facility use an estimated 768,000 KWh of energy annually. The installation of wind turbine system on the GLPTC premises is expected to provide over 90% of the total amount of electrical energy used by the transit agency. Based on U.S. EPA eGRID emission rates for the RFCW subregion (1,537.82 lbs CO_2/MWh, 18.23 lbs CH_4/GWh, and 25.71 lbs N_2O/GWh), the yearly savings in annual energy consumption equates to annual GHG emissions savings of approximately 482.2 tonnes of CO_2e.

Building Retrofits: Due to federal policy mandates as well as a boost from the American Recovery and Reinvestment Act of 2009 (ARRA), the best-funded opportunities for retrofit projects today are major upgrades in institutional buildings (Nock, 2009). Energy retrofits involve the improvement or replacement of a building's systems to increase energy efficiency. An energy retrofit program includes a detailed assessment or energy audit of the facility. A comprehensive energy audit entails a physical assessment of the building envelope, mechanical systems, and lighting systems. The energy audit also includes an evaluation of energy usage by fuel type, using metered data or utility bill data. The energy audit should provide a detailed analysis of the condition of existing systems, energy usage, and payback analysis for specific upgrades. A cost/benefit analysis should focus on strategies that are cost effective and result in the highest energy savings.

Energy Performance Contracting (EPC) is a project management and financing mechanism that is growing in popularity. EPC is a turnkey service, similar to design/build construction contracting which provides customers with a comprehensive set of energy efficiency measures, and often is accompanied by guarantees that the resulting savings from a project will be sufficient to finance the full cost of the project. The EPC is offered by an Energy Services Company (ESCO) and includes a combination of one or more of the following services: energy audit, design engineering, construction management, arrangement of long-term project financing, commissioning, operations and maintenance, as well as savings monitoring & verification (EPA, 2007).

Recommissioning is the practice of tuning up a building's HVAC, controls, and electrical systems. Building recommissioning is the same process as commissioning but applied to an existing building's systems. It is a quality assurance based process of verifying, and documenting that the performance of a facility's systems meets their defined objectives and criterion. Research indicates that recommissioning can typically translate into energy savings of 5 to 15 percent and that 80 percent of all savings from recommissioning comes from optimizing building control systems. Nearly all remaining savings results from improving operations and maintenance (EPA, 2010b).

<u>Example Building Retrofit Case Study</u>: **Greater Cleveland Regional Transit Authority Energy Retrofit.** In 2007, the Greater Cleveland Regional Transit Authority (GCRTA) launched a plan to reduce energy usage in its facilities by creating preliminary estimates and baseline assessments. Low-cost strategies were implemented including lowering thermostat settings, increasing technology sensor lightings, night temperature setbacks, insulating windows and closing unused spaces (GCRTA, 2009).

Upon further investigation, the GCRTA found that substantial savings would result from energy retrofits and modification to building structures in its antiquated buildings. A Comprehensive Energy Conservation Plan was developed which recommended corrective actions with the emphasis on 1) fast-payback energy conservation measures; and 2) long-term strategies that can be done by concentrating on modifications of building use patterns, operating procedures, and design aspects. Assessments showed that maintaining the facilities with short-term solutions and without building modifications could result in an estimated 8% in energy use savings. However with an investment toward building modifications the GCRTA could save up to 31% more, which can be paid back with savings in 4.5 years.

The facilities selected for retrofits were based on where the greatest savings would be achieved and where the most long-term gain would occur from energy retrofitting. The selected facilities for retrofitting include the Central Rail Maintenance Facility, The Central Bus Maintenance Facility, district bus garages, a paratransit facility, and the main office building.

Table 6.2 Example Retrofit Costs and Savings

Type of Retrofit	Total Cost	$ Savings/Yr.	Payback Yr.
Lighting Retrofits	$ 1,350,000	$ 313,190	4.3
Lighting Controls	$ 436,900	$ 104,084	4.2
Roof Replacement	$ 428,000	$ 75,088	5.7
Overhead Doors	$ 42,100	$ 7,550	5.6
Total	$ 2,257,000	$ 499,912	4.5

Of the total electricity consumption of these facilities, 45% was attributed to lighting. A total of 6,417 lighting fixtures will be replaced. An expected 4,038,576 kWh and $417,274 annual savings will occur with the lighting retrofits. Based on U.S. EPA eGRID emission rates for the RFCW subregion (1,537.82 lbs CO_2/MWh, 18.23 lbs CH_4/GWh, and 25.71 lbs N_2O/GWh), the yearly savings in annual energy consumption equates to annual GHG emissions savings of approximately 2,817.2 tonnes of CO_2e. Lighting fixture retrofits and lighting control retrofits include the following:

1. Replace T-12 fixtures with T-8 lamps and high efficiency ballasts.

2. Replace the high intensity discharge (HID) lighting with high efficiency T-8 fixtures.

3. Install occupancy sensors and lighting controls in rooms that are not fully occupied to turn back most of the lighting during the unoccupied periods.

4. Consolidate bus storage in one bus facility from four discrete storage bays to one or two storage bays. Energy savings will result from reducing the size of the space that must be heated and allowing the heating and lighting systems to be turned off in the storage areas used for obsolete storage or vacated/closed.

An infrared survey of the Woodhill Garage roof area indicated that 48,397 sq. ft. of roof area was saturated with water and had lost its insulation value. The proposed solution is a total removal of the existing roof and installation of a new four ply built up roof with rigid insulation. The energy savings with the new roof are expected to be $75,088.00 per year with a payback time of 5.7 years. Assuming an average rate of $0.10/kWh for electric heat, the energy savings equate to 523.8 tonnes of CO_2e avoided annually.

The existing 12'X 18' overhead doors in the Central Rail Maintenance Facility are over 25 years old. The doors are in disrepair with the seals broken and panel joints having air gaps from normal wear. The doors are used frequently and operate at a slow speed resulting in high-energy loss. The proposed solution is to replace the overhead doors with high-speed doors and new weather stripping. The total savings is expected to be 135,000 kWh/yr or $7,550.00/yr, with a payback time of 5.6 years. These energy savings equate to 94.2 tonnes of CO_2e avoided each year.

Embodied Energy of Building Materials: While energy used in operation of buildings is the majority of energy consumed by buildings, the embodied energy of the building's materials is also an important consideration. Embodied energy refers to the energy consumed in production and distribution of a product or material. Currently the embodied energy of building materials accounts for between 15 % to 20% of the energy used by a building over a 50 year period (Architecture 2030, 2010). The design of the building, size, regional material sources, and framing material selection all significantly affect the embodied energy and GHG emissions.

Use of Recycled Materials: One of the most effective ways to reduce the embodied energy of building materials is to salvage and reuse materials from demolished buildings, even considering the extensive cleaning and repair often required of the salvage materials (Brown *et al*, 2005): in LCA terms, this represents "downstream" (of direct, end user) energy consumption. Examples of strategies to reduce embodied energy in the building construction include use of fly ash in concrete mixes in place of cement, use of materials with recycled content, procuring materials harvested and manufactured from local regional sources, and minimizing construction waste.

Some transit agencies have again taken the lead in this area. Examples include the Rapid Central Station, operated by the Interurban Transit Partnership in Grand Rapids, MI. A terrazzo floor in the passenger waiting area and the mezzanine makes use of recycled glass, providing a durable flooring surface that is expected to last for decades with little or no maintenance other than cleaning. Not only does a percentage of the station's construction materials contain recycled content, another percentage was recycled after construction.[48] Other green building components include a layer of live sedum growing on flat portions of the roof to reduce storm water runoff, maintain temperature control in the building, and significantly increase the useful life of the roof

[48]See http://www.ridetherapid.org/about/environment

itself by shielding it from damaging ultraviolet rays.

