FTA RESEARCH

FEDERAL TRANSIT ADMINISTRATION

Transit Investments for Greenhouse Gas and Energy Reduction Program: Second Assessment Report Addendum

FEBRUARY 2016

FTA Report No. 0090
Federal Transit Administration

PREPARED BY
National Renewable Energy Laboratory
Leslie Eudy
Melanie Caton
Matthew Post

U.S. Department of Transportation
Federal Transit Administration

COVER PHOTO

VIA Metropolitan Transit bus, San Antonio, Texas; photo courtesy of NREL.

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Transit Investments for Greenhouse Gas and Energy Reduction Program: Second Assessment Report Addendum

TIGGER Transit Investments for Greenhouse Gas & Energy Reduction

FEBRUARY 2016

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

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13. ABSTRACT

This report is an addendum to the second assessment report of the U.S. Department of Transportation, Federal Transit Administration's Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) Program. The TIGGER Program provides capital funds to transit agencies for projects that work to reduce the agency's energy use and/or greenhouse gas (GHG) emissions from their operations. The purpose of this report is to provide an overall status update for the program, provide an outlook on specific projects, and present an analysis of program results provided to date. This report briefly outlines the program and its goals, as well as the technologies being implemented.

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ABSTRACT

This report is an addendum to the second assessment report of the U.S. Department of Transportation, Federal Transit Administration's Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) Program. The TIGGER Program provides capital funds to transit agencies for projects that work to reduce the agencies' energy use and/or greenhouse gas (GHG) emissions from their operations. The purpose of this report is to provide an overall status update for the program, provide an outlook on specific projects, and present an analysis of program results to date. This report briefly outlines the program and its goals, as well as the technologies being implemented. The second assessment report provides status updates for each project and analyzes results for projects that have accumulated a sufficient amount of data to do so.

EXECUTIVE SUMMARY

In 2009, the U.S. Department of Transportation's Federal Transit Administration (FTA) funded a program to promote energy-saving and sustainable technologies to the transit industry through a program entitled Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER).[1] The TIGGER Program made funds available for capital investments over a three-year period from 2009 through 2011 that would reduce greenhouse gas (GHG) emissions and/or lower the energy use of public transportation systems. In the initial round of the program (TIGGER I), funded through the American Recovery and Reinvestment Act of 2009 (ARRA), 43 projects were selected that represent a wide variety of technologies, including building efficiency improvements, solar installations, wind technology, wayside energy storage for rail, and purchase of technologically-innovative energy-efficient buses and bus components.

In 2010 and 2011, Congress appropriated additional funding through regular appropriations (not ARRA) for the TIGGER Program. Interested agencies submitted proposals to meet the original goals with an emphasis on innovation and national applicability. A total of 26 projects were selected in the second round (TIGGER II), and 17 projects were awarded in the third round (TIGGER III). Under the program, grants totaling nearly $225 million have been awarded to 86 competitively-selected projects implementing a wide variety of technologies to meet program goals. The awarded projects are geographically diverse, covering 35 states and 69 transit agencies in both urban and rural settings.

Through the TIGGER Program, transit agencies are implementing a diverse selection of technologies to meet the overall program goals of reducing energy and GHG emissions. Projects fall into three primary categories: Facility Efficiency, Bus Efficiency, and Rail Efficiency. These categories were assigned sub-categories according to technology type to support comparison of similar projects and provide information for transit agencies.

FTA established special reporting requirements to aid in determining the overall effectiveness of the program to ensure compliance with special reporting requirements set forth by Congress (as described in each TIGGER Notice of Funding Availability [NOFA]). The data collected for these requirements will be used in the program assessment and also will assist FTA in preparing a report to Congress on program results. All recipients of TIGGER funds must report the following after one full year of operation using the new technology:

- Actual annual energy consumed within the project scope attributable to the investment for energy consumption reduction projects, and/or
- Actual GHG emissions within the project scope attributable to the investment for GHG emissions reduction projects, and

[1] FTA's TIGGER Program should not be confused with the U.S. Department of Transportation's similarly named TIGER Program (Transportation Investment Generating Economic Recovery).

- Actual annual reductions or increases in operating costs attributable to the investment for each TIGGER project.

FTA is required to evaluate the results of the program and identify which technologies have the most potential impact on reducing emissions and increasing the energy efficiency of public transit agencies. To assist in developing a program analysis, FTA has enlisted the help of the National Renewable Energy Laboratory (NREL) through an interagency agreement to provide a third-party assessment of the TIGGER Program. Under FTA direction, NREL has collected data and information on each project. An analysis was conducted using data collected through December 2014 to determine the overall impacts of the completed projects toward meeting overall program goals. This report is an addendum to the second assessment report on the program.

The completed projects represent a combined annual energy savings of 109,781 million British thermal units (MBtu), or 24.6 million kilowatt-hours (kWh), and a reduction in GHG emissions (carbon dioxide equivalent, CO_2^e) of 31,028 tons. The data provided represent 42% of the total projects; this report summarizes the results to date. Based on reported annual savings attributed to the technologies used, the program has resulted in the following:

- Bus efficiency projects reported savings totaling more than 16,921 MBtu and 1,525 fewer tons CO_2^e emissions.
- Rail efficiency projects completed to date have resulted in an energy reduction of 16,887 MBtu.
- Facility efficiency projects have shown the most promise in reducing energy use, resulting in a combined reduction in annual energy use of 73,923 MBtu and 29,270 fewer tons CO_2^e emissions.
- Solar projects reported an annual energy savings of 17,230 MBtu.
- Wind projects reported an annual energy reduction of 507 MBtu.
- Geothermal projects reported a 97-ton decrease in CO_2^e emissions.

SECTION

1

Introduction

The Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER)[2] Program was implemented in 2009 by the U.S. Department of Transportation's Federal Transit Administration (FTA) and ran for three consecutive years, providing approximately $225 million in grants to the transit industry. The TIGGER Program made funds available for capital investments that would reduce greenhouse gas (GHG) emissions[3] and/or lower the energy use of public transportation systems. The projects selected under the TIGGER Program employ a variety of technologies or strategies to meet program goals. Projects incorporated, but were not limited to, such strategies as solar installations, building efficiency improvements, wind technology, wayside energy storage for rail, and purchase of more efficient buses and bus components. In 2012, FTA published the first TIGGER assessment report,[4] which provided a framework of the program and a status of the program's implementation, including descriptions of the goals and technologies being pursued and implemented. The report also summarized each of the projects by category and provided a preliminary analysis of estimated energy and GHG emissions savings. The second assessment report,[5] published in 2014, focused on the current status and early results of these energy and GHG emissions saving strategies through March 2014. This report serves as an addendum to the second assessment for the TIGGER Program and describes the impacts of the completed projects toward meeting overall program goals using data collected through December 2014.

[2] FTA's TIGGER Program should not be confused with the U.S. Department of Transportation's similarly named TIGER Program (Transportation Investment Generating Economic Recovery).

[3] Greenhouse gases trap heat in the atmosphere, contributing to the "greenhouse effect." Primary GHGs are carbon dioxide, methane, nitrous oxide, and fluorinated gases.

[4] *Transit Investments for Greenhouse Gas and Energy Reduction Program: First Assessment Report*, FTA Report No. 0016, Federal Transit Administration, June 2012.

[5] *Transit Investments for Greenhouse Gas and Energy Reduction Program: Second Assessment Report*, FTA Report No. 0064, Federal Transit Administration, August 2014.

SECTION

2

TIGGER Program Overview

Through the TIGGER Program, transit agencies across the country are implementing a diverse selection of technologies to meet the overall goals for reducing energy and GHG emissions within their operations. These projects support FTA's commitment to the environment while promoting cost-efficient alternatives and sustainable operations. Table 2-1 provides a summary of projects categorized by technology. The primary project categories are Bus Efficiency, Rail Efficiency, and Facility Efficiency. Many of the facility efficiency projects focus on secondary categories such as renewable power generation, including solar photovoltaic (PV), wind, geothermal, and fuel cell projects.

Table 2-1

Summary of Projects by Technology Category[a]

Technology Category	Sub-Category	Number of Projects
Bus Efficiency	Hybrid buses	19
	Efficiency retrofit	5
	Zero-emission buses	15
Total Bus Efficiency Projects		39
Rail Efficiency	Wayside energy storage system	3
	Locomotive upgrades	3
	On-board energy storage	2
	Controls	2
Total Rail Projects		10
Facility Efficiency	Facility upgrades	14
	Solar	15
	Wind	2
	Stationary fuel cell	3
	Geothermal	5
Total Facility Efficiency Projects		39

[a] Several projects employ multiple energy-efficient technologies.

