THE ECONOMIC AND FISCAL IMPACTS OF CONNECTICUT'S GREENHOUSE GAS REDUCTION STRATEGIES

45% below 2001 levels by 2030

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Introduction

Through the adoption of the Global Warming Solutions Act in 2008, Connecticut set a goal of reducing greenhouse gas (GHG) emissions by 80 percent below 2001 levels by 2050. Executive Order 46 in 2015 created the Governor's Council on Climate Change (GC3), which was tasked with examining the effectiveness of existing policies and regulations designed to reduce GHG emissions and identify new strategies to meet the state's 80 percent reduction goal. The strategies to achieve this goal encompass a transition to zero-carbon vehicles, building envelope improvements, building energy management systems improvements including high-efficiency thermal systems, and decarbonizing the electric grid with zero carbon resources such as solar photovoltaics (PV), wind, hydro, biomass and nuclear generation.

To inform the GC3's decision making, we examine the economic and environmental impacts of a consensus midterm (2030) GHG reduction target of 45 percent that includes reductions from the individual transportation, building and utility sectors as well as all sources combined. The economic analysis below focuses on 2020 through 2030 because while we have data to 2050, beyond 2030 there is significant uncertainty. Essential assumptions underpinning the economic analysis below appear in Appendix A.

Transportation Sector Assumptions

Transportation accounted for about 35 percent of Connecticut's GHG emissions in 2014. Reducing GHGs from this sector represents a significant portion of the total that must be eliminated to reach the 2030 target of 45 percent below 2001 emissions. The strategies to achieve the needed reduction include the electrification of passenger vehicles and light trucks, short haul trucks, busses and commuter rail. Long-haul trucks, diesel freight locomotives, ferries and off-road construction equipment will need to transition to alternative fuels as well. We do not assume any changes to aircraft and pleasure boat fueling.

The GHG reductions are achieved with an estimated rate of electric vehicle (EV) uptake and related changes in EV charger installation, electricity sales, retail gas station market exit and non-recurring gas station remediation. In addition, we assume there will be an increase in hydrogen-powered vehicles and their required filling stations.

Complementary to the GC3's selected GHG reduction strategies, the state's transportation infrastructure will be transformed according to the comprehensive *Let's Go CT* (LGCT) program contingent on the availability of necessary funding. Among many road, bridge and harbor improvement and expansion projects, elements of this program include improved mass transit systems, electrification of transit busses and commuter rail systems, and development of transit-oriented communities around commuter rail and bus rapid transit stops. These investments increase the efficiency of the movement of goods and people through and throughout the state. They will also improve the productivity of the private sector and their effects will be felt into the next century, similar to the benefits of the investment that produced the interstate highway system in the 1950s and 1960s.[1]

The 33-year, $130 billion LGCT program confers significant economic benefits to the state; however, the economic and fiscal impacts of the entirety of the LGCT program are beyond the scope of the current economic analysis.[2] About 65 percent of the LGCT investment preserves existing infrastructure and includes a large investment in repairing, reconstructing and replacing rail and bus infrastructure. For example, the rail

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[1] For one account of the benefits, see "The Best Investment a Nation Ever Made," by Wendell Cox and Jean Love (June 1996), for the American Highway Users' Alliance. Available at http://www.publicpurpose.com/freewaypdf.pdf. Twenty years later the 'TRIP' report updates the history and benefits as well as some costs of the system, but neither of these reports and others mention the interstate highways' effect on rail transportation (substantial reduction), pollution (vast increase in part due to congestion) and the hollowing out of urban areas. The June 2016 TRIP report, "The Interstate Highway System turns 60: Challenges to Its Ability to Continue to Save Lives, Time and Money," is available at http://www.tripnet.org/docs/Interstate_Highway_System_TRIP_Report_June_2016.pdf.

[2] See http://transformct.info.

preservation program includes replacing four movable bridges that will cost $500 million to $1 billion each. The fraction of the $130 billion investment attributable to GC3's GHG mitigation strategies (in this case, improved mass transit) is quite small and difficult to separate from the larger and more complex projects envisioned in the 33-year LGCT program. Therefore, the current analysis omits the contribution of that part of the LGCT program and the economic and fiscal impact results reported later should be regarded as less optimistic than if the improved mass transit contribution were included.

Electric Vehicles

To achieve the necessary level of GHG reduction, the market share of EVs must continue to grow. We assume there will be little change in overall vehicle sales [numbers or dollars] over time due to an assumed relatively low growth in Connecticut population and personal income, and because declining costs, range increases and incentives will drive the replacement of gasoline-powered vehicles, at least in the near term. We assume overall vehicle sales follow the deployment needed to achieve the 2030 target spurred in part between 2017 and 2021 by the state's Connecticut Hydrogen and Electric Automobile Purchase Rebate (CHEAPR) incentive program and the federal tax incentive while it is in effect. In addition to battery electric vehicles (BEVs), there will be a growing fraction of hydrogen fuel cell EVs (FCEVs) as their costs decline but we assume more slowly than those of BEVs. There will be (privately-funded) hydrogen filling stations built in the state commensurate with the deployment of FCEVs.

We assume there will be BEV charging stations installed in homes, businesses, parking facilities and public spaces to complement electric and plug-in hybrid vehicle uptake. Additionally, we assume hybrid vehicle sales will increase initially and then decline as BEVs become the new standard passenger and light truck vehicle (including SUVs). Therefore, hybrids will help in the near term, but will not drive charging station deployment.

As EVs displace gasoline- and diesel-powered vehicles, gasoline and diesel consumption and fuel tax revenue will decline. Gas stations will exit the market and there will be increased unemployment in this and related retail subsectors due to declining fuel sales and service.[3] Gasoline wholesalers' sales will decline as will taxes from other fossil fuels. As many of the state's 1,409 gas stations[4] close, there will be remediation costs beyond the normal life-cycle replacement of tanks and pumping equipment necessary to close these stations. The average cost for remediation of two to three underground storage tanks is between $20,000 and $30,000. This includes tanks, piping and dispenser removal, disposal, closure sampling/analysis/report and back-filling the excavation.[5] Gas station owners or operators typically incur remediation costs of the underground storage system, and, unlike the normal life-cycle replacement costs that would be recovered with future sales, these costs will not be recovered with future sales as stations exit the market and thus we count them as new expenditure and not net new investment.

