Sustainability Strategies to Minimize the Carbon Footprint for Connecticut Bus Operations

February 2018

A Report By

The Connecticut Academy of Science and Engineering

For

Connecticut Department of Transportation

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Origin of Inquiry:	Connecticut Department of Transportation
Date Inquiry Established:	October 31, 2016
Date Response Released:	February 9, 2018

This study was initiated at the request of the Connecticut Department of Transportation on October 31, 2016. The project was conducted by an Academy Study Committee with the support of faculty from the Connecticut Transportation Institute, University of Connecticut, with Nicholas Lownes, PhD, serving as Study Manager. The content of this report lies within the province of the Academy's Transportation Systems Technical Board. The report has been reviewed on behalf of the Academy's Council by Academy Members John N. Ivan, PhD, and Gary W. Yohe, PhD, and external reviewer Kenneth Gillingham, PhD. Martha Sherman, the Academy's Managing Editor, edited the report. The report is hereby released with the approval of the Academy Council.

Richard H. Strauss
Executive Director

Disclaimer

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1. Report No. CT-2304-F-17-9	**2. Government Accession No.**	**3. Recipients Catalog No.**
4. Title and Subtitle Sustainability Strategies to Minimize the Carbon Footprint for Connecticut Bus Operations		**5. Report Date** February 2018 **6. Performing Organization Code** SPR-2304
7. Author(s): Nicholas Lownes, Jeffrey Cohen, David Pines, Adrita Islam, and Donald Larsen		**8. Performing Organization Report No.** CT-2304-F-17-9
9. Performing Organization Name and Address Connecticut Academy of Science & Engineering, 805 Brook Street, Building 4-CERC, Rocky Hill, CT 06067-3405		**10. Work Unit No. (TRIS)** **11. Contract or Grant No.** CT Study No. SPR-2304 **13. Type of Report and Period Covered** Final Report, October 2016 – February 2018
12. Sponsoring Agency Name and Address Connecticut Department of Transportation, 2800 Berlin Turnpike, Newington, CT 06131-7546		**14. Sponsoring Agency Code** SPR-2304
15. Supplementary Notes Partners: Connecticut Department of Transportation, and the Connecticut Department of Energy and Environmental Protection; Connecticut Academy of Science and Engineering; and the Connecticut Transportation Institute, UConn. Prepared in cooperation with USDOT, Federal Highway Administration.		

16. Abstract: The objective of this study is to identify a strategy to minimize the carbon footprint for CTDOT-contracted bus operations in Connecticut, bus systems owned by CTDOT and branded as CT*transit*, including resulting benefits and challenges. The economic value of investments necessary to achieve strategy goals in terms of initial capital costs, ongoing operating costs including life-cycle costs, and overall benefits/savings were considered and presented in an easy-to-read and comprehensible format. The carbon footprint was calculated/estimated for all CTDOT-contracted bus operations. This analysis looked at the carbon footprint associated with day-to-day operations of equipment and facilities.

The recommendations are consolidated into four categories: rolling stock, facilities, resilience, and monitoring. The primary conclusion is as follows: the most effective strategy for minimizing the carbon footprint of CTDOT-contracted bus operations is to reduce greenhouse gas (GHG) emissions through the replacement of the existing fleet with battery electric buses over the next 12 years. Battery electric buses outperform existing and alternative fuel technologies with respect to the reduction of GHG emissions and provide the additional benefit of having the second lowest expected life-cycle cost of alternative fuel technologies. Additionally, CTDOT can effect further reductions by adopting recommendations and standards for retrofitting existing bus facilities and constructing new bus facilities that are designed to reduce GHG emissions and energy consumption. In adopting these strategies, CTDOT should consider the resilience of the fleet and its operations, and institute a practice of monitoring, and modifying as needed, the assumptions of this analysis and updating these strategies accordingly.