FTA established special reporting requirements to aid in determining the overall effectiveness of the program to ensure compliance with special reporting requirements set forth by congress (as described in each TIGGER Notice of Funding Availability [NOFA][6,7,8]). To assist in developing a program analysis, FTA enlisted the help of the National Renewable Energy Laboratory (NREL) through an interagency agreement to provide a third-party assessment of the TIGGER Program. Under FTA direction, NREL has collected data and information on each project. The data collected for these requirements will be used in the program assessment and also will assist FTA in preparing a report to Congress on program results. All recipients of TIGGER funds must report the following after one full year of operation using the new technology:

- Actual annual energy consumed within the project scope attributable to the investment for energy consumption reduction projects, and/or
- Actual GHG emissions within the project scope attributable to the investment for GHG emissions reduction projects, and
- Actual annual reductions or increases in operating costs attributable to the investment for each TIGGER project.

The annual cost savings for reduced fuel and electricity use by the reporting projects totals close to $3.4 million using the average cost of fuel and electricity in 2011 provided by the U.S. Energy Information Administration. Table 2-2 shows the average cost savings per TIGGER dollar for the project sub-categories. The calculations use the expected lifetime of the technology, the annual cost savings, and the TIGGER award amount. The overall cost savings for the agencies that have provided data is $1.04 per TIGGER dollar awarded. Some of these projects provided a partial data set; however, the total TIGGER award to the agency was used to calculate this amount. Two zero-emission bus projects have provided complete data sets since the Second Assessment Report was published. The projected lifetime cost saving for those projects combined was only two cents per TIGGER dollar. The current cost of these advanced technology buses is much higher than conventional buses because zero-emission buses are still in the commercialization process. This higher cost plus a low number of operating miles in the first year of deployment resulted in low cost savings per dollar. This is

[6] NOFA: 74 FR 12447—Solicitation of Comments and Notice of Availability of Fiscal Year 2009 Funding for Transit Investments for Greenhouse Gas and Energy Reduction Grants, http://www.gpo.gov/fdsys/granule/FR-2009-03-24/E9-6420/content-detail.html.

[7] NOFA: 75 FR 18942—FY 2010 Discretionary Sustainability Funding Opportunity; Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) Program and Clean Fuels Grant Program, Augmented With Discretionary Bus and Bus Facilities Program, http://www.gpo.gov/fdsys/granule/FR-2010-04-13/2010-8398/content-detail.html.

[8] NOFA: 76 FR 37175—FY 2011 Discretionary Sustainability Funding Opportunity Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) Program and Clean Fuels Grant Program, Augmented With Discretionary Bus and Bus Facilities Program, http://www.gpo.gov/fdsys/granule/FR-2011-06-24/2011-15913/content-detail.html.

expected to rise as the agencies become more familiar with the new technology and operation hours increase. Further description, details about the calculations and methodology can be found in the second assessment report. A summary of the assumptions are located in the Appendix to this report.

Table 2-2

Average Reported Cost Savings per TIGGER Dollar by Project Sub-Category

	TIGGER Award	Projected Lifetime Cost Savings per TIGGER $	Return on Investment (ROI)	Number of Projects Reporting
Diesel Hybrid Bus	$26,488,289	$0.96	-4%	11
Retrofit Bus	$1,070,000	$2.88	188%	2
Zero-Emission Bus	$12,241,003	$0.02	-98%	2
Facility Efficiency	$8,830,936	$3.93	293%	9
Solar PV	$30,607,500	$0.62	-38%	9
Wind	$2,180,750	$0.13	-87%	1
Geothermal	$450,000	$0.89	-11%	1
Rail	$2,484,766	$1.97	97%	1
Overall	**$84,353,244**	**$1.04**	**4%**	**36**

SECTION

3

Analysis of GHG Emissions, Energy, and Cost Savings

To frame the TIGGER analysis, NREL developed a comprehensive template to aid in collecting the required data from project partners. The template, in Microsoft Excel format, contains 28 separate tabs for the various types of data to be collected on TIGGER projects. This file provides a guideline to show what level of detail is preferred for data requests. NREL expects that a majority of transit agencies should be able to provide the requested level of detail; however, some agencies may not employ a data collection system able to provide such detail. In these cases, NREL worked with the agencies to determine what data could be reported to allow a sufficient analysis.

Of the TIGGER grantees currently able to provide data, most have reported approximately one year of data prior to project implementation and one year of data following the project completion. For building efficiency and renewable energy projects, data were collected from monthly energy company invoices. NREL tabulated total energy use before and after project completion and calculated the annual total savings in both kWh and MBtu. For projects that had not completed a full year of operation, NREL used the data provided to estimate the total savings for a full year. Building efficiency projects that resulted in heating fuel reductions could claim GHG emissions reductions as well as energy savings. For these projects, NREL calculated total fuel (natural gas, heating oil) used before and after project implementation and used conversion factors to calculate estimated GHG emissions savings. The list of conversion factors was originally developed for grantees to use during the application process when submitting proposals for the TIGGER Program. The list of all conversion factors is provided in the Appendix.

Summary of Results by Project Category

NREL received complete or partial data sets from 36 TIGGER projects. The data provided represent 42% of the total projects. This section summarizes results gathered through December 2014.

The tables in this section provide annual energy and GHG emissions savings, projected lifetime savings based on estimated life of the technology, and lifetime savings per TIGGER dollar invested, by specific categories. The energy savings are presented in million British thermal units (MBtu) and the GHG emissions savings are presented in tons of carbon dioxide equivalent (CO_2^e). The number of projects included in the analysis is also provided along with the total number of projects in each specific category and the percent of the total. Table 3-1 summarizes the results to date for the program by each funding round. As expected, the majority of projects providing data are from the earliest funding round—TIGGER I—because those projects have had sufficient time to be completed and to collect a full year of data. Seven of the TIGGER II projects have provided data, and none of the TIGGER III projects have progressed enough to provide sufficient data. All but five of the completed projects have provided a complete data set and three of those five have provided partial data for analysis.

Table 3-1 *Reported Energy and GHG Emissions Savings by Funding Round*

	Annual Energy Savings (MBtu)	Lifetime Energy Savings (MBtu)	Annual GHG Savings (tons CO_2^e)	Lifetime GHG Savings (tons CO_2^e)	Lifetime Energy Savings per TIGGER $ (Btu/$)	Lifetime GHG Savings per TIGGER $ (lb/$)	Number of Projects Reporting
TIGGER I	83,800	1,788,003	30,515	75,974	28,121	2.08	28
TIGGER II	23,929	309,196	280	5,603	40,974	2.24	6
TIGGER III	0	0	0	0	0	0.00	0
Total	**107,729**	**2,097,199**	**30,795**	**81,577**	**29,484**	**2.08**	**34**

Table 3-2 summarizes the results to date by technology category. A total of 20 facility projects, 15 bus efficiency projects, and 1 rail project have provided full or partial data sets for analysis. Figure 3-1 provides a pie chart with a breakdown of the total annual energy savings to date by technology category. Figure 3-2 provides a similar chart showing the total annual GHG emissions reductions to date.