We assume the state will find alternative revenue sources to make up the fuel tax shortfall as fossil fuel consumption declines due to EV uptake. Per CONNDOT, we assume that gasoline-related federal funds to the state do not decrease and that there are a variety of state-level revenue generating strategies to offset the decline in state taxes derived from gasoline, diesel and natural gas sales. The fuel tax shortfall arises from the differences between the reference case and the midterm target scenario assuming no changes in CONNDOT funding requirements.

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[3] Many other automotive-related retail and service establishments will close as well, including auto parts stores, transmission centers and lubrication shops. However, tire centers, brake repair and body shops will remain to service the EV fleet. Gasoline, diesel, LPG and kerosene retail establishments with and without convenience stores are part of the retail sector (NAICS industry 447).

[4] This number was estimated by Frank Greene at DEEP, January 13, 2017.

[5] Pat Bowe, Director of the Remediation Division, CT DEEP Bureau of Water Protection and Land Reuse (WPLR). We use $30,000 in the economic analysis below.

We assume the current state incentive for EVs, CHEAPR, which averages $1.5 million per year, will remain in place for five years (2017 through 2021). The funds for this incentive do not come from the General Fund, rather, other sources. We think that in this timeframe BEVs will achieve rough parity with gasoline-powered vehicles in terms of vehicle cost and range so that no further incentive will be needed. There is currently no state incentive for charging and hydrogen refueling stations and we assume households, businesses and government will self-fund their capital and installation costs to support the deployment of EVs and FCEVs.[6] In the short run, we assume the CHEAPR and the federal incentive will cause households to purchase an electric vehicle if they are ready to buy or lease a new car rather than a gasoline- or diesel-powered vehicle. We assume the newly-purchased EVs replace existing vehicles and the CHEAPR incentive does not cause an increase in the total number of vehicles, rather it helps to induce a switch to EVs.

The health benefits of reduced SOx, NOx, and primary PM emissions improve the state's quality of life and productivity and reduce health care costs (reduced mortality and morbidity), however the economic impacts of these benefits are not evaluated in this analysis. Further, we do not account for averted environmental costs and therefore to the extent that adaptation to climate change will generate new economic activity, our economic modeling results understate the economic benefit to the state.

Switching from internal combustion engines to electric powered vehicles results in an increased demand for electricity. For the transportation GHG mitigation strategy, we assume that electricity sales increase commensurate with the needs of EV uptake.

EV Charging and Hydrogen Refueling Stations

The switch to EVs may affect Connecticut's manufacturing sector depending on where EV components are made. We have no knowledge of this aspect of EV take up. For REMI modeling purposes, the sale of an EV instead of an internal combustion vehicle has no (known) local manufacturing impact. We assume the industries affected by installing and maintaining EV charging and FCEV hydrogen filling stations are local electrical contractors and capital equipment producers. We use average costs for residential, business, parking garages, and on-street charging station applications. In addition, we construct the breakdown between capital (hardware), installation and maintenance costs and how many of which type (or level) of charging station households, businesses and governments would install (see the Table B1 in Appendix B for details on EV charger data sources and assumptions). We assume maintenance costs for chargers accumulate over time and lag their installation by one year. Further, we assume that households reallocate their spending to install and maintain their charging stations. This means as households spend more on charging station installation and maintenance, they spend less on everything else. We assume business and government spending for their charging infrastructure is net new investment perhaps funded by bonding for capital improvement.

Input-output analysis (such as REMI) requires that only markups are used for wholesale and retail sales because a portion of the costs of production and transportation accrue to out-of-state firms. As some of the costs for installing charging stations involve retail and wholesale sales, we use an eight percent markup for gasoline retail sales[7] and a 20 percent markup for wholesale trade.[8]

For the transportation sector, we use the EV penetration levels from the *45 percent case* that was presented to the Council at its October 2017 and January 2018 meetings. Figure 1 shows the trajectory of BEV charging station investment for non-residential chargers (Level 1, Level 2 Public and DC fast charger - Level 3) for the *45%*

[6] There are federal tax credits for EVs and related chargers. See http://www.fueleconomy.gov/feg/taxevb.shtml and https://pluginamerica.org/why-go-plug-in/state-federal-incentives.

[7] NACS 2016 Retail Fuels Report (page 8). Available at http://www.nacsonline.com/YourBusiness/FuelsCenter/Documents/2016/2016-Retail-Fuels-Report.pdf

[8] See "Reasonable Markup to Distributors," by Thomas H. Gray. Available at http://www.tom-gray.com/2012/04/26/reasonable-markup-to-distributors/.

case. The investment consists of hardware costs modeled as wholesale trade increases (we assume the equipment is purchased from Connecticut electrical equipment wholesalers), installation costs modeled as power equipment installers' increased sales and maintenance modeled as electric equipment maintenance and repair sales increases. The data plotted represents the differences in the above expenditure categories between the reference case and the *45% case* and these differences drive economic impact. The spike in 2020 reflects our assumption that there is substantial ramp-up of EVs in the years before 2020 and 2020 represents the last year of rapid charger build out before accelerating again in 2025. We show the full wholesale cost in the plots below, while for the economic analysis, we input 20 percent of this value.

