CONNECTICUT
GREEN BANK

MOVING FORWARD WITH GREEN ENERGY

Market Potential Assessment for Alternative Fuel Vehicles in Connecticut

September 2016

The Connecticut Green Bank is the nation's first green bank.

We're creating a thriving marketplace to accelerate green energy adoption in Connecticut by making clean energy financing accessible and affordable for homeowners, businesses and institutions. Our mission is to accelerate clean energy deployment within the state by leveraging the limited public funds we receive to attract multiples of private capital. In doing this, we seek to achieve economic prosperity, create jobs, promote energy security and address climate change.

The Connecticut Green Bank would like to thank:

American Council on Renewable Energy (ACORE)

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FOREWORD

The Future of Clean Energy is Mobility

In 1896, industrialist Albert Augustus Pope founded the Columbia Electric Vehicle Company in Hartford, presenting an innovative glimpse into the future. Pope is credited with being the first automaker to use mass production practices.

For much of the 20th century however, fossil fuel power dominated automotive technology and movement. Today, a different movement is quietly underway – one toward the use of alternative fuels that minimize air pollution and lower fuel costs. These developments offer the promise of making mobility cleaner and cheaper.

In October of 2013, the governors of eight states including Connecticut signed a memorandum of understanding committing their states to coordinated action to implement zero-emission vehicle programs supporting battery electric, plug-in hybrid electric, and fuel cell vehicles. The states are committed to deploy at least 3.3 million such vehicles collectively by 2025, with the fueling infrastructure to support them.

This report examines the market potential of various types of alternative fuels in Connecticut across different vehicle segments using four criteria: near-term market feasibility; environmental performance; cost-effectiveness; and local economic benefits. The conclusion is that the best near-term opportunity for the Green Bank to catalyze market activity is with passenger plug-in electric vehicles.

Through our work with residential solar PV, we have succeeded in scaling up market activity by working on both sides of the deal to lower installation costs and reduce the customer's need for public subsidies. The Connecticut Green Bank now plans to apply this expertise and approach to the alternative fuel vehicles (AFV) market, helping to mainstream their adoption, integrate them into fleets, and support them with infrastructure deployment.

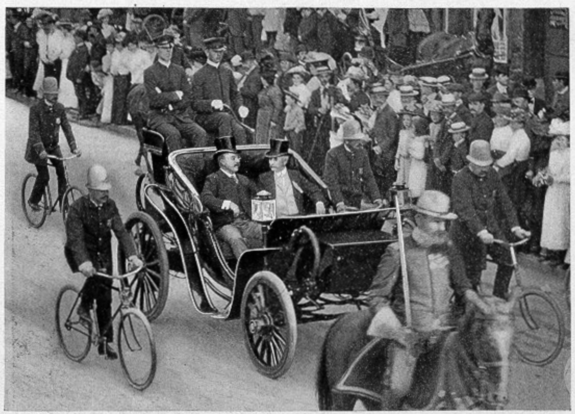
Our successes with solar PV will be useful in creating reproducible solutions for the complimentary EV market. Charging an EV with the help of solar PV is by far the most affordable refueling option for the end user of light-duty vehicles, which represent 95% of the state's vehicle stock.

Through public education and outreach, partnerships with manufacturers and other innovative approaches, the Green Bank's vision is to drive activity around zero-emission alternative fuel vehicles and scale up their adoption – while also reducing the need for public intervention over time through more private investment.

We thank all our stakeholders for their strong support of the Connecticut Green Bank as we continue working to make clean energy more affordable and accessible to customers.

In an example of the first presidential motorcade, President Theodore Roosevelt rode through the streets of Hartford in August 22, 1902. The crowd was likely electrified – and so too was the president's vehicle.

Photo credit: Warner Photo Company. "Theodore Roosevelt in an Electric Carriage, Hartford," 1902. Connecticut History Online, Connecticut Historical Society. http://collections.ctdigitalarchive.org/islandora/object/40002:17423



The President and Chairman Jacob L. Greene in an Electric Automobile.
The Police Squad are on Columbia Chainless Bicycles.

Contents

Executive Summary v

Introduction 9

Reducing Emissions From Transportation 10

Transportation Emissions In Connecticut 10

Alternative Fuel Options 15

Light-, Medium-, And Heavy-Duty Vehicles 15

Vehicle Miles Traveled 18

AFV Market Potential Assessment 18

Near-Term Market Feasibility Criterion 18

Environmental Performance Criterion 30

Cost Effectiveness Criterion 36

Local Economic Impact Criterion 43

Conclusion 47

Appendix A : Current Medium- And Heavy-Duty Vehicle Fleet In Connecticut 51

Appendix B : Calculation Explanations 52

Appendix C : Cost Effectiveness Assumptions 53

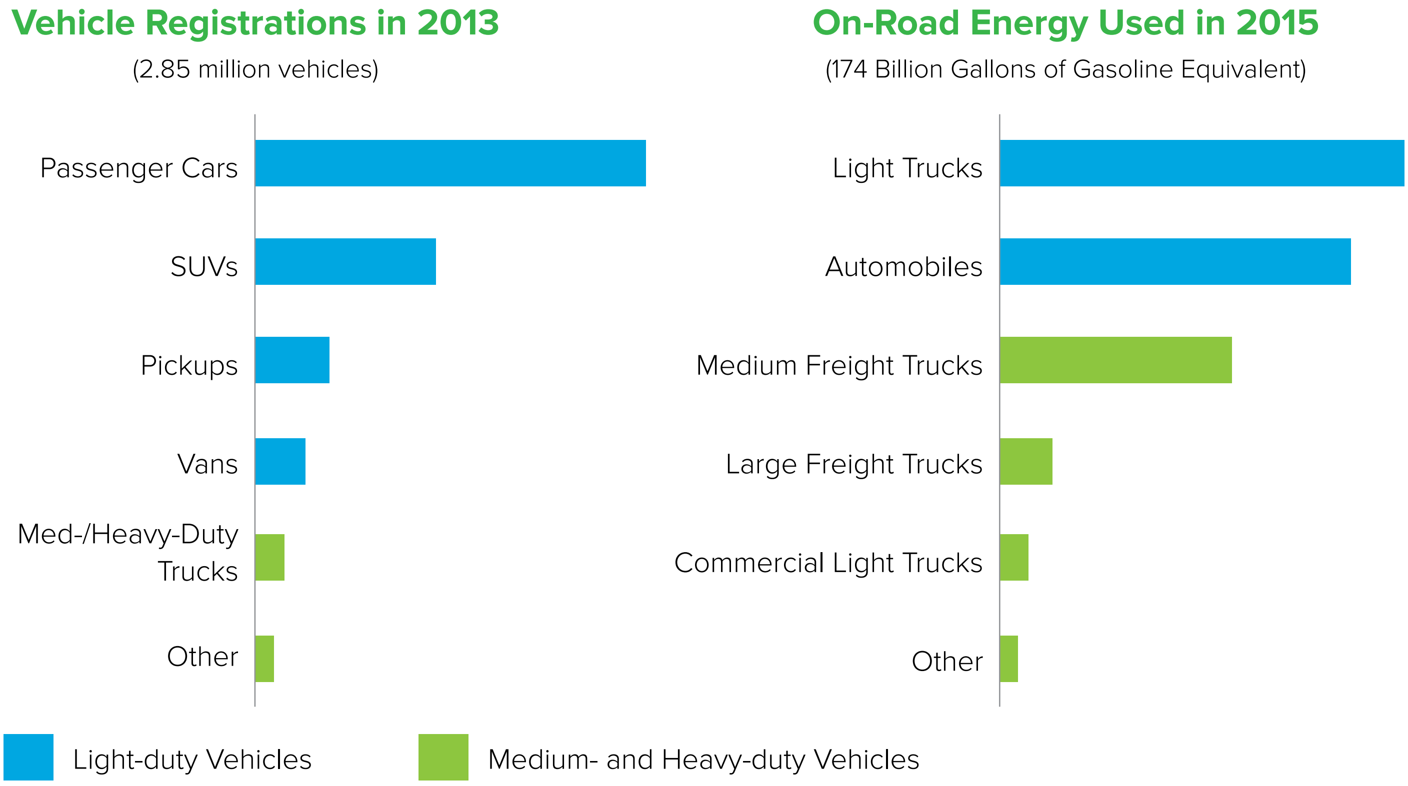
References 55

Executive Summary

The increased deployment of plug-in electric vehicles is the most promising approach to reduce emissions from Connecticut's transportation sector and to meet the state's energy and climate goals. The Connecticut Green Bank is in a unique position to help accelerate the deployment of these vehicles; the Green Bank has already worked with the private sector to engage Connecticut residents and businesses to improve building energy efficiency and accelerate the deployment of renewable energy through the use of innovative finance mechanisms. The Green Bank can now turn to transportation and explore new approaches to capturing the value of low-carbon fuels.

Transportation is the single largest source of emissions in the state, accounting for 40 percent of greenhouse gas emissions in 2014. The Global Warming Solutions Act of 2008 set a goal for the state to achieve an 80 percent reduction in greenhouse gas emission below 2001 levels by 2050, which will require steep reductions in emissions across all sectors of the economy, especially transportation. Achieving this goal would result in annual greenhouse gas emissions below 10 million metric tons of carbon dioxide equivalent. A recent analysis shows transportation emissions are expected to decrease only slightly through 2050 under a business as usual scenario, resulting in total emissions about three times above the state's 2050 goal.

Figure 1: Summary of Vehicle Registrations and Energy Use



This figure shows registrations and energy use by vehicle type. Blue indicates light-duty vehicles and green indicates medium- and heavy-duty vehicles.

Source: [1, 2]

Light-duty vehicles in Connecticut account for 95 percent of the state's vehicle stock and 70 percent of the state's on-road energy consumption (see **Figure 1**). Clearly, the greater deployment of alternative fuel vehicles, especially passenger vehicles, is essential for the state to have a higher likelihood of achieving its climate and clean air goals.

Connecticut's 2013 Comprehensive Energy Strategy highlights the need to increase market-based opportunities for clean fuels and clean vehicles. Accordingly, the Green Bank aims to leverage public funds to encourage greater private investment in clean alternative fuels for transportation (see **Box A**). In doing so, the Green Bank will foster increased use of cleaner, cheaper, and more reliable energy sources, while creating jobs and supporting local economic development. As a first step in this process, this report assesses the market potential for the use of alternative fuels in on-road vehicles in Connecticut using four criteria:

1. **Near-term market feasibility;**
2. **Environmental performance;**
3. **Cost-effectiveness; and**
4. **Local economic benefits.**

Under these criteria, the increased deployment of plug-in electric vehicles is the most promising approach for the state to achieve meaningful reductions in emissions from transportation (see **Table 1**). When considering current federal and state incentives, an electric vehicle powered by residential solar is the lowest cost option for Connecticut drivers. Hydrogen fuel cell vehicles are an attractive longer-term option if infrastructure is deployed and the costs of the fuel and vehicles decrease significantly.

Box A

Alternative Fuel Vehicles and Associated Infrastructure

Per Public Act 14-136, an amendment to C.G.S. §4a-59 defines "clean alternative fuel" as natural gas, propane, electricity, or hydrogen when used as a motor vehicle fuel. C.G.S. §14-212(5) defines "motor vehicle" as all vehicles used on the public highways. "Associated infrastructure" is defined by the Connecticut Green Bank as structures, machinery, and equipment necessary and integral to refuel an alternative fuel vehicle.

Plug-in electric vehicles have strong near-term market feasibility. Presently, these vehicles represent a fast-growing market in the light-duty segment and are expected to receive continued investment from automakers, government, and other private sector entities in the near term. The current policy framework in Connecticut is also supportive of electric vehicles; for example, the state follows the California Zero Emission Vehicle Program. The state has also put in place a sizeable vehicle incentive known as the Connecticut Hydrogen and Electric Automobile Purchase Rebate (CHEAPR) Program, which provides a rebate of up to $5,000 off the purchase price of a hydrogen fuel cell vehicle or up to $3,000 off a plug-in electric vehicle. Another important aspect of near-term viability is the presence of public fueling infrastructure; electric charging infrastructure is far more prevalent than fueling stations for other alternative fuels.

From an environmental perspective, electric drive vehicles powered by rechargeable batteries or hydrogen offer the greatest potential to reduce emissions from passenger vehicles. These reductions, however, are predicated on the electricity and hydrogen coming from low-carbon feedstocks. The Green Bank's existing programs to promote the increased deployment of renewable energy can help to address this need. Even when powered by the average electricity mix in the northeast, an electric vehicle has 55 percent fewer emissions than a gasoline vehicle.

Electricity also appears to be the most promising fuel for state economic growth for three reasons. First, the state has sizeable in-state power generation capacity that exceeds its demand, suggesting funds spent on electricity as a transportation fuel are likely to stay in the state's economy. Second, federal funds exist to support plug-in electric vehicles and charging infrastructure, which could lead to a net increase in state GDP. Third, today's plug-in electric vehicles offer lifetime cost savings over gasoline vehicles, providing additional discretionary funds for drivers and potentially increased consumer spending.

For medium- and heavy-duty vehicles, introducing alternative fuels can be complex and costly. Without common practices among manufacturers, identifying a clear strategy for the near-term to achieve emission and petroleum reductions through alternative fuel use is challenging. This report finds that renewable diesel offers the greatest near-term promise as a replacement fuel for medium-and heavy-duty vehicles. However, renewable diesel availability is limited due to a small number of suppliers. Renewable natural gas (RNG) from landfills and dairy farms has the greatest potential to reduce emissions, but its use as a transportation fuel must compete with other uses (e.g., electric power applications). Similarly, biodiesel offers promise as a cost-effective alternative fuel for some trucks, but concerns regarding durability during cold weather and competition for other uses (e.g., heating oil) limits its feasibility.

Looking ahead, the Connecticut Green Bank should leverage programs and experience in other domains to capture the value of electric vehicles. For example, the Green Bank has extensive experience with residential solar deployment and could link solar incentives to electric vehicle adoption.

Table 1: Summary of Market Potential Assessment

Criteria	Vehicle Type	Alternative Fuel	Key Factors
Near-term market feasibility	**Passenger Vehicle**	**Electricity**	• ZEV Program participation • Vehicle incentives • Available charging infrastructure
	Medium- and Heavy-duty Vehicles	Renewable Diesel	• Drop-in fuel • Cost effective compared to diesel • Limited supply
Environmental performance	**Passenger Vehicle**	**Electricity**, Hydrogen	• Greatest emission reduction potential • Requires low-carbon feedstocks
	Medium- and Heavy-duty Vehicles	RNG from landfills and dairy farms	• Greatest emission reduction potential • Displaces emissions
Cost-effectiveness	**Passenger Vehicle**	**Electricity**	• All-electric vehicles have lower abatement costs than social cost of carbon without vehicle incentives and with solar incentives • Residential solar is least cost option with incentives
	Delivery Trucks, Tractor-Trailers	Electricity (delivery trucks), Biodiesel (delivery trucks, tractor trailers)	• Electric delivery trucks cost less than diesel trucks • Biodiesel trucks have lower abatement costs than social cost of carbon

Table 1: Summary of Market Potential Assessment (cont.)

Criteria	Vehicle Type	Alternative Fuel	Key Factors
Local economic benefits	**Passenger Vehicle**	**Electricity**	• Sizable power generation capacity keeps transportation spending in state's economy • Federal funds exist to support plug-in electric vehicles and charging infrastructure • Electric vehicles can achieve a net costs savings over gasoline vehicles
	Medium- and Heavy-duty Vehicles	Renewable Diesel	• Existing capacity to produce biodiesel, plus a federal tax credit, make it the best option • CNG could be attractive if oil prices recover to levels seen before summer of 2014 • Large portion of commercially-generated waste cooking oil is currently being used for transportation fuel (biodiesel) or heating oil. • Potential to use residentially-generated waste cooking oil for biodiesel

The table above summarizes the results from each criterion's analysis. The results clearly indicate passenger electric vehicles are the best near-term opportunity for Connecticut to achieve its energy and climate goals.

Source: Atlas Public Policy Analysis

Introduction

Connecticut has long been a leader in innovative approaches to clean energy deployment, exemplified by the work of the Connecticut Green Bank. The mission of the Green Bank is to accelerate the deployment of clean, affordable, and reliable energy in support of the Governor's and Legislature's energy strategy and the state's ambition to develop its local economy [3]. Since its inception in 2011, the Green Bank has worked to accelerate the deployment of clean energy[1] in residential and commercial buildings throughout Connecticut through the use of innovative finance mechanisms, like the Commercial Property Assessed Clean Energy (C-PACE) program. The C-PACE program allows commercial property owners to finance costly clean energy upgrades through long-term, low-cost capital resulting in an immediate positive cash flow at no upfront cost [4].

The Green Bank is now turning to its next challenge: greening the transportation sector. The transportation sector accounted for 40 percent of greenhouse gas emissions in Connecticut in 2012, making it the largest source of emissions by sector [5]. The Green Bank aims to leverage public funds to encourage greater private investment in clean technology for transportation (see **Box 1**). One metric the Green Bank may use in estimating the Bank's willingness to make a public investment is the amount of low or zero emission miles traveled per public dollar.

As a first step in this process, this report assesses the market potential for alternative fuels and on-road vehicles in Connecticut using four criteria:

1. **Near-term market feasibility;**
2. **Environmental performance;**
3. **Cost-effectiveness; and**
4. **Local economic benefits.**

Box 1

Alternative Fuel Vehicles and Associated Infrastructure

Per Public Act14-136, an amendment to C.G.S. §4a-59 defines "clean alternative fuel" as natural gas, propane, electricity, or hydrogen when used as a motor vehicle fuel. C.G.S. §14-212(5) defines "motor vehicle" as all vehicles used on the public highways. "Associated infrastructure" is defined by the Connecticut Green Bank as structures, machinery, and equipment necessary and integral to refuel an alternative fuel vehicle [6].

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[1] "Clean energy means solar photovoltaic energy, solar thermal, geothermal energy, wind, ocean thermal energy, wave or tidal energy, fuel cells, landfill gas, hydropower that meets the low-impact standards of the Low-Impact Hydropower Institute, hydrogen production and hydrogen conversion technologies, low emission advanced biomass conversion technologies, alternative fuels, used for electricity generation including ethanol, biodiesel or other fuel produced in Connecticut and derived from agricultural produce, food waste or waste vegetable oil, provided the Commissioner of Energy and Environmental Protection determines that such fuels provide net reductions in greenhouse gas emissions and fossil fuel consumption, usable electricity from combined heat and power systems with waste heat recovery systems, thermal storage systems, other energy resources and emerging technologies which have significant potential for commercialization and which do not involve the combustion of coal, petroleum or petroleum products, municipal solid waste or nuclear fission, financing of energy efficiency projects, projects that seek to deploy electric, electric hybrid, natural gas or alternative fuel vehicles and associated infrastructure, any related storage, distribution, manufacturing technologies or facilities and any Class I renewable energy source, as defined in section 16-1." Source: https://www.cga.ct.gov/current/pub/chap_283.htm#sec_16-245n

Reducing Emissions from Transportation

Reducing greenhouse gas emissions from mobile sources may be more challenging than the building or power sectors. Local and state politics play a critical role in land use development and infrastructure planning resulting in a built environment that does not reflect a perfectly competitive market for transportation services. In addition, most consumers, especially individuals, do not value fuel savings and corresponding emission reductions in a way that reflects wider societal benefits. The reduced demand for efficiency causes consumers to use more fuel than is cost-effective. This imbalance is not as prevalent in other sectors, such as energy use from power plants. As a result, studies find that reducing emissions from transportation through only market-based carbon pricing mechanisms tends to cost far more than improving energy efficiency and adding low-carbon sources to the power sector. Substantial emission reductions are possible at a comparable cost to other sectors, however, when policymakers implement a suite of policies [7].

Energy security is also an important consideration, even in era of low oil prices. Historically, energy security focused on protecting the U.S. economy against the risk of substantial increases in energy costs. A 2009 study by RAND Corporation found that the United States spends $83 billion per year to secure the global supply and transit of oil [8]. Not including these military-related costs, a 2014 analysis estimated that an all-electric vehicle could provide over $2,000 in energy security benefits in 2025 [9]. Although these benefits can change with low oil prices, energy security risks remain. Low prices increase the concentration of low-cost suppliers in the market, thereby increasing the dependence on Middle East oil. The increase in market dependence on the Middle East leads to an increase in vulnerability to supply disruptions and potential price shocks [10]. In addition, consumers can be locked in to decisions made when prices are low because oil is not easily substitutable as a transportation fuel. This creates demand for oil that is inelastic, causing significant economic losses when prices spike [11].

Transportation Emissions In Connecticut

Transportation is the single largest source of greenhouse gas emissions in the state, accounting for 40 percent of these emissions in 2014. The on-road transportation sector, which includes light-, medium-, and heavy-duty vehicles, is also responsible for 53 percent of all nitrogen oxide (NO_X) emissions in Connecticut in 2011. NO_X is an especially important air pollutant for Connecticut because it is a precursor that forms ground-level ozone during the warmer months. Ground-level ozone, also known as smog, can cause inflammation and damage to the lining of the lung resulting in serious harm to human health [12]. According to the U.S. Environmental Protection Agency's Green Book of Nonattainment Areas (of the Clean Air Act), five of Connecticut's eight counties are in nonattainment of the 2008 8-hour ozone standard [13].

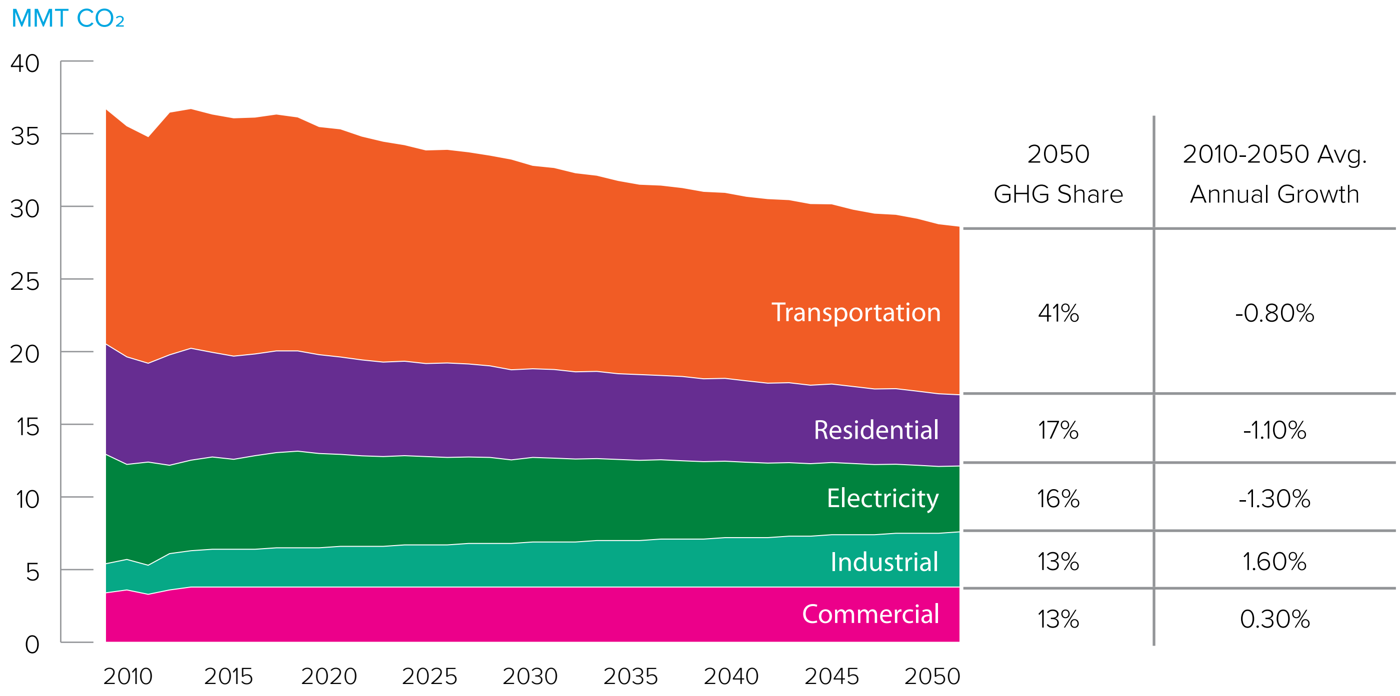
Box 2

Reducing Greenhouse Gas Emissions from the Power Sector in Connecticut

Connecticut is a part of the Regional Greenhouse Gas Initiative (RGGI), a market-based program aimed at reducing carbon dioxide emissions 2.5 percent per year to 2020 [14]. Connecticut also has a renewable portfolio standard requiring 20 percent of retail electricity load to be served by renewable energy by 2020 [15].

As of 2012, greenhouse gas emissions in the state were 10.5 percent below 1990 levels, in line with the state's 2020 goal (see **Box 2**). The Global Warming Solutions Act of 2008 set a goal for the state to achieve an 80 percent reduction in greenhouse gas emission below 2001 levels by 2050, which will require steep reductions in the state's largest emissions source: transportation [16]. Achieving this goal would result in annual greenhouse gas emissions below 10 million metric tons of carbon dioxide equivalent. A recent analysis showed transportation emissions are expected to decrease only slightly out to 2050, resulting in total emissions about three times above the state's 2050 goal (see **Figure 2**).