Table 3-2 *Reported Energy and GHG Emissions Savings by Technology Category*

	Annual Energy Savings (MBtu)	Lifetime Energy Savings (MBtu)	Annual GHG Savings (tons CO_2^e)	Lifetime GHG Savings (tons CO_2^e)	Lifetime Energy Savings per TIGGER $ (Btu/$)	Lifetime GHG Savings per TIGGER $ (lb/$)	Number of Projects Reporting
Bus	16,921	245,151	1,525	21,731	9,070	0.18	13
Facility	73,923	1,683,177	29,270	59,846	40,445	6.87	20
Rail	16,887	168,871	0	0	67,963	0.00	1
Total	**107,731**	**2,097,199**	**30,795**	**81,577**	**29,484**	**2.08**	**34**

Figure 3-1

Reported Annual Energy Savings by Project Type–109,781 MBtu Total

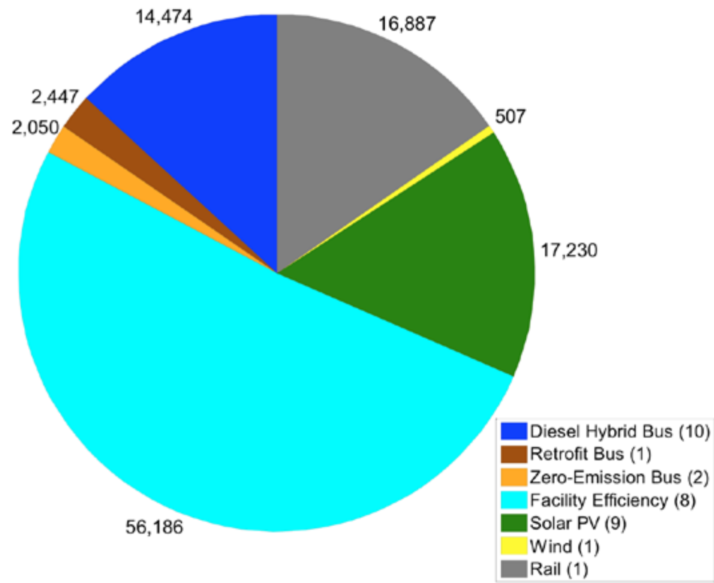


Figure 3-2

Reported Annual GHG Emissions Savings by Project Type–31,030 Tons CO_2e Total

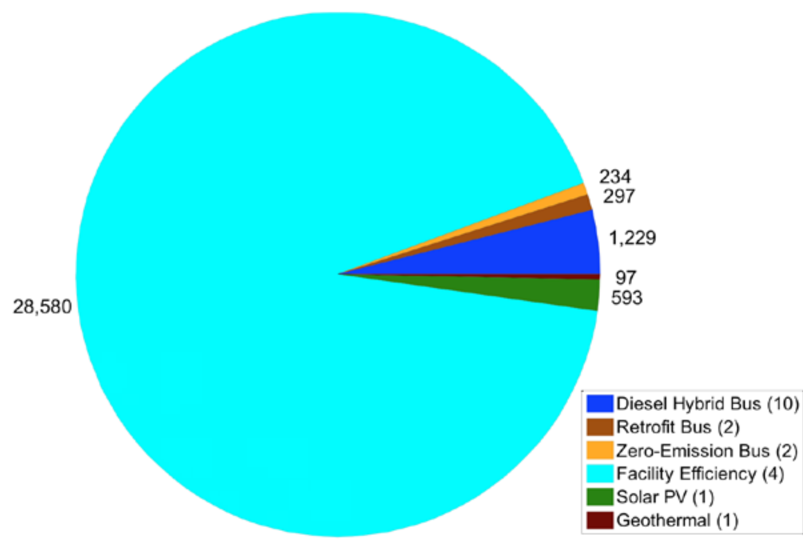


Table 3-3 summarizes the results to date for facility projects by sub-category. The majority of projects reporting have been sustainable facility upgrades and repairs or new solar installations. These have resulted in significant savings for the transit agencies involved. NREL did not receive any new data on facility projects since the second assessment report, therefore this table is unchanged.

Table 3-3 *Reported Facility Energy and GHG Savings by Sub-Category*

	Annual Energy Savings (MBtu)	Lifetime Energy Savings (MBtu)	Annual GHG Savings (tons CO_2e)	Lifetime GHG Savings (tons CO_2e)	Lifetime Energy Savings per TIGGER $ (Btu/$)	Lifetime GHG Savings per TIGGER $ (lb/$)	Number of Projects Reporting
Renewable – PV	17,230	412,204	593	7,115	13,469	0.15	9
Renewable – Wind	507	10,145	0	0	4,652	0	1
Renewable – FC	0	0	0	0	0	0	0
Upgrades	56,186	1,260,828	28,580	49,815	142,774	19.65	9
Geothermal	0	0	97	2,916	0	0.30	1
Total	**73,923**	**1,683,177**	**29,270**	**59,846**	**40,445**	**6.87**	**20**

Table 3-4 summarizes the results to date for bus efficiency projects by sub-category. The majority of projects that have been implemented have been hybrid bus deployments and bus retrofits. This is not unexpected because these technologies are commercially available products. Because zero-emission buses are still in the early development stages, they can take additional time to fully develop and deliver prior to being put into service. Several TIGGER electric bus projects have recently gone into service, and NREL collected data for two completed bus projects that were not included in the second assessment report. The resulting analysis is included in this report.

Table 3-4 *Reported Bus Energy and GHG Savings by Sub-Category*

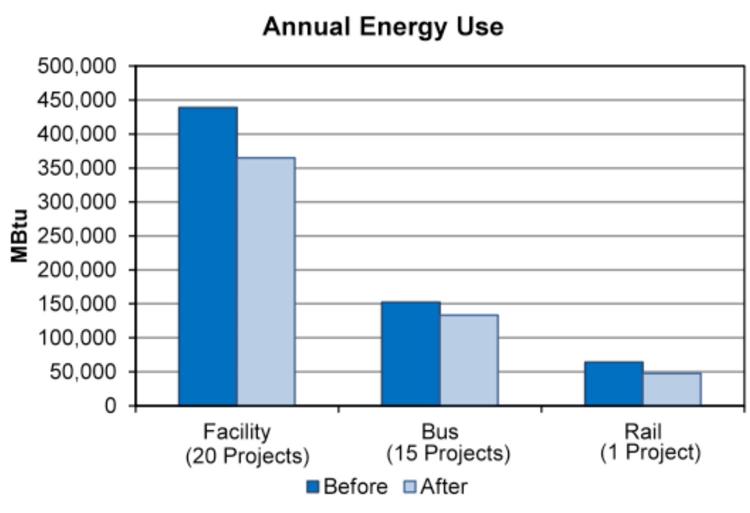
	Annual Energy Savings (MBtu)	Lifetime Energy Savings (MBtu)	Annual GHG Savings (tons CO_2e)	Lifetime GHG Savings (tons CO_2e)	Lifetime Energy Savings per TIGGER $ (Btu/$)	Lifetime GHG Savings per TIGGER $ (lb/$)	Number of Projects Reporting
Hybrid	14,474	205,999	1,228	17,317	7,839	0.16	11
Retrofit	2,447	39,152	298	4,414	52,203	0.75	2
Zero-Emission	0	0	0	0	0	0	0
Total	**16,921**	**245,151**	**1,525**	**21,731**	**9,070**	**0.18**	**13**

Several bus efficiency projects were not as successful as originally proposed. In some cases, the baseline and new buses were not similar enough with respect to size and weight to allow a direct comparison. For example, replacing a smaller vehicle with a larger one is not likely to show an advantage in fuel efficiency even if the new vehicle has a hybrid drivetrain. In these cases, fuel use actually increased with the new buses and therefore resulted in higher GHG emissions and energy use. If the larger vehicles increased the passenger capacity, calculations by passenger could show a reduction in energy use and GHG emissions. A majority of projects reporting increased energy use and GHG emissions were implementing a new-technology vehicle that was still in an early development and testing phase. Over the last two years, several of the original equipment manufacturers (OEMs) or technology providers within original project proposals or grant agreements have experienced economic problems (such as bankruptcy) or operational problems with the new-technology vehicles that have caused them to abandon their participation in TIGGER. As a result, transit agencies have had issues with implementing or adopting the new-technology vehicles originally proposed for implementation. When manufacturers stop actively participating, transit agencies are forced to troubleshoot and repair advanced technology vehicles with existing maintenance staff. Low reliability for the newer-technology buses and difficulties acquiring parts and technical support also resulted in higher costs for these specific agencies.

Annual energy use for the reporting projects is shown in Figure 3-3 by technology category. One rail project has been completed, and the data collected showed a 26% decrease in energy consumption. Facility projects resulted in a 17% energy reduction, and the bus projects showed a 12% decrease in energy use. Some of the analyzed bus projects showed increased energy use after the new technology was implemented. This lower savings for the bus projects is due primarily to two factors. First, the increased energy use for the projects mentioned above was subtracted from the total savings. Second, the fuel economy for hybrid buses is highly dependent on duty cycle. The early estimates for many of the projects assumed a fuel economy at the high end of the manufacturer-reported fuel economy range. In-use fuel economy is affected by several factors such as speed, idle time, number of stops, use of auxiliary loads (air conditioning, heating), and differences in terrain.