Figure 1: Non-Residential BEV Charging Station Investment for the *45% Case*

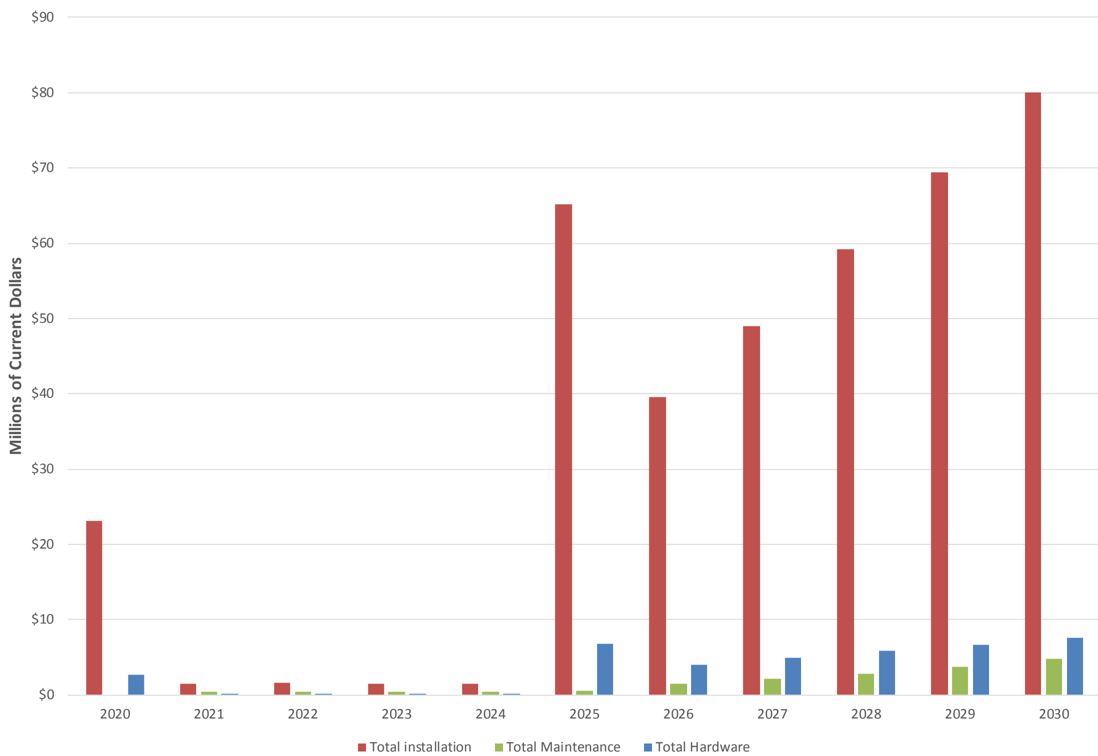
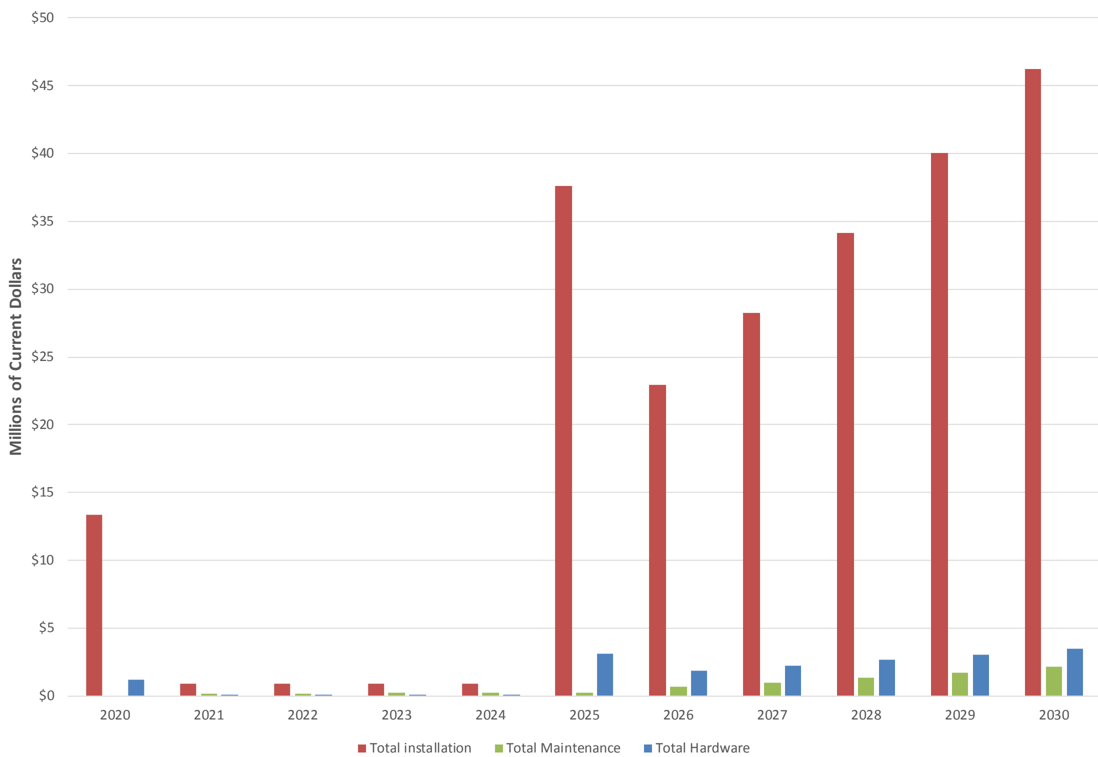


Figure 2 shows the trajectory for EV charging station investment for the AC Level 2 residential chargers for the *45% case*. In this case, consumers spend the total amount for hardware, installation and maintenance out of their household maintenance budget and spend correspondingly less on everything else (we assume their incomes do not change). The data plotted represents the differences in the hardware, installation and maintenance categories between the reference case and the *45% case*, while the changes in consumer spending drive economic impact. As is the case for the non-residential charger investment, the spike in 2020 reflects our assumption that there is substantial ramp-up of EVs in the years before 2020 and 2020 represents the last year of rapid charger build out before accelerating again in 2025.