Figure 2: Reference Case Analysis of Greenhouse Gas Emissions in Connecticut through 2050



	2050 GHG Share	2010-2050 Avg. Annual Growth
Transportation	41%	-0.80%
Residential	17%	-1.10%
Electricity	16%	-1.30%
Industrial	13%	1.60%
Commercial	13%	0.30%

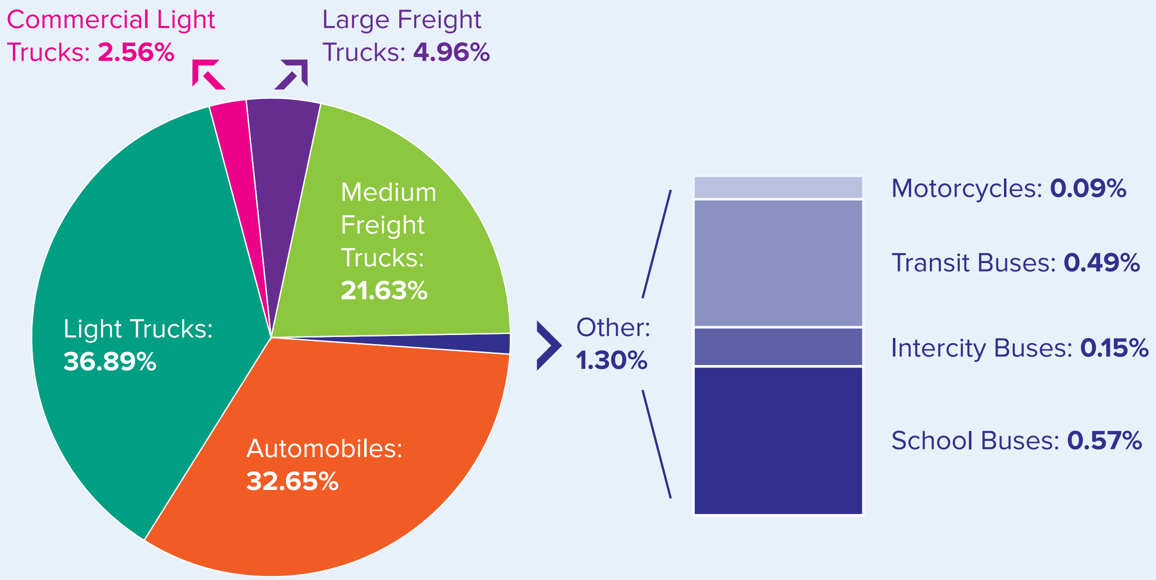
Source: [17]

Connecticut's 2013 Comprehensive Energy Strategy highlights the need to increase market-based opportunities for clean fuels and clean vehicles to meet multiple energy and environmental objectives [18]. To achieve its climate and clean air goals, Connecticut must significantly increase the use of low-carbon alternative fuels. A 2013 report by the National Research Council concluded substantial greenhouse gas emission reductions will require a wholesale shift to light-duty vehicles powered by low-carbon biofuels, electricity, and/or hydrogen [19]. Nationally, passenger cars and light trucks account for nearly 70 percent of energy consumption for on-road vehicles. Looking ahead, ambitious federal vehicle standards will increase fuel economy of these vehicles to help reduce their share of energy consumption to only just under 66 percent by 2025 (see **Figure 3**).

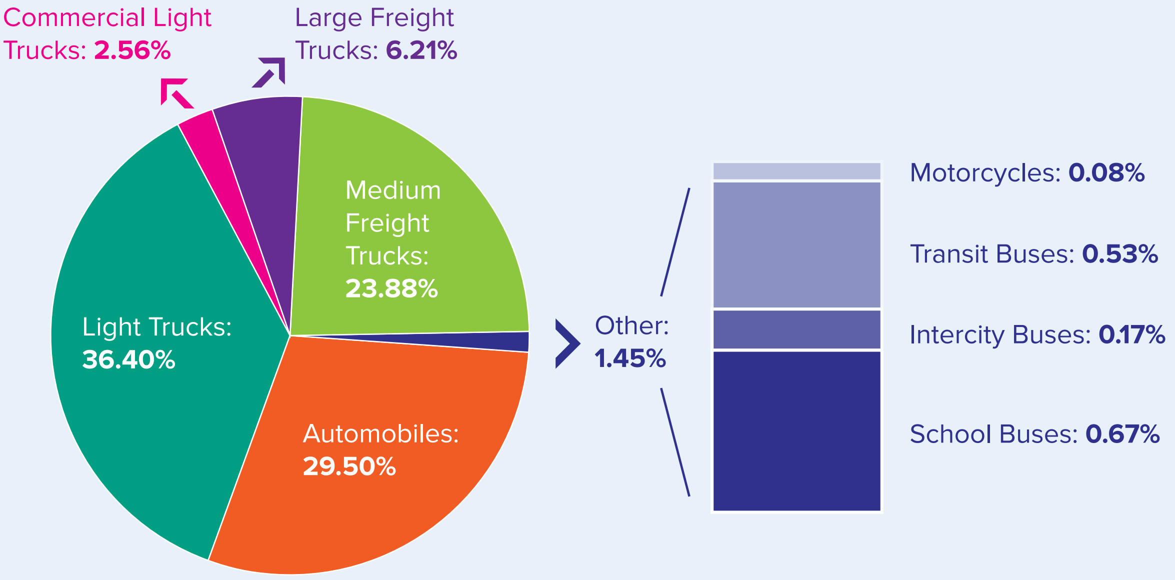
In New England, nearly 80 percent of on-road transportation energy consumption is from gasoline, mostly for passenger cars and light trucks. Even with federal vehicle standards and other policies to promote alternative fuels, the challenge is clear: the U.S. Energy Information Administration (EIA) forecasts that alternative fuels will account for less than 1 percent of transportation energy consumption in New England until at least 2025 under a business as usual scenario (see **Figure 4**) [1].

Figure 3: U.S. Energy Consumption by Vehicle Type (2015 And 2025)

2015 (174 Billion Gallons of Gasoline Equivalent)



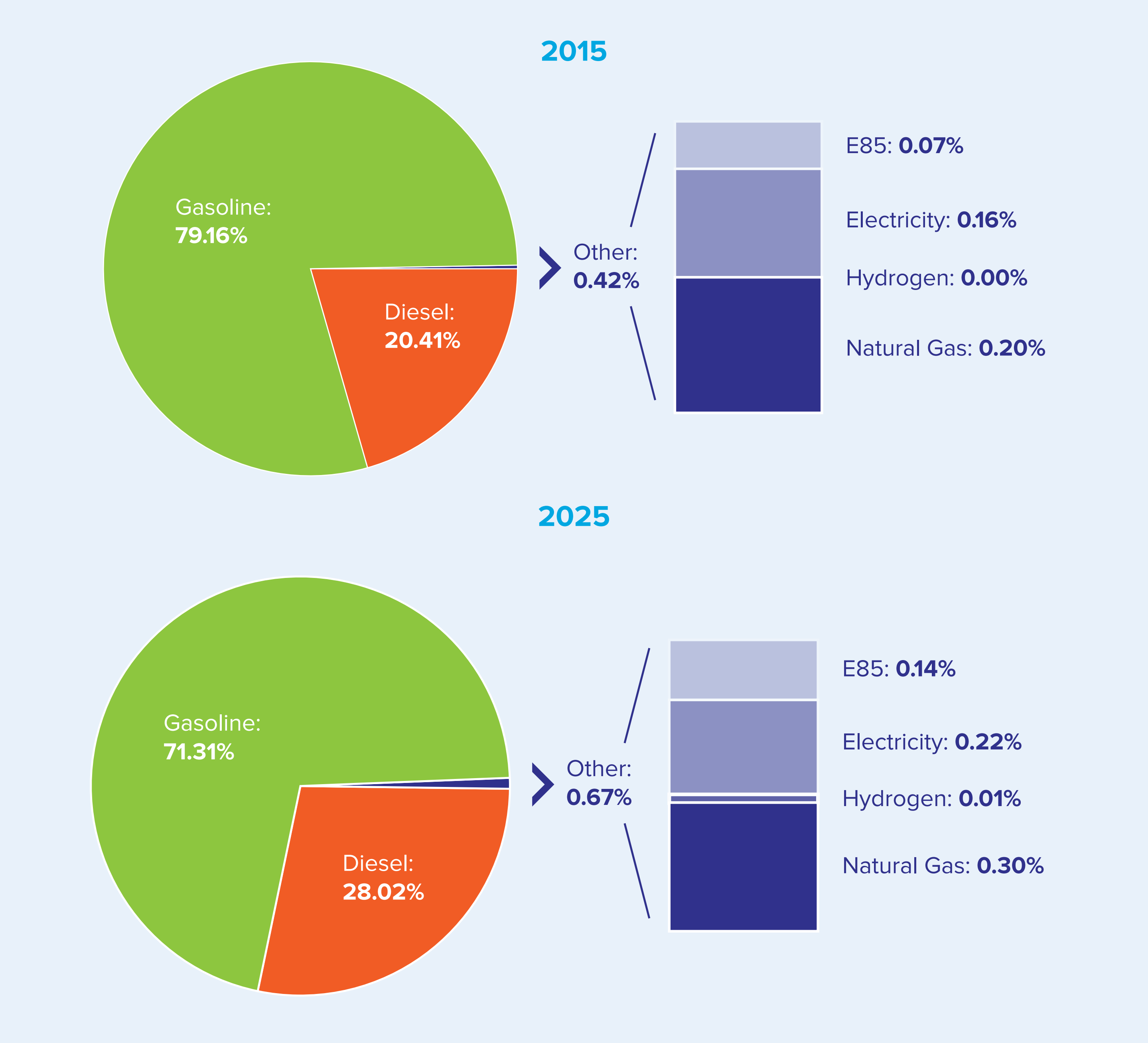
2025 (165 Billion Gallons of Gasoline Equivalent)



Source: [1]

Due largely to federal standards for light-, medium-, and heavy-duty vehicles, total energy use for U.S. on-road vehicles is expected to decline from 174 billion gallons of gasoline equivalent in 2015 to 165 billion gallons in 2025.

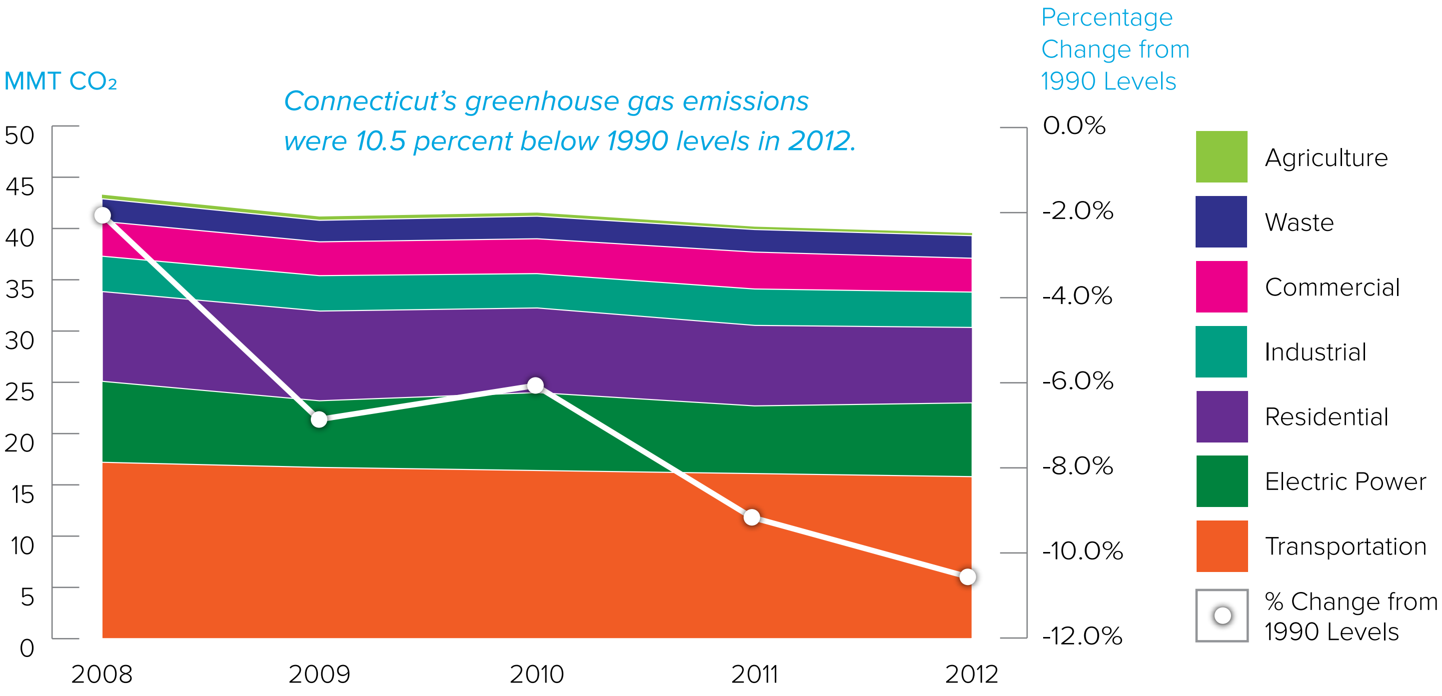
Figure 4: New England Road Transportation Energy Consumption by Source, Reference Case (2015 and 2025)



Source: [1]

Passenger vehicles, including cars and light trucks, constitute the largest share of emissions in the transportation sector. Over the next decade, federal fuel economy and greenhouse gas standards for light-duty vehicles are expected to increase the fuel economy of new cars and light trucks significantly, reaching about 50 miles per gallon. If automakers reach the greenhouse gas standard by only fuel economy improvements, the new vehicle fleet is expected to be 54.5 miles per gallon of gasoline equivalent in 2025 [20]. The U.S. Environmental Protection Agency estimates that sales of full hybrids and electric vehicles will only account for between 3 and 7 percent of vehicles purchased that year, meaning automakers can mostly meet the standard using gasoline combustion drivetrains [21].

Figure 5: Greenhouse Gas Emissions in Connecticut are Down Over 15 Percent from 1990 Levels



Source: [5]

While the federal vehicle standards as evidenced by **Figure 3** do not paint an optimistic picture for alternative fuels for these vehicles in the near term, evidence from the auto industry indicates growing interest in electric and hydrogen fuel cell vehicles. All major automakers have made these vehicles available for sale, with Americans purchasing 28 different electric-vehicle models of in January 2016. In total, Americans have purchased over 400,000 electric vehicles since their mass-market introduction in December 2010 [22].

At a national level, medium- and heavy-duty vehicles are responsible for 28 percent of petroleum use and 26 percent of greenhouse gas emissions in the transportation sector [1], and are major contributors to criteria pollutant emissions such as NOx and particulate matter (PM) [23]. Connecticut's medium- and heavy-duty vehicles contribute an estimated 22 percent of the state's transportation greenhouse gas emissions [5, 24], 29 percent of on-road NO_X emissions, 21 percent of on-road PM_{10} emissions, and 36 percent of $PM_{2.5}$ emissions [23]. EIA projects an 80 percent increase in truck miles traveled nationally between 2010 and 2040, making it one of the fastest growing segments of the transportation sector. Greater use of alternative fuels in these vehicles is one of the most promising ways to reduce emissions and displace petroleum consumption [7].

Alternative Fuel Options

Below are ten alternative fuels that could replace gasoline or diesel fuel.

- **Battery-Electric:** on-board battery storage powered by the electrical grid or distributed electricity sources.
- **Biodiesel from waste oils:** Liquid fuel produced through the transesterification of animal fats and waste oil and used in a diesel engine, blended with diesel at 5 percent (B5) to 100 percent (B100) by volume. Only B100 is considered in this report.
- **Renewable diesel:** Liquid fuel produced through hydrotreating of oils or Fischer-Tropsch synthesis of biogas. Renewable diesel is typically not blended with conventional diesel like biodiesel. As a "drop-in" fuel, renewable diesel requires no new infrastructure. The fuel is currently being sold in California at 32 public gasoline stations [25].
- **E85:** Liquid fuel produced from biomass (food- or waste-based) where up to 85 percent of the fuel is ethanol and 15 percent or more is gasoline, by volume.
- **Landfill/wastewater gas:** a mixture of mostly methane and carbon dioxide (CO_2) emitted from landfills and wastewater treatment plants. After processing to renewable natural gas (RNG), the gas is interchangeable with natural gas in an internal combustion engine.
- **Dairy biogas:** Similar to landfill/wastewater gas in composition once processed to RNG. Slightly more expensive to collect than landfill/wastewater gas, but is a substitute for natural gas.
- **Propane:** Also known as liquefied petroleum gas (LPG), propane is a clean-burning alternative fuel used mostly medium- or heavy-duty applications.
- **Compressed natural gas (CNG):** Compressed gas (mostly methane) combusted in an internal combustion engine and derived from fossil.
- **Liquefied natural gas (LNG):** CNG compressed and cooled until liquid and used in internal combustion engine.
- **Hydrogen (gaseous):** Compressed gaseous fuel typically used in a fuel cell to power an electric motor. The fuel can also be combusted in an internal combustion engine.

Light-, Medium-, and Heavy-Duty Vehicles

In 2013, light-duty vehicles made up over 95 percent of the vehicles registered in Connecticut. That year, Connecticut had about 1.47 million passenger cars and 1.17 million light trucks (vans, pickups and sport utility vehicles) on its roads, and about 120,000 buses, tractor-trailers, and other medium- and heavy-duty vehicles [2].

In 2013, Connecticut drivers consumed 1.4 billion gallons of gasoline, mostly in passenger cars and light trucks [26]. The economic and energy security implications of this dependency on a single fuel source puts the Connecticut economy at risk to market forces largely out of the control of the state. Had the Connecticut fleet been entirely electric, a domestic fuel, the state would have saved $3.5 billion in fuel costs in 2013, based on fuel prices that year [27].[2]

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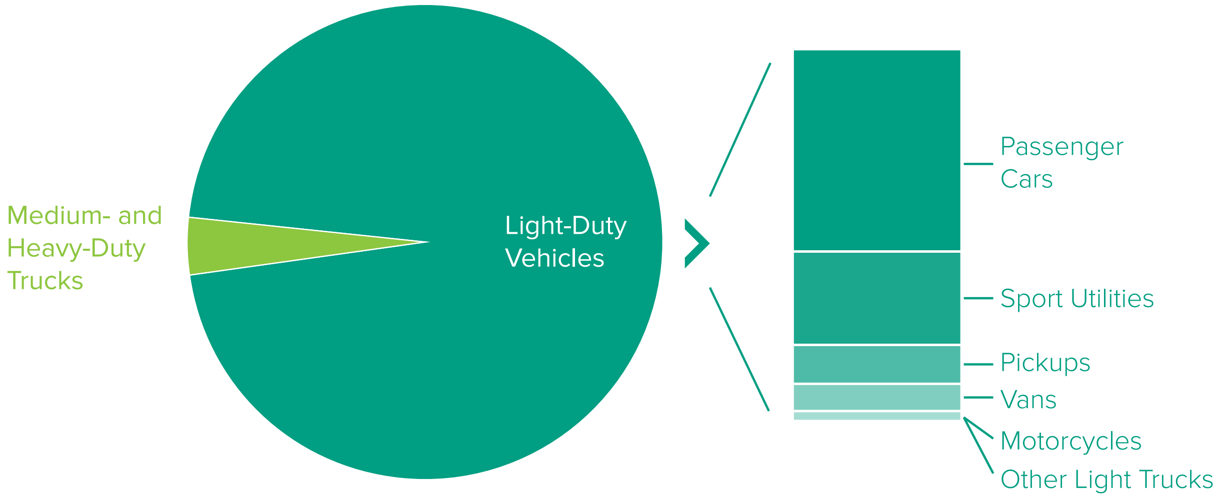
[2] In the United States in 2013, the passenger car fleet averaged 24.7 miles per gallon (114 million cars traveled 1.45 trillion miles and consumed 58.5 billion gallons of gasoline equivalent, see http://cta.ornl.gov/data/tedb34/Spreadsheets/Table2_14.xls. Gasoline prices averaged $3.68 and electricity prices averaged $0.16 per kilowatt-hour in Connecticut in 2013. The Nissan LEAF averages 112 miles per gallon of gasoline equivalent, see http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=37067.

Figure 6: Vehicle Registrations in Connecticut in 2013



Accurate data on medium- and heavy-duty trucks is difficult to attain. The Federal Highway Administration attempts to compile these data annually, but the breakdown of trucks is largely unassigned.

Source: [2]

Light-duty alternative fuel vehicles can be made for almost any fuel since original equipment manufacturers control the entire design and manufacturing process. U.S. federal and state policymakers have encouraged the development and deployment of various alternative fuels for several decades. From methanol to ethanol to the Synthetic Fuels Corporation of the Carter Administration, government has prioritized various alternative fuels for light-duty vehicles. More recently, electric vehicles have become the alternative fuel of choice for passenger cars, and hold a promising future due to advances in battery technology, consistently low electricity prices, and environmental considerations.

Introducing alternative fuels to medium- and heavy-duty vehicles can be more complex and costly than doing so for passenger vehicles. Unlike passenger vehicles, their engines, chassis, and supplementary equipment are rarely all designed and manufactured by a single firm, making systems integration a key challenge. Additionally, these vehicles have a much greater diversity in body types, weight classes, drive cycles, and uses than passenger vehicles so identifying a single strategy to achieve emission and petroleum reductions is challenging [28]. For these reasons, jurisdictions often focus on a single vehicle category (e.g., trash truck or transit bus) to switch to alternative fuels. St. Louis's evaluation of biodiesel for use in transit buses and the use of LNG in Dallas's rapid transit buses are two such examples [29, 30].

Table 2 shows the twelve largest categories of Class 3 through 8 vehicles in Connecticut. By far the single largest category is tractor trailer. According to the 2002 Vehicle Inventory and Use Survey (VIUS), there are three times as many tractor trailers as the next largest category, dump truck. Across each vehicle category, there is a range of different fuel economies and annual distances traveled – both of which impact emissions and petroleum use.

Table 2: Medium and Heavy-Duty Vehicles in Connecticut

Truck Category	Registered Vehicles in 2002 According to VIUS	Registered Vehicles in 2013 from the Federal Highway Administration
Tractor Trailer	34,165	6,555
Dump	11,077	Not available
Step Van	7,395	Not available
Box Van	7,180	Not available
All Public + Private Buses	Not available	12,379
Utility	4,008	Not available
Tow	1,623	Not available
Refrigerated Van	1,527	Not available
Trash	1,342	Not available
Concrete Mixer	579	Not available
Beverage	500	Not available
Unclassified	—	101,542
Total	**69,396**	**120,476**

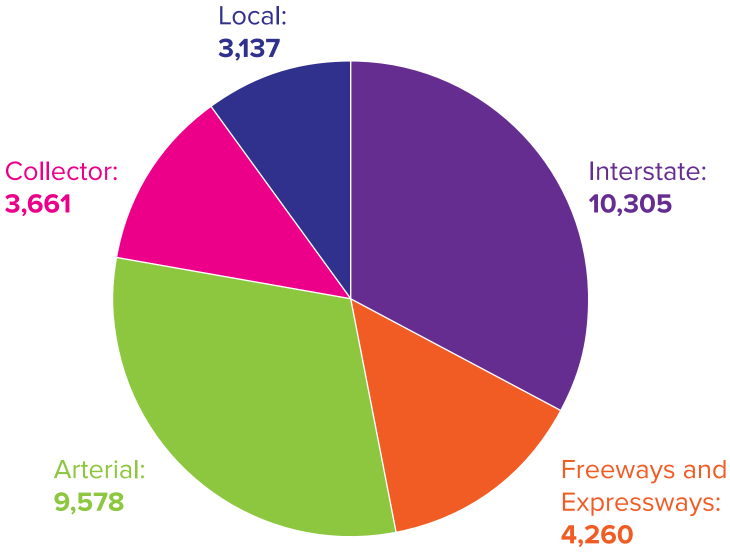
Sources: [2, 24]

Note that data in **Table 1** comes from the 2002 VIUS. Through the use of survey weights on individual responses, users of VIUS can estimate representative distributions of vehicles and vehicle characteristics at the national or state level. In several places below, VIUS is used to estimate fuel use or emissions. Despite its age, data in the VIUS survey is still utilized by the U.S. Department of Energy as the main nationally representative data source for heavy-duty trucks (e.g., Oak Ridge National Laboratory's Transportation Energy Data Book [31]). The next VIUS survey is scheduled for release in 2018.

Vehicle Miles Traveled

Drivers traveled about 31 billion miles on the roads in Connecticut in 2013, with the vast majority of travel occurring on interstates, freeways/expressways, and arterial roads (see **Figure 7**). Over 75 percent of miles traveled in the state were from passenger cars, with light trucks accounting for about 15 percent of travel on the state's roads (see **Figure 8**).