Figure 3-3

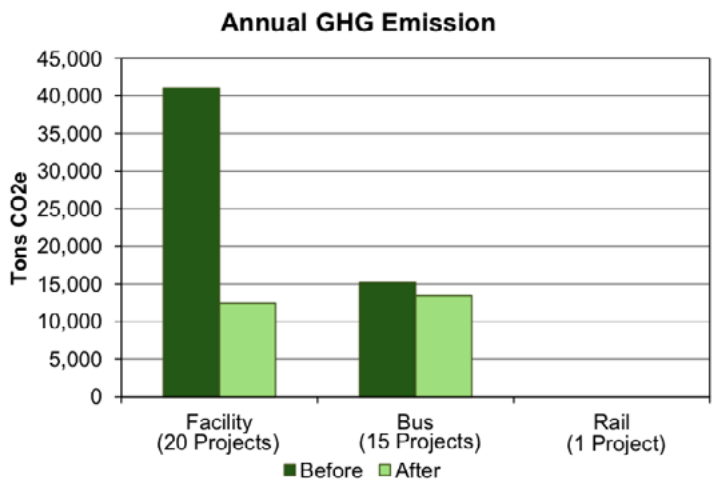
Annual Energy Use for Reported Projects by Technology Category



Annual GHG emissions for the reporting projects are shown in Figure 3-4. The chart shows the total annual emissions reported before and after the new technology implementation. Facility projects were only allowed to count GHG emissions reductions if the improvements lowered the use of fuel such as natural gas or heating oil. That was the case for four of the projects reported to date. Savings for these projects was 70% compared to prior emission levels. The bus efficiency projects resulted in GHG emissions savings of 12% for the same reasons mentioned earlier. The one rail project included in the analysis was for energy reduction and was only allowed to count energy savings.

Figure 3-4

Annual GHG Emissions for Reported Projects by Technology Category



Economic Analysis

Cost savings are based on the first year of results for the projects that have been completed and provided data sets. For projects that reduced fuel use, the MBtu savings was converted to gallons of fuel saved (for bus efficiency projects) or therms of natural gas saved (for facility efficiency projects). For energy-saving projects, the MBtu savings was converted to kWh of electricity saved. The costs were calculated based on the average 2011 U.S. energy prices from U.S. Energy Information Administration data as follows:

- Electricity cost per kWh: $0.099
- Diesel cost per gallon: $3.791
- Gasoline cost per gallon: $3.552
- Natural gas cost per 1,000 standard cubic foot (commercial rate): $8.16.

The calculations account for energy or fuel savings and maintenance or operating cost savings associated with the technologies provided by the agencies.

TIGGER projects have resulted in significant cost savings for most of the participating transit agencies. The transit agencies report very little cost to operate and maintain the new systems primarily because this cost is currently covered under manufacturer warranties. The facility and bus projects report lower-than-expected energy cost savings; however, most of the agencies report much lower costs to operate and maintain the newer technology. The maintenance cost analysis has been completed for 14 of the 15 bus efficiency projects. Of these, 12 report significant maintenance cost savings totaling more than $1.5 million for the first year of operation.

Table 3-5 presents the annual energy and cost savings for the projects included in the analysis by technology category. The table shows the actual annual energy savings, the estimated lifetime energy savings, and the cost savings associated with the reduction. The completed projects have reduced energy consumption by enough to power 2,851 homes annually. The per-TIGGER-dollar cost savings for each category is included in the table. The cost savings is based on the projected lifetime savings calculated using the data provided by the reporting agencies. Some of these are partial data sets, but the total award amount is used in the calculation as it is difficult to determine the dollar amount spent to date.

Table 3-5

Total Energy and Cost Savings by Category

	Annual Energy Savings (MBtu)	Lifetime Energy Savings (MBtu)	Total Annual Cost Savings (2011 $)	Lifetime Cost Savings per TIGGER $	Homes Powered for One Year	Number of Projects Reporting
Bus	18,971	269,751	$2,046,860	$0.72	493	15
Facility	73,923	1,683,177	$2,273,107	$1.29	1,920	20
Rail	16,887	168,871	$489,697	$1.97	439	1
Total	**109,781**	**2,121,799**	**$4,809,664**	**$1.04**	**2,851**	**36**

Table 3-6 presents the annual GHG emissions savings for the projects included in the analysis by technology category. The table shows the actual GHG emissions savings and estimated lifetime GHG emissions savings for the projects that had a goal of GHG emissions reduction (18 of the 36 projects). Facility projects were only allowed to count GHG emissions reductions if the improvements lowered the use of fuel such as natural gas or heating oil. That was the case for six of the projects reported to date. The facility and bus projects both estimated higher GHG emissions savings than they have achieved.

Table 3-6

GHG Emissions Savings by Technology Category

	Annual GHG Savings (tons CO_2^e)	Lifetime GHG Savings (tons CO_2^e)	Cars Removed from Road for One Year	Number of Projects Reporting
Bus	1,759	24,534	309	15
Facility	29,270	59,846	5,135	20
Rail	—	—	—	1
Total	**31,028**	**84,380**	**5,444**	**36**

The avoided costs from the annual CO_2^e emissions reductions are shown in Table 3-7. These values are published by the U.S. Environmental Protection Agency and applied to each metric ton of CO_2 reduced. These are indirect costs to society calculated using a range of cash discount rates to account for future inflation.

Because predicting the future value of the dollar is a controversial subject, a range of discount rates are used for the calculations.

Table 3-7

Total Avoided Costs from Annual GHG Emissions Reductions

Annual Social Cost of CO_2, 2015-2050[a] (in 2011 $)				
Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th percentile
2015	$372,341	$1,210,108	$1,892,732	$3,599,294
2020	$403,369	$1,427,306	$2,109,931	$4,250,891
2025	$465,426	$1,551,420	$2,296,102	$4,747,345
2030	$527,483	$1,706,562	$2,482,272	$5,274,828
2035	$620,568	$1,861,704	$2,637,414	$5,802,311

[a] The social cost of carbon values are dollar-year and emissions-year specific.

SECTION 4

Summary of Lessons Learned

This section outlines the project types by category that had the most impact to date and summarizes the lessons learned.

Bus Efficiency Projects

One of the most promising projects for bus efficiency was electronic cooling package retrofits. Electronic cooling systems can be retrofitted on existing buses, which makes it a technology that is applicable to all transit agencies. These systems can be a cost-effective solution to increase efficiency and lower fuel and maintenance costs. In addition, electronic cooling retrofits can reduce the risk of fires and avoid costly repairs. The age and current condition of a bus should be considered before deciding to do a retrofit to make the most of the efficiency gain. An agency should also consider purchasing new buses with an electronic cooling package installed by the OEM. The following recommendations are things to consider when planning these retrofits:

- Review existing bus fleets to determine which will provide the best return on investment for retrofit.
- Plan ahead to ensure the work can be completed within the desired timeframe.
- Review the engine layout for each bus fleet to ensure that the cooling system manufacturer understands the plumbing necessary for retrofit.

Hybrid electric buses are also a good choice for an agency to reduce fuel use if replacing similar-sized buses. Hybrid powertrains were developed for buses beginning in the 1990s and are considered a mature technology. All major manufacturers offer buses with hybrid powertrains as part of their line-up. Fuel economy improvements for hybrid transit buses relative to similar non-hybrid buses are highly dependent on duty cycle, so an agency should consider the type of route that the buses are best operated on to maximize efficiency.

Zero-emission buses have the potential to greatly reduce emissions for a fleet; however, these technologies are still in the process of being commercialized. These buses are being produced in relatively low volumes, which results in higher capital costs. As with other technologies, increased production will decrease costs. Electric drive buses are expected to cost more to operate in the early stage of deployment while staff address the learning curve required to become proficient with a new technology. Once these buses are out of warranty, advanced technology parts costs could be high. An agency should work with the manufacturer to determine what parts are needed for inventory and plan accordingly. Extended warranties could be beneficial during the early stage of development.

Facility Efficiency Projects

For any facility project, an agency should conduct an energy audit to identify and prioritize improvements. Energy audits can be obtained a number of ways such as from consultants, utility companies, software packages, Web tools, and government entities in the energy sector. The Clinton Climate Initiative established the Energy Efficiency Building Retrofit Program[9] to provide support to building projects worldwide, including free energy efficiency master planning and project support. There are many resources available on the Office of Energy Efficiency and Renewable Energy[10] website that can provide useful information about retrofits and other energy reduction measures for a variety of building types. Project managers can explore available state and federal funding through the Database of State Incentives for Renewables and Efficiency.[11]

Of all the facility projects funded through the TIGGER Program, lighting upgrades resulted in the most significant energy savings. A lighting retrofit is often the first measure taken when reducing energy consumption because it is often the most cost-effective choice. This is especially true in older buildings; however, it frequently requires installing new light fixtures in addition to replacing the bulbs. It is helpful to do a little upfront research to determine what type of lighting is needed for the facility and evaluate the options available. The TIGGER projects that involved lighting retrofits developed the following list of items to consider when planning a similar project:

- When selecting a contractor, go for best value as opposed to lowest bid.
- "Going big" with a project has its advantages. Standardizing fixtures and buying in bulk lowers costs.
- Longer-lasting light bulbs can save on labor costs over time.
- Planning for future technology changes can decrease costs even more.