Figure 2: Residential BEV Charging Station Investment for the *45% Case*



Hydrogen Filling Stations

We base our assumptions for FCEV deployment on California's study.[9] The California FCEV evaluation projects that there will be:

- 10,500 FCEVs registered in CA by 2018 and 34,300 FCEVs by 2021
- The current growth rate of the vehicles is 43 percent annually
- $20,000,000 in investments to cover 100 fueling stations
- 65 publicly-funded, operational fueling stations by 2018

We use California's FCEV projections, scaled to account for the differences in population; however, accounting for the suggested 10-year lag in Connecticut's deployment, there is no difference between hydrogen filling station investment in the reference case and the *45% case* until 2028, at which point investment jumps to $1.2 million and then declines to $600,000 (all in current dollars). These investments contribute to economic impact.

Internal Combustion Engine Vehicle Retail Products Demand Changes

The time path of retail (gas station) and electric utility employment and/or industry sales changes follows the deployment of EVs based on LEAP projections for the required GHG reduction to meet the 45 percent midterm target. From the displacement of gasoline-powered vehicles, we calculate the loss of retail/wholesale fuel sales (note, because we ignore the loss of retail establishments that supply parts and services for gasoline- and diesel-powered vehicles not used in EVs, the economic analysis below is optimistic, that is, the REMI results are more positive than they would be if we included the loss of these complementary retail establishments; see note 3 above). Figure 3 shows the trajectories of total fuel sales (in current dollars) from 2020 through 2030 for

[9] "2015 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development," California Environmental Protection Agency, Air Resources Board, July 2015. Available at https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2015.pdf.

gasoline, diesel, LPG, ethanol, CNG and hydrogen. The difference in total fuel sales between the reference case and the *45% case* drives the economic and fiscal impact in terms of a contraction of the motor fuel retail sector modeled as households' decreased spending on motor vehicle fuels and lubricants.

Figure 3: Total Fuel Sales for the *45% Case* (Billions of Current Dollars)

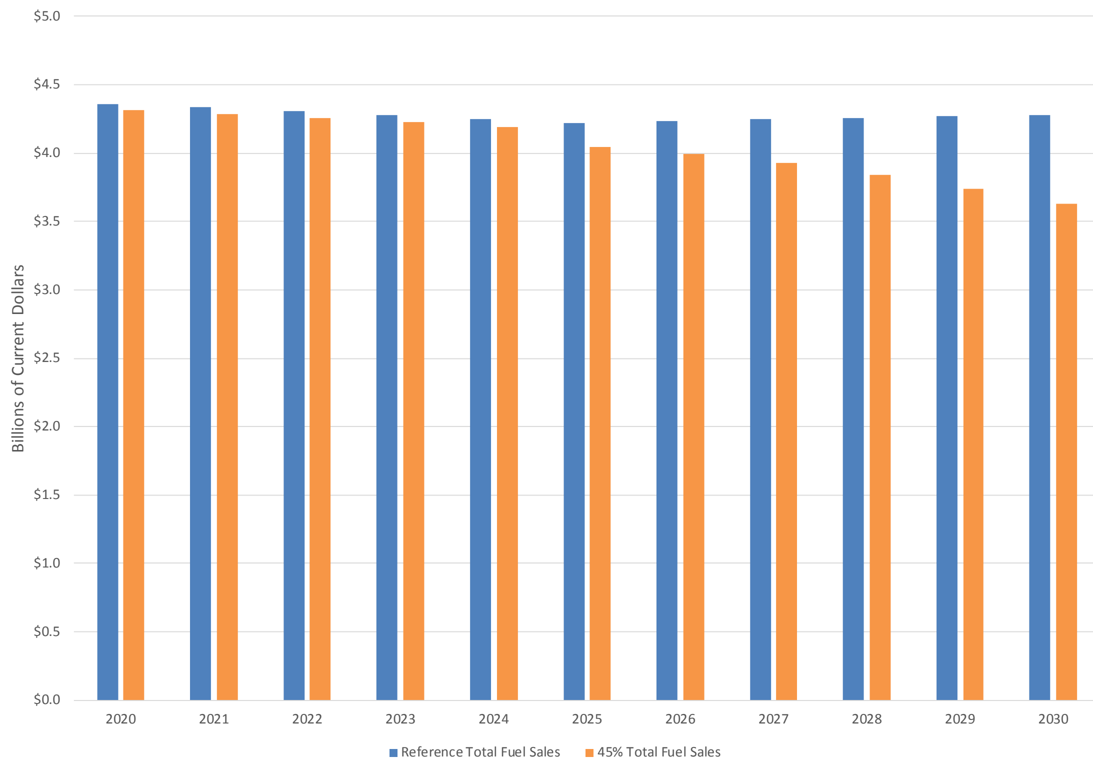
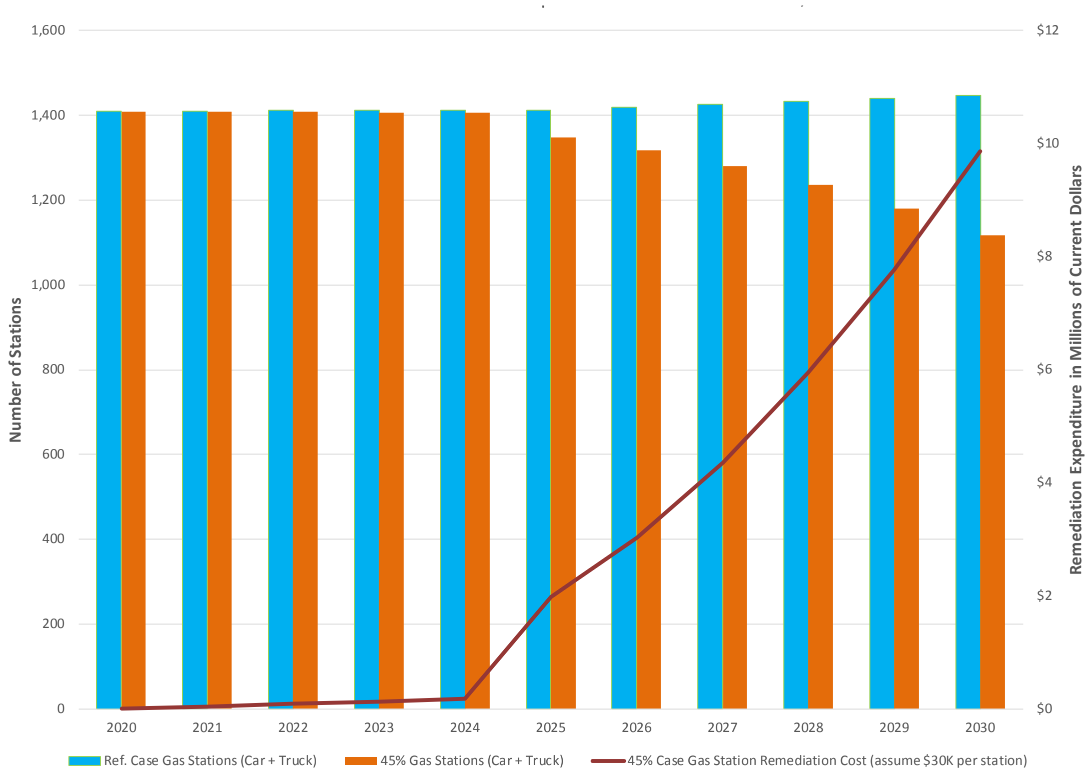