Given the variety of building types owned and operated by public transit agencies, a wide range of opportunities exist to select "green" construction materials and components. Among the more significant choices in terms of their volume and impacts on GHG savings, are the replacement of traditional wooded rail ties with ties made from composites of aluminum, recycled plastic, waste tires, waste fiberglass, and structural mineral fillers (see MTA, 2010). New York's Metropolitan Transportation Authority (MTA) is also introducing aluminum composite third rail to its system, along with remote operated third rail heating systems. As a way to use trash that would have been headed for the landfill, San Francisco's Bay Area Rapid Transit (BART) is using discarded grocery bags, milk bottles and car tires to plastic ties that are more environmentally friendly than old-fashioned wooden ties (which need to be soaked in creosote, a byproduct of chemicals derived from heating coal). The process used to create these plastic ties is considered three times cleaner than that required to manufacture wooden ties (BART, 2009).

6.3 GHG Emissions Can Be Reduced Through Employee Travel Savings

Most transit agencies appear to carry their concerns for energy efficiency into their support for green employee travel, and notably commuting, practices. Programs being offered that lend themselves to reduced fuel consumption and GHG emissions through reductions in vehicles of travel include:

1. Employee transit passes
2. Employee rideshare/rideshare matching and incentive programs
3. Employee flextime/variable time work weeks
4. Employee telecommuting programs
5. Employee secure bicycle storage facilities

All transit agencies responding to a request for information on such programs indicated the use of transit passes, while more than half indicated the use of flextime/variable time work weeks. While the energy and emissions savings benefits of these programs rarely appear to be evaluated, for the larger transit agencies these programs can yield significant GHG savings. For example, transit passes for all employees at the Chicago Transit Authority (CTA) were estimated to yield an annual average of 2.8 million rides between 2007 and 2009, with rides not limited to commute trips. In addition to indentifying carpooling or vanpooling opportunities, an agency can also offer employees financial incentives to rideshare to and from work. For example, the Pace Suburban Bus program in South Holland, Illinois offers its employees a $75/month incentive to use a vanpool.

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7. AN EXAMPLE GREENHOUSE GAS FOOTPRINT
(Metropolitan Atlanta Rapid Transit Authority, 2008)

7.1 Components of an Agency's GHG Footprint

This chapter describes the estimation of an agency's GHG footprint. The footprint is based on data made available by the Metropolitan Atlanta Rapid Transit Authority (MARTA), one of the nation's largest public transit agencies, with extensive heavy rail, fixed route bus and paratransit services. The chapter follows closely the reporting recommendations made by APTA (2009), and thus follows the Scope 1, Scope 2 and Scope 3 emissions accounting system used by The Climate Registry (TCR, 2008) and other greenhouse gas (GHG) emissions inventory protocols.

This three-scope accounting system includes all direct and indirect GHG emissions resulting from the agency's operations and activities. Scope 1 emissions are from direct GHGs produced by processes under the agency's control or ownership. Scope 2 emissions are all "indirect GHGs associated with the consumption of purchased or acquired electricity, steam, heating, or cooling" (TCR, 2008). Scope 3 emissions are "All other indirect emissions not covered in Scope 2, such as upstream and downstream emissions, emissions resulting from the extraction and production of purchased materials and fuels, transport related activities in vehicles not owned or controlled by the reporting entity, use of sold products and services, outsourced activities, recycling of used products, waste disposal, etc." (TCR, 2008).

In addition to following standard GHG emissions accounting, this GHG footprint is organized by the agency's various modal services and facility operations categories. In accordance with APTA recommended practices, the estimated GHG emission categories are reported as total emissions, emissions per vehicle mile, emissions per revenue vehicle hours, and emissions per passenger mile. This style of reporting helps to identify opportunities for improving GHG emissions performance in terms of the current supply of, and demands for, transit service. The GHG footprint presented below represents a baseline estimation of the annual greenhouse gases emitted by the agency's various operations and activities. While most of the estimated emissions occurred during the 2008 calendar year, some of the emissions, such as those arising from vehicle manufacturing, occurred in previous years and a proportion of the past emissions are allotted to the 2008 calendar year based on the total service life of the asset.

Following the approach recommended by APTA (2009) we first compute the emissions produced by MARTA's transit operations. Then we compute the emissions displaced as a result of MARTA's transit ridership.

7.2 Emissions Produced by Transit

Table 7.1 summarizes MARTA's GHG footprint for 2008, organized by major emissions-generating services, activities, and assets (see APTA, 2009, Figure 10). The following sections describe these emissions estimates, the sources of data used and the methods of computation. The Vehicle Miles, Revenue Vehicle Hours, and Passenger Miles data shown in Table 7.1 are taken from the 2008 data tables in the National Transit Database (FTA, 2009).

The example calculations illustrate the relationship between direct, operational emissions and indirect "upstream" emissions, notably the emissions generated by fuel production and vehicle manufacture. In all cases GHG emissions are reported as the sum of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions, translated into CO2 equivalent (CO_2e) emissions based on the following global warming potential (GWP) factors from the IPCC (2007):

GWP (CO_2) = 1;   GWP (CH_4) = 21 , and GWP(N_2O) = 310.

Table 7.1 MARTA GHG Performance Metrics, Annual CO_2e Scope 1, 2, and 3 Emissions for 2008

Mode	Fuel / Energy	Emissions (E)	Vehicle Miles (VM)		Revenue Vehicle Hours (RH)		Passenger Miles (PM)	
		Metric Tons	Total (000s)	E/VM (lbs)	Total (000s)	E/RH (lbs)	Total (000s)	E/PM (lbs)
Bus (MB)	Diesel & CNG	98,628	30,765	7.07	2,191	99.2	213,460	1.019
Paratransit (DR)	Diesel	11,536	6,196	4.10	284	89.6	5,423	4.689
Heavy Rail (HR)	Electricity	84,771	24,063	7.77	873	214.0	593,419	0.315
Non-Revenue Vehicles	Diesel & Gasoline	8,735	5,953	3.23	--	--	--	--
Stationary Sources	Electricity & Nat. Gas	88,750	--	--	--	--	--	--
Total[1]		292,420	66,978	9.63	3,349	192.5	812,302	0.794

[1] Includes Emissions from stationary sources

7.3 Scope 1 Emissions

The principal sources of Scope 1 emissions of greenhouse gases are the direct operation of both revenue generating and non-revenue generating vehicles owned and operated by the transit agency (see Figure 7.1). At the end of 2008, MARTA reported a fleet of 189 diesel and 441 compressed natural gas (CHG) buses (616 active buses reported in the 2008 NTD), and 255 diesel powered paratransit vans (141 reported as active in the 2008 NTD). In addition, the agency operated a fleet of 446 non-revenue, unleaded gasoline powered vehicles as well as a number of off-road, diesel-powered vehicles, used principally for maintenance of way (MOW) activities.