17. Key Words Carbon footprint, greenhouse gas emissions, greenhouse gas inventory, social cost of carbon, life-cycle cost analysis, battery electric buses, alternative fuel buses, hydrogen fuel cell buses, and hybrid diesel-electric buses		**18. Distribution Statement** No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (Of this report) Unclassified	**20. Security Classif. (Of this page)** Unclassified	**21. No. of Pages** 165	**20. Price** N/A
Form DOT F 1700.7 (8-72)	**Reproduction of completed page authorized**		

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GLOSSARY

APTA	American Public Transportation Association
BEB	Battery Electric Bus
BCA	Benefit-Cost Analysis; alternatively denoted as Cost-Benefit Analysis
CH_4	Methane
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide Equivalent
COBRA	EPA's Co-Benefits Risk Assessment Screening Model
DEEP	Connecticut Department of Energy and Environmental Protection
EPA	US Environmental Protection Agency
FCB	Hydrogen Fuel Cell Bus
FTA	Federal Transit Administration
GHG	Greenhouse Gas(es)
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
LBT	Long Beach Transit
LCCA	Life-Cycle Cost Analyses
LDV	Light-Duty Vehicle
MT	Metric Ton
MMT	Million Metric Tons
MWh	Megawatt Hours
N_2O	Nitrous Oxide
NREL	National Renewable Energy Laboratory
NYMTA	New York Metropolitan Transit Authority
TCRP	Transit Cooperative Research Program
USDOE	US Department of Energy
VMT	Vehicle Miles Traveled
VTA	Martha's Vineyard Transit Authority
VTPI	Victoria Transport Policy Institute

EXECUTIVE SUMMARY

This study was conducted for the Connecticut Department of Transportation (CTDOT) by the Connecticut Academy of Science and Engineering (CASE) to identify a strategy to achieve a vision of a pathway to minimize the carbon footprint for CTDOT-contracted bus operations in Connecticut (bus systems owned by CTDOT and branded as CT*transit*), including resulting benefits and challenges. The economic value of investments necessary to achieve strategy goals in terms of initial capital costs, ongoing operating costs including life-cycle costs, and overall benefits/savings were considered and utilized to estimate the efficiency of the identified strategies. The carbon footprint was calculated/estimated for all CTDOT-contracted bus operations. Additionally, this analysis looked at the carbon footprint associated with day-to-day operations of bus facilities and equipment. The study did not address carbon emissions associated with the supply chain or rail operations.

OVERVIEW

Study research methods included the following:

- a literature review, supported by other information-gathering methods, to identify strategies developed by other transit agencies, as well as other industries, as appropriate, to reduce greenhouse gas emissions
- review methods for applicability for use by CTDOT to measure progress for the reduction of carbon footprint
- conduct a calculation/estimation of the carbon footprint for all CTDOT-contracted bus operations. The analysis included an inventory of the carbon footprint associated with day-to-day operations of facilities and equipment
- review the findings and recommendations from the 2014 CASE study on *Energy Efficiency and Reliability Solutions for Rail Operations and Facilities* for applicability
- interviews, surveys, and guest presentations to the CASE Study Committee to inform the study findings and recommendations

The study report includes the following sections: Background, Literature Synthesis, Public Transportation in Connecticut, Economic Cost Analysis Overview, Scenario Development and Analysis, Recommendations, and References. Appendices include a Bibliography by Topic for References Reviewed (Not Cited), Models for Estimating Transportation Emissions, Examples of Transit System Sustainability Plans, Performance Metrics Examples, Sample Battery Electric Bus Procurement Guidelines, Battery Electric Bus Deployment Examples, APTA's Energy Saving Strategies for Transit Facilities, Output from Baseline Scenarios, and Study Committee Meetings and Guest Speakers.

BRIEF STATEMENT OF PRIMARY CONCLUSION

The most effective strategy for minimizing the carbon footprint of CTDOT-contracted bus operations is to reduce greenhouse gas (GHG) emissions through the replacement of the existing fleet with battery electric buses over the next 12 years. Battery electric buses outperform existing and alternative fuel technologies with respect to the reduction of GHG emissions and provide the additional benefit of having the second lowest expected life-cycle cost of alternative fuel technologies. Additionally, CTDOT can effect further reductions by adopting recommendations and standards for retrofitting existing bus facilities and constructing new bus facilities that are designed to reduce GHG emissions and energy consumption. In adopting these strategies, CTDOT should consider the resilience of the fleet and its operations, and institute a practice of monitoring, and modifying as needed, the assumptions of this analysis and updating these strategies accordingly.

RECOMMENDATIONS

The eight transit divisions under the CT*transit* brand operate a fleet of 549 buses on behalf of CTDOT (CTDOT-contracted bus operations). CTDOT owns the rolling stock and facilities in three of the CT*transit* divisions (Hartford, New Haven, and Stamford), and only the rolling stock in the remaining divisions (Bristol, Meriden, New Britain, Wallingford, and Waterbury). For the CT*transit* bus fleet and the three operating and maintenance facilities CTDOT owns, the annual greenhouse gas (GHG) emissions are estimated to be 0.07 $MMTCO_{2e}$, a small fraction of the roughly 15 $MMTCO_{2e}$ (million metric tons carbon dioxide equivalent) emitted by the transportation sector in Connecticut or the 8 $MMTCO_{2e}$ from light-duty vehicles statewide.