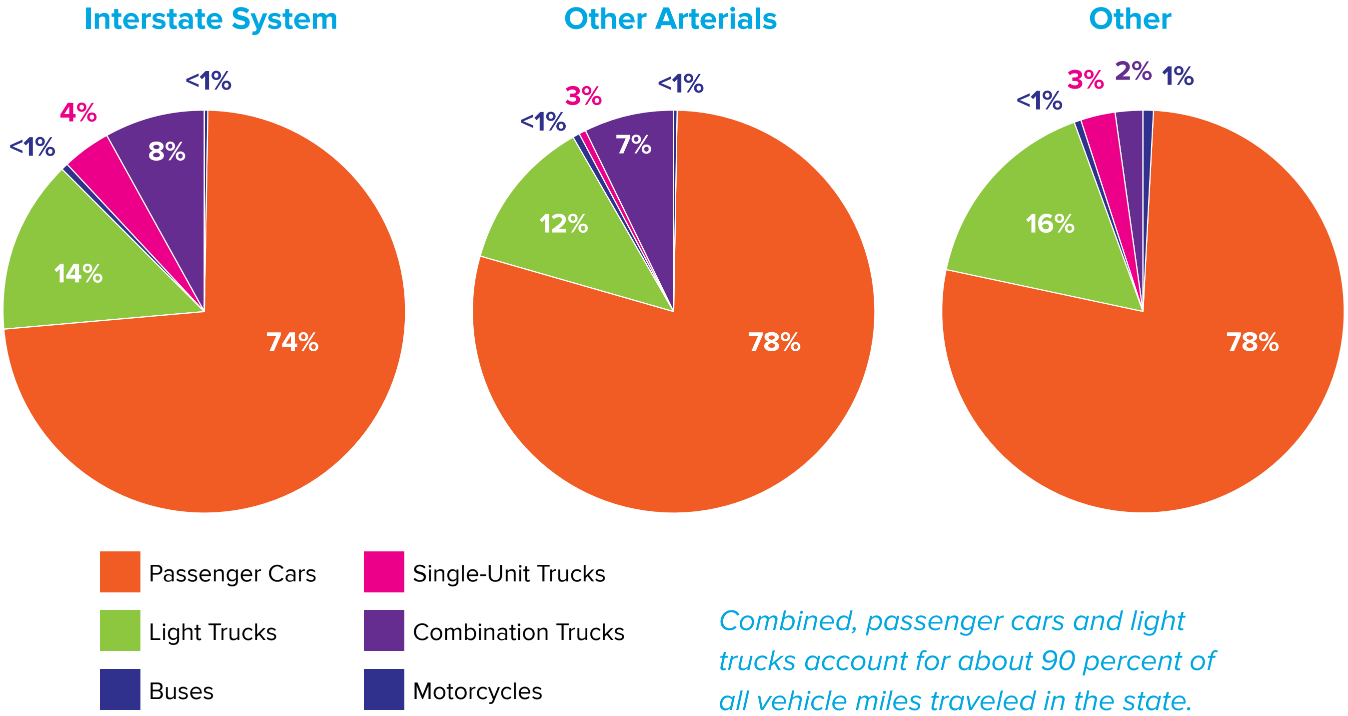
Figure 7: 2013 Annual Vehicle Miles Traveled on Connecticut Roads in Million Miles



Most travel in Connecticut occurs on major roadways (interstates, freeways/expressways, and arterials).

Source: [2]

Figure 8: Share of Miles Traveled by Vehicle

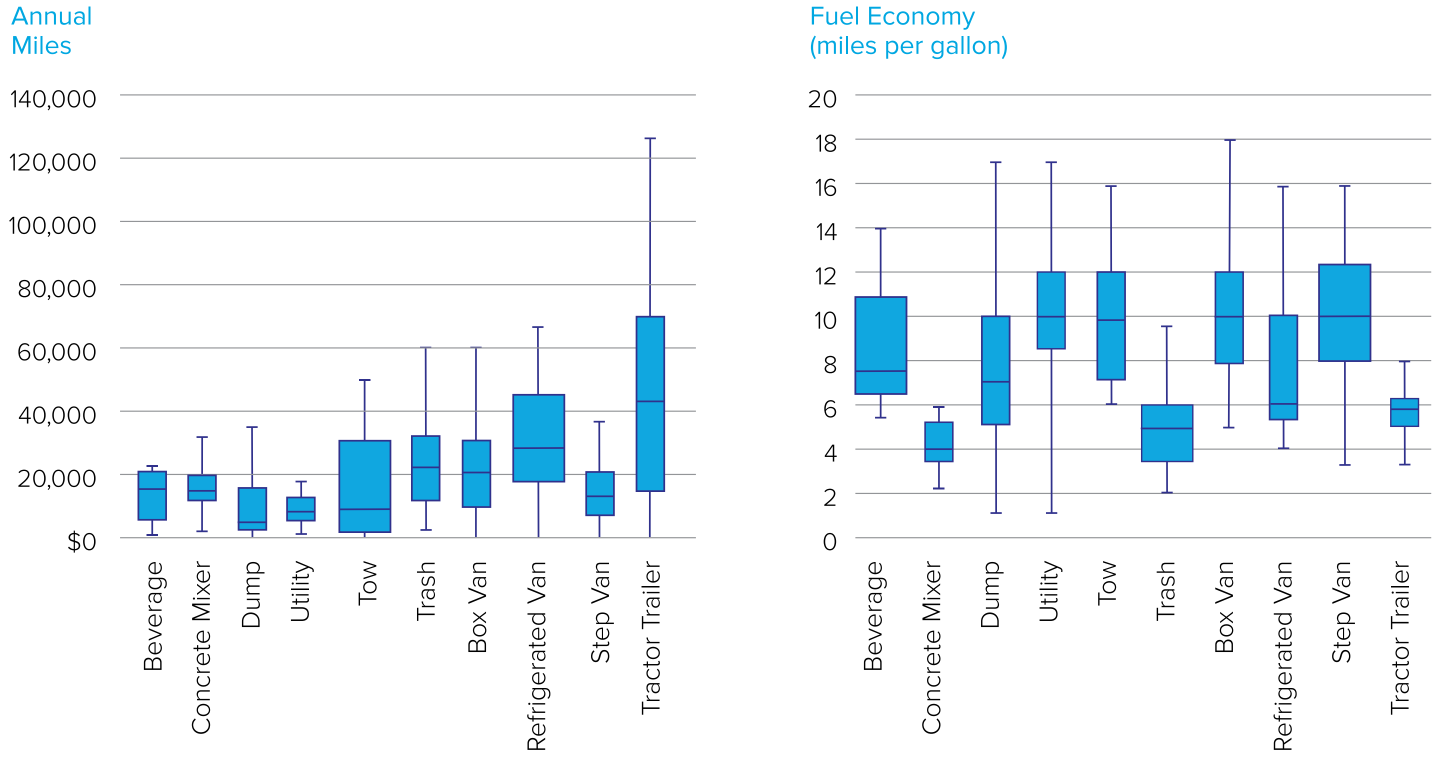


Combined, passenger cars and light trucks account for about 90 percent of all vehicle miles traveled in the state.

Source: [2]

Figure 9 shows the distributions in quartiles of annual miles and fuel economy of each of 10 medium- and heavy-duty truck categories. Notes these figures show only trucks that have home bases in Connecticut and excludes trucks that pass through the state and are homebased elsewhere. Numerical values for **Figure 9** are in Appendix A.

Figure 9: Annual Mileage and Fuel Economy of Medium- and Heavy-duty Vehicles



Data for school and transit buses was unavailable. These box-and-whisker plots divide the vehicle dataset into quartiles. The lower quartile is between the lower error bar and the bottom of the box. The second quartile is between the horizontal line and the bottom half of the box, the third quartile is between the horizontal line and the top of the box, and the fourth quartile is between the upper error bar and the top of the box. Outliers, defined as 1.5 times the length of the box, are not shown.

Source: [24]

AFV Market Potential Assessment

The market potential of alternative fuels in the vehicle market depend on the following four factors:

1. **Near-term market feasibility:** feasibility within the next five years based on vehicle availability and other practical considerations.
2. **Environmental performance and petroleum displacement potential:** the potential to reduce greenhouse gas and criteria pollutant emissions based on vehicles registered in Connecticut.
3. **Cost-effectiveness:** greenhouse gas emission abatement costs of using alternative fuel vehicles compared to diesel and gasoline vehicles considering upfront and operating costs.
4. **Local economic benefits:** estimates of potential benefits in Connecticut from greater use of an alternative fuel.

Each criterion helps the state prioritize investments and clarifies the vehicle and fuel combinations that offer the best chance to accomplish the state's environmental, energy, and economic objectives. The order of the criteria above is deliberate since the state wishes to prioritize alternative fuel and vehicle opportunities in the near term. For vehicles targeted at individual consumers, alternative fuels with little to no public infrastructure or no vehicle availability could be deemphasized or eliminated in subsequent criteria analyses. For example, since no automakers have announced mass production of a natural gas passenger car in 2016 or beyond, natural gas is excluded from the assessment for passenger vehicles.

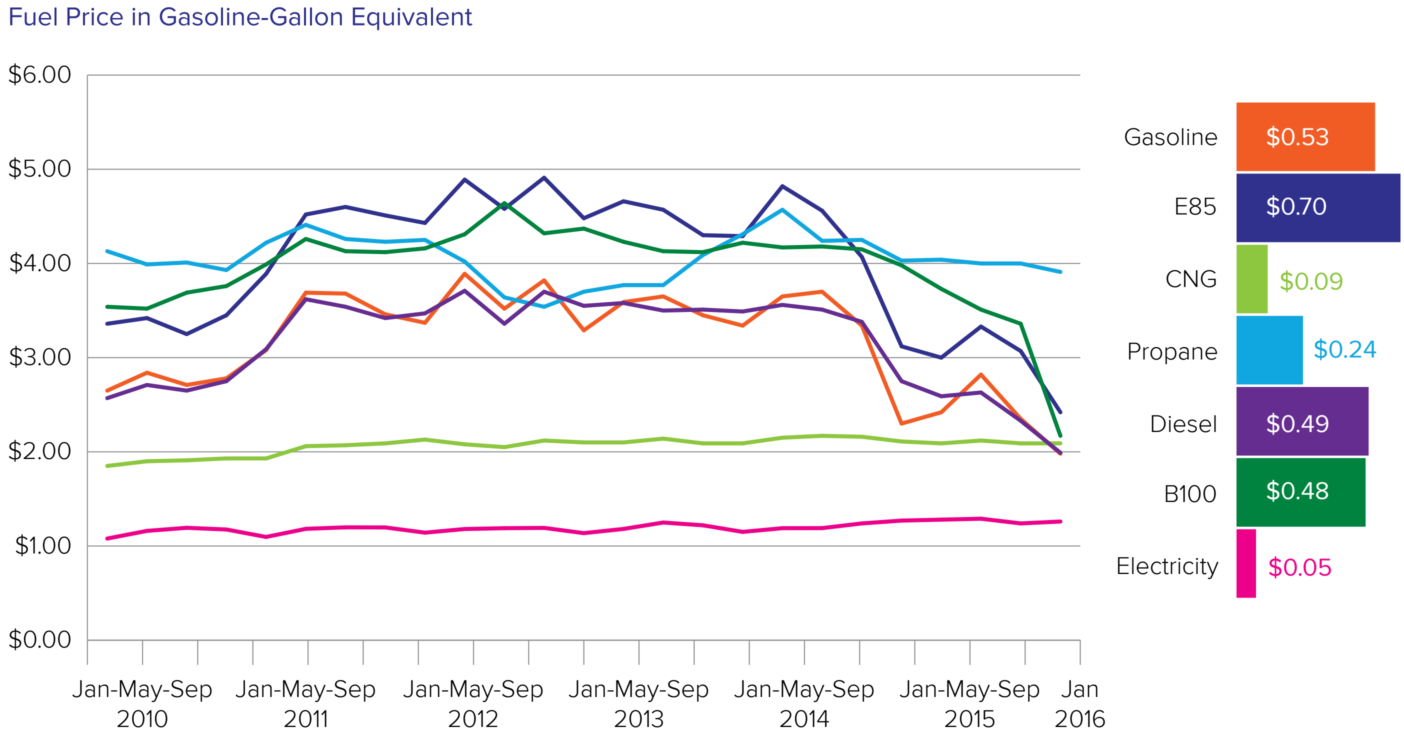
Near-term Market Feasibility Criterion

Near-term market feasibility provides Connecticut with evidence about which vehicle and fuels combinations might be deployed within the next five years. This criterion is divided into four components: fuel price, public fueling infrastructure availability, vehicle availability, and public policy. Following an exploration of each component, a summary is provided of the most desirable alternative fuel and vehicle combination for light-, medium-, and heavy-duty vehicles based only on near-term market feasibility.

FUEL PRICE CONSIDERATIONS

Price volatility in the alternative fuel market can vary greatly by region and fuel type, with the exception of electricity since its price is often regulated. Prices for E85 and biodiesel tend to follow swings of petroleum prices in part because these fuels often compete directly with gasoline and diesel, respectively. The price of CNG can vary greatly by region, while the price volatility tends to be low. For example, CNG prices ranged between $2.09 and $2.17 per gallon of gasoline equivalent nationally between 2014 and 2016. In the Rocky Mountain states, prices were as low as $1.79 per gallon during this period and as high as $2.61 per gallon in New England. See **Figure 10** for an overview of national alternative fuel prices from 2010 through 2015 [32].

Figure 10: National Transportation Fuel Prices in Gasoline-Gallon Equivalent



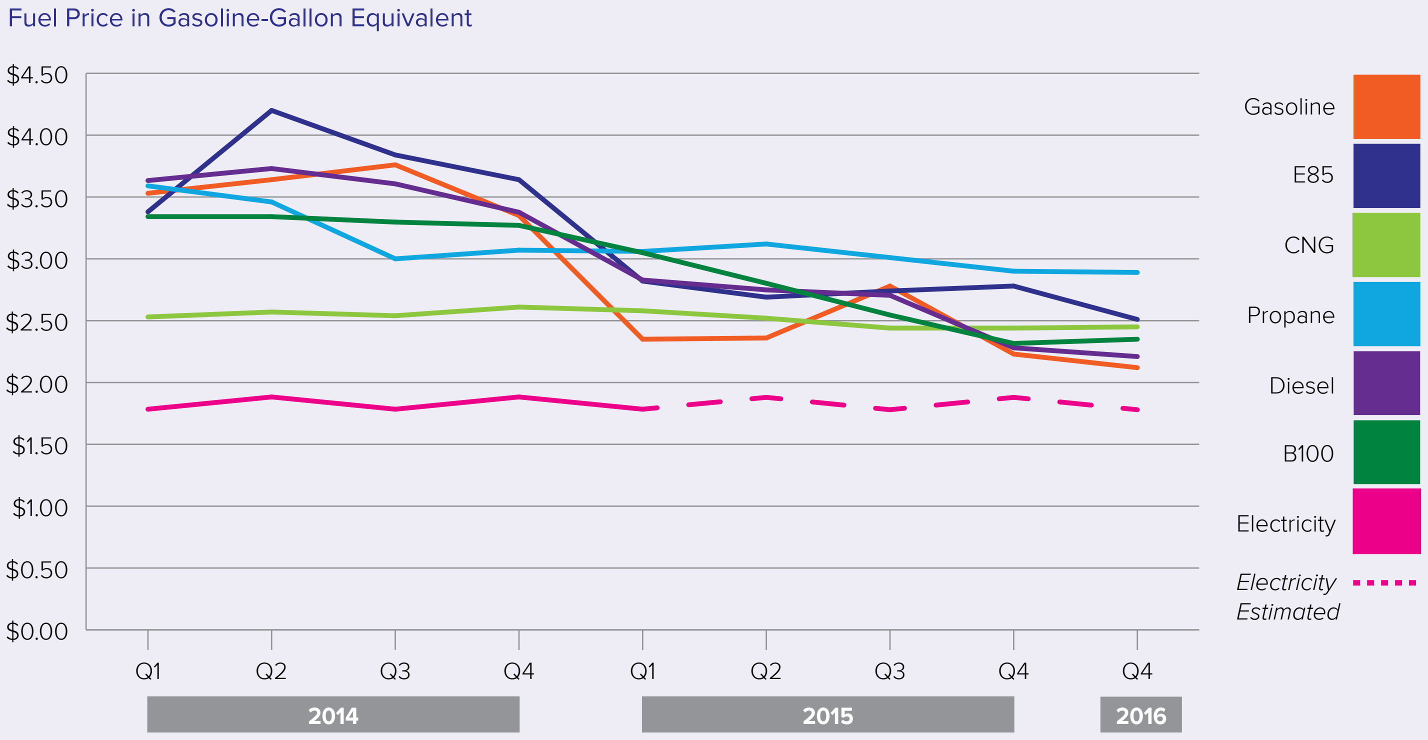
National prices are shown on the left. Price volatility, a way to measure the extent to which a price changes over time, is shown on the right. The volatility is the amount by which prices deviated from the average price from January 2010 to September 2015.

Source: [33]

In Connecticut and New England, more broadly, fuel prices have generally followed the national trend since the first quarter of 2014. While electricity remains the least expensive transportation fuel, its lead over other fuels has decreased significantly. Other alternative fuels, including E85, CNG, propane, and B100 are more expensive than gasoline and diesel on an equivalent basis as of the first quarter of 2016 (see **Figure 11**). Propane has consistently been the most expensive transportation fuel since the first quarter of 2014. Supply chains for renewable diesel and hydrogen have not been established in Connecticut – current selling price in California for these fuels as of early 2016 is $2.39 per gallon and $13.59 per kilogram, respectively [34, 35].

Nationally, consumer preferences have shifted towards vehicles with lower fuel economy following a fall in gasoline prices beginning in the summer of 2014. Stubbornly high gasoline prices influenced consumers to purchase more efficient vehicles, reaching 25.6 miles per gallon (mpg) in the third quarter of 2014. Once gasoline prices began to fall, however, consumers almost immediately began purchasing larger vehicles with a lower fuel economy, falling to 25.1 mpg in the fourth quarter of 2015 (see **Figure 12**).

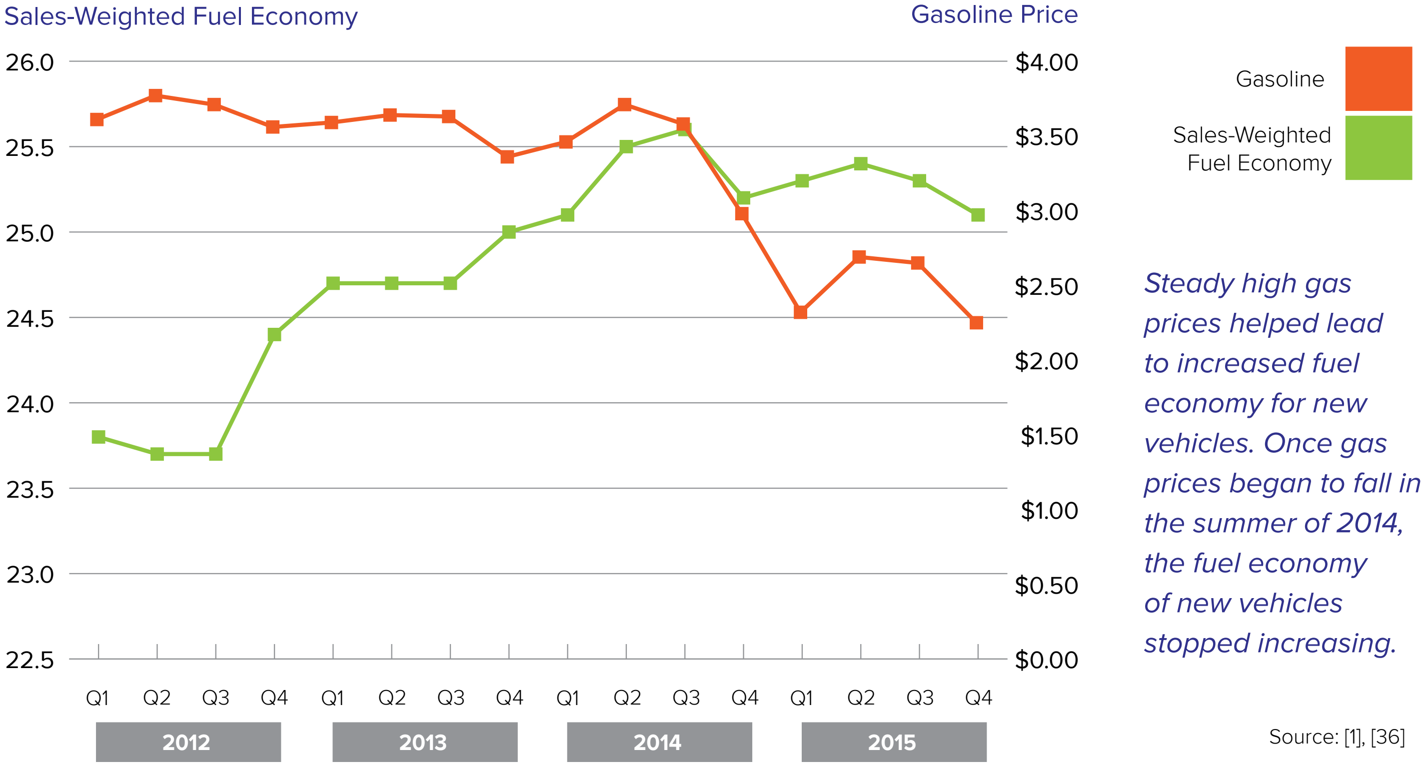
Figure 11: Fuel Price in Gasoline-Gallon Equivalent in New England



2014 electricity prices are for Connecticut only and 2015 electricity prices were estimated based on historical prices.

Source: [33]

Figure 12: Consumer Response to Gasoline Prices



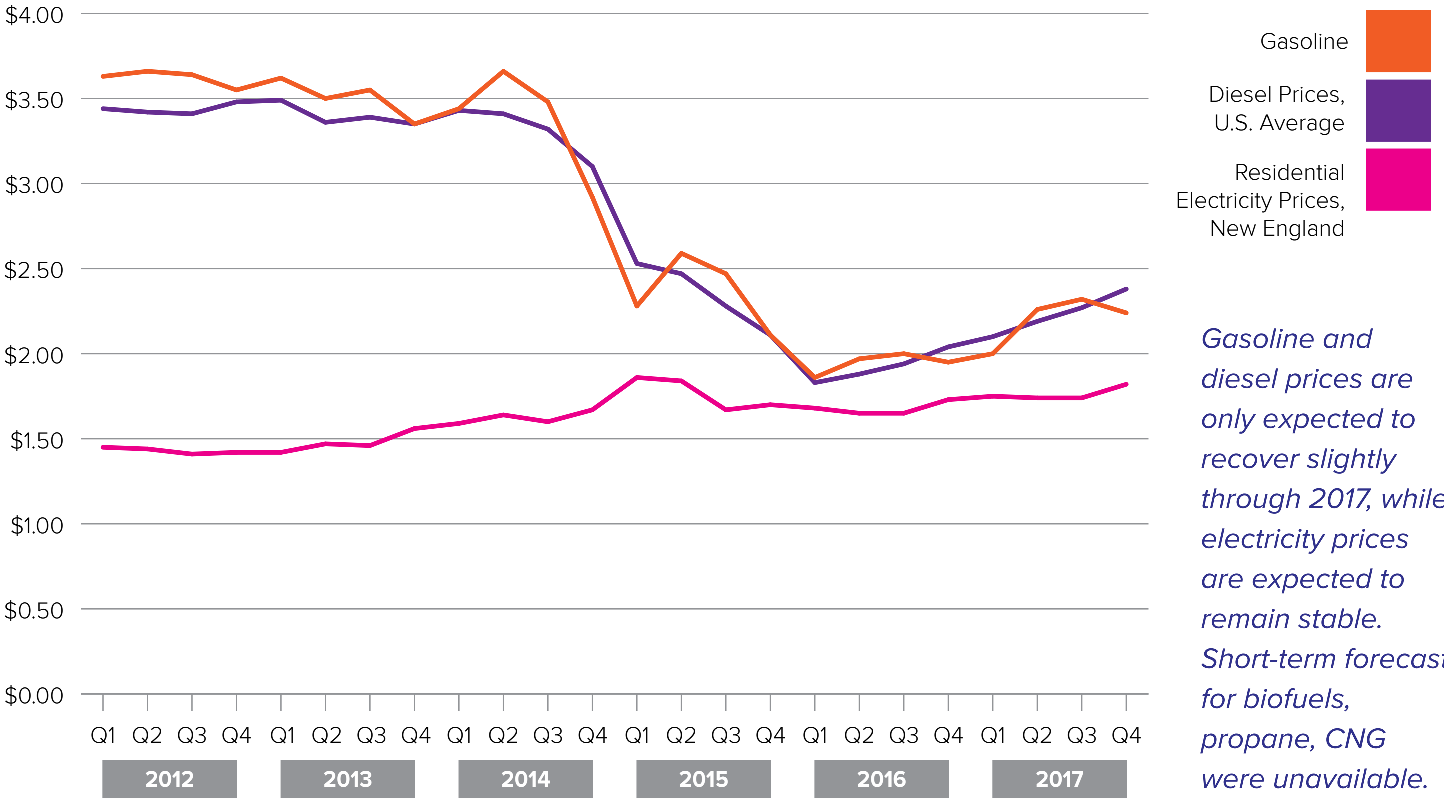
Steady high gas prices helped lead to increased fuel economy for new vehicles. Once gas prices began to fall in the summer of 2014, the fuel economy of new vehicles stopped increasing.