Bus and Paratransit Fleet Operations: Direct, mobile source CO_2 emissions are calculated directly from fuel and modal service-specific energy consumption numbers reported by MARTA. For diesel-fueled buses and paratransit vehicles the following equation is used:[49]

CO_2 metric tons = (Fuel gallons)$_{mode}$ x (CO_2 Kg/gallon)$_{mode}$ x (1 metric ton/1,000 Kg)   (7.1)

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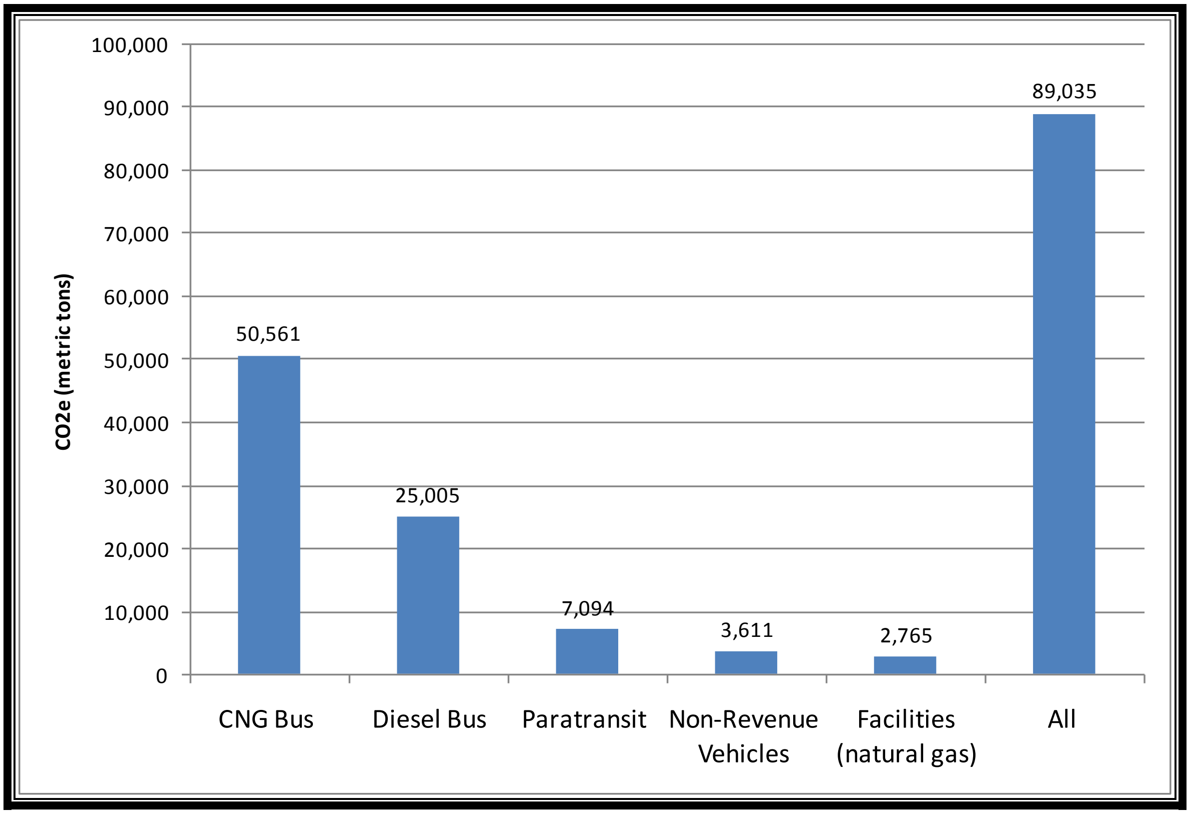
[49] For diesel, gasoline, and CNG emission factors, see Chapter 13 of The Climate Registry (TCR) General Reporting Protocol, May, 2008 http://www.theclimateregistry.org/downloads/GRP.pdf

The same general formula is used to estimate on-road, non-revenue gasoline and diesel-fueled vehicles. For CNG buses the direct mobile source CO_2 emissions are calculated by the following equation, based on fuel consumption data reported in decatherms:

CO_2 metric tons = (CNG decatherms) x (CO_2 Kg/ MMBtu) x (1 MMBtu/1 decatherm)
x (1 metric ton/1,000 Kg) (7.2)

Figure 7.1 MARTA Scope 1 GHG Emissions for 2008



CH4 and N2O emissions are highly dependent upon vehicle combustion technology and vehicle activity, thus a calculation from VMT data is preferred to a calculation from fuel consumption data:

(CO_2 metric tons)$_{mode}$ = (VMT)$_{mode}$ x (CH_4 grams/mile)$_{mode}$ x (1 metric ton/ 1,000,000 grams)
x (21grams of CO_2e /1 gram of CH_4)
(7.3)

(CO_2 metric tons)$_{mode}$ = (VMT)$_{mode}$ x (N_2O grams/mile)$_{mode}$ x (1 metric ton/ 1,000,000 grams)
x (310 grams of CO_2e /1 gram of N_2O)
(7.4)

Non-Revenue Vehicle Operations: In 2008, MARTA owned 446 on-road non-revenue vehicles, including a number of sedans (such as MARTA police vehicles), SUVs, pickup trucks, minivans, cargo vans, and dump trucks. The agency also operated a number of off-road (or hi-rail), notably rail, maintenance of way (MOW) vehicles and heavy equipment, including a 15-ton crane, loader, backhoe, forklifts, stabilizer, tampers, bridge inspection truck, tunnel washer truck, and a diesel-electric locomotive. For off-road, non-revenue vehicles, GHG emissions calculations are based on reported fuel consumption[50]:

$$CO_2 \text{ metric tons} = (\text{Fuel gallons}) \times (CO_2 \text{ Kg/gallon}) \times (1 \text{ metric ton}/1{,}000 \text{ Kg}) \quad (7.5)$$

$$CH_4 \text{ metric tons} = (\text{Fuel gallons}) \times (CH_4 \text{ grams/gallon}) \times (1 \text{ metric ton}/1{,}000{,}000 \text{ gram}) \quad (7.6)$$

$$N_2O \text{ metric tons} = (\text{Fuel gallons}) \times (N_2O \text{ grams/gallon}) \times (1 \text{ metric ton}/1{,}000{,}000 \text{ gram}) \quad (7.7)$$

using the coefficients reported in TCR (2008) Tables 13.1 and 13.6 (see Appendix)

A final category of Scope 1 emissions accounts for the on-site burning of natural gas in agency buildings. These emissions are estimated by summing over the monthly natural gas usage reported for each facility (in therms), and then multiplying this result by average GHG/MMBtu rates.[51]

Other Scope 1 emissions to be included are fugitive leaks of HFCs and CFCs from air conditioning equipment. Although a complete inventory of MARTA's air conditioning equipment was unavailable, a "screening method" (see TCR, 2008) calculation based on an equipment inventory estimate indicates that refrigerant GHG emissions are less than five percent of total agency emissions.

7.4 Scope 2 Emissions

Scope 2 emissions consist of GHGs resulting from purchased electricity, heating, cooling and steam. In the MARTA system, Scope 2 emissions arise solely from purchased electricity (see Figure 7.2). MARTA's purchased electricity is used for two main purposes: heavy rail vehicle propulsion, and stationary facility operations.