Many TIGGER projects incorporated renewable energy generation to reduce facility power needs. Because renewable energy resources vary across the country, the location and type of renewable energy technology used should be carefully considered before implementation. Studies have been conducted to estimate the technical potential of solar, wind, and other renewable resources in the United States. In a recent NREL study, renewable energy technical potential

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[9] http://www.presidentsclimatecommitment.org/resources/eebrp/.

[10] http://energy.gov/eere/buildings/improving-energy-efficiency-commercial-buildings.

[11] http://www.dsireusa.org/.

is defined as the achievable energy generation of a particular technology given system performance, topographic limitations, environmental considerations, and land-use constraints.[12] (See http://www.nrel.gov/gis/maps.html for detailed maps showing the renewable energy potential for various energy technologies.) An energy storage system should also be evaluated for the agency to get the most out of their investment; selling the excess energy back to the utility does not provide the maximum benefit in most cases.

The most common type of renewable energy deployed through the TIGGER Program was solar power systems. The amount of savings varied from site to site depending on many factors including the available solar resource, the operating characteristics of the facility, and the net metering agreement with the local utility provider. Transit agencies implementing solar power systems provided input on lessons learned for this type of project. This included the following recommendations:

- Review similar projects to gain an understanding of what might be possible.
- Evaluate installation options for the renewable technology to get what is needed to meet the objectives.
- Be rigorous in the pre-qualification and selection process for proposers to ensure the most qualified and committed bidders rise to the top.
- Initiate discussions with utility companies and permitting officials early on to streamline the process.
- Plan for functionality—include aspects such as easy access for cleaning PV panels and electric plugs to provide power when needed for working under canopy systems.
- Scalable construction allows for future growth.
- Consider upgrading the monitoring software to provide long-term storage of data. Monitoring software systems often provide real-time data but do not store historical data on system performance. Access to historical data allows an agency to see how the system performs over time. Transit agencies could add an automatic back-up capability to the system or they could request that the installer include software to provide storage.

One aspect of transit that makes it a challenge to maximize the use of renewable energy is the operating characteristics. Transit facilities often employ two to three shifts for maintaining equipment. Renewable energy is produced mostly during the day but much of the work done at the facility is conducted during evening and night hours. Excess power produced during the day can be sold back to the utility, although at a lower price than the cost of energy during the night shifts. A renewable energy power system could benefit from a storage system

[12] *U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis Technical Report*, NREL/TP-6A20-51946, July 2012, http://www.nrel.gov/docs/fy12osti/51946.pdf.

to maximize the energy produced during times the facility use is low. This can increase the complexity of the system and add cost to the overall project.

Rail Efficiency Projects

NREL has received a full data set from only 1 of the 10 rail efficiency projects. That project installed new, more efficient switch heaters and controls. The new heaters have better heat transfer characteristics and are controlled to heat the track only during freezing conditions. The older heaters were configured to heat the track during the entire fall and winter season, wasting a significant amount of energy. The energy savings during the first season of operation was nearly 5 million kWh—a 26% savings over that of the previous year. This technology could be installed at all transit agencies where colder winters require track and switch heaters.

SECTION

5

Project Summaries

Project summaries for most of the TIGGER projects are included in the second assessment report. Each summary includes the status of the project and a detailed analysis of the results if complete data sets were provided. NREL collected data for two additional projects since publication of the assessment report; the analysis is provided in this section.

Project Name: StarMetro Electric Bus Project

Transit Agency:	City of Tallahassee, StarMetro
Location:	Tallahassee, Florida
Award Amount:	$7,241,003
Award Year:	2010
TIGGER Goal:	Both energy and GHG emissions reduction

Results Summary

First Year Energy/GHG Savings: 1,664 MBtu / 190 Tons CO_2^e
First Year Fuel Cost Savings: $13,521
Projected Lifetime Energy/GHG Savings: 19,965 MBtu / 2,757 Tons CO_2^e

Transit Agency Profile: StarMetro, part of the Department of Public Works for the City of Tallahassee, is the public transit system serving Tallahassee, Florida. StarMetro operates 12 fixed routes as well as shuttles for the local universities, paratransit, and dial-a-ride services in the area.

Project Description: StarMetro is using TIGGER funds to replace older diesel buses with fast-charge battery electric buses. These zero-emission buses were built by Proterra and feature an electric drive propulsion system powered by lithium titanate batteries. The 35-foot bus chassis is built of lightweight composites but seats a similar number of passengers as a 40-foot bus. Table 5-1 provides selected specifications for the electric and diesel baseline buses. The agency plans to operate the buses on its Canopy route, a main east to west route that services downtown Tallahassee. The project includes installation of a fast charger on the route at a layover point and a slow charging station at the bus depot. During every circuit, the buses are fully charged in less than 12 minutes. In 2012, StarMetro was awarded additional funding ($2 million) from another TIGGER project that was canceled. The funds are being used to purchase two more buses, bringing the fleet to five electric buses.

Table 5-1

Specifications for StarMetro Electric and Diesel Buses

Star Metro	Electric Buses	Electric Buses	Diesel Buses
Number of Vehicles	3	2	5
Model Year	2012	2013	2010
Manufacturer	Proterra, Inc	Proterra, Inc	Gillig
Model	EcoRide BE35	EcoRide BE35	G27D102N4
Length (ft)	35	35	40
Weight (lb)	27,250	27,250	27,740
Motor/Engine OEM	UQM	UQM	Cummins
Motor/Engine: Rated Power	100 kW	120 kW	280 hp
Energy Storage Type	Lithium-titanate	Lithium-titanate	N/A
Cell Manufacturer	Altairnano	Altairnano	N/A
Energy Storage Pack Manufacturer	Proterra, Inc	Proterra, Inc	N/A
Total Capacity (kWh)	**72**	**72**	**N/A**

Project Status: This project is complete. StarMetro received all five buses from Proterra between June and July 2013 and the fast charger installation was completed in July 2013. Figure 5-1 shows one of the electric buses. The fast charger is installed on-route and can fully charge the bus in less than 12 minutes. The agency also installed a slow charger at the depot to provide additional charging as needed. The estimated time for this charger to fully charge the bus is 1.5 hours. The agency is working with the Center for Transportation and the Environment (CTE) to manage the project and handle the data collection requirements. StarMetro accepted the buses and put them in service in late July 2013 along the Canopy route. The route schedule was modified to accommodate the new bus technology.

Figure 5-1

StarMetro Fast-Charge Electric Bus

Photo courtesy of StarMetro

Summary of Results: StarMetro added a total of five battery electric buses to its fleet, replacing five older 40-foot diesel buses. Table 5-2 summarizes the energy use and GHG emissions for the project. Figure 5-2 presents the energy savings results graphically. Based on the data analysis, StarMetro has an annual energy savings of 76%. Because the buses offset all the fuel use of the diesel buses, the project results in 100% fewer GHG emissions. This is the equivalent of removing approximately 33 cars from the road each year.