Of the CT*transit* emissions, 0.05 $MMTCO_{2e}$ is from bus fleet (mobile) emissions, with the remainder split between purchased gases at facilities at 0.015 $MMTCO_{2e}$, and 0.0025 $MMTCO_{2e}$ each for both electricity consumption and refrigeration. This study concludes that the most important strategies that CT*transit* can deploy to control GHG emission reduction in Connecticut are associated with the rolling stock, though other strategies were considered. The recommendations are consolidated into four categories: rolling stock, facilities, resilience, and monitoring.

Additionally, the source(s) of electricity as fuel for the battery electric buses must be considered, in order to attain maximum GHG emission reduction and to justify the initial capital investments for a battery electric bus fleet. The maximum GHG emission reduction will be achieved only if the state meets its Class I renewable energy source goals for generating electricity.

RECOMMENDATION #1: ROLLING STOCK

Reducing GHG emissions from the CTtransit rolling stock was found to be the most impactful strategy. Nine baseline scenarios, the year 2050 GHG profile, and sensitivity analyses were conducted and confirm that battery electric buses are the best fleet option to reduce public transit's GHG emissions and contribute to Connecticut's GHG emission reduction targets. The scenarios presented and analyses conducted were based on assumptions presented in Chapter 5. Battery electric buses were shown to have the second lowest life-cycle cost of the alternative fuel technologies, with hybrid diesel-electric buses comparatively having a slighly lower life-cycle cost of between 0.2% - 6%. This result holds true under all assumptions in the baseline and sensitivity analyses.

Supporting this recommendation further, the local pollutant reduction from eliminating diesel buses from the CT*transit* fleet has a combined health benefit estimated at $2 million - $9 million in the year 2030, not including intermediate years. These benefits are in addition to the social cost of carbon benefits associated with GHG reduction.

RECOMMENDATION #2: FACILITIES

As reported, CT*transit* facilities produce the least significant proportion of CT*transit* GHG emissions, though there are several strategies that can help to reduce this further.

- High Performance Building Standards: CTDOT advised that public transit's operating and maintenance facilities are exempt from the state's high-performance building standards as defined in CGS Chapter 298 §16a-38k(a), with additional guidance from the Connecticut Department of Administrative Services: Capital Projects High Performance Buildings Guidelines, as follows:

  > *… to adopt state building construction standards that are consistent with or exceed the silver building rating of the Leadership in Energy and Environmental Design's rating system for new commercial construction and major renovation projects, as established by the United States Green Building Council, including energy standards that exceed those set forth in the 2004 edition of the American Society of Heating, Ventilating and Air Conditioning Engineers (ASHRAE) Standard 90.1 by not less than twenty per cent, or an equivalent standard, including, but not limited to, a two-globe rating in the Green Globes USA design program, and thereafter update such regulations as the Commissioner of Energy and Environmental Protection deems necessary.*

  CTDOT further advised that energy efficient options would be used whenever possible in the construction of public transit facilities.

  Therefore, it is suggested that the state's high performance buildings guidelines, including LEED or Green Globes USA design program specifications, be used as a best practice whenever possible for the construction of public transit facilities, including the new CTtransit Hartford Division Facility. Additionally, internationally recognized standards for achieving near-zero energy consumption and measurable carbon reduction in facilities, such as Passive House, should be considered to further reduce GHG emissions.

- Virtual Net Metering: CTDOT should research the potential and possibility of deploying behind-the-meter installations of renewable energy and the advantages of virtual net metering, and if benefits are determined, include these as part of facilities planning, maintenance and the rehabilitation of existing facilities. According to DEEP, virtual net metering allows state and municipal customers with United Illuminating and/or Eversource who "…*operate behind-the-meter generation (Customer Host) to assign surplus production from their generator to other metered accounts (Beneficial Accounts) that are not physically connected to the Customer Host's generator*." (DEEP website) Energize Connecticut, an initiative to help homeowners and businesses optimize energy efficiency and clean energy improvements, provides additional guidance for state customers to encourage the installation of Class I and Class III distributed generation (Energize CT website).