Heavy Rail Vehicle Propulsion Emissions: The following equation was used for each of the greenhouse gases (GHGs) and shows how to estmate metric tons of CO_2e, as presented in Table7.1 above[52]:

$$\begin{aligned} CO_2 \text{ metric tons} = &(\text{Elect. MWh}) \times (CO_2 \text{ lbs/MWh}) \times (0.4536 \text{ Kg/ 1lb}) \\ &\times (1 \text{ metric ton/ } 1{,}000 \text{ Kg}) \end{aligned} \quad (7.8)$$

---

[50] See Chapter 13 of The Climate Registry (TCR) General Reporting Protocol, May, 2008 http://www.theclimateregistry.org/downloads/GRP.pdf

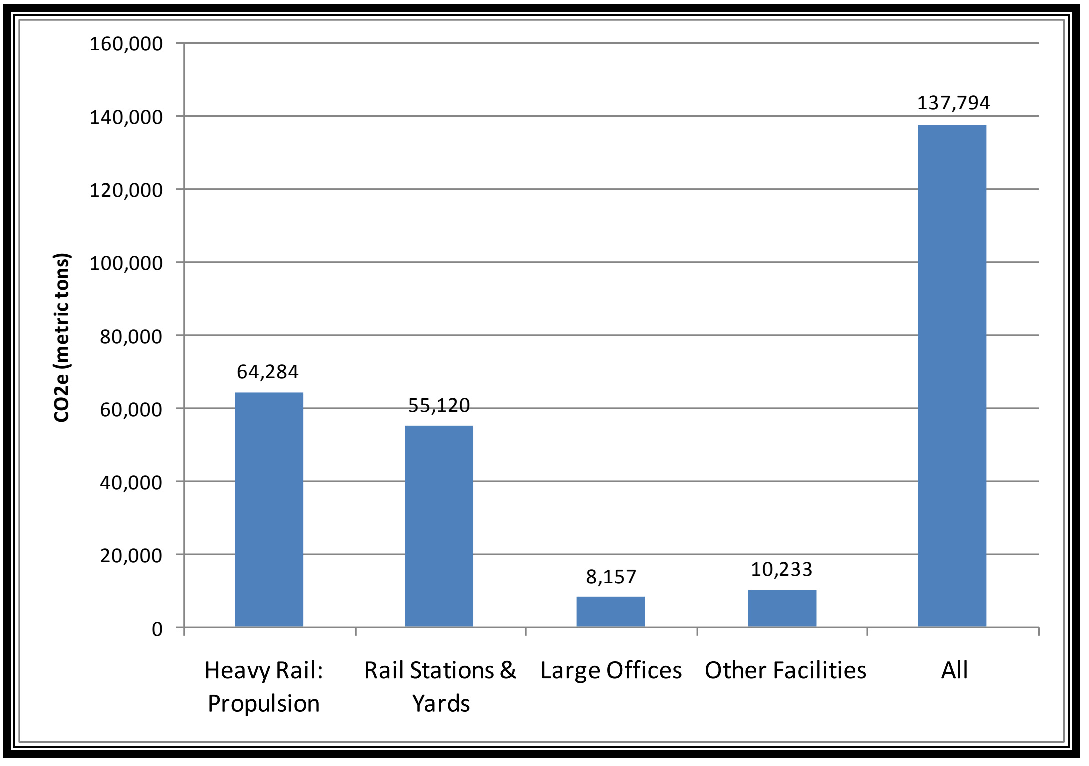
[51] See Chapter 12 of The Climate Registry (TCR) General Reporting Protocol, May, 2008 http://www.theclimateregistry.org/downloads/GRP.pdf

[52] See Chapter 16 of The Climate Registry (TCR) General Reporting Protocol, May, 2008 http://www.theclimateregistry.org/downloads/GRP.pdf
See U.S. EPA eGRID 2007 for emission factors (2005 data)

$$CO_2e \text{ metric tons} = (\text{Elect. GWh}) \times (CH_4 \text{ lbs/GWh}) \times (0.4536 \text{ Kg/ 1lb}) \times (1 \text{ metric ton/ 1,000 Kg}) \times (21 \text{grams of } CO_2e \text{ /1 gram of } CH_4) \quad (7.9)$$

$$CO_2e \text{ metric tons} = (\text{Elect. GWh}) \times (N_2O \text{ lbs/GWh}) \times (0.4536 \text{ Kg/ 1lb}) \times (1 \text{ metric ton/ 1,000 Kg}) \times (310 \text{ grams of } CO_2e \text{ /1 gram of } N_2O) \quad (7.10)$$

Figure 7.2 MARTA Scope 2 GHG Emissions for 2008



Emissions from Stationary Facilities: GHG emissions associated with the electrical energy consumed in agency owned and operated buildings are calculated by the same method used for heavy rail vehicle propulsion emissions. The only difference is that these emissions are accounted separately as stationary sources. Stationary facility energy consumption is calculated by summing the monthly MWh of electricity use reported for each facility.

A Note on Emission Rates from Electricity Consumption: It is important to note that a good deal of variability exists in emission rates of GHGs associated with electricity generation. Much depends on the energy feedstock, which varies a great deal across regions of the country. These rates also change from year to year according to the principal sources of this data: the U.S. EPA's eGRID[53] and the U.S. EIA's State Electricity Profiles.[54] Although the reporting protocols recommend use of local data to develop GHG footprints where feasible, local data such as plant-level power generation emission factors may not always provide the most accurate GHG

[53] http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html
[54] www.eia.doe.gov/fuelelectric.html.

emission estimation for the end-user. Some electricity may be imported to the local grid from outside production areas, thereby resulting in a different energy production mix. The production mix will also vary locally and/or regionally depending on the time of day, with peak load times possibly drawing on a different mix of energy feedstocks than off-peak loadings.

Differences in the electricity production mix affect the GHGs from purchased electricity, since the production mix includes power generated by carbon-intensive coal as well as nuclear, hydro, or other low or non-carbon energy sources. Four options were identified for use in this footprint:

1. Locally derived emissions rates based on eGRID plant level energy consumption
2. Statewide average emissions rates based on eGRID reporting
3. Statewide average emissions rates estimates based on EIA State Electricity Profiles
4. Regional average emissions rates estimates based on eGRID reporting

In this report the 2007 statewide average CO_2 emissions of 1,447 lbs/MWh was used, based on the EIA State Electricity Profile for Georgia, because no out-of-state importing of electricity sources could be identified.[55] In comparison, the EPA's most recent eGRID estimate for the state (2005 data) is a little lower, at 1,402.5 lbs/MWh.[56] In sharp contrast, and based on local plant level eGRID reporting, the power generation-weighted average emissions rate for the seven local power plants serving MARTA region produced an estimate of 2,039 lbs CO_2/MWh, which is more than 40% higher than the statewide average value. This higher emission rate is largely due to a much larger percentage of the energy (97% VS. 64%) being produced by coal combustion.

Based on discussions with local energy use experts, the importing of electricity from other parts of Georgia into the Atlanta metro area, coupled with the absence of any of this imported electricity from other states led us to use the statewide emissions factors. Table 7.2 summarizes the Scope 1 and 2 emissions estimates for each of the major emissions sources identified above. That is, the table presents the results in Table 7.1, less the Scope 3, upstream emissions described in the following section.

Table 7.2 MARTA GHG Performance Metrics, Annual CO_2e Scope 1 and 2 Emissions for 2008

Mode	Fuel	Emissions (E)	Vehicle Miles (VM)		Revenue Vehicle Hours (RH)		Passenger Miles (PM)	
		Metric Tons	Total (000s)	E/VM (lbs)	Total (000s)	E/RH (lbs)	Total (000s)	E/PM (lbs)
Bus (MB)	Diesel & CNG	75,565	30,765	5.41	2,191	76.0	213,460	0.780
Paratransit (DR)	Diesel	7,094	6,196	2.52	284	55.1	5,423	2.884
Heavy Rail (HR)	Electricity	64,284	24,063	5.89	873	162.3	593,419	0.239
Non-Revenue Vehicles	Diesel & Gasoline	3,611	5,953	1.34				
Stationary Sources	Electricity & Nat. Gas	76,275						
Total[1]		226,829	66,978	7.47	3,349	149.3	812,302	0.616

[55] http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html
[56] http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