Source: [1], [36]

The total effect of falling gasoline prices on alternative fuel vehicles (e.g., electric and E85 vehicles in the passenger vehicle segment), is unclear. One challenge unique to electric vehicles is the lack of offerings across vehicle segments. If consumers continue to favor large vehicles, the lack of a wide selection of plug-in electric vehicles in those segments could limit interest in the technology. In addition, low gasoline prices reduce a key component of the value proposition of electric vehicles, low operating costs.

In the near term, EIA expects gasoline and diesel prices to recover slightly from the low levels in 2015 and 2016. Gasoline and diesel prices are expected to remain below $2.50 per gallon of gasoline equivalent through 2017. During this period, EIA expects electricity prices to remain stable (see **Figure 13**). The EIA does not provide short-term forecasts for natural gas, propane, or biofuel prices for use in transportation. The EIA's Annual Energy Outlook for 2015 estimated propane prices to increase through 2017 from $1.78 to $1.90 per gallon of gasoline equivalent, and ethanol prices to increase from $2.16 to $2.68 per gallon of gasoline equivalent [1].

Figure 13: Near-term Forecast for Gasoline, Diesel, and Electricity Prices



Gasoline and diesel prices are only expected to recover slightly through 2017, while electricity prices are expected to remain stable. Short-term forecasts for biofuels, propane, CNG were unavailable.

Source: [37]; electricity costs converted to gasoline-gallon equivalent using U.S. Department of Energy's eGallon methodology: http://energy.gov/downloads/egallon-methodology.

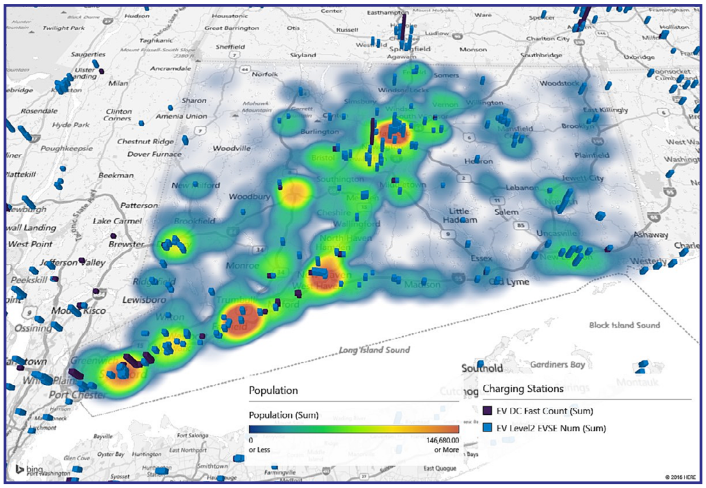
PUBLIC FUELING INFRASTRUCTURE AVAILABILITY IN CONNECTICUT

Two factors related to fueling infrastructure availability can affect the market potential of an alternative fuel. First, some publicly available fueling infrastructure is necessary in order to accommodate the daily driving needs of all consumers and many fleets. Second, fueling stations should be located near the drivers most dependent on them.

To illustrate these two factors, **Figure 14** shows that at least some publicly available electric vehicle charging is deployed in the state's most populated regions. Conversely, **Figure 15** shows very few public stations for biofuels, including no B100 stations. The state has two private-access biodiesel stations, but neither offer B100. Adding new biodiesel capacity could be challenging, since a large portion of commercially-generated waste cooking oil is currently being used to produce transportation fuel (biodiesel) or heating oil. Potential exists for biodiesel using residentially-generated waste cooking oil as well as fats, oils, and grease from grease traps at restaurants. These sources could provide an increased supply of biodiesel fuel for commercial users (e.g., truck fleets) who typically purchase their biodiesel fuel directly from distributors and store it on-site rather than purchase it at private biodiesel stations.

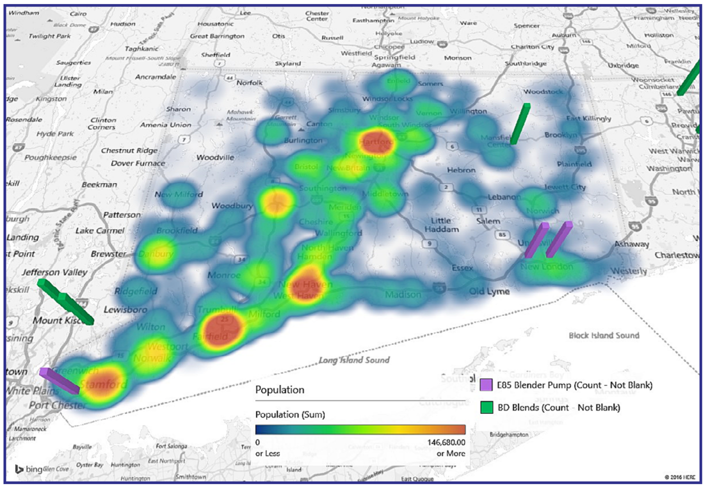
Connecticut has nine publicly accessible "primary" propane stations and 13 other propane stations, as defined by the U.S. Department of Energy.[3] Most propane stations are concentrated in the southwestern part of the state (see **Figure 16**). For CNG, Connecticut has seven public fueling stations, sited in some of the most populated parts of the state (see **Figure 17**). CNG stations could offer drivers natural gas or RNG (from dairy biogas or landfill/wastewater gas) depending on the site's configuration. The availability of these lower-carbon natural gas alternatives is limited in Connecticut. Existing biogas facilities are used for other purposes and no landfill gas is available. As with waste oil, an assessment is needed to determine if using biogas for transportation would provide more value to the state. For example, a new anaerobic digester project may produce more biogas than is needed for its primary use and transportation services could help to fill that gap.

Figure 14: Public electric vehicle charging infrastructure with population heat map



Some public charging infrastructure is available throughout the most populous parts of Connecticut. The height of the bar is proportional to the number of charging ports at a site.

Figure 15: Public Biodiesel and E85 stations with population heat map



Connecticut has only one biodiesel station (colored in green) and it does not offer B100. Each bar denotes a single fueling station.

Source: Atlas Public Policy analysis of data from the U.S. Census Bureau and the U.S. Department of Energy

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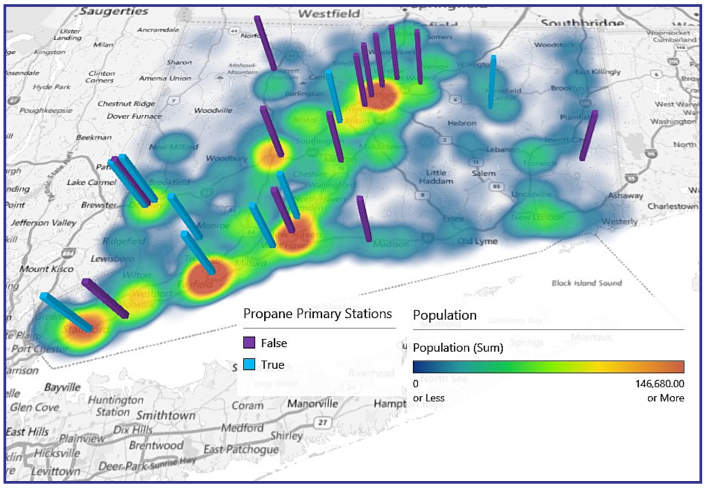
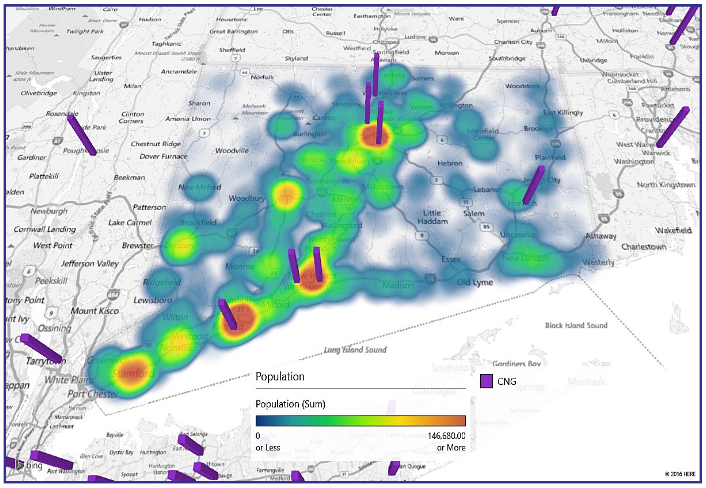
[3] Primary stations are those that offer fueling services consistently during business hours and special vehicle fuel pricing.

Figure 16: Public propane stations with population heat map



Connecticut has nine "primary" propane stations concentrated in the southwestern part of the state. The state has 13 other propane stations that have limited vehicle-specific fueling capabilities as defined by the U.S. Department of Energy. Each bar denotes a single fueling station.

Figure 17: Public CNG stations with population heat map



Connecticut has seven CNG stations located in some of the most populated regions of the state. Each bar denotes a single fueling station.

Source: Atlas Public Policy analysis of data from the U.S. Census Bureau and the U.S. Department of Energy

VEHICLE AVAILABILITY IN CONNECTICUT

Near-term consideration of an alternative fuel vehicle is only possible if the vehicle is readily available on the market. **Table 3** shows the vehicle-fuel combinations that exist in the 2016 U.S. vehicle market. Note that green indicates the vehicle is widely available, orange indicates some availability or that the vehicle-fuel combination has been used in demonstration projects in the United States, and purple indicates no availability.

Table 3: Expected Near-Term Availability of Alternative Fuel Vehicles in Connecticut

🟩 widely available 🟧 limited availability/demonstrations only 🟪 no availability

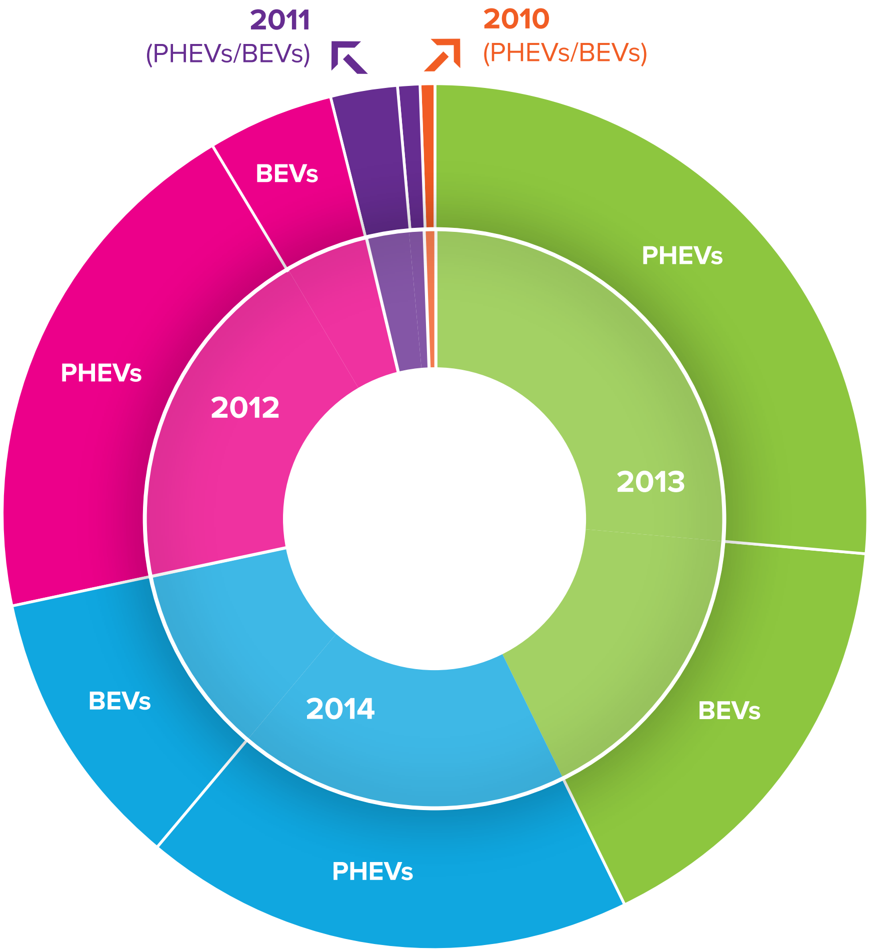
Vehicle Class	Vehicle Type	Biogas or Landfill Gas to RNG	Biodiesel (B100) or E85	Renewable Diesel	Electricity	Propane	CNG	LNG	Hydrogen (Gaseous)
Light-Duty	Passenger Cars	🟪	🟩	🟩	🟩	🟪	🟪	🟪	🟧
	Light Trucks	🟧	🟩	🟩	🟧	🟧	🟧	🟪	🟪
Medium- & Heavy-Duty	Beverage, Dump, Tow, Utility, Refrigerated Van	🟩	🟩	🟩	🟪	🟩	🟩	🟧	🟪
	Box Van, School Bus, Step Van	🟩	🟩	🟩	🟧	🟩	🟩	🟧	🟪
	Concrete Mixer, Trash	🟩	🟩	🟩	🟪	🟩	🟩	🟩	🟪
	Tractor Trailer	🟩	🟩	🟩	🟧	🟩	🟩	🟩	🟪
	Transit Bus	🟩	🟩	🟩	🟧	🟩	🟩	🟧	🟪

Source: Atlas Public Policy and Cadmus Group analysis using [38, 39]

Electric drive vehicles are increasingly available in Connecticut. **Figure 18** shows plug-in electric vehicle registrations in the state 2010 to 2014. Automakers have announced plans to introduce a number of new electric and hydrogen fuel cell cars in near term. For electric vehicles, upcoming offerings should give greater range and selection at a lower price than earlier offerings. For example, General Motors will introduce the 200-mile Chevy Bolt in late 2016 with a price of nearly $30,000 after federal tax incentives [40]. Honda expects to make the hydrogen-powered FCX Clarity available in California at the end of 2016 for about $60,000 [41].

While automakers continue to sell flex-fuel vehicles capable of running on E85, recent changes in compliance credits for federal vehicle standards could deter the widespread availability of these vehicles in the near future. Beginning in 2016, automakers must demonstrate their flex-fuel vehicles consumed an alternative fuel in order to receive credit [42].

Figure 18: Electric Vehicle Registrations in Connecticut (2010-2014)



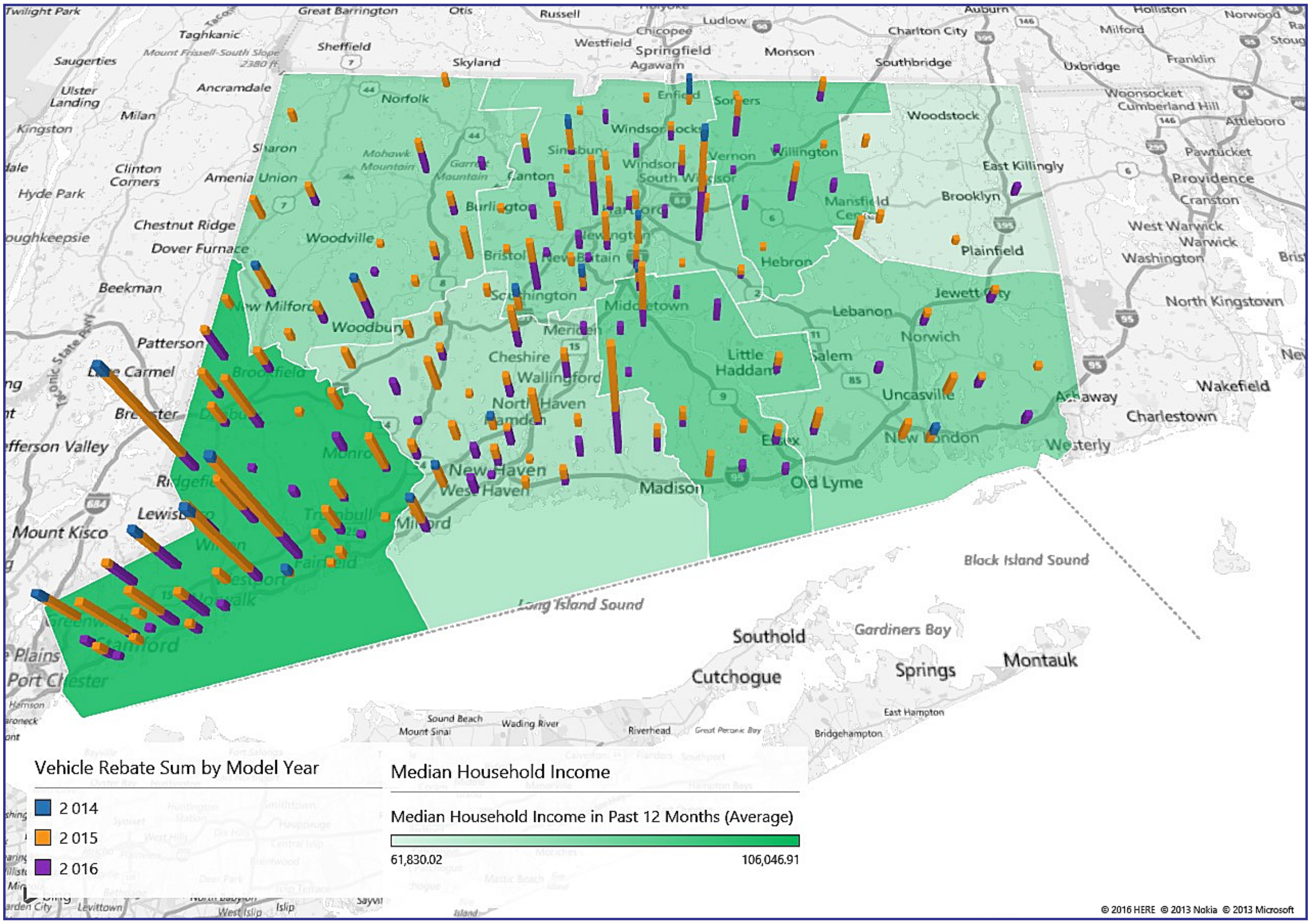
Source: Atlas Public Policy analysis of data from NREL.

Vehicle manufacturers have been generally slower to offer alternative fuel medium- and heavy-duty trucks. Diesel substitutes like biodiesel and renewable diesel can be used in any diesel vehicle type, although some engine manufacturers still void warranties in biodiesel blends over 20 percent [43]. Most categories of trucks have CNG and propane versions, or versions that can run on RNG [28]. Additionally, retrofit companies can install CNG or propane tanks and engines on most truck types. However, while several demonstration or prototype vehicles have been built for electric and hydrogen fuel cell vehicles, these offerings are much more limited.

PUBLIC POLICY EFFECTS

Connecticut has a number of incentives and regulations in place to encourage the adoption of alternative fuel vehicles. The most notable program is the Connecticut Hydrogen and Electric Automobile Purchase Rebate (CHEAPR) Program, which provides a rebate of up to $5,000 off the purchase price of a hydrogen fuel cell vehicle or up to $3,000 off a plug-in electric vehicle (see **Figure 19**). As other states like Georgia and California have demonstrated, the program has the potential to be a significant driver of vehicle adoption if adequately funded and promoted. Another key initiative is the state's participation in California's Zero Emission Vehicle program, which requires automakers to attain an increasing amount of zero emission vehicle credits based on the number of vehicles produced and delivered for sale in participating states. One way automakers can earn credits is to produce and deliver for sale electric and hydrogen fuel cell vehicles in these states [44]. As a result, this program provides an incentive for automakers to encourage the sale of these passenger vehicles in Connecticut.

Figure 19: Electric Vehicle Rebates and Median Household Income



As of February 2016, Connecticut drivers from all counties have purchased electric vehicles through the state's rebate program. The map shows median household income by county with electric vehicle rebates by ZIP code to illustrate that these vehicles are being deployed in economically diverse communities.

Source: Atlas Public Policy Analysis of data from the U.S. Census Bureau and the Connecticut Department of Energy and Environmental Protection

The Connecticut Department of Transportation also administers the Connecticut Clean Fuel Program, which provides grants to municipalities and public agencies for the purchase, operation, and maintenance of alternative fuel vehicles. The state also has a number of policies in place to address other deployment issues, such as labeling requirements and fuel tax policies. While these policies may not have a significant effect on deployment, they provide evidence of stakeholder interest in the relevant alternative fuels.

At the federal level, two key policies driving the expansion of alternative fuels and vehicles are the plug-in electric vehicle tax credit [45], which provides a tax credit worth up to $7,500 for the first 200,000 electric vehicles manufactured by an automaker and the Renewable Fuel Standard [46], a market-based system of tradeable credits that categorizes renewable fuels by their carbon content. See **Table 4** for a full list of policies in place in Connecticut according the U.S. Department of Energy's Alternative Fuel Data Center.

Table 4: Active Federal and State Policies for Alternative Fuel Vehicles

Policy Description	Category	Start Date
Qualified Plug-In Electric Drive Motor Vehicle Tax Credit	Federal Incentives	1/1/2010
Fuel Cell Motor Vehicle Tax Credit	Federal Incentives	1/1/2015
Alternative Fuel Excise Tax Credit	Federal Incentives	1/1/2015
Alternative Fuel Infrastructure Tax Credit	Federal Incentives	1/1/2015
Biodiesel Income Tax Credit	Federal Incentives	1/1/2005
Biodiesel Mixture Excise Tax Credit	Federal Incentives	1/1/2005
Ethanol Infrastructure Grants and Loan Guarantees	Federal Incentives	11/2/2015
Renewable Fuel Standard (RFS) Program	Laws and Regulations	9/1/2007
Aftermarket Alternative Fuel Vehicle Conversion Requirements	Laws and Regulations	Unknown
Alternative Fuel and Advanced Technology Vehicle Grants	State Incentives	Unknown
Alternative Fuel and Fuel-Efficient Vehicle Acquisition and Emissions Reduction Requirements	Laws and Regulations	Unknown
Alternative Fuel Vehicle Procurement Preference	Laws and Regulations	Unknown
Biofuels Research Grants	State Incentives	Unknown
Compressed Natural Gas Tax	Laws and Regulations	6/11/2014
Electric Vehicle Emissions Inspection Exemption	State Incentives	Unknown
Electric Vehicle Supply Equipment Grants	State Incentives	7/15/2014
Emissions Reduction Credits	Laws and Regulations	Unknown
Ethanol Labeling Requirement	Laws and Regulations	Unknown
Hydrogen and Plug-In Electric Vehicle Rebate	State Incentives	Unknown
Idle Reduction Requirement	Laws and Regulations	Unknown
Idle Reduction Weight Exemption	State Incentives	7/8/2009
Low Emission Vehicle Standards	Laws and Regulations	Unknown
Reduced Registration Fee for Electric Vehicles	State Incentives	1/1/2013
School Bus Emissions Reduction	Laws and Regulations	Unknown
Vehicle Greenhouse Gas Labeling Requirement	Laws and Regulations	Unknown
Zero Emission Vehicle Deployment Support	Laws and Regulations	10/24/2013
Zero Emissions Bus Implementation Plan	Laws and Regulations	7/2/2009

Connecticut has a broad range of policies and programs to support alternative fuel vehicles.

Source: [47]

SUMMARY

When relying only on the near-term factors, a number of vehicle and fuel combinations appear to have a low market potential. As the state looks to prioritize its resources to achieve its environmental, energy, and economic objectives, an assessment of the near-term provides a valuable criterion to narrow the state's focus. To that end, the following vehicle and fuel combinations appear to have the greatest near-term potential:

- **Passenger electric vehicles:** Electric vehicles are presently a popular alternative fuel vehicle in the light-duty segment and are expected to experience continued investment from automakers, government, and other private sector entities in the near term. Other factors affecting their near-term potential include:
  - Connecticut follows the California Zero Emission Vehicle Program and has developed a sizeable vehicle incentive known as CHEAPR. As of February 2016, the program has issued 448 rebates for electric vehicles since May 2015 [48].
  - The state has over 210 Level 2 charging sites (388 charging ports) and 29 DC fast charging sites as of April 2016 [49].
- **Renewable diesel used in existing diesel engines:** Because the vast majority of the state's medium- and heavy-duty vehicles run on diesel, renewable diesel offers the greatest near-term promise as a replacement fuel. Several corporations and public entities have announced plans to switch their fleet diesel vehicles to renewable diesel (e.g., City of San Francisco, City of Oakland, State of California, UPS). The price of renewable diesel benefits from current policy incentives such as the Renewable Fuel Standard and biodiesel tax credits ($1 per gallon) (see **Table 4**). The main barrier to introducing renewable diesel in the state is the limited number of suppliers, as noted above. Biodiesel is another possible diesel replacement, but wintertime gelling concerns and competition for other uses (e.g., heating oil) limits its feasibility [50].