Table 5-2

Summary of Energy and GHG Savings for StarMetro Electric Bus Project

Star Metro	Baseline	Electric	Savings	Unit
Total Fuel Used	17,150	0	17,150	gal
Annual GHG Emissions	189.9	0	190	tons CO_2^e
Annual Energy Use	2,195	531	1,664	MBtu
Lifetime of Technology			12	Years
Projected Lifetime GHG Savings			2,279	tons CO_2^e
Projected Lifetime Energy Savings			19,965	MBtu
Lifetime GHG Savings per TIGGER $			0.6	lbs CO_2^e
Lifetime Energy Savings per TIGGER $			2,757	Btu

Figure 5-2

Annual Energy Use for StarMetro Electric Bus Project

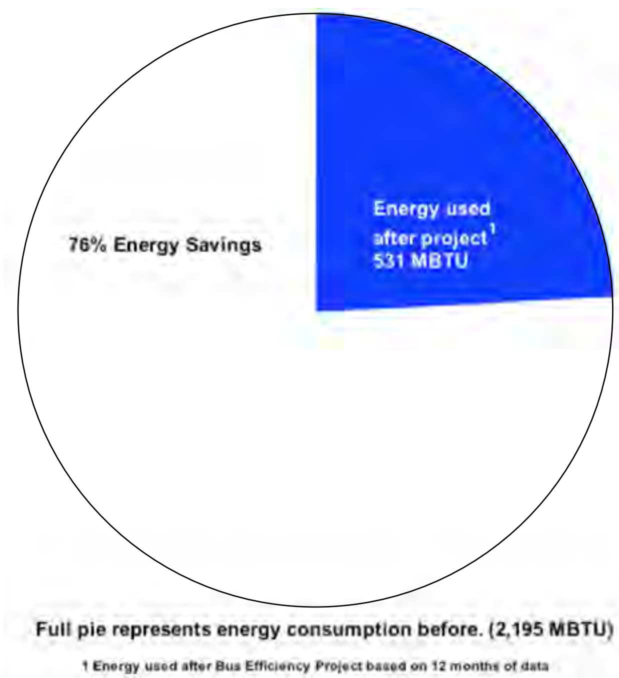

Figure 5-3 shows the monthly fuel economy for the baseline and electric buses in miles per diesel gallon equivalent (DGE).[13] The electric buses have an energy equivalent fuel economy that is 4 times higher than that of the baseline diesel buses. This is estimated to save the agency more than $13,000 each year in fuel costs at the current rate of bus use. For the first year, the electric buses were operated fewer miles than the diesel buses were. This is expected of newer technology as it is being integrated into a fleet. Once the agency and manufacturers work through the early issues, the bus use should increase. If

[13] Calculations for converting kWh use to diesel gallon equivalent were based on 128,450 Btu/gallon of diesel fuel and 3,414 Btu/kWh for electricity.

these buses were to operate an average of 30,000 miles per year, the annual fuel savings would increase to approximately $25,400 per year.

Figure 5-3

Monthly Average Fuel Economy for StarMetro Electric and Diesel Buses

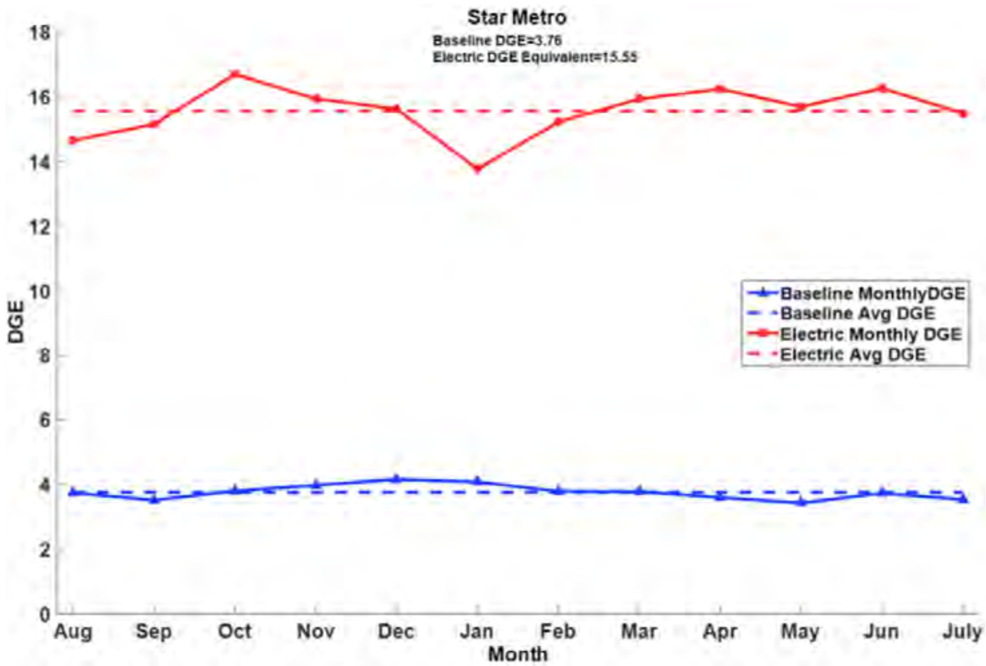

Table 5-3 summarizes the costs for the new electric and baseline diesel buses at StarMetro. The maintenance costs per mile for the electric buses were more than 2 times higher than that of the diesel buses. The majority of costs were for unscheduled repairs. There were some early bus-related issues with the doors and air conditioning during the start-up of operation for the buses. These types of problems can occur with any new bus order and are typically solved within the break-in period. Costs are expected to drop as these issues get resolved. StarMetro provided detailed maintenance records that allowed NREL to eliminate costs such as accident-related repairs from the analysis. This is important because accidents are extremely variable from bus to bus. The level of detail also allowed NREL to categorize the repairs by system. The propulsion-related-only maintenance costs are provided in the table. The electric buses had issues with the charging system and batteries. The costs were entirely for labor because the parts were supplied under warranty.

Table 5-3

Summary of Operational Costs for StarMetro Electric Bus Project

Star Metro	Electric	Baseline
Total Miles	64,302	248,068
Parts Cost	$11,563.00	$33,791.87
Labor Cost	$57,793.57	$51,024.04
Total Maintenance Cost	$69,356.57	$84,815.91
Maintenance Cost per Mile	$1.08	$0.34
Scheduled Maintenance Cost	$11,418.72	$40,494.68
Scheduled Maintenance Cost per Mile	$0.18	$0.16
Unscheduled Maintenance Cost	$57,937.85	$44,321.23
Unscheduled Maintenance Cost per Mile	$0.90	$0.18
Propulsion-Related Unscheduled Maintenance Costs	$23,187.29	$13,404.52
Propulsion-Related Unscheduled Maintenance Costs per Mile	$0.36	$0.05
Fuel Economy (mpDGE)	15.55	3.75
Total Fuel Used (kWh/gal)	155,613.8	66,161.4
Fuel Cost (at $0.31/ kWh, $3.51/gal)	$46,715.28	$232,384.54
Fuel Cost per Mile	$0.73	$0.94
Total Cost per Mile	**$1.81**	**$1.28**

Using the mileage of the electric buses as the baseline, the operational cost difference is summarized in Table 5-4. The electric buses saved more than $13,000 in fuel costs.

Table 5-4

Operational Cost Differences for StarMetro Electric Bus Project

Star Metro	Electric	Baseline	Difference
Total Maintenance Cost	$69,356.57	$21,985.13	-$47,371.44
Total Fuel Cost	$46,715.28	$60,236.39	$13,521.11
Total Cost	$116,071.85	$82,221.52	-$33,850.33

Project Name: VIA Fast-Charge Electric Bus Project

Transit Agency: VIA Metropolitan Transit of San Antonio, Texas
Location: San Antonio, Texas
Award Amount: $5,000,000
Award Year: 2009 (Recovery Act)
TIGGER Goal: Both energy and GHG emissions reduction

Results Summary

First Year Energy/GHG Savings: 385 MBtu / 45 Tons CO_2^e
First Year Fuel Cost Savings: $8,299
Projected Lifetime Energy/GHG Savings: 4,624 MBtu / 536 Tons CO_2^e

Transit Agency Profile: VIA Metropolitan Transit covers a service area comprising 1,213 square miles in Bexar County, Texas, and includes San Antonio. VIA's fixed-route services are accomplished with a fleet of 446 buses. These buses are predominantly 40-foot coaches operating with a range of propulsion technologies and fuels, including diesel-electric hybrid, conventional diesel, propane, and compressed natural gas.

Project Description: VIA replaced three older diesel buses with battery electric buses from Proterra. The buses use a quick-charge station that can fully charge the batteries in less than 10 minutes. VIA contracted with its local energy provider, CPS Energy, to receive 100% of the electricity used by the buses through its Windtricity program. Windtricity uses wind-powered turbines to generate grid electricity. VIA also installed solar PV panels at the bus charging station for supplemental power. Table 5-5 provides selected specifications for the electric and diesel baseline buses at VIA.