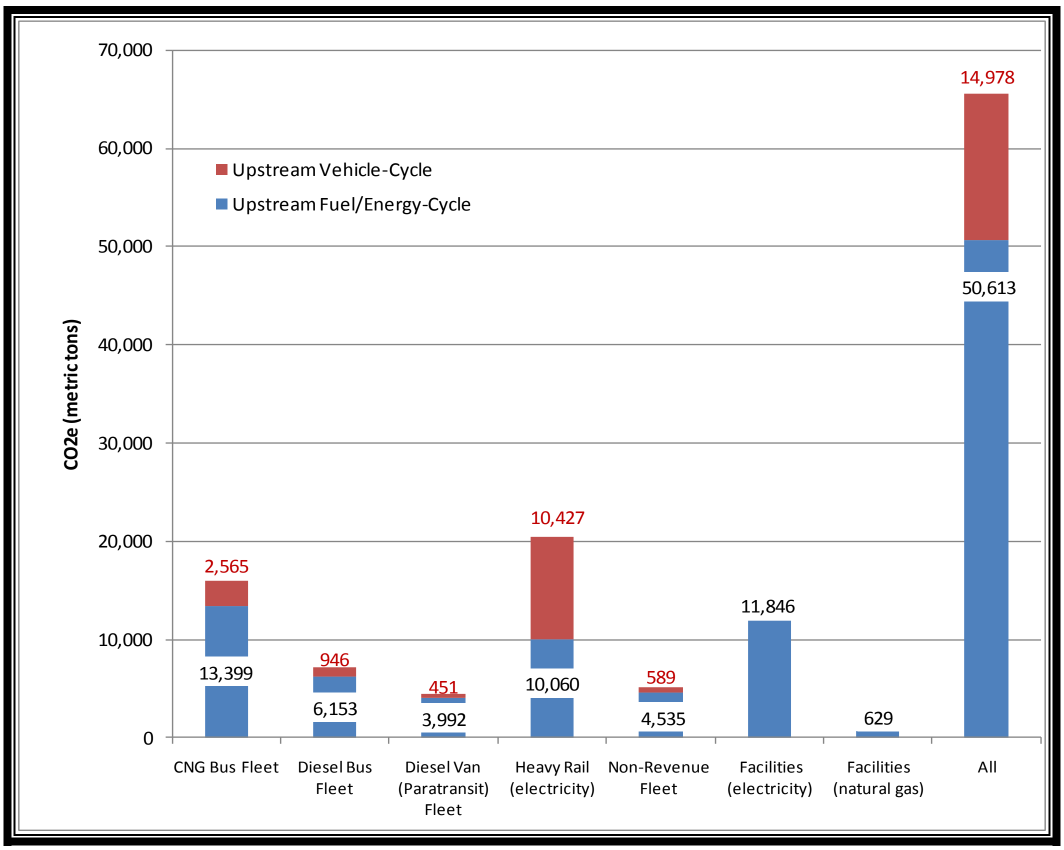
7.5 Scope 3 Emissions

While Scope 3 emissions are listed as optional by APTA (2009), they may in some instances offer useful information when comparing, for example, the purchase of alternatively fueled vehicles. While the development of standards for indirect, notably "upstream" (EPA, 2006) emissions reporting is still a work in progress, a number of software programs and methods exist for estimating these emissions. Included in the Table 7.1 emissions reported above, and presented in Figure 7.3 are emissions associated with:

1. vehicle-cycle emissions from vehicle manufacture, rebuild, maintenance, and disposal;
2. fuel-cycle emissions from fuel extraction, refining and transportation

Note that since vehicles operate over a number of years - an annual GHG footprint that incorporates such upstream vehicle emissions must represent the emissions on an annual basis. This may be accounted for by dividing the estimated lifetime vehicle-cycle emissions by the proportion of VMT occurring during the accounting year.

Figure 7.3 MARTA Scope 3 GHG Emissions for 2008



Bus and Vanpool Upstream Emissions: A number of spreadsheet software programs exist for this purpose, breaking down both the vehicle- and fuel-production cycles on the basis of the typical amount of materials or energy required at each stage in the extraction, manufacturing, assembly and delivery process,. This includes the transportation energy used to deliver the vehicles and fuel itself (see Weigel, Southworth and Meyer, 2010, which provides a review of available GHG calculators). The GREET[57] and GHGenius software programs were identified as the most advanced and readily available tools for computing the upstream vehicle- and fuel-cycle emissions associated with transit buses and vanpools. For immediate ease of application to bus emissions GHG computations, we selected GHGenius (Version 3.15).[58] GHGenius is a life cycle assessment (LCA) tool built to consider the environmental impacts of introducing alternative transportation fuels and the vehicles that use them into the marketplace.[59]

An LCA analyzes the cumulative impacts of a product's lifecycle, from extraction of raw materials to their end-use and disposal, computing the emissions associated with each process. In this context a 'product' such as bus transportation requires the ability to inventory and measure the many different materials and activities needed to get the bus operating on the region's transit routes, including the extraction, manufacture and delivery of the fuel it uses. Specifically, the upstream fuel-cycle emissions estimates from GHGenius are composed of emissions associated fuel production, dispensing, storage and distribution, fuel feedstock transport, and CO_2 and CH_4 and leaks and flares. Upstream vehicle manufacture and delivery ("vehicle-cycle") emissions include emissions associated with the materials used in vehicle assembly, transport and delivery. Figure 7.3 shows the estimates developed using GHGenius for a typical diesel and CNG bus, using a diesel powered light duty vehicle approximation for a diesel vanpool vehicle.

Rail Upstream Emissions: In contrast to the LCA of highway modes, rail transport options have to date received much less attention, at least in terms of their energy and GHG emissions impacts.

The estimation of the upstream emissions associated with heavy rail vehicle manufacture, rebuild, and maintenance used data on vehicle purchase price and vehicle expected life reported by MARTA and APTA. These dollar valued estimates are then combined with estimated emissions from the rail vehicle manufacturing sector, based on a run of Carnegie-Mellon's Economic Input-Output Life Cycle assessment (EIO-LCA) model.[60] The EIO-LCA approach builds on Leontief's Input-Output Modeling framework for relating the dollar valued outputs of one industry to the dollar valued inputs of another industry, converting these monetary transactions into their equivalent energy consumption and emissions production estimates based on the types of commodities traded. In doing so it traces both direct and indirect impacts of one industry on another, with the purchase of goods from industry A affecting not only the receiving industry B but also the industries supplying A, and so on. The resulting inter-industry accounting framework offers a cost effective, if necessarily more approximate, alternative to carrying out a complete LCA based on identifying the inputs and outputs at every step in a product's supply

[57] http://www.transportation.anl.gov/modeling_simulation/GREET/
[58] http://www.ghgenius.ca/
[59]It is worth noting here that a preliminary bus fleet GHG estimator based on the GREET software is also now available at:
http://www.transportation.anl.gov/modeling_simulation/GREET/footprint_calculator.html
[60] http://www.eiolca.net/