Environmental Performance Criterion

In addition to affordability and reliability, Connecticut identifies environmental performance as one of the three key aspects of any form of energy that the state should support. For the environmental performance criterion, the greenhouse gas emissions from a variety of vehicle and fuel combinations was assessed. Following an assessment of greenhouse gas emissions for vehicles and fuels, a summary is provided of the most desirable alternative fuel and vehicle combination for light-, medium-, and heavy-duty vehicles based only on environmental performance.

An assessment of the environmental performance of alternative fuels and vehicles depends in part on the method of measurement. The measurements can rely on assumptions related to vehicle efficiency, vehicle lifetime, fuel carbon intensity, travel, and fleet size. Emissions can be measured on a per-mile basis, taking into account the vehicle's fuel economy and the carbon intensity of the fuel. Emissions can also be measured annually, building off the per-mile method and incorporating the expected miles traveled yearly. A third measurement method factors in the number of vehicles on the road, which is useful when considering emissions with cumulative effects, like greenhouse gases.

LIGHT-DUTY VEHICLES

Various alternative fuels could potentially power light-duty vehicles in Connecticut. For the purposes of this assessment, only passenger cars were evaluated due to broad market availability of alternative fuel vehicles for this segment. In addition, CNG-powered passenger cars are excluded from this assessment, since they are not expected to be broadly available in the near term.

Table 5: Passenger Vehicle Configurations

Primary Fuel	Drivetrain	Primary Fuel	Secondary Fuel	Emission Scenario
Gasoline Car	Conventional drivetrain	E10	N/A	High
	Hybrid electric drivetrain	E10	N/A	Low
E85 Car	Conventional drivetrain (flex fuel)	E85	N/A	High
	Hybrid electric drivetrain (flex fuel)	E85	N/A	Low
Hydrogen Car	Fuel cell drivetrain	Gaseous hydrogen (natural gas)	N/A	High
	Fuel cell drivetrain	Gaseous hydrogen (solar)	N/A	Low
Battery Electric Car	Battery electric drivetrain	Average Northeast Electricity Mix	N/A	High
	Battery electric drivetrain	Solar Electricity	N/A	Low
Plug-in Hybrid Electric Car	Plug-in hybrid electric drivetrain	E10	Average Northeast Electricity Mix	High
	Plug-in hybrid electric drivetrain	E10	Solar Electricity	Low

In the above table, Average Northeast Electricity Mix refers to the average mix in the Northeast Power Coordinating Council grid according to GREET. This grid includes the six New England states and New York.

Source: Atlas Public Policy analysis using Argonne National Laboratory's GREET model, 2016.

The assessment evaluated vehicles powered by gasoline, E85, hydrogen, and electricity. Since the environmental performance depends on the carbon intensity of the fuel and the vehicle's efficiency, a low and high emissions scenario was considered. All vehicles evaluated besides plug-in hybrid electric vehicles can be powered by only one fuel. **Table 5** summarizes the passenger vehicles and fuels considered in the environmental performance assessment.

The next three figures summarize the environmental performance of passenger vehicles and alternative fuels from three perspectives using Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model.

The analysis is lifecycle-based and only considered presently available technology. **Figure 20** shows emissions on a per-mile basis, which incorporates fuel carbon intensity and vehicle fuel economy. **Figure 21** shows annual emissions on a per-vehicle basis, which incorporates average annual travel. Finally, **Figure 22** shows annual emissions for the entire passenger car fleet to show potential emission savings for a total fleet transition.

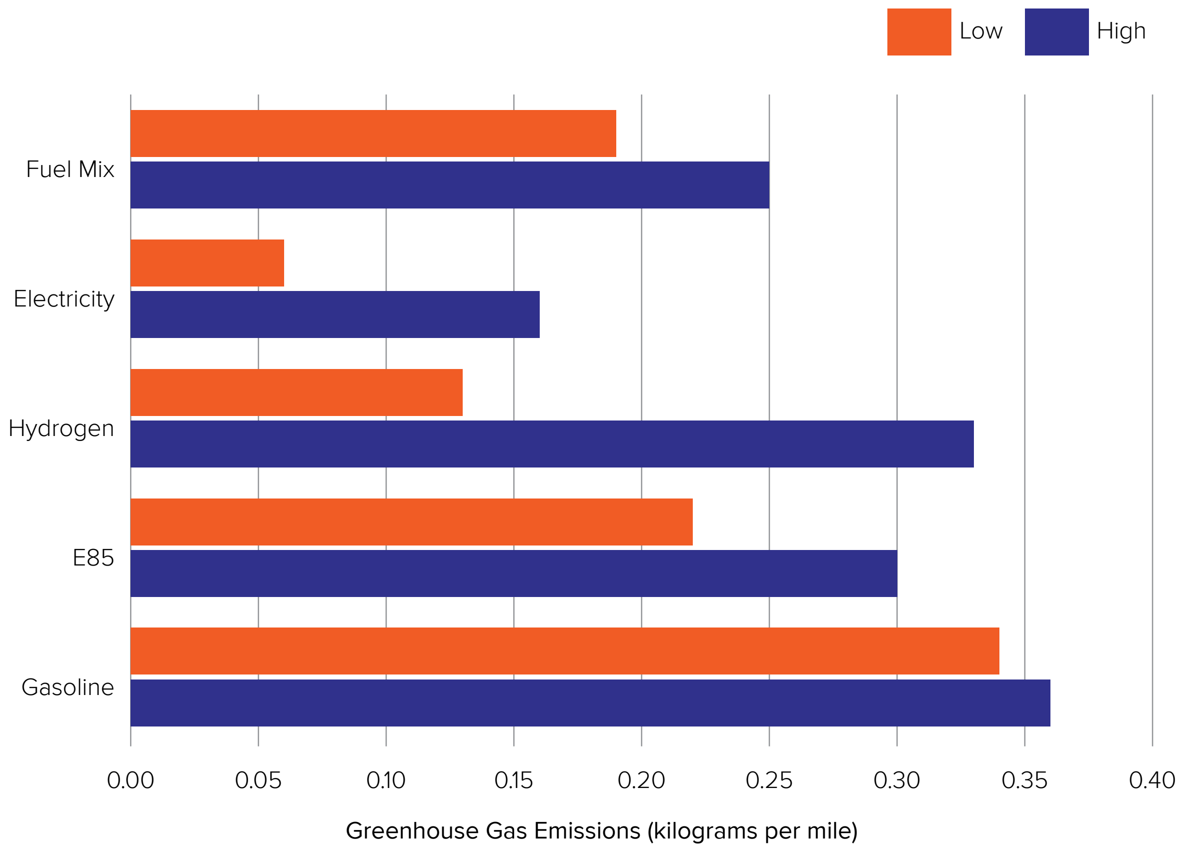
Each figure is proportional since the assumptions about travel and fleet size are constant across all vehicles. The perspectives offered by **Figure 21** and **Figure 22** may be most useful when comparing the environmental performance of passenger vehicles with other vehicle classes.

While improved fuel economy through hybridization and other means can greatly reduce emissions from gasoline vehicles in the future, a near-term assessment shows alternative fuels hold the most promise to reduce emissions. For example, an electric vehicle powered by average electricity in the northeast has 55 percent fewer emissions than a gasoline vehicle. If renewable electricity is used, electric vehicles have over 80 percent lower emissions than the gasoline vehicle.

Leveraging existing programs to reduce emissions from the power sector, including RGGI and the state's RPS, could decrease the mitigation cost from transportation through the greater deployment of electric vehicles.

A similar potential exists for reducing emissions using hydrogen fuel cell vehicles. Emissions can be decreased by between 7 and 64 percent depending on the hydrogen feedstock.

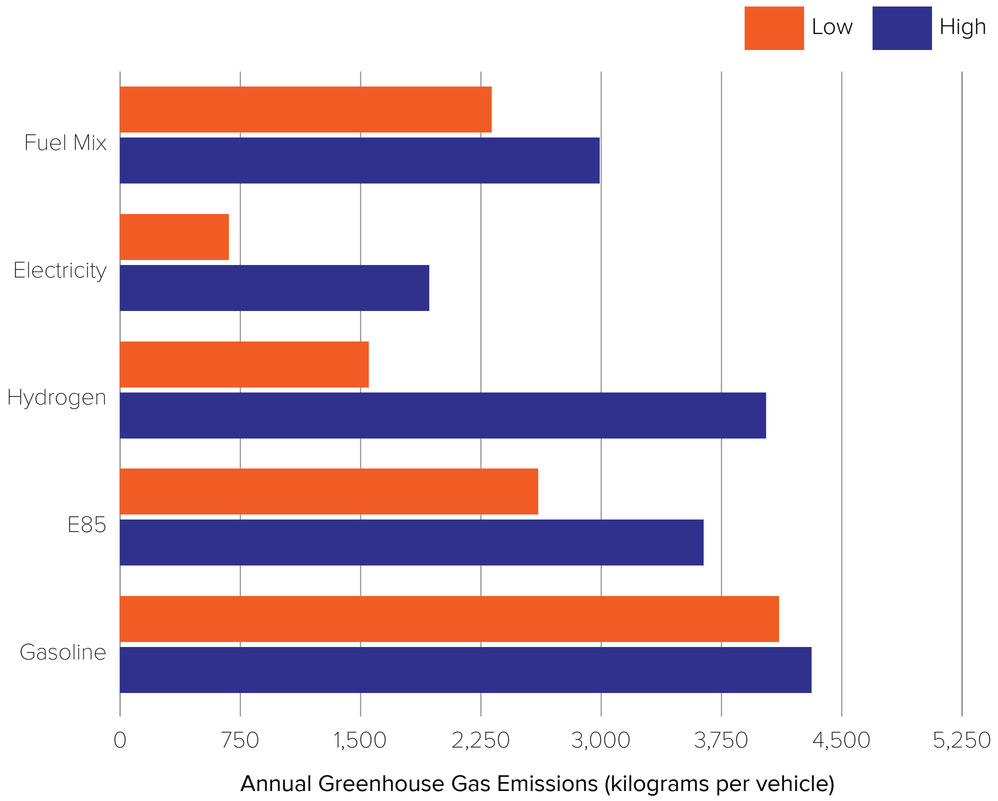
Figure 20: Environmental Performance of Various Passenger Vehicles on a Per-mile Basis



Fuel Mix is a plug-in hybrid electric vehicle, Electricity is a battery electric vehicle, Hydrogen is a fuel cell vehicle, and E85 and Gasoline are conventional and hybrid vehicles. For Fuel Mix and Electricity, Northeast Grid Mix refers to the average electricity mix according to GREET. Low and High corresponds to the Emissions Scenario column of Table 5*.*

Source: Atlas Public Policy analysis using Argonne National Laboratory's GREET Model, 2016

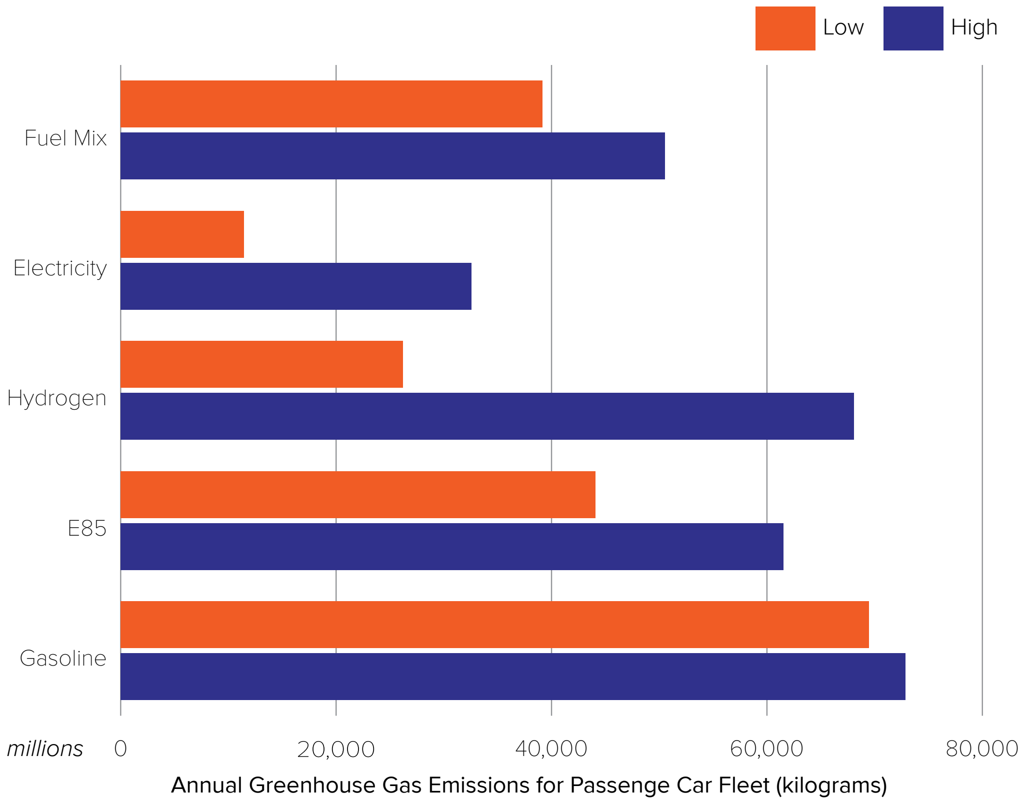
Figure 21: Environmental Performance of Various Passenger Vehicles on an Annual Per-vehicle Basis



Fuel Mix is a plug-in hybrid electric vehicle, Electricity is a battery electric vehicle, Hydrogen is a fuel cell vehicle, and E85 and Gasoline are conventional and hybrid vehicles. For Fuel Mix and Electricity, Northeast Grid Mix refers to the average electricity mix according to GREET. Low and High corresponds to the Emissions Scenario column of Table 5.

Source: Atlas Public Policy analysis using Argonne National Laboratory's GREET Model, 2016

Figure 22: Environmental Performance of Various Passenger Vehicles for Connecticut Passenger Vehicle Fleet on an Annual Basis



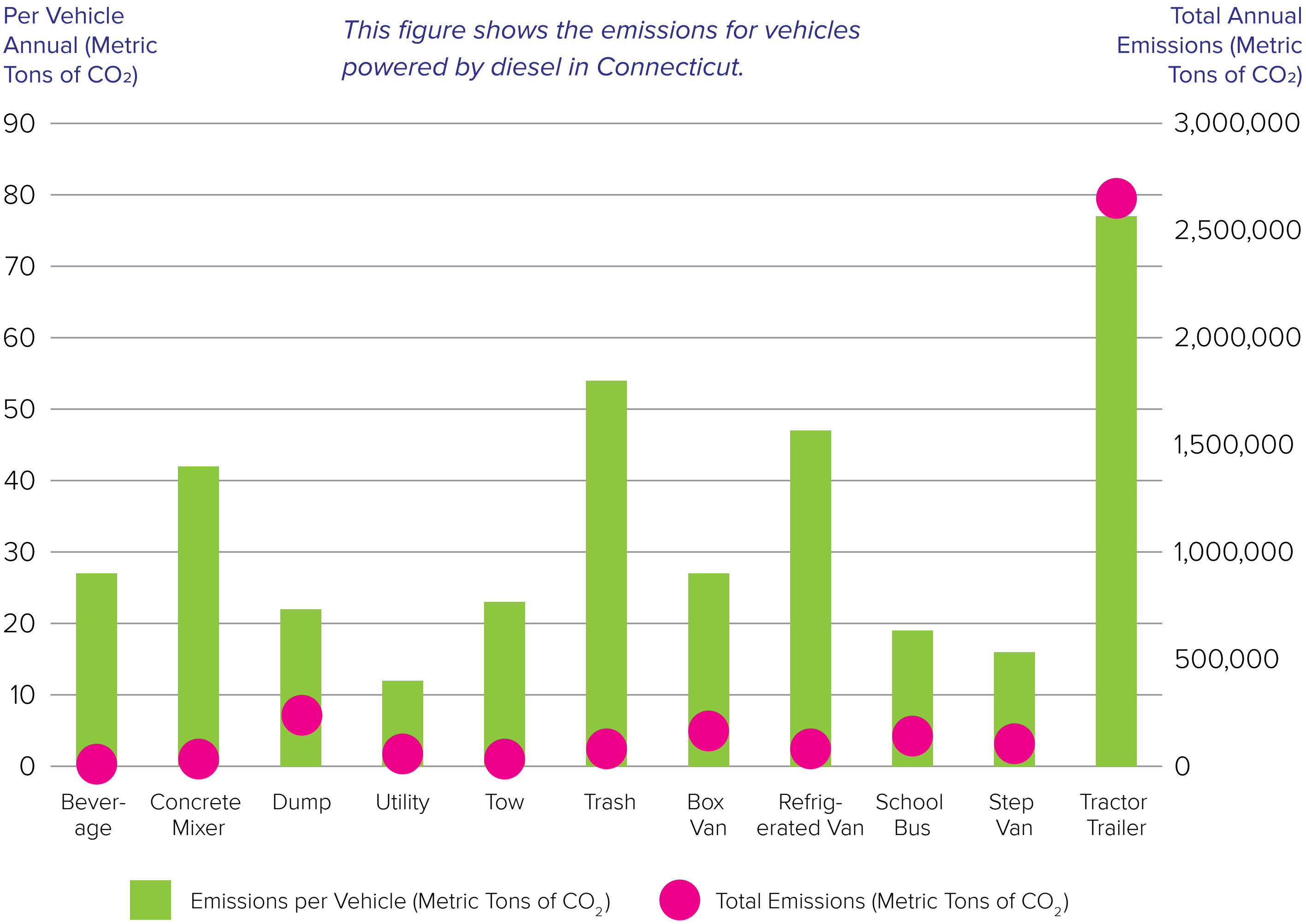
Fuel Mix is a plug-in hybrid electric vehicle, Electricity is a battery electric vehicle, Hydrogen is a fuel cell vehicle, and E85 and Gasoline are conventional and hybrid vehicles. For Fuel Mix and Electricity, Northeast Grid Mix refers to the average electricity mix according to GREET. Low and High corresponds to the Emissions Scenario column of Table 5.

Source: Atlas Public Policy analysis using Argonne National Laboratory's GREET Model, 2016

MEDIUM- AND HEAVY-DUTY VEHICLES

Figure 23 below shows annual CO_2 emissions on a per vehicle basis and on an aggregate emissions basis (i.e., for all vehicles in a given vehicle category). Data on total transit buses was not available. Information about the data behind the figure is in the Appendix A. Tractor trailers in Connecticut have both the highest emissions per vehicle (76 metric tons of CO_2 per vehicle per year) and highest aggregate emissions (2.45 million metric tons of CO_2 per year) of any vehicle category. This is due to their high annual mileage, low relative fuel economy, and high vehicle population. In other vehicle categories, there is a tradeoff between reducing the per vehicle emissions and reducing aggregate emissions from a category. For example, replacing a single trash truck with an alternative fuel vehicle will have a larger beneficial impact than replacing a single dump truck. However, replacing all dump trucks with alternative fuel vehicles has a larger net impact than replacing all trash trucks. Estimates in this figure are described in Appendix B.

Figure 23: Per Vehicle and Aggregative Emissions from Medium- and Heavy-Duty Vehicles

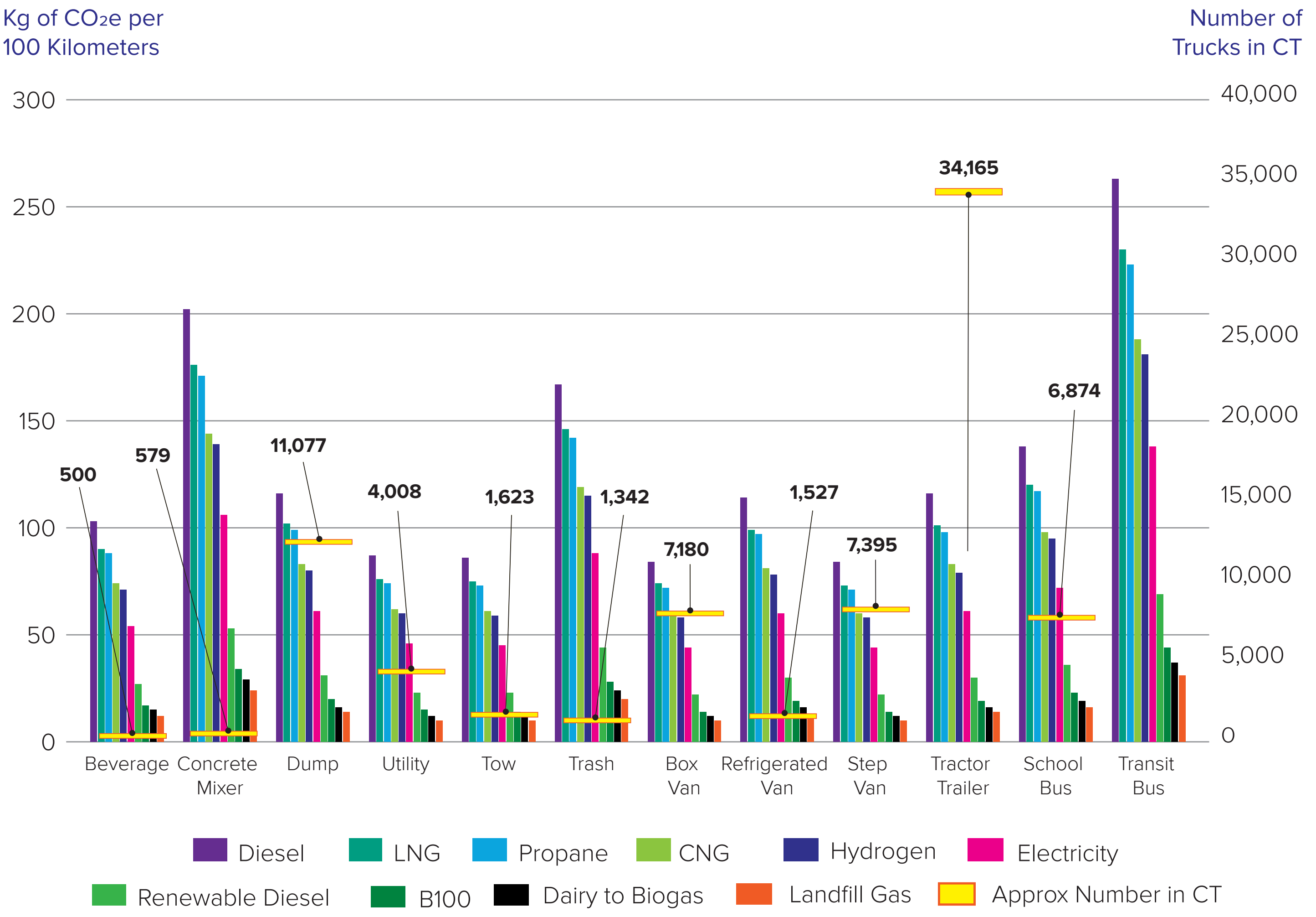


This figure shows the emissions for vehicles powered by diesel in Connecticut.

Source: Cadmus Group calculations using VIUS, 2002

A third perspective to consider other than per-vehicle and total emissions from a given vehicle category, is the greenhouse gas emissions per distance traveled. **Figure 24** shows the estimated greenhouse gas intensity per 100 kilometers and vehicle population for the 12 vehicle categories in Connecticut. Across vehicle types, landfill gas has the lowest greenhouse gas intensity (in kilograms of CO_2 per 100 kilometers) of any replacement fuel examined, closely followed by RNG from dairy biogas and biodiesel (B100). As with the figure above, **Figure 24** highlights a tradeoff for most vehicle categories between reducing the per vehicle emissions and aggregate emissions from a category. Estimates in this figure come directly from weighted responses in the VIUS survey as described in Appendix B.

Figure 24: Greenhouse Gas Emission Intensity and Vehicle Population by Truck Vocation



Sources: Cadmus Group calculations using [51, 24]

Criteria pollutant emissions is another environmental performance category. Across the eight fuel types discussed in this section, only battery electric and gaseous hydrogen have the potential to eliminate criteria pollutant emissions at the tailpipe, although some upstream emissions may still occur depending on the source of electricity or hydrogen. Compared to conventional diesel, RNG from landfill gas or dairy biogas, CNG, and LNG have approximately half to two-thirds lower NO_x emissions, similar levels of particulate matter emissions, and approximately three times higher volatile organic compound (VOC) emissions, which can combine with NO_x to form ground-level ozone. Biodiesel has about 20 percent higher NO_x emissions than diesel but similar emission levels for other pollutants. Renewable diesel produces similar emission levels as diesel.

SUMMARY

The greater use of electricity, renewable biofuels, landfill gas, and hydrogen can significantly reduce greenhouse gas emissions in Connecticut. The environmental performance of an alternative fuel vehicle is one of the three reasons for encouraging its use that the state identified in its energy strategy [18]. The following vehicle and fuel combinations appear to have the greatest potential to reduce greenhouse gas emissions:

- **Passenger electric and hydrogen fuel cell vehicles:** Electric drive vehicles powered by rechargeable batteries or hydrogen offer the greatest potential to reduce emissions from passenger vehicles. To achieve the greatest reductions, the electricity and hydrogen must come from low-carbon feedstocks.
- **RNG from landfills and dairy farms used in compressed natural gas engines:** The favorable environmental performance of RNG is mainly due to its displacement effect – i.e., the dairy biogas and landfill gas would be released to the atmosphere were it not combusted in an engine. As mentioned earlier, Connecticut does not have excess biogas supply and would need to develop new production facilities or import biogas to provide this alternative fuel to medium- and heavy-duty vehicles.