Figure 4 shows the trajectories of the decline in the number of retail gas stations across the state for the *45% case*. Note that in the reference case, the number of stations increases slightly over time. Using estimates for the costs of remediation for closed gas stations (note 5 above), we have net new expenditure in the waste management industry. Corresponding to the yearly decline in gas stations and fuel sales is the increase in non-recurring remediation cost that has offsetting effects on the economic impact. In this analysis, we assume the ratio of vehicles to stations remains roughly constant at its 2020 level (between 1,623 and 1,624 vehicles per station) from 2020 to 2030. In 2030, there are 1,117 retail gas stations remaining in the *45% case*. Remediation expenditures in 2030 are $9.9 million in current dollars. The annual fuel sales differences between the reference case and the *45% case* (modeled as decreased consumer spending on gasoline and diesel) as well as the non-recoverable remediation expenditures (that increase as the number of stations exiting the market increases) drive the economic and fiscal impact of declining fuel sales.

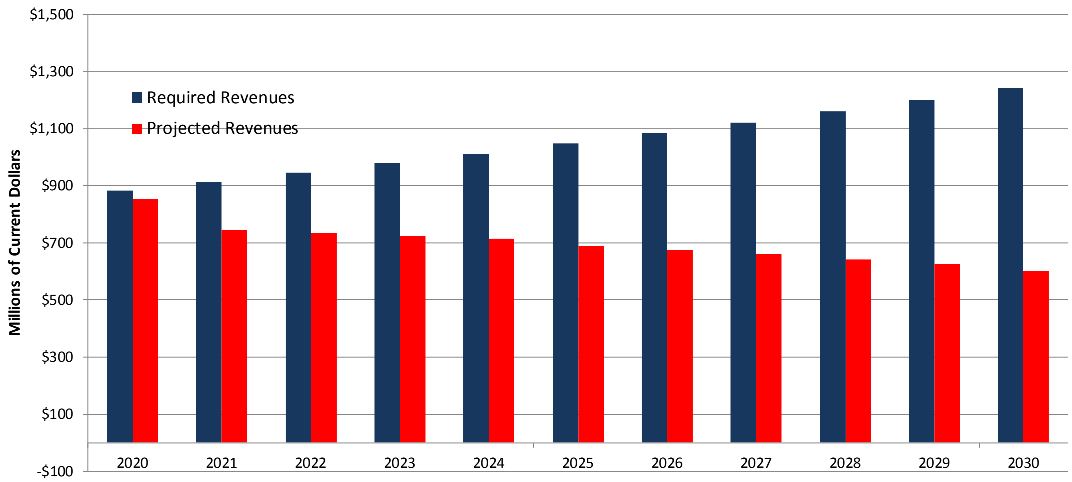
Figure 4: The Decline in Retail Gas Stations and the Increase in Remediation Expenditure, *45% Case*



We do not include in the economic model the gas tax revenue shortfall relative to the CONNDOT required revenue as a decline in state and local government spending because we assume there will be an offsetting revenue-generating policy. For illustrative purposes only, Figure 5 shows projected CONNDOT revenue requirements to maintain the safety and reliability of the state's transportation network. The difference between the CONNDOT requirement and the *45% case* constitutes the reduction in state revenue relative to CONNDOT revenue requirements and we include them in Figure 5 for illustrative purposes only. Note the revenues are in nominal dollars, that is, unadjusted for inflation.