- Other Options: CTDOT should explore other ways to reduce the GHG emissions, including the recommendations in a 2014 CASE study conducted for CTDOT, *Energy Efficiency and Reliability Solutions for Rail Operations and Facilities* (CASE website), as applicable to bus operating and maintenance facilities. These recommendations included conducting an energy audit, transitioning to LED lighting, utilizing radiant floor heating (potentially reducing methane usage, which is purchased by CT*transit* primarily for heating), and use of solar PV systems in conjunction with virtual net metering.

RECOMMENDATION #3: RESILIENCE

System resilience is a potential negative consequence from converting to an entirely battery electric bus fleet. If there is an extended power outage, CT*transit* might not be able to maintain basic operations or assist in an emergency response for areas that lack electricity. While specific recommendations to address this challenge are beyond the scope of this study, CTDOT should review the 2017 TCRP report, *Improving the Resilience of Transit Systems Threatened by Natural Disasters Volumes 1, 2, and 3: A Guide*. Additionally, the following are important considerations that must be included as part of the GHG reduction strategy:

- Emergency Scenarios: What emergency scenarios and duty cycle should the CT*transit* fleet be able to withstand and/or assist with? This decision will frame the minimum amount of operations and rolling stock diversity that need to be maintained for an emergency during which no electrical recharge is available.
- Leveraging Existing Resources: What existing energy resources can CTDOT leverage in an emergency, and for what duration and capacity (# of diesel or hybrid diesel-electric buses)? Such resources may include the state's reserve diesel fuel that currently provides several days' worth of operations. This fuel could be used to power a mixed fleet of diesel/hybrid diesel-electric buses or generators in an emergency to charge the battery electric bus fleet. Emergency operations could also incorporate use of existing facility power plants such as combined cycle fuel cell or micro turbines.
- Other Benefits: Consider the potential benefits of battery electric buses and hybrid diesel-electric buses, such as use of the buses to power emergency shelters, medical facilities or other critical response infrastructure during power outages.

RECOMMENDATION #4: MONITORING

Given the uncertain nature of predictions through 2030 and 2050, it is almost certain that the assumptions underlying this analysis will need to be modified to provide an accurate portrayal of future conditions. To mitigate this situation, CTDOT should adopt a strategy of revisiting this study's analysis on a periodic basis to update the assumptions and/or perform additional sensitivity analyses.

The following supports this recommendation:

- Conservative assumptions for electricity production (percent of Class I renewables), light- duty vehicle fleet electrification, and battery electric bus price reductions were used whenever possible. If actual numbers are more favorable than the conservative assumptions used for this study's analysis and/or the price of battery electric buses declines more significantly than assumed in the analysis, the results would further support the recommendation to convert to a battery electric bus fleet.
- The baseline scenario analysis assumed a bus fleet turnover cycle that follows the practice used by CTDOT over the past 12 years. CTDOT should evaluate whether an optimized fleet replacement schedule could reduce life-cycle costs and result in even greater GHG reductions.
- To facilitate CTDOT's periodic review and update of strategies to reduce GHG emissions, the methodology used for this study's analysis is available as a tool for the department's use. The Greenhouse Gas Inventory and Life-cycle Cost Tool will be accessible by March 1, 2018, to CTDOT staff via the University of Connecticut's t-HUB: The Public Transportation Data Hub of Connecticut.

  The Greenhouse Gas Inventory and Life-cycle Tool should be used to update assumptions and/or perform additional sensitivity analyses. However, the tool was not designed to optimize a bus fleet turnover strategy. Alternative turnover strategies could be evaluated and updated from a set of feasible alternatives, such as a delayed transition to battery electric buses, a mixed fuel technology fleet, or a more uniform turnover of vehicles than the existing fleet turnover cycle.

  The Greenhouse Gas Inventory and Life-cycle Tool can also be utilized to input data based on future operating practices and policy developments. CTDOT should use the tool to inform transit-supportive legislation and policies, such as transit-oriented development and complete streets. The input data for this analysis can then be updated based on actual ridership, interest rates and discount rates, to provide an improved estimate of GHG emission reductions and expected life-cycle cost.

at fixed transit facilities, such as maintenance facilities. Indirect strategies are also important, including collaboration with local, regional and statewide authorities to coordinate transit system planning and transit-supportive development and land use policies. These strategies can lead to travel and residence location choices that are more compatible with GHG reduction than suburban, single family dwelling practices. A state can also choose suppliers of electricity that use a larger share of renewable power generation technologies, thereby addressing upstream carbon footprint contributions. Each of these strategies is discussed in further detail in Chapter 2. This report focuses on the direct strategic elements, though their compatibility with the indirect elements and their combined possible impacts were also considered.