Cost Effectiveness Criterion

The affordability of an energy source relative to gasoline- or diesel- powered vehicles is one the three key factors Connecticut identified in its energy strategy [18]. In this analysis, the cost effectiveness of alternative fuels was evaluated using greenhouse gas emission abatement cost.

The costs of using alternative fuels includes the lifetime costs of owning and operating an alternative fuel vehicle and, potentially, its associated infrastructure. In this analysis, the cost of alternative fueling infrastructure is not considered.

Cost effectiveness of using alternative fuels is included for individuals and fleets. Vehicle owners can be an individual or a fleet while infrastructure can be owned by the vehicle operator or a third party. While, fleets could operate light-, medium-, or heavy-duty vehicles, the analysis assumed individuals operate a passenger vehicle and fleets operate a medium- or heavy-duty vehicle. For individual vehicles, the analysis used the U.S. Department of Energy's Vehicle Cost Calculator, a free tool available online. For fleets, the analysis used the AFLEET model, another free tool developed by Argonne National Laboratory.

To make cost effectiveness calculations, a reference case technology was compared to a replacement technology, and the difference in cost was divided by the difference in CO_2 emissions, resulting in a dollars-per-ton mitigated.

PASSENGER VEHICLES

The Vehicle Cost Calculator is an online tool that relies on basic information about driving habits to calculate total cost of ownership and emissions for many vehicles. The vehicles in **Table 6** were selected to allow for an approximate apples-to-apples comparison. The tool includes native support for many alternative fuels, except hydrogen.

Two hydrogen fuel cell passenger cars are available for purchase or lease in the United States.[4] Both vehicles are currently only available in California [52]. The Toyota Mirai gets about 66 miles per gasoline-gallon equivalent at a price of $57,000 [53]. The federal government website, fueleconomy.gov estimates hydrogen could cost as low as $5.55 per kilogram (a kilogram of hydrogen is roughly the same as a gasoline-gallon) [54].[4] The total cost of ownership for the Mirai was estimated using these data on hydrogen fuel cell vehicles and additional assumptions from the Vehicle Cost Calculator for electric vehicles (see Appendix C). In addition, the analysis included Toyota's current policy of covering hydrogen fuel costs for the first three years of vehicle ownership.

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[4] The Hyundai Tucson fuel cell vehicle is available for lease in California only and "will be available in other regions as fueling infrastructure becomes available." See https://www.hyundaiusa.com/tucsonfuelcell

Table 6: Vehicles Compared Using the Vehicle Cost Calculator

Vehicle Make and Model	Model Year	Fuel Economy (City/Highway)	Fuel Type	Vehicle Price (with & without incentives)	Fuel Price
Chevrolet Cruze	**2016**	22/35 mpg	Gasoline	$16,120	$2.50/gallon
Nissan LEAF (24kWh)	**2016**	126/101 mpge	Electricity	$29,010, $18,510	$0.21/kWh, $0.11/kWh
Chevrolet Volt	**2016**	43/42 mpg 116/99 mpge	Gasoline/ Electricity	$33,170, $22,670	$2.50/gallon, $0.21/kWh
E85 Car	**2016**	16.5/26.25 mpg	E85	$16,120	$2.75/gallon
Toyota Mirai	**2016**	66 mpge	Hydrogen	$57,000, $46,000	$5.55/kilogram

The first three vehicles in this table are available nationwide. In this table, the fuel economy of electric vehicles powered by rechargeable batteries and hydrogen fuel cell vehicles is in mile per gasoline-gallon equivalent (mpge). For the Nissan LEAF, the first fuel price is for grid-based electricity and the second price is for incentive-based residential solar, as explained in Box 3*. E85 car was a custom vehicle in order to evaluate an E85-powered vehicle similar to the Chevrolet Cruze. Fuel prices are in gasoline gallons, E85 gallons, kilowatt-hours (kWh), or kilograms.*

Source: [55]

Box 3

Comparing Solar and Gasoline Costs in Connecticut

Connecticut's solar industry has grown rapidly in the last five years, reaching 127 megawatts of installed capacity in early 2016 [56]. An internal analysis by the Connecticut Green Bank estimated homeowners would spend $0.11 per kilowatt-hour to install and operate 3 kilowatts of residential solar for dedicated use by an electric vehicle. Without federal and state incentives, that cost would rise to $0.18 per kilowatt-hour, which is lower than the current cost of residential electricity in the state. In gallons of gasoline equivalent, the cost to fuel an electric vehicle with residential solar would be about $1 per gallon with incentives and $1.63 per gallon without incentives.[5]

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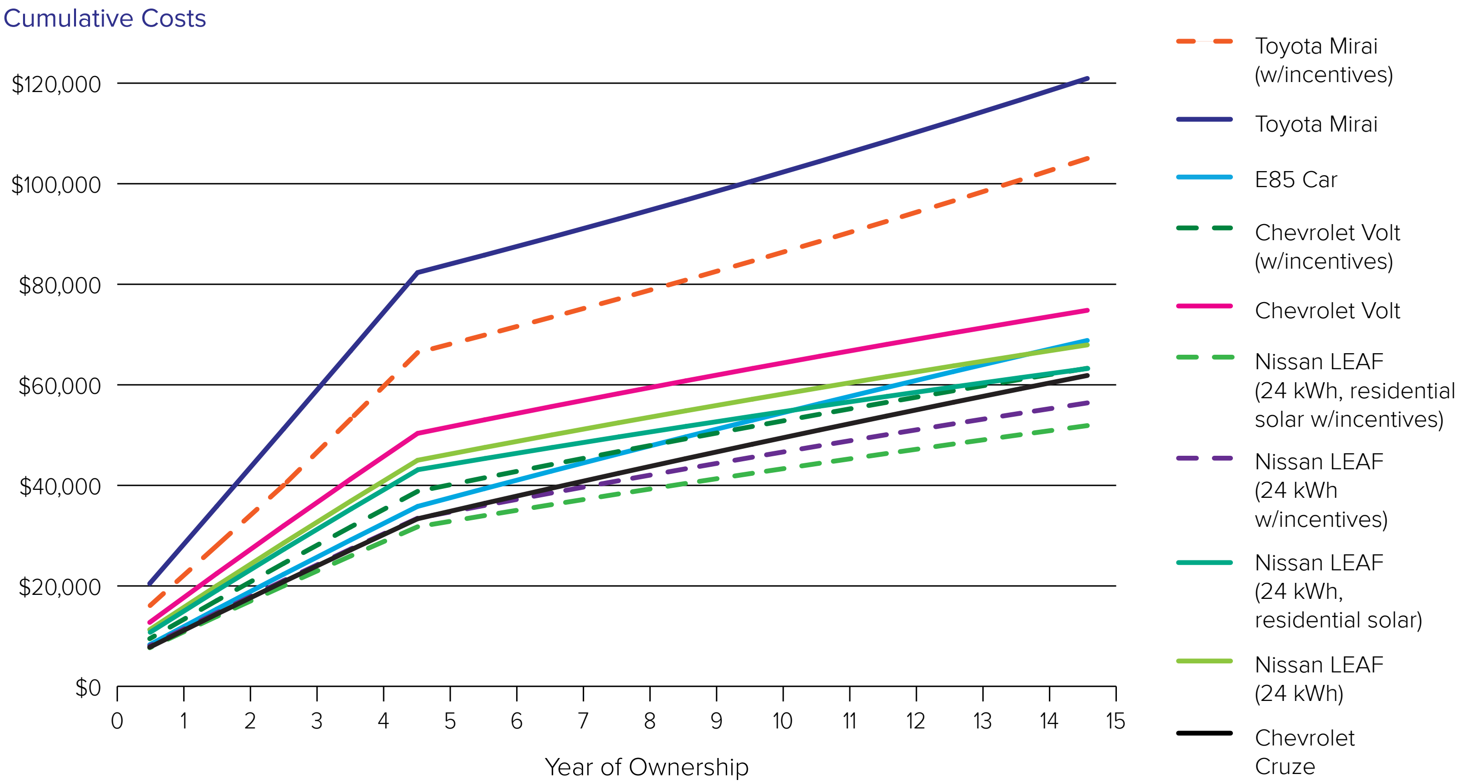
[5] Gasoline-gallon equivalent cost calculated using U.S. Department of Energy's eGallon methodology: http://energy.gov/downloads/egallon-methodology.

With existing federal and state vehicle incentives, the analysis shows that the Nissan LEAF is the least expensive vehicle for drivers in Connecticut, assuming gasoline costs about $2.50 per gallon. When including residential solar incentives, LEAF drivers who use solar to recharge their vehicles can achieve the lowest lifetime cost (see **Box 3**).[6] With vehicle incentives, the Chevrolet Volt is only $1,500 more expensive than the gasoline vehicle. The E85 car is more expensive than a gasoline vehicle since it performs similarly at a higher fuel cost. The Toyota Mirai is the most expensive vehicle by several thousand dollars. Importantly, the Mirai is the first generation of fuel cell vehicles and has not benefited from cost reductions due to mass production and learning by doing. The gasoline vehicle is the least expensive option when no vehicle incentives are available (see **Figure 25**).

Figure 25: Discounted Lifetime Costs of Various Passenger Vehicles in Connecticut



Where noted, the Nissan LEAF, Chevrolet Volt, and Toyota Mirai graphs include the federal tax credits and Connecticut vehicle rebate. Gas prices were assumed to be $2.50 per gallon and current residential electricity prices in Connecticut were used, except for the residential solar scenario. The price of E85 was the approximate fuel price in New England in the fourth quarter of 2015 from the Clean Cities Alternative Fuel Price Report. The analysis assumed the E85 car only used E85. The cost estimate for the Toyota Mirai was calculated by Atlas Public Policy for the purpose of this research (see Appendix C).

Source: Atlas Public Policy analysis using Vehicle Cost Calculator and independent analysis.

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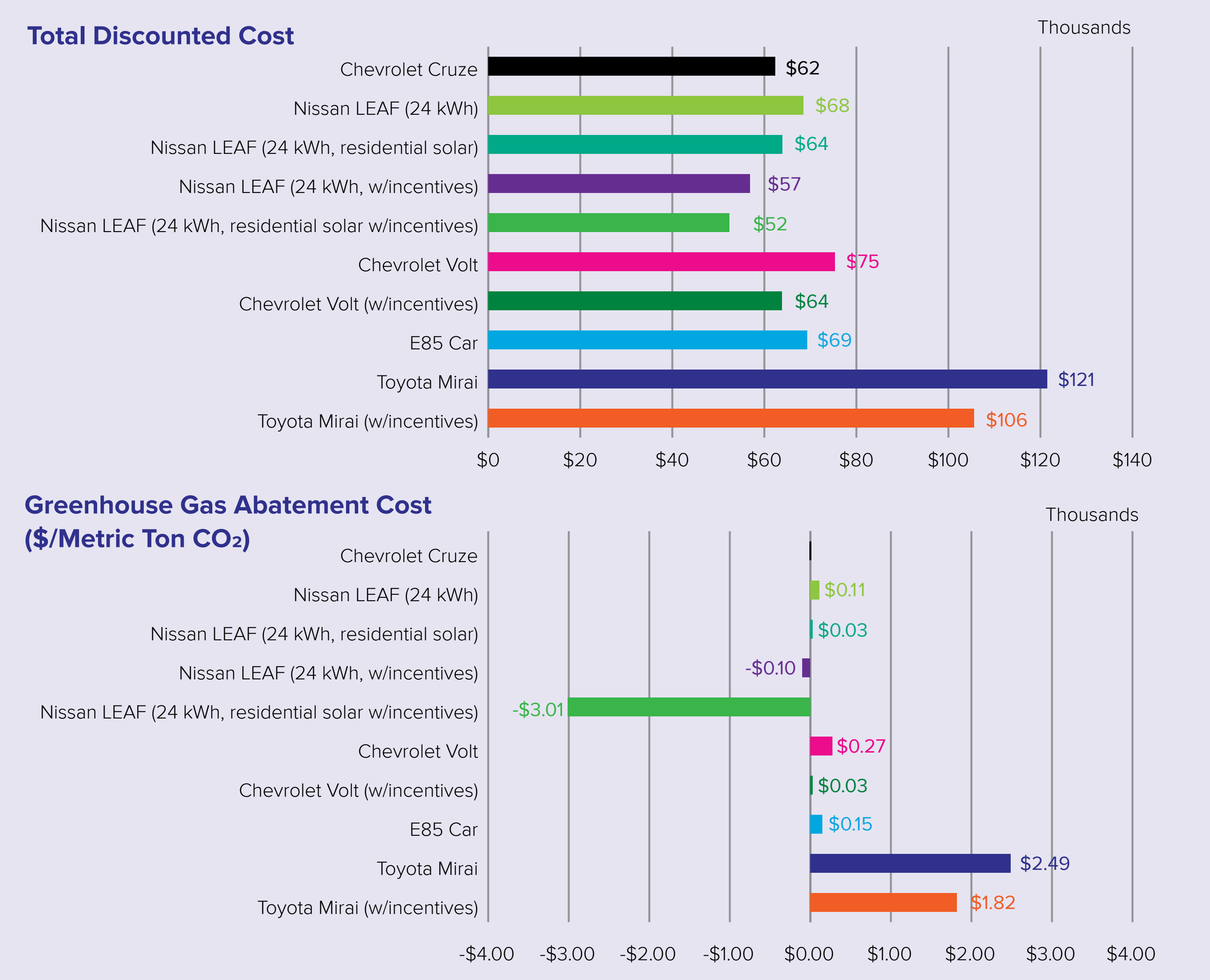
[6] All additional assumptions used in the Vehicle Cost Calculator analysis are the default values for the tool.

The analysis also shows that greenhouse gas emissions can be cost-effectively reduced in Connecticut with electric vehicles. Without vehicle incentives and with solar incentives, the cost of greenhouse gas abatement for the all-electric Nissan LEAF is less than the federal government's social cost of carbon ($41 per metric ton of CO_2 in 2016 dollars) [57]. The abatement cost for the Chevrolet Volt is higher than the social cost of carbon without incentives and lower with incentives. The E85 vehicle does not have an abatement cost since it is estimated to emit more greenhouse gases than the Chevrolet Cruze. The Toyota Mirai has an abatement cost of 1.8 and 2.5 thousand dollars per ton with and without incentives, respectively (see **Figure 26**).

Figure 26: Total Discounted Lifetime Cost and Greenhouse Gas Abatement Cost for Passenger Vehicles in Connecticut



Source: Atlas Public Policy analysis using Vehicle Cost Calculator.

This figure shows the total cost of ownership for several passenger vehicles and their associated greenhouse gas abatement cost. Greenhouse gas emissions are fuel lifecycle emissions, accounting for fuel combustion and upstream emissions. Emissions from vehicle production and disposal are not included. With incentives, the Nissan LEAF has a lower total cost of ownership than the Chevrolet Cruze resulting in a negative abatement cost. The E85 car is estimated to emit more greenhouse gases than the Cruze, so it does not have an abatement cost.

Drilling into the analysis results offers insight into the efficiency benefits of electric drive over conventional vehicles. Even when gasoline prices are $2.50 per gallon and vehicles are recharged on the electrical grid, the cost per mile of the Volt and LEAF are 11 and 14 percent lower than the Chevrolet Cruze, respectively. When using incentive-based residential solar, the cost per mile of the LEAF is 25 percent lower than the Cruze. Gasoline would have to be $0.80 per gallon for the Cruze to cost less to operate than the LEAF or Volt. From an environmental perspective, the Vehicle Cost Calculator estimates the Volt and LEAF only emit a fraction of the CO_2 emissions compared to the gasoline and E85 vehicles. The Vehicle Cost Calculator includes emissions from fuel combustion in the vehicle and upstream emissions for electric vehicles; the tool does not include lifecycle emissions as found in the *Environmental Performance Criterion* section.

Table 7: Detailed Results of Lifecycle Cost Analysis

Vehicle Make and Model	Annual Fuel Use (gallons/ kilograms)	Annual Electricity Use (kWh)	Annual Fuel/ Electricity Cost	Annual Operating Cost	Cost Per Mile	Annual Emissions (pounds CO_2)
Chevrolet Cruze	430	0	$1,076	$3,333	$0.28	10,326
Nissan LEAF (24 kWh)	0	3,620	$756	$2,861	$0.24	2,243
Nissan LEAF (24 kWh, residential solar)	0	3,620	$398	$2,503	$0.21	0
Chevrolet Volt	68	2,812	$759	$3,017	$0.25	3,386
E85 Car	574	0	$1,578	$3,835	$0.32	10,882
Toyota Mirai	181	0	$1,177	$2,480	$0.31	6,836

All data above is from the Vehicle Cost Calculator except for the data for the Toyota Mirai, which was estimated by Atlas Public Policy based on the Vehicle Cost Calculator methodology. The Toyota Mirai emissions are well-to-pump as defined by GREET. The figures for the Nissan LEAF with solar include federal and state incentives.

Source: Atlas Public Policy Analysis and [55]

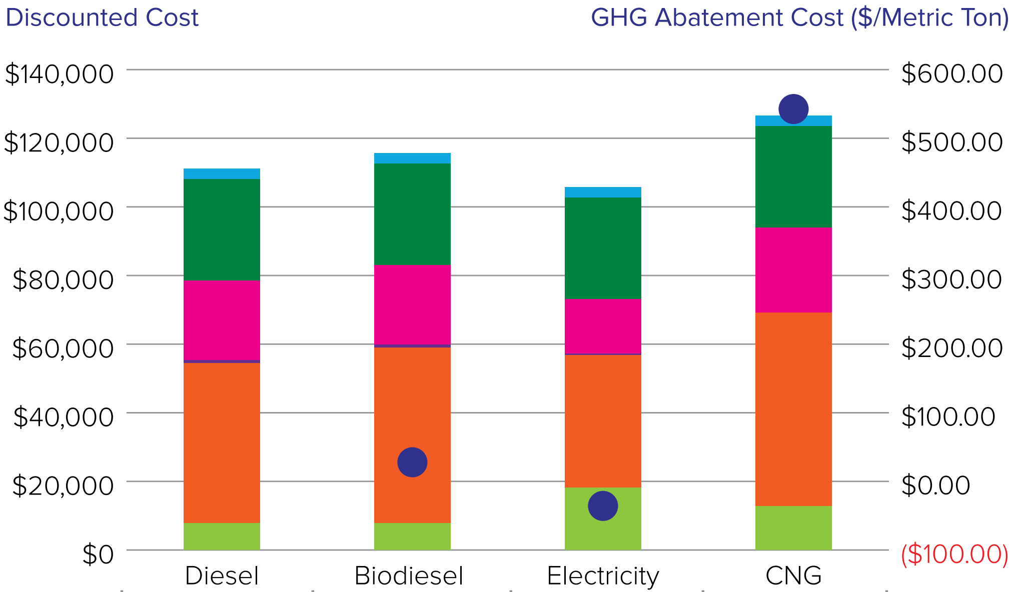
The analysis does not include the cost of charging or refueling infrastructure. For E85 and hydrogen fuel cell vehicles, consumers are very unlikely to provide infrastructure for their vehicles directly. Many consumers can recharge an electric vehicle conveniently at home, however, which could require an upfront investment of a Level 2 home charging station costing between $650 and $1,800 [58]. On the other hand, the daily driving needs of many consumers could be accommodated by Level 1 charging access through a standard 120-Volt power outlet, which often requires no upfront costs.

MEDIUM- AND HEAVY-DUTY VEHICLES

This section compares the cost effectiveness of a medium-duty delivery truck and heavy-duty, long-haul tractor-trailer using diesel, biodiesel (B100), electricity, and CNG. Propane was excluded from the analysis because the fuel costs are higher than diesel, the vehicle costs are the same or higher, and the fuel economy is the same or lower, resulting in a higher total cost of ownership than diesel. Other alternative fuels (e.g., RNG or renewable diesel) do not have readily available fuel price data for Connecticut. Biodiesel does not require a vehicle or engine replacement. CNG and battery electric vehicles require an engine and/or full drivetrain replacement.

Figure 27: Lifetime Discounted Cost and Greenhouse Gas Abatement Cost for Delivery Trucks in Connecticut

This figure shows the total discounted cost of various fuels for a delivery truck along with the CO₂ abatement cost. The abatement cost of electric trucks is negative because these vehicles were estimated to have a lower lifetime cost than a diesel truck.



	Diesel	Biodiesel (B100)	Electricity	CNG
License and Registration	$3,105	$3,105	$3,105	$3,105
Insurance	$29,482	$29,482	$29,482	$29,482
Maintenance and Repair	$23,117	$23,117	$15,986	$24,842
Diesel Exhaust Fluid	$1,005	$1,005	$355	$0
Fuel	$46,539	$51,082	$38,647	$56,447
Depreciation	$0	$0	$0	$0
Financing	$7,869	$7,869	$18,158	$12,711
Greenhouse Gas Abatement Cost ($/Metric Tons)	$0.00	$27.14	($36.54)	$541.79

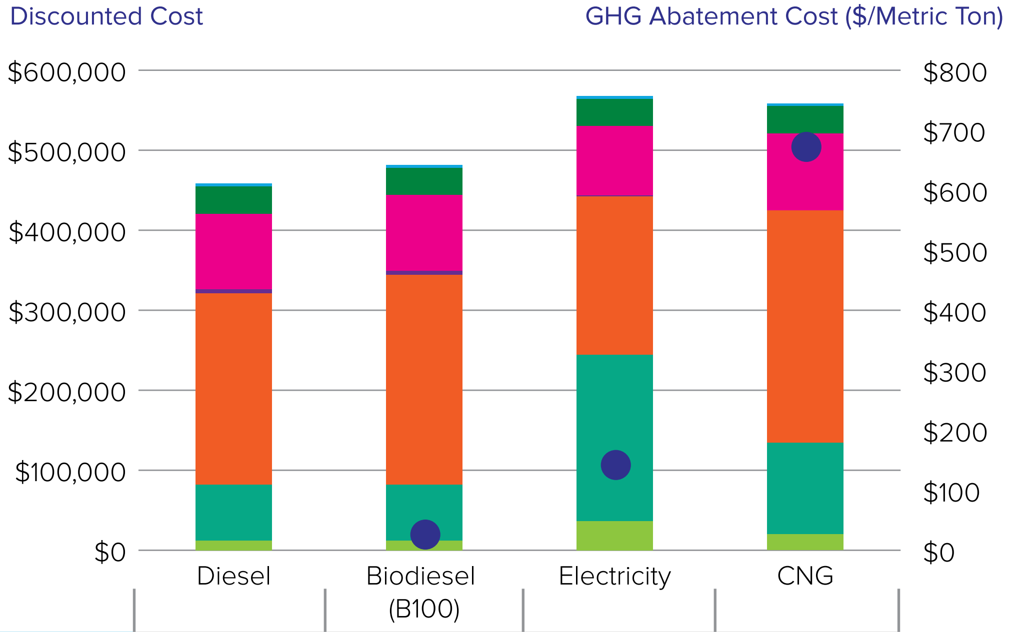
Source: Atlas Public Policy and Cadmus Group analysis using the AFLEET tool.

In this section, a tractor trailer and delivery truck is used as an example of how to estimate the cost effectiveness for a number of different alternative fuel and vehicles. The methodology could be extended to other vehicles given data on vehicle fuel economy, vehicle miles traveled, and fuel prices. Appendix C shows the assumptions behind the calculations for tractor trailers and for delivery trucks. Appendix C also shows the assumed vehicle fuel economy and purchase cost for each vehicle and fuel combination. All vehicle costs are from the AFLEET model other than the electric tractor-trailer, which is estimated by the authors.

The results of the analysis indicate some alternative fuel and vehicle combination for delivery trucks or tractor trailers are a cost effective solution to reduce greenhouse gas emissions under current market conditions. The use of public infrastructure makes the fleets subject to retail prices, which can be much higher than fuel costs a fleet could acquire through a fuel purchase agreement [59]. For example, if a tractor-trailer fleet acquired CNG at a price below $2 per gallon, the lifetime cost would be less than a diesel truck at $3 per gallon.

Figure 28: Lifetime Discounted Cost and Greenhouse Gas Abatement Cost for Tractor Trailers in Connecticut

This figure shows the total discounted cost of various fuels for a tractor-trailer along with the CO_2 abatement cost.



	Diesel	Biodiesel (B100)	Electricity	CNG
License and Registration	$3,592	$3,592	$3,592	$3,592
Insurance	$34,108	$34,108	$34,108	$34,108
Maintenance and Repair	$94,799	$94,799	$86,317	$96,351
Diesel Exhaust Fluid	$5,167	$5,167	$1,826	$0
Fuel	$239,227	$262,580	$197,676	$290,117
Depreciation	$69,353	$69,353	$208,058	$114,432
Financing	$12,106	$12,106	$36,317	$19,974
Greenhouse Gas Abatement Cost ($/Metric Tons)	$0.00	$26.75	$142.75	$672.89

Source: Atlas Public Policy and Cadmus Group analysis using the AFLEET tool.