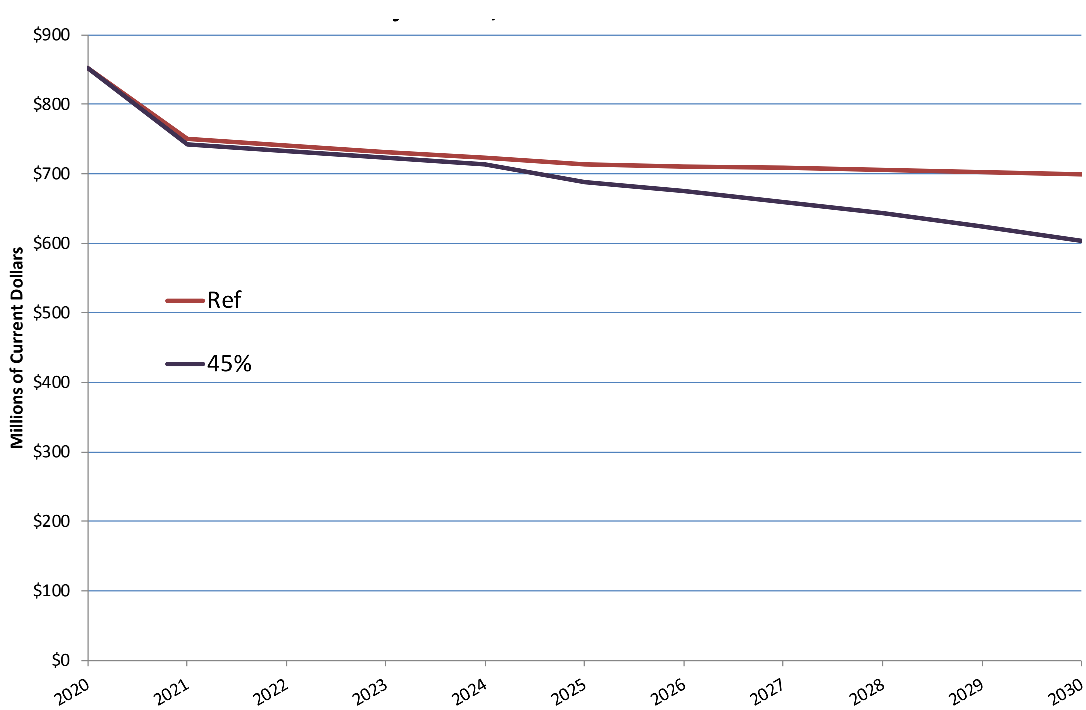
Expected CONNDOT required revenue to maintain the state's transportation network is based on a compound increase of 3.5 percent per year from a base of $768.2 million in 2016. Expected fuel tax revenue is based on an assumed 25 cents per gallon plus a gross receipts tax of 8.1 percent. The LEAP model estimates the MMBTU consumed for all vehicle types and we convert total BTU to gallons of fuel consumed.

Figure 5: CONNDOT Revenue Requirement and Fuel Tax Revenue Projections for the *45% Case*



We do count the annual fuel sales tax revenue differences between the LEAP reference case and the *45% case* as they represent a shortfall that contributes to the economic and fiscal impact, because these differences arise from the GC3's GHG reduction strategies. Figure 6 shows the fuel tax revenue trajectories of the *45% case* relative to the reference case. The fuel tax shortfall in this case represents a reduction in state spending (service production) without state employment or compensation effects. It is likely that as state revenue falls from a particular source, state spending is reallocated, curtailed or delayed. The fuel tax shortfall in 2030 is $95 million in current dollars.

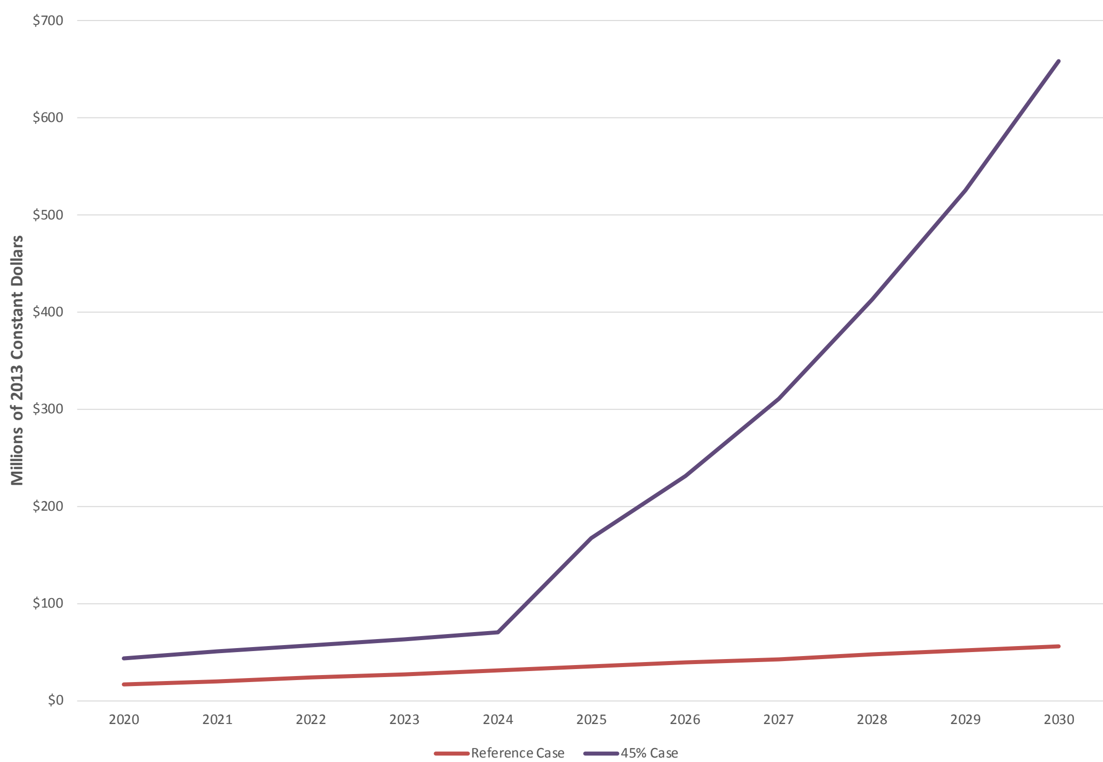
Figure 6: Fuel Tax Shortfall for the *45% Case* Relative to the Reference Case



Changes in Electricity Demand (Sales)

We estimate the increase in electricity sales from the increase in demand for electricity needed to charge EVs. Figure 7 shows the trajectory of electricity sales for the 45 percent midterm GHG reduction target. The annual sales differences between the reference case and the *45% case* contribute to the economic impact. Note, in this case, electricity sales (from LEAP) appear in 2013 constant dollars (that is, adjusted for inflation with 2013 as the base year) in Figure 7. Increased electricity sales represent increases in the utility bills of households (modeled as increased consumer spending for electricity).[10] Receipts of the state's electric utility companies increase accordingly. These new sales represent in part the power purchased from regional generating assets and renewable energy credits (RECs) as well as the transmission and distribution services the state's utilities provide. For the transportation sector GHG mitigation strategy, we assume the increased demand for electricity is met with existing regional supply including imports. Later in the electricity sector impact, we assume most demand is satisfied by renewable supply.