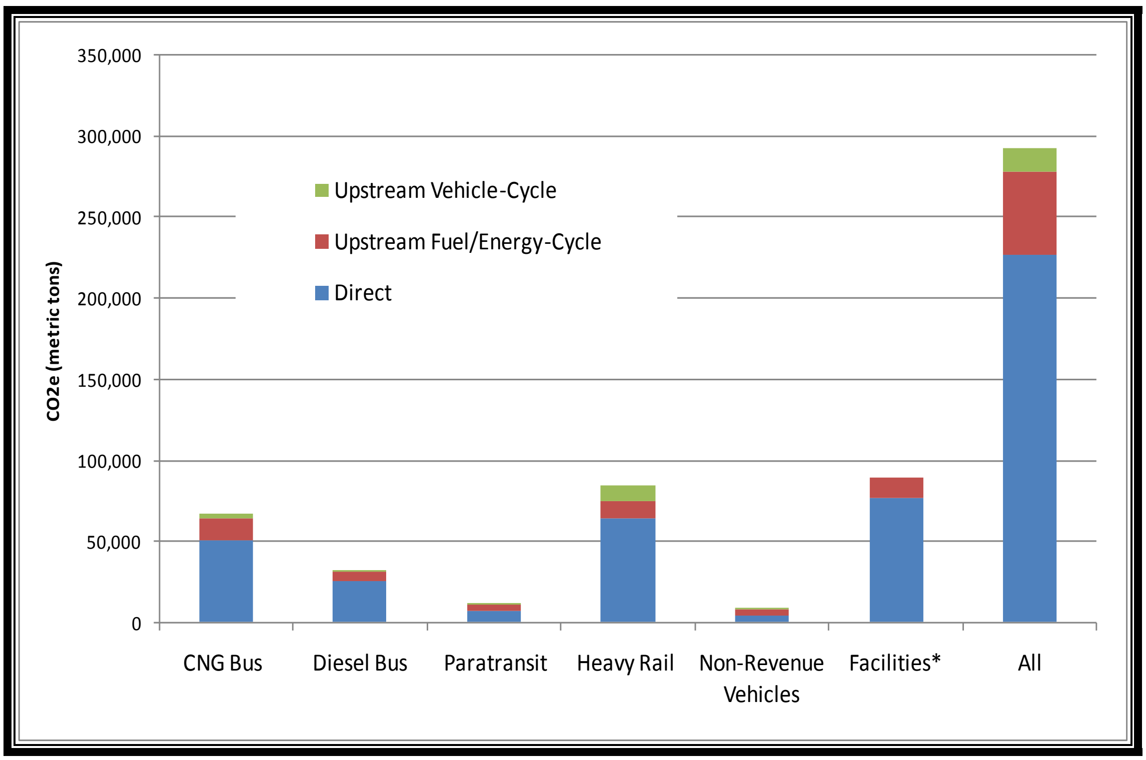
chain (as is done by GREET and GHGenius for highway vehicle and fuels manufacture and delivery).

The original rail fleet build cost and rebuild costs are added together and entered into the EIO-LCA model to calculate the upstream manufacturing emissions resulting from the many industrial processes involved. These emissions are then divided by 40 years of estimated service life. Added to this are maintenance emissions, which are estimated to be 19 percent of the original manufacture emissions (distributed over an original 25 year service life). The sum of these estimates is a total vehicle-cycle GHG emissions estimate for one heavy rail vehicle (two car set) of 35.2 Mt CO_2e.

7.6 Footprint Summary

Figure 7.4 shows the breakdown of Scope 1 and 2 'direct' operating emissions plus their associated Scope 3 upstream emissions, for each of the major emissions sources and combined emissions values listed in Table 7.1.

Figure 7.4 MARTA Direct plus Upstream GHG Emissions for 2008



Upstream or "indirect" emissions represent between 25% and 30% of total operating plus upstream emissions. Such indirect emissions are necessarily approximate given current data sources and an agency can refine them on the basis of detailed vehicle manufacturing and facility design data in particular.[61]

7.7 GHG Emissions Displaced by Transit

The option of public transportation mobility within a metropolitan area can offer GHG savings opportunities in three major categories (see APTA, 2009):

1. Modal shift benefits: Avoided low occupancy private vehicle trips

2. Congestion relief benefits: Reduced congestion due to fewer automobiles in the traffic stream leading to less idling and stop-go traffic movement.

3. Land-use multiplier benefits: Reduced car use through transit-enabled dense land-use patterns that promote shorter trips, and walking and cycling.

Of these benefits, mode shift benefits are the easiest to compute. Congestion relief benefits are less easily determined and depend a great deal on the levels of congestion experienced by the region's highways, and how persistent this congestion is over the course of a day. Land use multiplier effects are even more difficult to assess with certainty, and there is no consensus agreement at the present time on how to compute them: although recent evidence (Bailey, Mohktarian and Little, 2008) suggests that they are quite large and should not be ignored in regions such as metropolitan Atlanta, where there is a significant public transit presence.

The mode shift, congestion relief, and land-use multiplier GHG emissions benefits described were calculated for MARTA's 2008 operations in accordance with APTA Recommended Practice (see APTA, 2009). Below is a description of the calculation procedures and results.

Mode Shift: Calculation of the GHG emissions reductions achieved through a mode shift to transit is based largely on the calculation of a mode shift factor. The mode shift factor may be calculated by three alternative tiers, ordered by decreasing levels of specificity: Tier A – Model-based; Tier B – Survey-based; and Tier C – Default by agency type. The mode shift calculations presented here follow the Tier B – Survey-based approach. APTA (2009) suggests use of the following formula for Tier B and C calculations of the mode shift factor:

Mode shift factor = % of transit riders stating they would drive alone
+ % stating that someone else would drive them
+ % shifting to taxi

[61] As a check on our estimates, the vehicle- and fuel-cycle emissions were also generated for the bus and automobile modes using Argonne National Laboratory's GREET and GREET Fleet[61] life cycle analysis software (,http://www.transportation.anl.gov/modeling_simulation/GREET/) with closely comparable results in terms of the percentages achieved.

+ % stating they would carpool / average carpool occupancy

The 2001-2 Regional On-Board Transit Survey, published by the Atlanta Regional Commission, provided the estimates of how MARTA transit riders would respond to a loss of transit service (ARC, 2001: see Table 7.3). The survey data exceeds the five-year age limit specified by APTA; however the data provides a more specific characterization of transit mode in the Atlanta region than does a Tier C default approach. A 2009-10 Regional On-Board Transit Survey is currently underway in the Atlanta region, and the results of this survey can be used to update the mode shift factor calculation.

Table 7.3 Data Used to Compute Transit Mode Shift Factor

If bus or rail service was not available, how would you MAKE THIS TRIP?	Bus	Rail
% who would drive alone	16.6	48.7
% who would take a taxi	13.7	6.5
% who would ride with someone*	30.7	20.8
% who would walk	14.0	6.3
% who would bicycle	2.0	1.2
% who would not make the trip	23.0	16.5
default carpool occupancy	2.5	2.5
% stating they would carpool / average carpool occupancy	12.3	8.3
* interpreted as carpooling		

Unlike the Tier C default data, the transit survey data enables calculation of separate mode shift factors for bus and rail transit, and also allowed the results to be weighted by weekday versus weekend travel. The calculated bus and rail mode shift factors used in this study are 0.426 and 0.635 respectively. That is, 42.6% of buses riders and 63.5% of rail riders are estimated to travel by private automobile should public transit service not be available to them. These percentages were based on the following (weekday and weekend weighted average)[62] responses to the ARC 2001-2 On-Board Transit Survey of MARTA riders:

The bus and rail mode shift factors in this case are computed using the above formula as:

Mode shift factor (bus) = 16.6 + 13.7 +(30.7/2.5) = 13.6 + 13.7 + 12.3 = 42.6%

Mode shift (rail) = 48.7 + 6.5 + (20.8/2.5) = 48.7 + 6.5 + 8.3 = 63.5%

[62] The weights used here were derived from data reported in the 2007 NTD, which reports an average daily PMT split of 83.7% on weekdays versus 16.3% on weekends for rail riders, and a daily PMT split of 85.9% weekday versus 14./1% weekends for bus and paratransit combined.

With no equivalent data for the paratransit van operations, this service was assumed to have the same responses as those obtained from the system's bus riders.