SUMMARY

When considering only cost-effectiveness, all-electric and plug-in hybrid electric vehicles, electric delivery trucks, biodiesel delivery trucks, and biodiesel tractor trailers are all viable alternative fuel vehicles. With vehicle incentives, all-electric vehicles can have a negative greenhouse gas abatement cost because the lifetimes costs are less than a comparable gasoline vehicle. For trucks, an electric delivery truck has a lower lifetime cost than a diesel truck without any incentives. In addition, biodiesel trucks and all-electric vehicles have abatement costs below the social cost of carbon without incentives.

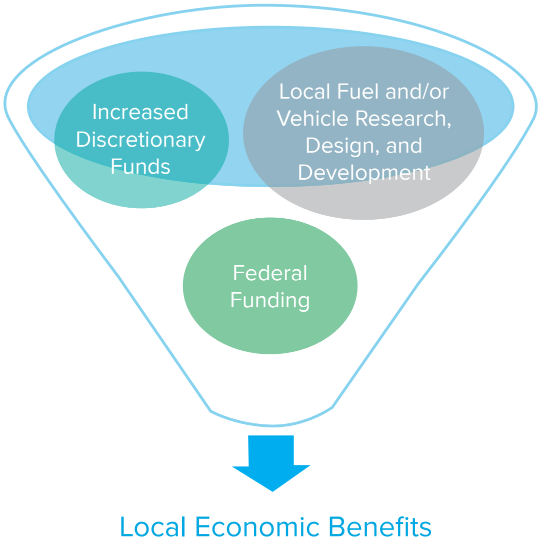
Local Economic Impact Criterion

A primary driver for switching to alternative fuels is the economic benefit to Connecticut (e.g., job creation) associated with the greater use of these fuels. Potential increases in state gross domestic product (GDP) primarily come from three sources: local fuel and/or vehicle research, design and development; increased discretionary funds from cost savings of alternative fuel use; and federal funding. For example, electricity or biodiesel can be produced in Connecticut unlike gasoline or diesel. In addition, fleets or individuals who spend less on transportation may use those funds on other economic activities that benefit the state. Finally, Connecticut drivers can receive a federal tax credit of up to $7,500 following the purchase of a plug-in electric vehicle.

Factors affecting the economic benefits are not uniform across all fuel types and accurately quantifying these benefits is very challenging. The fuel production, fuel delivery, and support systems and staff differ between fuels, for example. In addition, increased discretionary funds depends largely on changes in the oil market, which are very difficult to predict. Finally, federal funding can be provided in several ways including temporary or permanent tax credits or discretionary grants.

This section assesses the qualitative benefits for several alternative fuels and vehicles using the three sources of economic benefits defined in **Figure 29**. A summary is then provided of the most desirable alternative fuel and vehicle combination for light-, medium-, and heavy-duty vehicles based only on local economic benefits.

Figure 29: Potential Economic Benefits of Greater Alternative Fuel Use



INCREASED DISCRETIONARY FUNDS

Connecticut spent $6.75 billion on transportation in 2013, spending more money per unit of energy than any state [60]. Reducing these costs puts more money in the pockets of Connecticut residents and fleet operators, thereby keeping more money in the state's economy. Studies have shown that reducing transportation spending results in a significant boost to state GDP [61, 62].

Net cost savings for alternative fuel vehicles was assessed in the cost effectiveness analysis from *Cost Effectiveness Criterion*. For example, passenger electric vehicles should result in more funds in the state economy due to substantial fuel and maintenance costs savings over the life of the vehicle. Biodiesel and CNG fuel prices do not offer noticeable cost savings, especially under current market conditions (see **Table 8**).

Table 8: Expected Effects from Increased Discretionary Funds

Vehicle	Alternative Fuel	State Economic Impact from Cost Savings
Passenger Car	Electricity	**Positive**
Medium-Duty Delivery Truck	Electricity	**Positive**
Medium-Duty Delivery Truck	Biodiesel (B100)	**Neutral**
Heavy-Duty Tractor Trailer	Biodiesel (B100)	**Neutral**
Passenger Car	E85	**Negative**
Passenger Car	Hydrogen	**Negative**
Medium-Duty Delivery Truck	CNG	**Negative**
Heavy-Duty Tractor Trailer	Electricity	**Negative**
Heavy-Duty Tractor Trailer	CNG	**Negative**

In this table, the effects on state GDP are with respect to increased discretionary funds from vehicle owners due to net costs savings of using an alternative fuel vehicle. Positive indicates an expected net gain for state GDP, neutral indicates a marginal change in GDP, and negative indicates an expected loss of GDP.

Source: Atlas Public Policy analysis

FEDERAL FUNDS

Federal funding has been a key driver of alternative fuel vehicle deployment for decades. Many programs are in place to advance alternative fuels through tax credits, grants, and other incentives. Federal funds from these policies can result in a net gain for Connecticut's GDP. These incentives can encourage the design and manufacture of vehicles as well as the development and production of fuels and fueling infrastructure. For this report, only policies and programs that affect vehicle owners and fueling infrastructure operators are considered.

Operators of fueling infrastructure for several alternative fuels (electricity, B100, CNG, propane, and hydrogen) are supported through a federal tax credit of 30 percent of the equipment cost, not to exceed $30,000. The tax credit expires on December 31, 2016, though it has expired previously and been renewed retroactively by the U.S. Congress. In addition, special grants and loans are available for ethanol fueling infrastructure. A federal tax credit also exists for biodiesel retailers of $1 per gallon. Similar to the fueling infrastructure tax credit, the biodiesel credit is scheduled to expire on December 31, but has expired previously and been subsequently reinstated.

For vehicles, federal tax credits exist for up to $7,500 for light-duty plug-in electric vehicles, $8,000 for light-duty hydrogen vehicles, and up to $40,000 for medium- and heavy-duty hydrogen vehicles.

See **Table 4** for more information on federal policies and programs described above.

LOCAL FUEL AND/OR VEHICLE RESEARCH, DESIGN, AND DEVELOPMENT

The increased use of alternative fuels can benefit Connecticut from the greater use of "home grown" fuels as well as industries that work in advanced vehicle and fueling infrastructure industries. Below are some illustrations of potential economic and jobs-related benefits from alternative fuels:

- **Electricity:** Connecticut is currently a net exporter of electricity and could use some of that excess electricity to power electric vehicles. In 2015, Connecticut produced 37.65 terawatt-hours of electricity and consumed 29.48 terawatt-hours of electricity for a net difference of about 8 terawatt-hours [63]. By using a "home grown" fuel, the state is encouraging the greater use of an energy source it can produce locally, potentially spurring economic development.
- **Biodiesel from waste oils:** The three operating biodiesel plants in Connecticut have a combined 24.8 million gallons per year capacity and use multiple feedstocks, some of which include used cooking oil and animal fats (New Haven, Greenleaf Biofuels facility). Biodiesel has job-creation potential in Connecticut, but the exact impact has not been quantified. As mentioned earlier, a large portion of commercially-generated waste cooking oil is currently being used to produce transportation fuel (biodiesel) or heating oil. Potential exists for biodiesel using residentially-generated waste cooking oil as well as fats, oils, and grease from grease traps at restaurants.
- **CNG:** Natural gas is produced out of state and transported via pipeline to Connecticut. Thus, the job creation potential within Connecticut from increased natural gas use stems from the operation and maintenance of pipelines and construction of new natural gas dispensing stations. The Argonne National Laboratory JOBS model suggests that for a fast fill, 300 gasoline-gallon-equivalent-per-hour CNG dispensing station will create five jobs in the construction of the station (four jobs in the supply chain of station parts and one job induced in other sectors). In addition, the station will sustain eight jobs in the supply chain and two induced jobs during the operation of the station [64].
- **RNG from dairy biogas:** Connecticut has 41 dairy farms spread across the state [65], two of which have operational biogas systems [60]. The American Biogas Council, a 501(c)(6) organization, suggests that every dairy biogas project creates 25 new short-term construction jobs and two new long-term jobs [66]. Further development of biogas would need to compete with other uses, such as heating and electric power applications.
- **Propane:** As with CNG, propane is imported from out-of-state, which limits its job creation potential within Connecticut to additional truck drivers and construction/maintenance crews at propane dispensers and tanks.
- **E85:** U.S. ethanol production facilities are located primarily in Midwest states and delivered by rail to fuel providers in Connecticut. Thus, an expansion of E85 in Connecticut has no likely near-term job creation potential on the production side and only minimal job creation from increased fuel deliveries. In the longer term, Connecticut could feasibly develop in-state ethanol production capacity. The state currently has 22,000 acres of corn, which goes entirely for animal feed [67]. The U.S. Department of Energy estimates that one job is created for every 350,000 gallon of corn ethanol production and 300,000 gallons of corn stover cellulosic ethanol [68].
- **Hydrogen (gaseous):** Connecticut is a leader in the stationary and mobile hydrogen fuel cell industry with manufacturers such as Doosan Fuel Cell America,

Fuel Cell Energy, and Proton Onsite. Investments in research, design, and development enable these companies to hire a skilled workforce that manufactures clean energy producing technologies.[7] Currently, gaseous hydrogen production for fuel cell electric vehicles in California is primarily produced via centralized steam methane reforming. In 2008, the U.S. Department of Energy used an equilibrium model (IMPLAN) to estimate that the U.S. employment would be expanded by 675,000 jobs by 2050 assuming a rapid expansion of hydrogen fuel cell vehicles [69].

- **RNG from landfill/wastewater gas:** Similar to dairy biogas, the production facilities for landfill and wastewater gas already exist in Connecticut – the state has 21 active landfills in the state and an estimated 200 wastewater treatment plants [70]. As with dairy biogas, the use of this low-carbon fuel would need to compete with other uses.
- **Renewable diesel:** Currently, there are 10 renewable diesel producers worldwide and the majority of production occurs in Europe [71]. The U.S.-based Diamond Green Diesel facility recently opened in Louisiana, producing 142 million gallons per year. As with other types of liquid biofuel, expanding renewable diesel use in Connecticut would imply minimal new jobs in the state, limited to delivery and dispensing systems. In the longer term, it is possible the state could construct new renewable diesel facilities. Such projects tend to be capital intensive and require long planning horizons.

SUMMARY

The Connecticut economy has the potential to greatly benefit from the increased use of some alternative fuels. For light-duty vehicles, electricity appears to be the most promising fuel for three reasons. First, the state has sizeable power generation capacity, indicating funds spent on electricity as a transportation fuel are more likely to stay in the state's economy. Second, federal funds exist to support plug-in electric vehicles and charging infrastructure, which could lead to a net increase in state GDP. Finally, plug-in electric vehicles can achieve a net costs savings over gasoline vehicles, which would provide greater discretionary funds for drivers.

For medium- and heavy-duty vehicles, biodiesel appears to hold the most promise. The state's existing capacity to produce biodiesel combined with the federal tax credit for using biodiesel make it the best alternative fuel option for these vehicles under current market conditions. If oil prices recover to levels seen in 2012 through the summer of 2014, CNG would also provide a positive local economic impact. Although a large portion of commercially-generated waste cooking oil is currently being used to produce transportation fuel (biodiesel) or heating oil, the potential exists for biodiesel using residentially-generated waste cooking oil as well as fats, oils, and grease from grease traps at restaurants.

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[7] A promising application of fuel cells is co-production, which relies on natural gas and fuel cells to produce multiple valuable outputs, including electric power, heat, and hydrogen for vehicles. See http://www.fuelcellenergy.com/advanced-technologies/hydrogen-co-production for more information.

Conclusion

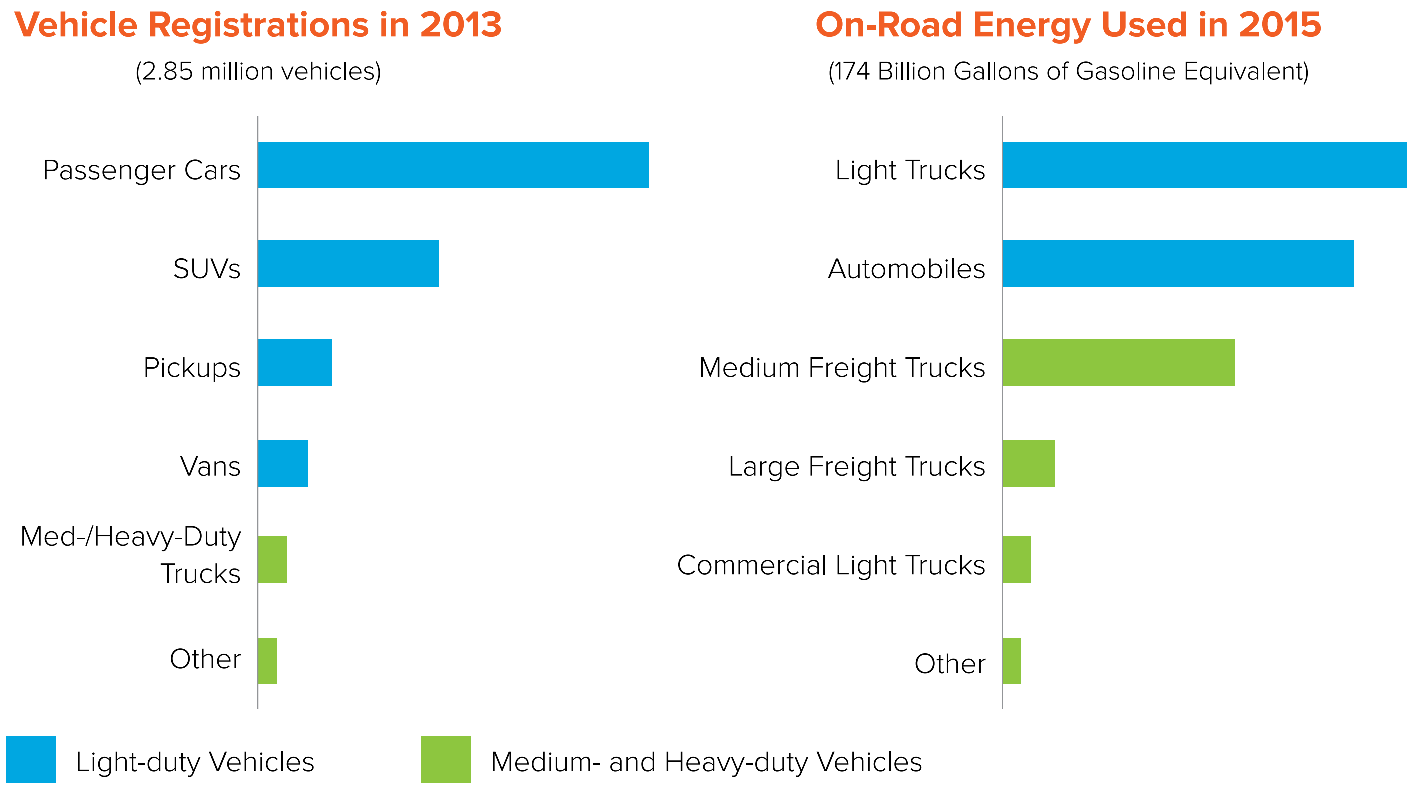
Connecticut has an ambitious goal to reduce greenhouse gas emissions by 80 percent below 2001 levels by 2050. A recent analysis shows transportation emissions are expected to decrease only slightly out to 2050 under a business as usual scenario, resulting in total emissions significantly above the state's 2050 goal. To meet its objective, the state must advance new policies to catalyze the deployment of low-carbon sources, especially in the transportation sector.

Transportation emissions are currently the state's largest source of emissions and is expected to continue to be in the coming decades. Nearly 95 percent of registered vehicles in Connecticut are light-duty, with automobiles and light trucks accounting for 70 percent of all energy consumption (see **Figure 30**).

The greater deployment of alternative fuel vehicles, especially passenger vehicles, is essential for the state to have a higher likelihood of achieving its climate and clean air goals.

The Connecticut Green Bank is in a unique position to help accelerate the deployment of these vehicles, especially zero emission passenger vehicles. The Green Bank has successfully worked with the private sector to engage Connecticut residents and businesses to improve building energy efficiency and accelerate the deployment of renewable energy through the use of innovative finance mechanisms. The Green Bank can now turn to transportation and explore new approaches to capturing the value of low-carbon fuels.

Figure 30: Summary of Vehicle Registrations and Energy Use



Source: [1, 2]

The Green Bank must identify its role in facilitating the deployment of alternative fuel vehicles. As a first step, this report assessed the market potential for alternative fuels and on-road vehicles in Connecticut using four criteria:

1. **Near-term market feasibility;**
2. **Environmental performance;**
3. **Cost-effectiveness; and**
4. **Local economic benefits.**

The results of the study indicate that passenger vehicles are the most worthwhile area for the Green Bank to focus its resources. Connecticut spent $6.75 billion on transportation in 2013 – more money per unit of energy than any state. Light-duty vehicles made up over 95 percent of the vehicles registered in Connecticut that year, nearly all of which were powered by gasoline. Passenger vehicles fleet made up 75 percent of miles traveled in the state.

Considering the criteria listed in **Table 9**, the increased deployment of plug-in electric vehicles is the most promising approach for the state to meet its energy and climate goals. Hydrogen fuel cell vehicles may also be a viable alternative if infrastructure is deployed and the costs of fuel and vehicles decrease significantly.

From an environmental perspective, electric drive vehicles powered by rechargeable batteries or hydrogen fuel cells offer the greatest potential to reduce emissions from passenger vehicles. To achieve the greatest reductions, the electricity and hydrogen must come from low-carbon feedstocks.

Table 9: Summary of Market Potential Assessment

Criteria	Vehicle Type	Alternative Fuel	Key Factors
Near-term market feasibility	**Passenger Vehicle**	**Electricity**	• ZEV Program participation • Vehicle incentives • Available charging infrastructure
	Medium- and Heavy-duty Vehicles	Renewable Diesel	• Drop-in fuel • Cost effective compared to diesel • Limited supply
Environmental performance	**Passenger Vehicle**	**Electricity**, Hydrogen	• Greatest emission reduction potential • Requires low-carbon feedstocks
	Medium- and Heavy-duty Vehicles	RNG from landfills and dairy farms	• Greatest emission reduction potential • Displaces emissions
Cost-effectiveness	**Passenger Vehicle**	**Electricity**	• All-electric vehicles have lower abatement costs than social cost of carbon without vehicle incentives and with solar incentives • Residential solar is least cost option with incentives
	Delivery Trucks, Tractor-Trailers	Electricity (delivery trucks), Biodiesel (delivery trucks, tractor trailers)	• Electric delivery trucks cost less than diesel trucks • Biodiesel trucks have lower abatement costs than social cost of carbon

Table 9: Summary of Market Potential Assessment (cont.)

Criteria	Vehicle Type	Alternative Fuel	Key Factors
Local economic benefits	**Passenger Vehicle**	**Electricity**	• Sizable power generation capacity keeps transportation spending in state's economy • Federal funds exist to support plug-in electric vehicles and charging infrastructure • Electric vehicles can achieve a net costs savings over gasoline vehicles
	Medium- and Heavy-duty Vehicles	Renewable Diesel	• Existing capacity to produce biodiesel, plus a federal tax credit, make it the best option • CNG could be attractive if oil prices recover to levels seen before summer of 2014 • Large portion of commercially-generated waste cooking oil is currently being used for transportation fuel (biodiesel) or heating oil. • Potential to use residentially-generated waste cooking oil for biodiesel

The table above summarizes the results from each criterion's analysis. The results clearly indicate passenger electric vehicles are the best near-term opportunity for Connecticut to achieve its energy and climate goals.

Source: Atlas Public Policy Analysis

Electric vehicles are presently a popular alternative fuel vehicle in the light-duty segment and are expected to receive continued investment from automakers, government, and other private sector entities in the near term. The current policy framework in Connecticut is also supportive of electric vehicles. For example, the state follows the California Zero Emission Vehicle Program and has developed a sizeable vehicle incentive known as CHEAPR. Another important aspect of near-term viability is the presence of public fueling infrastructure; electric charging infrastructure is far more prevalent than fueling stations for alternative fuel vehicles.

Electricity also appears to be the most promising fuel for state economic growth for three reasons. First, the state has sizeable power generation capacity indicating funds spent on electricity as a transportation fuel are more likely to stay in the state's economy than other fuels. Second, federal funds exist to support plug-in electric vehicles and charging infrastructure, which could lead to a net increase in state GDP. Third, all-electric vehicles can achieve a net costs savings over gasoline vehicles, which would provide greater discretionary funds for drivers.

For medium- and heavy-duty vehicles, introducing alternative fuels can be complex and costly. Vehicle engines, chassis, and supplementary equipment are rarely all designed and manufactured by a single firm, making systems integration challenging. These vehicles also come in a variety of body types, weight classes, drive cycles, and uses. Thus, without common practices among manufacturers, identifying a strategy for the near-term to achieve emission and petroleum reductions can be cost prohibitive.

This report indicates that renewable diesel offers the greatest near-term promise as a replacement fuel for medium-and heavy-duty vehicles. However, renewable diesel availability is limited due to a small number of suppliers. RNG from landfills and dairy farms has the greatest potential to reduce emissions, but its use as a transportation fuel must compete with other uses. Similarly, biodiesel offers promise as a cost-effective alternative fuel for some trucks, but may also be limited due to competition for other uses (e.g., heating oil).

The analysis in this report reveals the increased deployment of passenger electric vehicles offer the greatest opportunity for Connecticut to achieve its energy and climate goals. The analysis shows that electric vehicles have the greatest potential for each criterion: near-term market potential, environmental performance, cost effectiveness, and local economic impact.

Looking ahead, the Connecticut Green Bank should explore programs that capture the value of electric vehicles laid out in this report while leveraging its existing experience. For example, combining residential solar and electric vehicles offer a compelling alternative to gasoline vehicles because the vehicle emits far fewer emissions and can cost less to own and operate. The Green Bank has extensive experience with residential solar deployment and could apply its expertise with Connecticut residents to assist them with the selection of their personal vehicle.

Appendix A: Current Medium- and Heavy-Duty Vehicle Fleet in Connecticut

The following table displays the data used to calculate fuel economy for medium- and heavy-duty vehicles.

Table A1: Current Medium- and Heavy-Duty Vehicle Fleet in Connecticut

Fleet Type	Number in CT	Min MPG	Max MPG	Mean MPG	Std Dev MPG	Min Annual Miles	Max Annual Miles	Mean Annual Miles	Std Dev Annual Miles	Per Vehicle Emissions (metric tons CO_2)	Aggregate Emissions (metric tons CO_2)
Beverage	500	5.4	14.0	8.4	2.9	400	23,000	13,633	7,743	27	13,354
Concrete Mixer	579	2.3	8.0	4.3	1.2	1,771	35,000	17,351	7,653	42	24,566
Dump	11,077	1.0	18.0	7.5	3.0	65	100,000	11,705	15,195	22	246,843
Utility	4,008	2.7	15.9	9.9	3.4	1,000	31,983	9,834	6,585	12	47,377
Tow	1,623	6.0	20.0	10.1	3.6	100	83,463	18,723	21,204	23	36,975
Trash	1,342	2.0	15.0	5.2	2.4	2,000	70,000	23,641	15,406	54	71,932
Box Van	7,180	0.9	20.0	10.3	3.3	50	100,000	23,293	18,316	27	191,565
Refrig. Van	1,527	4.1	16.0	7.6	3.6	100	66,156	30,975	18,347	47	72,101
Step Van	7,395	3.3	16.0	10.3	2.5	200	52,678	15,102	10,902	16	115,367
Tractor Trailer	34,165	2.5	10.0	5.8	1.2	152	163,000	45,632	34,755	77	2,622,044

Source: [24]; Cadmus estimates

Appendix B:
Calculation Explanations

The methodologies below were used to calculate the emissions per vehicle per year and aggregate emissions from medium- and heavy-vehicle classes, except school buses.

Emissions per vehicle per year: For each observation in VIUS, fuel economy (MPG) and annual miles driven are provided. The emissions for a given vehicle, then, are annual miles multiplied divided by MPG multiplied by 22 pounds of CO_2 per gallon [72]. To obtain representative statistics and account for under-sampled vehicle types, sample weights from VIUS are applied to all estimates. For school buses, the estimated fuel economy and annual miles traveled was from the American School Bus Council [73].

Aggregate emissions: Similarly, aggregate emissions for a given truck category (e.g., Beverage Truck) are estimated by taking the summation of the annual emissions of all vehicles in that category. Again, sample weights are applied to each truck observation except for school buses. The Greater New Haven Clean Cities Coalition provided the number of school buses in Connecticut.

The following methodologies were used to calculate the amount of CO_2 attributable to medium- and heavy-duty vehicle types, as well as the aggregate vehicle count.