As noted earlier, the economic value of investments necessary to achieve strategy goals in terms of initial capital costs, ongoing operating costs including life-cycle costs, and overall benefits/ savings were considered and utilized to estimate the efficiency of the identified strategies for this study.

1.4 ORGANIZATION OF REPORT

The following is an overview of the remaining chapters of this report:

- Chapter 2 presents a comprehensive literature synthesis of relevant topics.
- Chapter 3 details the existing GHG conditions in Connecticut and provides an estimate of the GHG inventory associated with Connecticut bus operations used as the baseline value against which strategies for GHG reductions will be compared.
- Chapter 4 reviews several cost analysis approaches and identifies life-cycle cost analysis as the preferred approach in the context of GHGs. This chapter considers issues related to the life-cycle cost analysis approach and offers an approach to consider health costs.
- Chapter 5 provides detailed results from the GHG Inventory and life-cycle cost analysis.
- Chapter 6 includes a discussion of the specific recommendations based on the results obtained through the GHG Inventory and life-cycle cost analysis.
- Chapter 7 includes the references cited, followed by Appendices A through I.

4. Reduce carbon-intensive travel activity: reduce on-road VMT by reducing the need for travel, increasing vehicle occupancies, and shifting travel to more energy-efficient options that generate fewer GHG emissions (Cambridge Systematics[c] 2010, p. ES3-ES5).

Since fossil fuel combustion is the overwhelming source of transportation GHGs, it is important to understand the production of GHGs from various fuel sources. Table 2.2 includes the carbon content by weight per unit for use of selected fuels.

TABLE 2.2: SELECTED CONVERSION FACTORS USED IN CALCULATING ENERGY AND GHG EMISSIONS
(SOURCE: EUDY, CATON, POST 2016, P. 30)

Fuel or Energy Type	Units	BTU/Unit	lb CO_2/Unit
B10 Biodiesel	gal	127,560	22.0385
Compressed Natural Gas	gge[a]	114,717	14.7272
Diesel Fuel	gal	128,450	22.1447
E10 Ethanol	gal	112,114	16.9935
Electricity	kWh	3,414	N/A
Gasoline	gal	116,090	19.6658
Hydrogen	kg	113,724	0.0000
Liquid Petroleum Gas/Propane	gal	84,950	12.7467
[a]gge = gasoline gallon equivalent and is defined as the amount of alternative fuel required to equal the energy content of one liquid gallon of gasoline			

Public transportation plays an important role in reducing the nation's energy use and GHG emissions (Neff and Dickens 2015, p. 21). Public transit is an avenue to address Strategy 4 — reduce carbon-intensive travel activity — included in the referenced USDOT report to Congress by offering an alternative that is not only more efficient but also able to reduce on-road VMT. The Federal Highway Administration (FHWA) states in their *Reference Sourcebook for Reducing Greenhouse Gas Emissions from Transportation Sources* that *"transit systems (which include bus, light rail, heavy rail, commuter rail, and paratransit) can generally transport people more efficiently, with fewer GHG emissions than cars, particularly in comparison to single-occupancy vehicle trips."(*FHWA Reference Sourcebook 2016, p. 5) It should be noted that these assertions hold when bus occupancy exceeds ridership thresholds — in the case of a diesel bus operating at a fuel efficiency of four miles per gallon versus a single-occupant gasoline-powered vehicle operating at 25 miles per gallon, the CO_2 emissions per passenger are equivalent if there are seven passengers on the bus[7]. Fewer passengers result in higher per passenger emissions from the bus, with more than seven passengers resulting in lower emissions per passenger. For high ridership corridors, the carbon savings can be substantial. American Public Transportation Association (APTA) reinforces this idea with their suggestion that even the greenest transit system will not be an effective means of mitigating environmental impacts and GHG emissions if it is not used (APTA[d] 2011).

7 For the bus example, 25/4 gallons of fuel will be required to travel an equivalent distance to the example passenger vehicle. For a 100-mile trip, this would require 25 gallons of diesel fuel generating 22.1 lb CO_2 per gallon, or 552.5 lb CO_2. The single occupant passenger car would consume 4 gallons of fuel at 19.7 lb CO_2 per gallon over the same distance, or 78.8 lb CO_2. This implies that the bus would need 552.5/78.8 = 7.0 passengers on board during the trip to have an equivalent amount of emissions on a per-passenger basis.