Following APTA (2009, page 34), with no detailed data on trip lengths by mode/service types, and using the assumption "that one passenger mile on transit is equivalent to one passenger mile in a private auto — i.e., that the distances are comparable" leads to the following formula:

$(CO_2 \text{ metric tons})_{mode}$ = *(# passenger miles by transit)*$_{mode}$ *x (mode shift factor) x* $(CO_2Kg/gallon)$ ** (1/mpg for an average automobile)* (7.11)

For rail trips this yields the following result:

CO_2 rail emissions savings = 593,419,400 passenger miles * 0.635 mode shift factor * 8.81 kgCO_2/gallon * (1/17 mpg) *(1/0000) = <u>195,371 metric tons of CO_2e</u>

Formulas similar to (12) are also used for CH_4 and N_2O emissions; but here the emission factors are based on vehicle distance rather than vehicle fuel economy, and a GWP is multiplied by the result. For example,

CH_4 bus emissions savings = 213,459,600 passenger miles * 0.426 mode shift factor * 0.0000147 Kg CH_4/gallon * (1/0000) * a GWP of 21 = <u>1,336 metric tons of CO_2e</u>

Note the for methane (CH_4) emissions, and also for N_2O emissions rates per mile are used (for N_2O this rate was 0.000069 Kg/mile).

The assumption being made is that each transit passenger mile equals, on average, an automobile passenger mile. An alternative computation based on regional knowledge of average transit passenger trip lengths may provide a better answer (since transit passenger miles of travel statistics reported in the NTD are themselves approximations). The following example shows how different the results can be, based on average transit ride trip lengths derived from the Atlanta Regional Commission's (ARC) 2001 survey of MARTA riders, as derived (in two draft report) by the Georgia Regional Transportation Authority (GRTA, 2009a, 2009b). Using this data the following more elaborate GHG emissions formula is employed, making use of NTD reporting of number of unlinked passenger trips in each modal category. This approach can be stated succinctly as:

$(CO_2$ *metric tons) = (avoided automobile miles - automobile miles used to access transit for these mode shifted trips) * automobile emissions per passenger mile* (7.12)

A close approximation to this result can be computed as follows:

$(CO_2$ *metric tons) = [(# unlinked passenger trips by transit mode) * (mode shift factor)] * [(average avoided miles/trip) – [(proportion of transit trips with an access and/or egress auto trip to/from transit) * (average access/egress auto miles per transit trip)]] * [(*CO_2*Kg/gallon) * (1/mpg for an average automobile) *(1/1000)]* (7.13)

To use this approach data is required on the average 'avoided' automobile miles per trip, the proportion of transit trips that use automobile as and access and/or egress mode, and the average automobile miles associated with this access/egress activity. According to the Georgia Regional Transportation Authority's draft report of MARTA Rail Emissions Benefits (which is based on the 2001-2 Regional On-Board Transit Survey), the heavy rail transit values for these variables are 17.9 miles, 0.537, and 6.3 miles respectively (GRTA, 2008a). The number of unlinked trips is taken from the 2008 NTD. For example:

CO_2 rail emissions savings = 82,940,000 unlinked trips * [(0.635 mode shift factor * 17.9 average avoided miles per trip) - [(0.537 auto trips to/from transit per trip * 6.3 auto miles to/from transit per trip)] * [8.81 $kgCO_2$/gallon * (1/17 mpg) * (1/1000)] = <u>343,552 metric tons</u>
Similarly,

CH_4 bus emissions savings = 67,519,400 unlinked trips * [(0.426 mode shift factor * 12.6 average avoided miles per trip) – (0.106 auto trips to/from transit per trip * 6.3 average auto miles to/from transit per trip)] * (0.0000147 $KgCH_4$mile)* (1/1,000 grams) = 4.66 metric tons * a GWP of 21 = <u>4,661 metric tons of CO_2e</u>

assuming that 10.6% of all bus transit trips involve an auto access/egress trip that averages 6.3 highway miles, and that on average an avoided auto trip has a distance of 12.6 highway miles. The following results summarize the results from both approaches, and assuming that paratransit trips have the same 12.6 miles per avoided trip as bus trips, with none of these trips requiring auto access/egress:

Estimated Annual CO_2e Emissions Savings from Mode Shifts:

	Approach 1	**Approach 2**
Bus (MB)	47,332 metric tons	165,126 metric tons
Paratransit (DR)	1,202 metric tons	1,144 metric tons
Heavy Rail (HR)	196,294 metric tons	345,174 metric tons
Total:	244,819 metric tons	511,445 metric tons

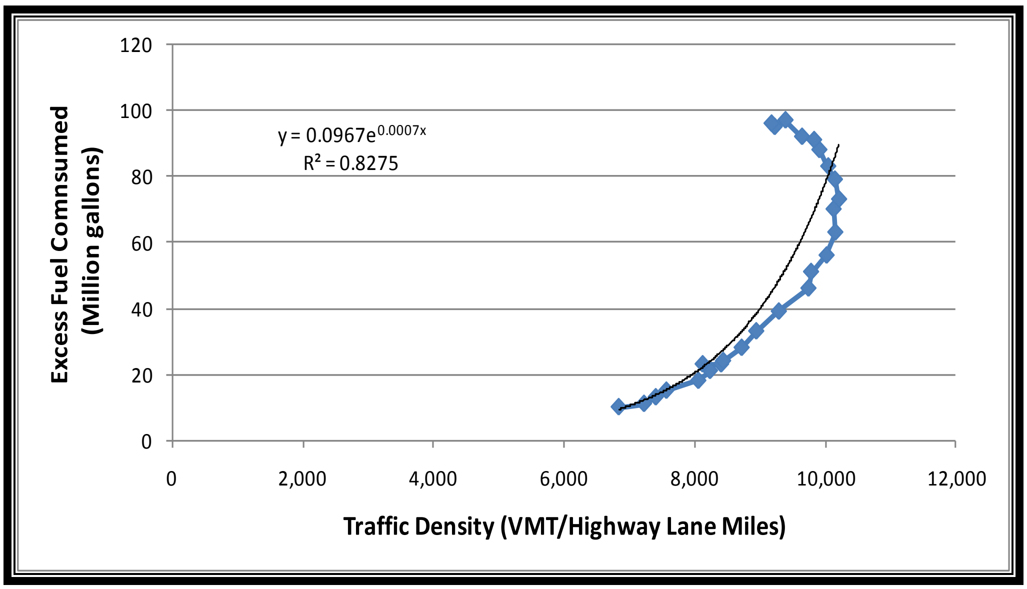
Clearly, very different results can be generated based on both the automobile avoided and, if to a lesser extent, also on the automobile access/egress trip lengths used. In what follows the results from the more conservative 'Approach 1" are used, as they appear to reflect a more reasonable treatment of urban bus emissions savings, if on the low side. It is likely that this approach also underestimates the effects of riding rail transit on resulting emissions savings.

Congestion Relief: Ideally, an estimate of regional congestion relief should be generated by running a regional transportation planning model (i.e. a model simulation) and comparing a base case 2008 traffic flow scenario with one in which the transit system riders have been allocated to their respective second choice modes of transport. This is in line with APTA's (2009) preferred or Tier A approach. In this study the GHG emissions reductions from MARTA-supported congestion reduction are instead calculated in accordance with APTA's *much more approximate* Tier B approach, which is based on data for the Atlanta region reported in the Texas Transportation Institute's (TTI) *Urban Mobility Report*.

Twenty-six years of historical data for the Atlanta metropolitan area, spanning the period 1982 to 2007, were extracted from the Excel data tables found on the *Urban Mobility Report* website.[63] These data were used to create the following time series of values:

Highway VMT = Freeway daily vehicle-miles of travel + Arterial daily vehicle-miles of travel
Highway Lane-miles = Freeway lane-miles + Arterial lane-miles
Traffic Density = Highway VMT /Highway lane-miles
Excess Fuel Consumed in Congestion (total gallons) (also supplied as a TTI data product)

Figure 7.5 Relationship Between Traffic Density and Excess Fuel Consumption due to Congestion, based on TTI data for Atlanta



Fitting the traffic density to excess fuel relationship using the GROWTH function in Excel produced the statistical relationship between traffic density (vehicle miles of travel /highway lane miles of capacity) graphed in Figure 7.5.