Table 5-5

Specifications for VIA Electric and Diesel Buses

VIA	Electric Buses	Diesel Buses
Number of Vehicles	3	3
Model Year	2012	2008
Manufacturer	Proterra, Inc	New Flyer
Model	EcoRide BE35	D40LF
Length (ft)	35	40
Weight (lb)	27,250	27,500
Motor/Engine OEM	UQM	Cummins
Motor/Engine: Rated Power	100 kW	280 hp
Energy Storage Type	Lithium-titanate	N/A
Cell Manufacturer	Altairnano	N/A
Energy Storage Pack Manufacturer	Proterra, Inc	N/A
Total Capacity (kWh)	**54**	**N/A**

Project Status: This project is complete. The buses were placed into service in early 2013. The buses are being used in a downtown circulator service. VIA has contracted CTE to support the project, including collecting data to be submitted for analysis.

Figure 5-4

VIA Quick-Charge Battery Bus

Summary of Results: VIA added a total of three battery electric buses to its fleet, replacing three older 40-foot diesel buses. Table 5-6 summarizes the energy use and GHG emissions for the project. The data were provided for a full year for the diesel baseline and electric buses. Figure 5-5 presents the energy savings results graphically. Based on the data analysis, VIA has an annual energy savings of 74%. The analysis calculates the difference between the diesel bus fuel use and electric bus electricity use on the basis of energy content in MBtu. Because the electric buses offset all of the fuel use of the diesel buses, the project results in 100% fewer GHG emissions.

Table 5-6

Summary of Energy and GHG Savings for VIA Electric Bus Project

VIA	Baseline	Electric	Savings	Unit
Total Fuel Used	4,032	0	4,032	gal
Annual GHG Emissions	44.6	0	45	tons CO_2^e
Annual Energy Use	518	133	385	MBtu
Lifetime of Technology			12	Years
Projected Lifetime GHG Savings			536	tons CO_2^e
Projected Lifetime Energy Savings			4,624	MBtu
Lifetime GHG Savings per TIGGER $			0.2	lbs CO_2^e
Lifetime Energy Savings per TIGGER $			925	Btu

Figure 5-5

Annual Energy Use for VIA Electric Bus Project

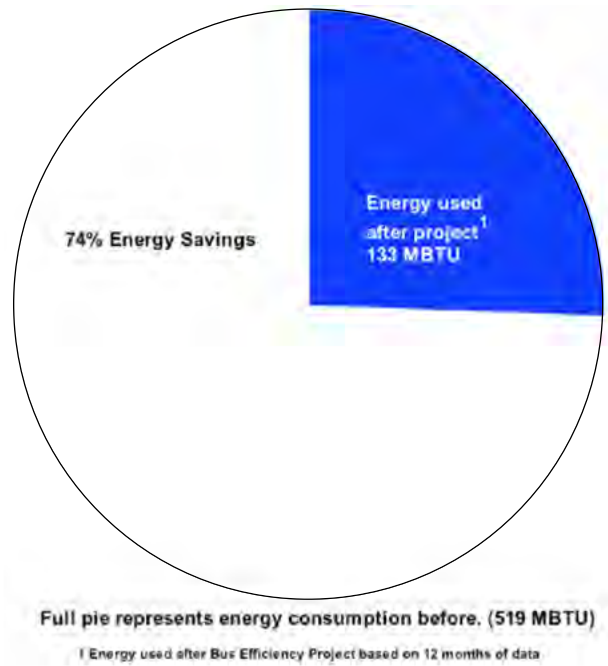

Figure 5-6 shows the monthly fuel economy for the baseline and electric buses in miles per DGE.[14] The electric buses have an average fuel economy that is 4 times higher than that of the baseline diesel buses. This is estimated to have saved the agency more than $8,000 in fuel costs for the first year in service. During the early operation, the electric buses were operated fewer miles than typical buses were. As the agency becomes more familiar with the buses, the usage is expected to increase and will result in even more fuel cost savings.

[14] Calculations for converting kWh use to diesel gallon equivalent were based on 128,450 Btu/gallon of diesel fuel and 3,414 Btu/kWh for electricity.

Figure 5-6

Monthly Average Fuel Economy for VIA Electric and Diesel Buses

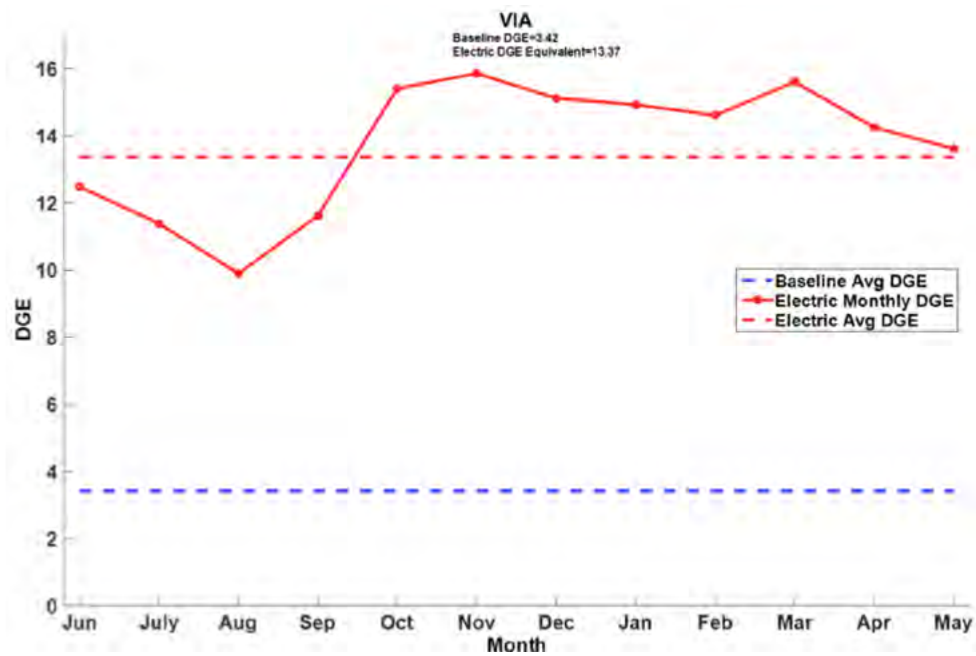

Table 5-7 summarizes the costs for the new electric and baseline diesel buses at VIA. The maintenance data for the diesel baseline buses included a full year of operation. Maintenance data for the electric buses were only available for a 6-month period. NREL used the maintenance data and mileage for that 6-month period to calculate a per-mile cost and then estimated the total maintenance cost for the full one year of service. The maintenance costs per mile for the electric buses were 53% lower than that of the diesel buses. As expected, parts costs are low because they are covered under warranty. For some new-technology bus projects, the manufacturer provides on-site support that is not reflected in the agency work orders. There were no records of scheduled services in the data set provided, only unscheduled maintenance.

There were some early bus-related issues with the doors and air conditioning during the start-up of operation for the buses. These types of problems can occur with any new bus order and are typically solved within the break-in period. Costs are expected to drop as these issues get resolved. VIA provided maintenance records with a level of detail that allowed NREL to categorize the repairs into scheduled, bus-related, and propulsion-related repairs. The electric buses had issues with the charging system and batteries. The costs were entirely for labor because the parts were supplied under warranty.

Table 5-7

Summary of Operational Costs for VIA Electric Bus Project

VIA	Electric	Baseline
Total Miles (maintenance data period)	9,090	153,003
Parts Cost	$734.76	$34,566.87
Labor Cost	$1,081.26	$29,944.59
Total Maintenance Cost	$1,816.02	$64,511.46
Maintenance Cost per Mile	$0.20	$0.42
Scheduled Maintenance Cost	$0.00	$9,014.00
Scheduled Maintenance Cost per Mile	$0.00	$0.06
Unscheduled Maintenance Cost	$1,816.02	$55,497.46
Unscheduled Maintenance Cost per Mile	$0.20	$0.36
Propulsion-Related Unscheduled Maintenance Costs	$98.65	$24,354.05
Propulsion-Related Unscheduled Maintenance Costs per Mile	$0.01	$0.16
Total Miles (fuel data period)	13,809	153,003
Fuel Economy (mpg)	13.37	3.42
Total Fuel Used (kWh/gal)	38,849.9	44,677.0
Fuel Cost (at 0.12 per kWh and $3.21 per gallon)	$4,661.99	$143,608.42
Fuel Cost per Mile	$0.34	$0.94
Total Cost per Mile	**$0.71**	**$1.36**

Using the mileage of the electric buses as the baseline, the operational cost difference is summarized in Table 5-8. During the first year of operation the electric buses saved more than $8,000 in fuel costs and $3,000 in maintenance costs.