Kilograms of CO_2e per 100 km: California's Low Carbon Fuel Standard (LCFS) lookup table was used to estimate the kilograms of CO_2-equivalent per Megajoule of energy for each fuel type [74]. Fuel economy averages within a given vehicle class is used to ratio the grams per MJ to estimate grams per 100 km. The final calculation is:

$$\frac{\text{kg of CO}_2\text{e}}{\text{100 km}} = Y\,\frac{\textit{grams CO}_2}{\textit{megajoule}} \times \left(X\,\frac{\textit{diesel-gallon}}{\textit{mile}}\right) \times \left(146\,\frac{\textit{megajoules}}{\textit{diesel-gallon}}\right) \times \left(\frac{\textit{mile}}{\textit{1.6 km}}\right) \times \left(\frac{\textit{kg}}{\textit{1000 grams}}\right)$$

Where Y = the grams CO_2e/MJ given in CARB (2016)
X = fuel economy of vehicle category estimated using VIUS survey

Vehicle Count: the number of each vehicle type (triangles) is taken directly VIUS by summing the sample weights.

Appendix C:
Cost Effectiveness Assumptions

The following table provides assumptions underlying the total cost of ownership calculations for a hydrogen fuel cell vehicle (Toyota Mirai). In addition, the analysis assumes the hydrogen fuel is free for the first three years of vehicle ownership, reflecting Toyota's current policy on hydrogen.

Table C1: Assumptions for Total Cost of Ownership for Hydrogen Fuel Cell Vehicles

Assumption Description	Value
Discount Factor Applied to Fuel and Operating Costs (%)*	2.30%
Loan Interest Rate (%)*	6%
Loan Length (Years)*	5
Loan Down Payment (%)*	10%
Vehicle Price ($)	$57,000
Fuel Economy (miles/kilogram)	66
Annual Vehicle Miles Traveled (miles)*	11,926
Lifetime of Vehicle (years)*	15
Hydrogen Fuel Price ($/kilogram)	$5.53
Maintenance Cost Per Mile (same as Nissan LEAF, $/mile)*	$0.041
Other Operating Expenses (license, registration, insurance)*	$1,616

*The * denotes assumptions from the Vehicle Cost Calculator. The annual operating cost for the Nissan LEAF was used and includes fuel, tires, maintenance, registration, and insurance.*

Source: [54, 55, 53]

The following tables provide the assumptions necessary for making vehicle lifecycle cost comparisons across fuel types.

Table C2: Financing and Market Assumptions for Heavy-Duty Tractor Trailers and Medium-Duty Delivery Trucks

Assumption	Tractor-Trailer	Delivery Truck
Years of Planned Ownership	7 years	6.5 years
Loan Term	5 years	5 years
Interest Rate	4.14%	4.14%
Discount Factor	4.0%	4.0%
Annual Mileage	75,000 miles	20,000 miles
Diesel Price ($/gallon)	$2.99	$2.99
Biodiesel/B100 ($/gallon)	$3.03	$3.03
Electricity ($/kWh)	$0.19	$0.19
CNG ($/DGE)	$2.83	$2.83

The years of planned ownership and annual mileage were from the U.S. Department of Energy's VICE model. Diesel, biodiesel, CNG were the average 2015 prices in New England from the Clean Cities Alternative Fuel Price Report. The loan term and interest rate were default assumptions from the AFLEET tool. The discount rate was assumed to be 4 percent at the authors' discretion.

Source: [75, 32, 76]

Table C3: Vehicle Assumptions for Tractor Trailers and Delivery Trucks

	Tractor-Trailer		Delivery Truck	
	Miles per Gallon Gasoline Equivalent	Vehicle Cost	Miles per Gallon Gasoline Equivalent	Vehicle Cost
Diesel	5.2	$100,000	6.2	$65,000
Biodiesel (B100)	5.2	$100,000	6.2	$65,000
Electricity	14.7	$300,000	17.5	$150,000
CNG	4.7	$165,000	5.6	$105,000

All costs were the default values from the AFLEET tool except the vehicle cost for an electric tractor-trailer, which was estimated by the authors.

Source: [75]

References

[1] U.S. Energy Information Administration, “Annual Energy Outlook 2015,” U.S. Energy Information Administration, 14 April 2015. [Online]. Available: http://www.eia.gov/forecasts/aeo/data/browser/#/?id=45-AEO2015&region=0-0&cases=ref2015&start=2012&end=2040&f=Q&linechart=ref2015-d021915a.4-45-AEO2015&sourcekey=0. [Accessed 29 March 2016].

[2] Federal Highway Administration, “Highway Statistics Series,” January 2015. [Online]. Available: http://www.fhwa.dot.gov/policyinformation/statistics/2013. [Accessed 20 April 2016].

[3] Connecticut Green Bank, “About Us,” Connecticut Green Bank, 2016. [Online]. Available: http://www.ctgreenbank.com/about-us/. [Accessed 23 January 2016].

[4] Connecticut Green Bank, “Commercial Contractors,” 2016. [Online]. Available: http://www.ctgreenbank.com/programs/commercial-contractors/. [Accessed 23 January 2016].

[5] Connecticut Department of Energy and Environmental Protection, “Connecticut Greenhouse Gas Emissions Inventory 2012,” 2015. [Online]. Available: http://www.ct.gov/deep/lib/deep/climatechange/2012_ghg_inventory_2015/2012_ct_ghg_inventory_final.pdf.

[6] Connecticut Green Bank, “Comprehensive Plan: Fiscal Years 2015 and 2016,” 16 October 2015. [Online]. Available: http://www.ctgreenbank.com/wp-content/uploads/2015/11/CGB_FY15_and_FY16_Comprehensive_Plan.pdf. [Accessed 4 May 2016].

[7] D. Greene and S. Plotkin, “Reducing Greenhouse Gas Emissions from U.S. Transportation,” January 2011. [Online]. Available: http://www.c2es.org/publications/reducing-ghg-emissions-from-transportation. [Accessed 20 April 2016].

[8] K. Crane, A. Goldthau, M. Toman, T. Light, S. E. Johnson, A. Nader, A. Rabasa and H. Dogo, “Imported Oil and U.S. National Security,” 2009. [Online]. Available: http://www.rand.org/pubs/monographs/MG838.html. [Accessed 29 March 2016].

[9] P. Leiby and M. Shelby, “Electric Vehicles & Energy Security,” 15 January 2014. [Online]. Available: http://cta.ornl.gov/TRBenergy/trb_documents/2014_presentations/854_Shelby.pdf. [Accessed 20 April 2016].

[10] International Energy Agency, “World Energy Outlook 2015,” 10 November 2015. [Online]. Available: http://www.iea.org/Textbase/npsum/WEO2015SUM.pdf. [Accessed 20 April 2016].

[11] C. Liu, D. Greene and Z. Lin, “Assessing the Outlook of US Oil Dependence Using Oil Security Metrics Model (OSMM),” 11 June 2015. [Online]. Available: http://energy.gov/sites/prod/files/2015/07/f24/van010_liu_2015_p.pdf. [Accessed 29 March 2016].

[12] U.S. Environmental Protection Agency, “March 2008 Final National Ambient Air Quality Standards for Ground-level Ozone,” March 2008. [Online]. Available: https://www3.epa.gov/apti/video/ozone2008/wegman.pdf. [Accessed 26 April 2016].

[13] U.S. Environmental Protection Agency, “8-Hr Ozone (2008) State/Area/County Report,” U.S. Environmental Protection Agency, 22 April 2016. [Online]. Available: https://www3.epa.gov/airquality/greenbook/hncs.html#CONNECTICUT. [Accessed 26 April 2016].

[14] Regional Greenhouse Gas Initiative, “Program Design,” Regional Greenhouse Gas Initiative, 2016. [Online]. Available: http://www.rggi.org/design. [Accessed 2 April 2016].

[15] Connecticut Department of Energy & Environmental Protection, “Connecticut Renewable Portfolio Standards Overview,” Connecticut Department of Energy & Environmental Protection, April 2015. [Online]. Available: http://www.ct.gov/pura/cwp/view.asp?a=3354&q=415186. [Accessed 2 April 2016].

[16] Connecticut General Assembly, “An Act Concerning Connecticut Global Warming Solutions,” 2 June 2008. [Online]. Available: https://www.cga.ct.gov/2008/ACT/PA/2008PA-00098-R00HB-05600-PA.htm. [Accessed 26 April 2016].

[17] Connecticut Department of Energy and Environmental Protection, “GC3 Analysis, Data, and Metrics Working Group Meeting,” 10 March 2016. [Online]. Available: http://www.ct.gov/deep/lib/deep/climatechange/gc3_adm_group/adm_meeting_3_10_2016.pdf. [Accessed 20 April 2016].

[18] Connecticut Department of Energy and Environmental Protection , “2013 Comprehensive Energy Strategy for Connecticut,” 19 February 2013. [Online]. Available: http://www.ct.gov/deep/lib/deep/energy/cep/2013_ces_final.pdf. [Accessed 3 May 2016].

[19] National Research Council, “Transitions to Alternative Vehicles and Fuels,” 2013. [Online]. Available: http://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels.

[20] Center for Climate and Energy Solutions, “Federal Vehicle Standards,” Center for Climate and Energy Solutions, 2015. [Online]. Available: http://www.c2es.org/federal/executive/vehicle-standards. [Accessed 30 March 2016].

[21] U.S. Environmental Protection Agency, “2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards,” 15 October 2012. [Online]. Available: https://www.gpo.gov/fdsys/pkg/FR-2012-10-15/pdf/2012-21972.pdf. [Accessed 30 March 2016].

[22] Hybridcars.com, “December 2015 Dashboard,” 6 January 2016. [Online]. Available: http://www.hybridcars.com/december-2015-dashboard. [Accessed 20 April 2016].

[23] U.S. Environmental Protection Agency, “2011 National Criteria Pollutant Emission Inventory,” 2011. [Online]. Available: https://www.epa.gov/air-emissions-inventories/2011-national-emissions-inventory-nei-data. [Accessed 20 April 2016].

[24] U.S. Census Bureau, “Vehicle Inventory and Use Survey,” April 2002. [Online]. Available: https://www.census.gov/svsd/www/vius/2002.html.

[25] Fleetsandfuels.com, “Propel Hayward Has Renewable Diesel,” Fleetsandfuels.com, 2 October 2015. [Online]. Available: http://www.fleetsandfuels.com/biofuels-2/2015/10/propel-hayward-has-renewable-diesel. [Accessed 4 May 2016].

[26] U.S. Energy Information Administration, “Table C8. Transportation Sector Energy Consumption Estimates, 2013,” 2015. [Online]. Available: http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_sum/html/sum_btu_tra.html&sid=US. [Accessed 20 April 2016].

[27] Oak Ridge National Laboratory, “Table 2-14: Passenger Car Travel,” 2015. [Online]. Available: http://cta.ornl.gov/data/chapter2.shtml. [Accessed 20 April 2016].

[28] U.S. Department of Energy, “Alternative Fuel and Advanced Vehicle Search,” U.S. Department of Energy, 8 February 2016. [Online]. Available: http://www.afdc.energy.gov/vehicles/search/. [Accessed 16 April 2016].

[29] National Renewable Energy Laboratory, “Dallas Area Rapid Transit’s LNG Bus Fleet: Final Results,” 2000. [Online]. Available: http://www.nrel.gov/docs/fy01osti/28739.pdf. [Accessed 2016 20 April].

[30] National Renewable Energy Laboratory, “St. Louis Metro Biodiesel Transit Bus Evaluation,” 2008. [Online]. Available: http://www.nrel.gov/docs/fy08osti/43486.pdf. [Accessed 20 April 2016].

[31] Oak Ridge National Laboratory, “Transportation Energy Data Book,” 2015. [Online]. Available: http://cta.ornl.gov/data/chapter5.shtml.

[32] U.S. Department of Energy, “Fuel Prices,” 17 February 2016. [Online]. Available: http://www.afdc.energy.gov/fuels/prices.html. [Accessed 2016 20 April].

[33] U.S. Department of Energy, “Retail Fuel Prices with Electricity,” 29 February 2016. [Online]. Available: http://www.afdc.energy.gov/uploads/data/data_source/10326/10326_retail_fuel_prices_with_electricity.xlsx. [Accessed 20 April 2016].

[34] J. Cannon, “Is renewable diesel the first alt fuel ‘no-brainer’?,” Commercial Carrier Journal, 8 January 2016. [Online]. Available: http://www.ccjdigital.com/is-renewable-diesel-the-first-altfuel-no-brainer/. [Accessed 20 April 2016].

[35] E. Surtherland and F. Joseck, “Low Volume Production and Delivery Cost,” U.S. Department of Energy, 2015.

[36] M. Sivak and B. Schoettle, “Monthly monitoring of vehicle fuel economy and emissions,” University of Michigan Transportation Research Institute, April 2016. [Online]. Available: http://www.umich.edu/~umtriswt/EDI_sales-weighted-mpg.html. [Accessed 6 April 2016].

[37] U.S. Energy Information Administration, “Short-Term Energy Outlook,” U.S. Energy Information Administration, 8 March 2016. [Online]. Available: http://www.eia.gov/forecasts/steo/query/index.cfm?periodType=QUARTERLY&startYear=2012&endYear=2017&formulas=x27xgx9xgx24x8. [Accessed 2016 30 March].

[38] Union of Concerned Scientists, “Truck Electrification,” Union of Concerned Scientists, 2012.

[39] California Air Resources Board, “Technology Assessment: Medium and Heavy Duty Battery Electric Trucks and Buses,” http://www.arb.ca.gov/msprog/tech/techreport/bev_tech_report.pdf, 2015a.

[40] Motor Trend, “2017 Chevrolet Bolt EV First Drive Review,” Motor Trend, 7 January 2016. [Online]. Available: http://www.msn.com/en-us/autos/autos-compact/2017-chevrolet-bolt-ev-first-drive-review/ar-AAgrCLN?ocid=spartanntp. [Accessed 16 April 2016].

[41] C. von Kaenel, “Carmakers flaunt low-emission rides despite low consumer interest,” 22 January 2016. [Online]. Available: http://www.eenews.net/climatewire/2016/01/22/stories/1060031016. [Accessed 20 April 2016].

[42] U.S. Environmental Protection Agency, “EPA and NHTSA Finalize Historic National Program to Reduce Greenhouse Gases and Improve Fuel Economy for Cars and Trucks,” April 2010. [Online]. Available: https://www3.epa.gov/otaq/climate/regulations/420f10014.pdf. [Accessed 20 April 2016].

[43] National Biodiesel Board, “Biodiesel standard (ASTM D6751),” National Biodiesel Board, 2016 2016. [Online]. Available: http://biodiesel.org/using-biodiesel/oem-information. [Accessed 4 May 2016].

[44] Center for Climate and Energy Solutions, “ZEV Program,” Center for Climate and Energy Solutions, 2013. [Online]. Available: http://www.c2es.org/us-states-regions/policy-maps/zev-program. [Accessed 4 April 2016].

[45] Internal Revenue Service, “Plug-In Electric Drive Vehicle Credit (IRC 30D),” 2016. [Online]. Available: https://www.irs.gov/Businesses/Plug-In-Electric-Vehicle-Credit-IRC-30-and-IRC-30D. [Accessed 20 April 2016].

[46] U.S. Environmental Protection Agency, *Renewable Fuel Standard Program*, https://www.irs.gov/businesses/plug-in-electric-vehicle-credit-irc-30-and-irc-30d, 2007.

[47] U.S. Department of Energy, “Alternative Fuel Data Center,” U.S. Department of Energy, February 2016. [Online]. Available: http://www.afdc.energy.gov/laws. [Accessed 16 April 2016].

[48] Center for Sustainable Energy, “Connecticut Hydrogen and Electric Automobile Purchase Rebate,” 25 February 2016. [Online]. Available: http://ct.gov/deep/cwp/view.asp?a=2684&q=565018. [Accessed 20 March 2016].

[49] U.S. Department of Energy, “Alternative Fueling Station Locator,” 4 April 2016. [Online]. Available: http://www.afdc.energy.gov/locator/stations/. [Accessed 4 April 2016].

[50] U.S. Department of Energy, “Alternative Fuel Vehicles Beat the Heat, Fight the Freeze, and Conquer the Mountains,” U.S. Department of Energy, 26 January 2016. [Online]. Available: http://www.afdc.energy.gov/case/2328. [Accessed 3 May 2016].

[51] California Air Resources Board, “Carbon Intensity Lookup Table for Gasoline and Fuels that Substitute for Gasoline,” 14 December 2009. [Online]. Available: http://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf. [Accessed 4 April 2016].

[52] Toyota, “Frequently Asked Questions,” Toyota, 2016. [Online]. Available: https://ssl.toyota.com/fcv-content/faq.html. [Accessed 2 April 2016].

[53] Toyota, “Toyota Mirai,” Toyota, 2015. [Online]. Available: https://ssl.toyota.com/mirai/fcv.html. [Accessed 1 April 2016].

[54] Oak Ridge National Laboratory, “Compare Fuel Cell Vehicles,” U.S. Department of Energy, 2015. [Online]. Available: http://www.fueleconomy.gov/feg/fcv_sbs.shtml. [Accessed 1 April 2016].

[55] U.S. Department of Energy, “Vehicle Cost Calculator,” 18 February 2016. [Online]. Available: http://www.afdc.energy.gov/calc/.

[56] Atlas Public Policy, *Analysis of Connecticut Green Bank data on solar installations in Connecticut*, Washington, DC, 2016.

[57] U.S. Environmental Protection Agency, “The Social Cost of Carbon,” U.S. Environmental Protection Agency, July 2015. [Online]. Available: http://www3.epa.gov/climatechange/EPAactivities/economics/scc.html. [Accessed 6 April 2016].

[58] J. Agenbroad and B. Holland, “RMI: What’s the true cost of EV charging stations?,” 8 May 2014. [Online]. Available: https://www.greenbiz.com/blog/2014/05/07/rmi-whats-true-cost-ev-charging-stations. [Accessed 4 March 2016].

[59] N. Nigro, D. Welch and J. E. Park, “Strategic Planning to Enable ESCOs to Accelerate NGV Fleet Deployment: A Guide for Businesses and Policymakers,” November 2015. [Online]. Available: http://www.c2es.org/publications/strategic-planning-enable-escos-accelerate-ngv-fleet-deployment-guide-businesses-policy. [Accessed 20 April 2016].

[60] U.S. Energy Information Administration, “Table F30: Total Energy Consumption, Price, and Expenditure Estimates, 2013,” 2015. [Online]. Available: http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_fuel/html/fuel_te.html&sid=US&sid=CT. [Accessed 20 April 2016].

[61] R. Wescott, K. Archer and C. Egan, “Impact of Eliminating the Zero Emissions Vehicle Tax Credit on the Georgia State Economy,” 18 February 2015.

[62] R. Wescott, K. Archer and C. Egan, “Impact of Eliminating the Alternative-Fuel Vehicle Tax Exemption on the Washington State Economy,” 3 March 2015. [Online]. Available: http://secureenergy.org/wp-content/uploads/2016/02/SAFE_EC_Study_WA_Report_Final_0.pdf. [Accessed 13 March March].

[63] U.S. Energy Information Administration, “Electricity Data Browser,” U.S. Energy Information Administration, 2016. [Online]. Available: http://www.eia.gov/electricity/data/browser. [Accessed 4 April 2016].

[64] Argonne National Laboratory, “JOBS Models Track Expenditure Flows,” 9 June 2014. [Online]. Available: http://jobsmodels.es.anl.gov. [Accessed 13 March 2016].

[65] Connecticut Department of Agriculture, “CT Dairy Farms,” 2015. [Online]. Available: http://www.ct.gov/doag/lib/doag/marketing_files/brochures/2015/revised_dairy_web_site_pages_singles_updated.pdf. [Accessed 20 April 2016].

[66] American Biogas Council, “Biogas State Profile: Connecticut,” 2015. [Online]. Available: https://www.americanbiogascouncil.org/State%20Profiles/ABCBiogasStateProfile_CT.pdf. [Accessed 2016 20 April].

[67] U.S. Department of Agriculture, “Connecticut State Agriculture Overview,” 2015. [Online]. Available: http://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=CONNECTICUT. [Accessed 20 April 2016].

[68] National Renewable Energy Laboratory, “Jobs and Economic Development Impact Models,” 2016. [Online]. Available: http://www.nrel.gov/analysis/jedi/download.html. [Accessed 20 April 2016].

[69] U.S. Department of Energy, “Effects of a Transition to a Hydrogen Economy,” U.S. Department of Energy, July 2008. [Online]. Available: https://www.hydrogen.energy.gov/pdfs/epact1820_employment_study.pdf. [Accessed 13 March 2016].

[70] Connecticut Department of Energy and Environmental Protection, “Active Landfill Sites in Connecticut,” Connecticut Department of Energy and Environmental Protection, 2016. [Online]. Available: http://www.ct.gov/deep/cwp/view.asp?a=2718&depNav_GID=1646&q=325462. [Accessed 16 April 2016].

[71] Biomass Magazine, “Renewable Diesel Production, Planned Projects on the Rise,” 2015. [Online]. Available: http://biomassmagazine.com/articles/12559/renewable-diesel-production-planned-projects-on-the-rise. [Accessed 20 April 2016].

[72] U.S. Energy and Information Administration, “Frequently Asked Questions: How Much CO2 is produced by burning gasoline or diesel,” 2016. [Online]. Available: http://www.eia.gov/tools/faqs/faq.cfm?id=307&t=11. [Accessed 20 April 2016].

[73] American School Bus Council, “Environmental Benefits,” American School Bus Council, 2011. [Online]. Available: http://www.americanschoolbuscouncil.org/issues/environmental-benefits. [Accessed 14 April 2016].

[74] California Air Resources Board, “Carbon Intensity Lookup Table for Low Carbon Fuel Standard,” 2016. [Online]. Available: http://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf. [Accessed 2016 20 April].

[75] Argonne National Laboratory, “AFLEET Tool,” Argonne National Laboratory, 28 October 2013. [Online]. Available: https://greet.es.anl.gov/afleet. [Accessed 16 April 2016].

[76] U.S. Department of Energy, “VICE 2.0: Vehicle and Infrastructure Cash-Flow Evaluation Model,” 17 January 2014. [Online]. Available: http://www.afdc.energy.gov/vice_model.

[77] M. Smith and J. Castellano, “Costs Associated With Non-Residential Electric Vehicle Supply Equipment,” Department of Energy, November 2015.

[78] D. Santini , Y. Zhou and M. Rood Werpy, “Status and Issues for Plug-in Electric Vehicles and Hybrid Electric Vehicles in the United States,” Argonne National Laboratory, Department of Energy, 2015.

[79] D. Santini , M. Rood, D. Santini, Y. Zhou, L. Bluestein, G. Mitchell, T. Stephens and J. Ward, “An Assessment of Causes of PEV Success Across U.S. Metro Areas,” EVS29 Symposium , Montreal, Quebec, Canada, 2016.

[80] D. Santini, J. Zhu, M. Rood and K. Vazquez, “EV Everywhere Utility Outreach Study Findings,” Argonne National Lab, Washington, DC, April 14, 2016.

[81] D. Santini, Y. Zhou, G. Mitchell, T. Stephens and J. Ward, “Plug-in Vehicle Attributes’ Influence on U.S Sales in 2014 in States without Preferential Incentives for ZEVs,” EVS 29 Symposium, Montreal, Quebec, Canada, 2016.

[82] D. Santini, M. Rood, Y. Zhou, T. Stephens, J. Miller and L. Bluestein, “Implications of Successes and Failures of BEV-Focused Incentive Support for PEVs in the U.S., Canada and Europe,” EVS29 Symposium, Montreal, Quebec, Canada, 2016.

[83] N. Nigro and G. Morrison, “Market Potential Assessment,” Atlas Public Policy, Connecticut Green Bank, 2016.

[84] National Renewable Energy Laboratory, “UPS CNG Truck Fleet,” 2002. [Online]. Available: http://www.nrel.gov/docs/fy02osti/31227.pdf.

[85] California Air Resources Board, “Technology Assessment: Medium and Heavy Duty Fuel Cell Electric Vehicle,” http://www.arb.ca.gov/msprog/tech/techreport/fc_tech_report.pdf, 2015b.

[86] Atlas Public Policy, “State-Based Strategic Plan,” Washington, DC, 2016.

[87] National Renewable Energy Laboratory, “SCAQMD Electric Drayage Truck Testing,” 2016. [Online]. Available: http://www.nrel.gov/transportation/fleettest_electric_scaqmd.html. [Accessed 20 April 2016].

[88] Atlas Public Policy, “EV Market Dashboard,” Washington, DC, 2016.

[89] Department of Energy, “EV Everywhere Workplace Charging Challenge,” Office of Energy Efficiency & Renewable Energy, 2015. [Online]. Available: http://energy.gov/eere/vehicles/ev-everywhere-workplace-charging-challenge. [Accessed 27 April 2016].

[90] D. Santini , M. Rood, Z. Joann and K. Vazquez , “EV Everywhere Utility Outreach Study Findings,” Argonne National Lab, Washington, DC, April 14, 2016.

[91] U.S. Department of Energy, “Average fuel economy of major vehicle categories,” 2015. [Online]. Available: http://www.afdc.energy.gov/data/10310. [Accessed 2016 20 April].

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