Adding the almost 1.3 million extra vehicle miles of travel from the estimated transit mode shift to the rest of these daily vehicle miles produced an estimated additional fuel consumption of just under 49 million gallons in 2008. These fuel savings in turn yielded the 431,627 metric tons in annual emissions reduction benefits (in CO_2 only)[64], summed over all three of the agency's transit modes (i.e. over heavy rail, fixed route bus and paratransit services), again using an emissions rate of 8.81 kilograms of CO_2 per gallon of gasoline equivalent fuel consumed:

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[63] http://mobility.tamu.edu/ums/congestion_data/tables/complete_data.xls.

[64] APTA (2009) recommends omitting N_2O or CH_4 emissions computation s here since the relationship between congestion and emissions on a per-mile basis is unclear at the present time.

Land-Use Multiplier Effects: The long term impacts of a significant public transit service on a region's residential, commercial and industrial land development pattern can be significant (see Bailey, Mokhtarian and Little, 2008; TRB, 2009). In particular, mass transit systems are believed to encourage reduced vehicle trip frequencies as well as shorter trip lengths (APTA, 2009), by encouraging higher-density and mixed use land development that supports cycling and walking in place of vehicular trips, while also allowing more efficient multi-stop vehicle travel based trip chaining. Over time such non-or limited vehicle use-based accessibility may also encourage households to reduce their vehicle ownership. For a region as large and complex as the Atlanta MSA, which also operates other, if much smaller regional bus transit services, obtaining a transit-induced land use impact on tripmaking from MARTA services is a challenging task that requires the application of a regional land use and transportation planning model. Lacking the resources in the present project for running such a model we choose to exclude this effect here.

7.8 Savings Estimates and Summary Net Benefits Table

Table 7.4 summarizes the emissions production versus emissions savings attributed to MARTA in 2008 based on the above described calculations.

Table 7.4 MARTA Annual Emissions Savings vs. Emissions Produced, 2008 CO2e Estimates

Mode	Emissions Benefits in metric tons		Emissions Produced by Transit Operations	
	Mode Shifts	Congestion Relief	Scopes 1 & 2 Only	Scopes 1 & 2, +3 (Partial)
Bus (MB)	47,322		75,565	98,628
Paratransit (DR)	1,202		7,094	11,536
Heavy Rail (HR)	196,294		64,284	84,771
Non-Revenue Vehicles	na	na	3,611	8,735
Stationary Sources	na	na	76,275	88,750
Total	244,819	431,627	226,829	292,420

The results indicate that the regionwide GHG emissions reductions benefits from keeping transit riders out of their automobiles exceeds MARTA's current vehicle operating emissions from bus, rail and paratransit trips by between 2-to-1 and 3-to-1. The following emissions benefits/ emission production ratios tell the story, noting that a very conservative estimate has been produced of the mode shift benefits associated with MARTA's heavy rail service.

Total emissions benefits /Agency Scope 1 and 2 emissions only = 676,446 / 226,829 = 2.98

Total emissions benefits/ Agency Scope 1, 2, and 3 (partial) emissions = 676,446 / 292,417 = 2.31

On a modal service basis, both rail and bus operations offer significant emissions reductions. Only MARTA's paratransit services produce significant net GHG emissions.

Acknowledgements

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7. 9 References

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APPENDIX TO CHAPTER 7: DATA SOURCES

Fuel Consumption and VMT Data:

Provided by MARTA and reported in the Federal Transit Administration's 2008 National transit Database (NTD). Facility electricity and natural gas consumption data provided by MARTA and S.L. King Technologies, Inc.

Table 7A- 1: GHG Coefficient Data Sources

GHG Coefficient	**Source**
Decatherms/DGE	Atlanta Gas Light, (http://www.atlantagaslight.com/)
Metric tons of CO_2/Decatherm	EIA http://www.eia.doe.gov/oiaf/1605/coefficients.html)
GWP(CH_4)	Table B.1 TCR GRP (2008)*
GWP(N_2O)	Table B.1 TCR GRP (2008)
GramsCO_2/Gallon of Diesel	Table 13.1 TCR GRP (2008)
Grams CO_2/Gallon of Gasoline	Table 13.1 TCR GRP (2008)
GramsCH_4/VMT (diesel, gasoline)	Table 13.4 TCR GRP (2008)
GramsN_2O/VMT (diesel, gasoline)	Table 13.4 TCR GRP (2008)
GramsCH_4/gal (diesel, non-highway)	Table 13.6 TCR GRP (2008)
GramsN_2O/gal (diesel, non-highway)	Table 13.6 TCR GRP (2008)
lbs CO_2/MWh of Electricity	EIA State Electricity Profiles (2007)**
lbs CO_2/MWh of Electricity	U.S. EPA eGRID (2005)
CH_4/MWh of Electricity	U.S. EPA eGRID (2005)***
lbs N_2O/MWh of Electricity	U.S. EPA eGRID (2005)
kg CO_2/MMBtu of Natural Gas	Table 12.1 TCR GRP (2008)
kg CH_4/MMBtu of Natural Gas	Table 12.9 TCR GRP (2008)
kg N_2O/MMBtu of Natural Gas	Table 12.9 TCR GRP (2008)

* TCR GRP (2008) = The Climate Registry (TCR) General Reporting Protocol, May, 2008 http://www.theclimateregistry.org/downloads/GRP.pdf
*** U.S. EPA eGRID 2007 Version 1.1 (Year 2005 Data) http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html
** EIA State Electricity Profiles (Year 2007 Data) http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html

Scope 3 Upstream Emissions

Buses, Paratransit and Automobile Vehicles:

Fuel Production Cycle and Emissions:

GHGenius Version 3.15
http://www.ghgenius.ca/

Vehicle Manufacture Cycle Emissions:

GHGenius Version 3.15
http://www.ghgenius.ca/

Heavy Rail Vehicles:

Electricity Production Cycle and Emissions:

Scope 3 upstream GHG emission rates associated with electrical power generation for heavy rail vehicle propulsion were derived from GHGenius Version 3.15 (http://www.ghgenius.ca/), Table 53c. Upstream GHG emission rates were multiplied by state-level electrical feedstock ratios and total propulsion power consumption.

Vehicle Manufacture Cycle Emissions:

Scope 3 upstream GHG emissions rates associated with heavy rail vehicle manufacture and rebuild were derived using the Economic Input-Output Life Cycle Assessment (EIO-LCA) on-line software found at http://www.eiolca.net/ , using the US 2002 Benchmark I-O data tables, and deriving GHG emissions per dollar expenditure rates from the “railroad rolling stock manufacturing” economic subsector. Railcar manufacture expenditures are based on average expenditure data from APTA and rebuild expenditures are based on data from MARTA.

Vehicle service life (in years and miles) are estimated from MARTA vehicle inventory data. See table A-2 below.

Facilities:

Electricity Production Cycle and Emissions:

Scope 3 upstream GHG emission rates associated with electrical power generation for facility operations were derived from GHGenius Version 3.15 (http://www.ghgenius.ca/), Table 53c. Upstream GHG emission rates were multiplied by state-level electrical feedstock ratios and total facility electrical power consumption.

Natural Gas Production Cycle and Emissions:

Scope 3 upstream GHG emission rates associated with natural gas production for facility operations were derived from GHGenius Version 3.15 (http://www.ghgenius.ca/), Tables 55a, 55b, and 55c, "NG to commerce" data. Upstream GHG emission rates were multiplied by facility natural gas consumption data and appropriate GWP factors.