Figure 7: Electricity Sales Increase as BEVs Deploy, *45% Case*

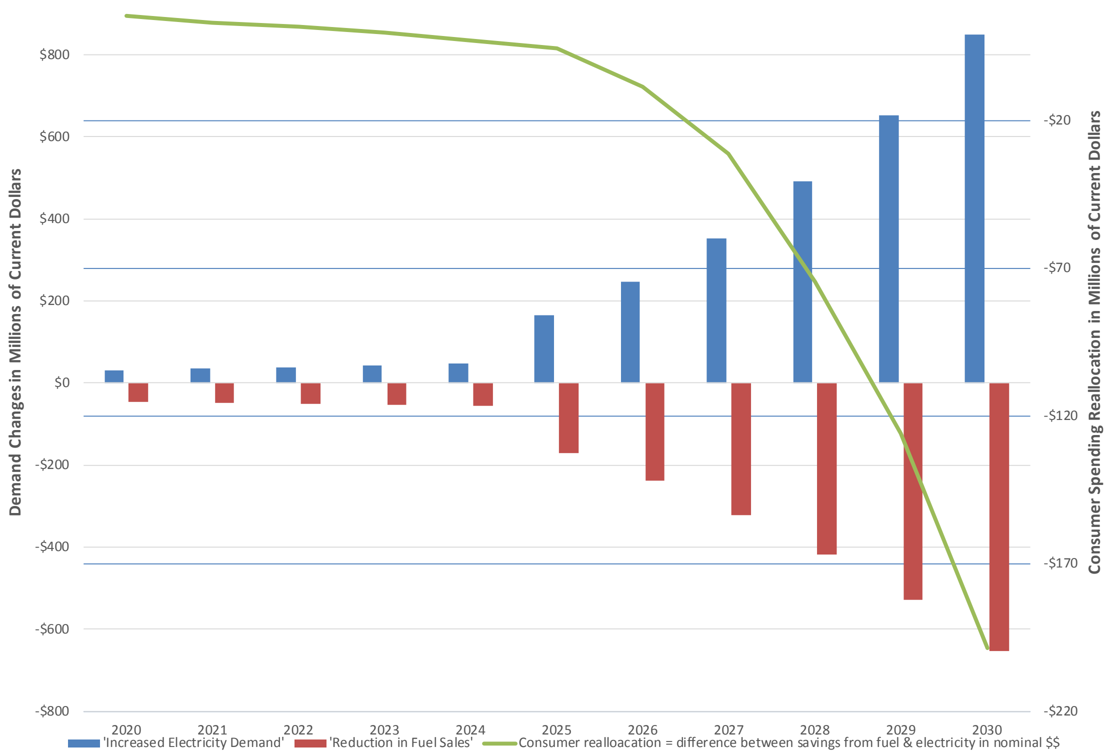


It is useful to note that the decline in motor fuel sales (consumer savings) is offset by the increased demand for electricity. In 2030, the decline in fuel sales is $652 million in nominal dollars while the increase in electricity demand (the difference between the reference case and the *45% case* in Figure 7 below) is $850 million in nominal dollars ($602 million converted from 2013 constant dollars using the REMI consumer expenditure price index). The offset is positive between 2020 and 2025 and steadily declines as the increasing demand for electricity gradually outstrips the savings from reduced motor fuel consumption. We reallocate the offset to

[10] We assume for simplicity all new demand for electricity arises from household spending for electricity as they purchase almost all the battery-powered light trucks and passenger vehicles.

increased consumer spending on other goods and services between 2020 and 2025 and reduced spending on other goods and services for the remainder of the forecast period (solid line in Figure 7A).

Figure 7A: Changes in Electricity and Motor Fuel Demand, Consumer Spending Reallocation, *45% Case*



The CHEAPR Incentive

The cost to the state of its CHEAPR incentive program for EVs averages $1.5 million annually and continues for five years (2017 through 2021 in nominal dollar terms). We assume government spending is not reduced by that amount because funding comes from sources outside the state's General Fund. Further, the switch to EVs induced by the incentive does not increase the total number of vehicles, rather it causes a switch to EVs (about 600 vehicles per year). However, for economic modeling purposes, we assume the $1.5 million represents additional consumer spending on motor vehicles that offsets the current relatively higher cost of EVs.

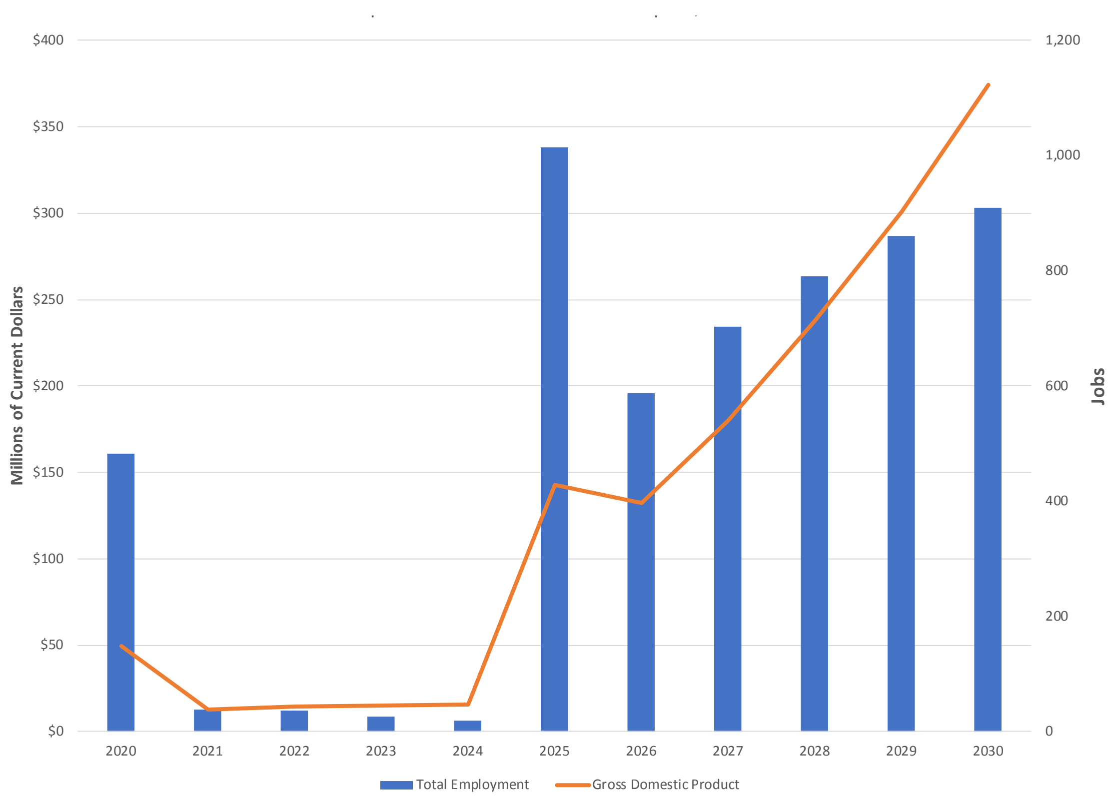
Transportation Infrastructure Improvements