Table 5-8

Operational Cost Differences for VIA Electric Bus Project

VIA	Electric	Baseline	Difference
Total Maintenance Cost	$2,758.65	$5,822.19	$3,063.54
Total Fuel Cost	$4,661.99	$12,960.73	$8,298.75
Total Cost	$7,420.64	$18,782.93	$11,362.29

APPENDIX

Calculation Methodology and Assumptions

Energy Use and GHG Emissions Calculations

TIGGER grantees reported approximately one year of data prior to project implementation and one year of data following the project completion. For building efficiency and renewable energy projects, data were collected from monthly energy company invoices. NREL tabulated total energy use before and after project completion and calculated the annual total savings in both kWh and MBtu. For projects that had not completed a full year of operation, NREL used the data provided to estimate the total savings for a full year. Building efficiency projects that resulted in heating fuel reductions could claim GHG emissions reductions as well as energy savings. For these projects, NREL calculated total fuel (natural gas, heating oil) used before and after project implementation and used conversion factors to calculate estimated GHG emissions savings. The list of conversion factors originally was developed for grantees to use during the application process when submitting proposals for the TIGGER Program. The list of all conversion factors is provided in Table A-1.

To calculate projected lifetime energy and GHG emissions savings, NREL used the total savings for the first year and the estimated lifetime of the technology. For solar technology, NREL used the estimated lifetime recommended by the specific solar panel manufacturer. In some cases, this lifetime was different than what was originally proposed. NREL used several modeling tools to verify projected performance results. The System Advisor Model[15] predicts performance and cost estimates for grid-connected power projects based on installation and operating costs and system design parameters that are specified as user inputs to the model. NREL's PVWatts was used for many of the PV projects to estimate the lifetime energy production and obtain the efficiency of each system. PVWatts is a Web application used to estimate the electricity production of a grid-connected roof- or ground-mounted PV system based on a few simple inputs that allow homeowners, installers, manufacturers, and researchers to easily gauge the performance of hypothetical PV systems that use crystalline modules. A normalized degradation factor of 0.5% was applied to all PV systems over the expected lifetime beginning in the second year of operation.

For bus efficiency projects, two sets of individual fueling records for each applicable bus were provided: one year of baseline fueling records for buses that were

[15] https://sam.nrel.gov/

replaced with buses funded through TIGGER and one year of fueling records for the new buses procured under the program. In a few cases, data for the replaced buses were not available because the buses were not being used. For these projects, the agencies provided data for buses of the same type and size. For the bus retrofit projects, grantees provided fueling records from one year prior to and one year after the installation of the new system on the bus. These records were used to calculate individual fuel economy values for each bus, the monthly average fuel economy for the TIGGER and baseline buses, and an overall average fuel economy for the entire data period for each bus group. Erroneous fueling records were removed from the data set. These erroneous records were most often due to inaccurate odometer readings or missing fuel records. Many of the grantees provided the individual fueling records requested. Some projects only reported monthly total fuel and miles for each bus. For many projects, the older buses that were being replaced accumulated much fewer miles because of low reliability. A comparison of actual fuel used would skew the results to favor the lower-use buses. To fairly calculate energy use and GHG emissions, NREL used the average fuel economy for each bus group and normalized for the mileage of the new buses.

Table A-1

Conversion Factors Used in Calculating Energy and GHG Emissions

Fuel or Energy Type	Units	Btu/unit	lb CO_2/unit
Diesel fuel	gal	128,450	22.1447
Gasoline	gal	116090	19.6658
E10 Ethanol	gal	112,114	16.9935
E85 Ethanol	gal	82,294	13.6669
E100 Ethanol	gal	76,330	12.6083
Compressed Natural Gas	scf	930	0.1194
Compressed Natural Gas	therms	100,000	12.8378
Compressed Natural Gas	gge	114,717	14.7272
Compressed Natural Gas	lb	20,268	2.6020
Liquefied Natural Gas	gal	74720	10.5497
Liquefied Petroleum Gas / Propane	gal	84,950	12.7467
B2 Biodiesel	gal	128,272	22.1235
B5 Biodiesel	gal	128,005	22.0916
B10 Biodiesel	gal	127560	22.0385
B20 Biodiesel	gal	126,670	21.9324
B50 Biodiesel	gal	124,000	21.6139
B80 Biodiesel	gal	121,330	21.2955
B100 Biodiesel	gal	119550	21.0832
Hydrogen	kg	113,724	0.0000
Hydrogen	scf	289	0.0000
Dimethyl Ether	gal	68,930	10.6251
Heating Oil	gal	128450	22.1447
Kerosene	gal	128,450	22.1447
M100 Methanol	gal	57,250	9.1123
Electricity	kWh	3,414	N/A

Cost Calculations

Reported costs for energy and fuel varied from one location to another and tended to increase over time. For the individual project summaries, NREL used actual costs per unit when reported by the agencies for the year after a project was completed. NREL used actual maintenance costs to determine cost per mile and then normalized the estimated total cost by the mileage of the new buses.

Aggregated results for the program were normalized by using average utility and fuel costs from the U.S. Energy Information Administration (EIA). For consistency and to facilitate comparison from year to year, NREL has set the monetary values to that of calendar year 2011. For the building efficiency projects, the average cost per unit (kWh, therm, gallon) for the year after implementation was used to estimate the total cost of energy before and after project implementation. For the bus efficiency projects, the average fuel cost per gallon for the year after implementation was used to normalize the data.

This report provides cost savings based on the first year of results for the projects that have been completed and provided a full data set. For projects that reduced fuel use, the MBtu savings was converted to gallons of fuel saved (bus efficiency projects) or therms of natural gas saved (facility efficiency projects). Energy savings projects were converted to kWh of electricity saved. The costs were calculated based on the average 2011 U.S. energy prices from EIA data as follows:

- Electricity cost per kWh: $0.099
- Diesel cost per gallon: $3.791
- Gasoline cost per gallon: $3.552
- Natural gas cost per 1,000 standard cubic foot (commercial rate): $8.16.

The calculations account for energy or fuel savings and maintenance or operating cost savings associated with the technologies provided by the agencies.

Operational Cost Calculations

TIGGER grantees also were required to provide data on the difference in operational costs and related expenses for each project. This information was most often provided as maintenance costs for parts and/or labor. For building efficiency projects, maintenance for most of the new technologies—such as solar systems or wind turbines—is covered under a warranty and does not result in out-of-pocket costs to the agency. NREL reports any cost for warranty or maintenance on these projects as provided by the agencies.

For bus projects, NREL requested detailed maintenance records for the baseline and new buses. The level of detail provided by each agency varied from monthly totals by bus to actual detailed work orders on each maintenance action. For the more detailed data, NREL was able to separate the maintenance by system as well as to report scheduled and unscheduled maintenance separately. NREL used the actual data to calculate cost per mile for each bus type. The actual costs are provided for each project. As with the energy use and GHG emissions calculations, NREL used the mileage of the new buses to normalize the comparison of costs between the agency's old buses and the new TIGGER buses. The results are summarized for each project in tabular form. Projections can be made on total lifetime savings based on the estimated useful life provided by the agency. However, these projections should be used cautiously, as they assume the same savings per year without taking into account any degradation of performance over time.

NREL quantified GHG emission reductions (CO_2e) using the Social Cost of Carbon (SCC) estimates published by the Environmental Protection Agency. The SCC uses a combination of three models—DICE, PAGE, FUND—to develop the estimated cost of impacts per ton of CO_2 emissions. The models assess numerous environmental factors such as agricultural productivity, human health, and property damage impacted by CO_2 emissions. Inputs such as sea-level rise, carbon cycle, temperature rise, and ecosystem carbon saturation are used to assess the cost of damages with the increase or decrease of carbon emissions.[16] A wide range of costs are included in the SCC factors, using 2011 dollars and different discount rates as shown in Table A-2. These costs are used in this report to quantify the social benefits, or avoided costs, of GHG emissions reductions achieved by the TIGGER projects.

Table A-2

Social Cost of CO_2, 2015–2050[a] (in 2011 $)

Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th percentile
2015	$12	$39	$61	$116
2020	$13	$46	$68	$137
2025	$15	$50	$74	$153
2030	$17	$55	$80	$170
2035	$20	$60	$85	$187
2040	$22	$65	$92	$204
2045	$26	$70	$98	$220
2050	$28	$76	$104	$235

[a] The SCC values are dollar-year and emissions-year specific.

[16] http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf, http://www.epa.gov/climatechange/EPAactivities/economics/scc.html/

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