The state's transportation infrastructure will be transformed according to the comprehensive LGCT program (see note 2). Among many road, bridge and harbor improvement and expansion projects, elements of this program include improved mass transit systems, electrification of busses and commuter rail systems, development of transit-oriented communities around commuter rail and bus rapid transit stops. These investments increase the efficiency of the movement of goods and people through and throughout the state. These investments in turn will improve the productivity of the private sector and their effects will be felt into the next century. However, the portion of the investment attributable to GHG mitigation (transit and transit-oriented development improvements) is small relative to the total 33-year investment of $130 billion. Moreover, separating the transit portion from the whole is difficult. For the transportation sector therefore, we omit the transit portion of LGCT and acknowledge that the analysis is conservative meaning if we included transit improvements, the REMI results would be more positive. The economic impact of LGCT is beyond the scope of the present analysis.

Transportation Sector REMI Results

Figure 8 shows the economic impact (changes from the baseline business-as-usual forecast) of the transportation strategy to reduce GHG emissions. We show two economic variables that characterize the changes in the economy as a result of achieving the *45% case* as described above. Total employment includes public and private sector employment and excludes farm employment. Note that REMI measures employment in jobs, not workers, as some workers have more than one job.[11] Gross domestic product is the monetary value of all goods and services produced in the state in a given year. The monetary values expressed in these charts (except as noted) are in nominal or current dollar terms and do not reflect the effect of inflation.

Figure 8: Transportation Strategy Economic Impact for the *45% Case*



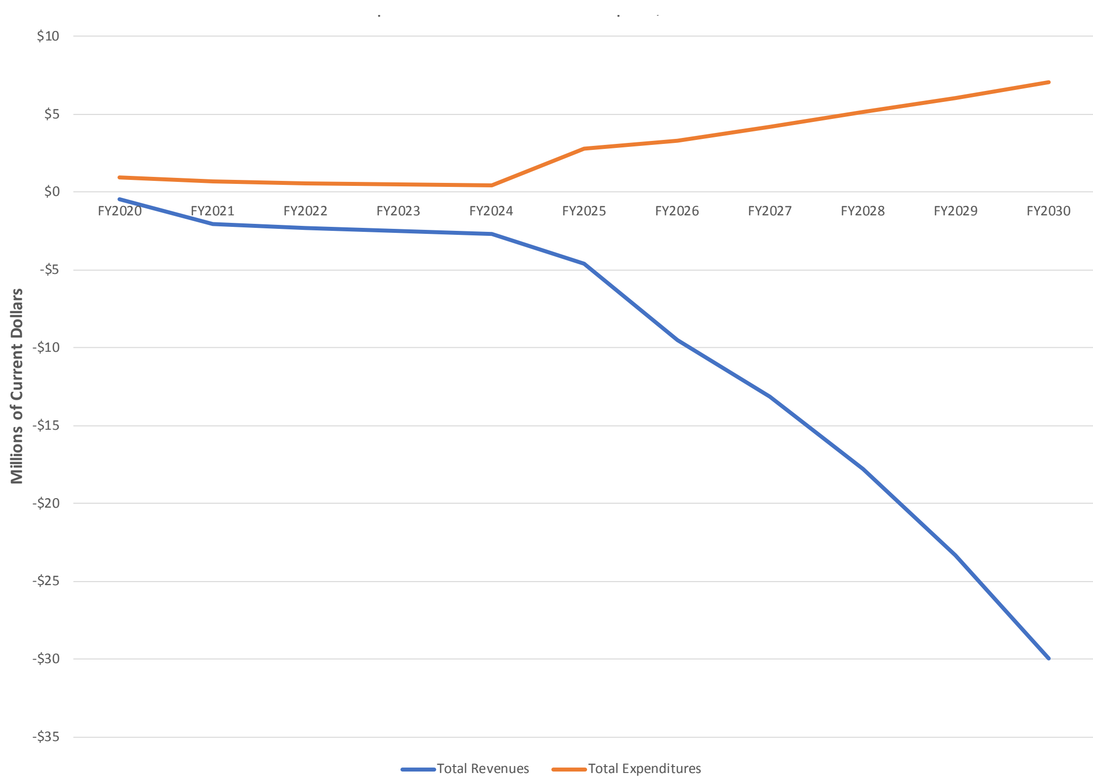
Total employment increases steadily after 2024 and peaks in 2030 at 908 (or 0.037%) more jobs than the baseline forecast jobs, while state GDP exhibits the same trend and peaks at $374 million (0.08%) higher than the baseline forecast in 2030. The spike in employment in 2020 is due to the spike in EV charger deployment which we assume has been growing since 2016. Thereafter, EV charger infrastructure buildout relaxes until

[11] From REMI's data sources documentation, "Employment can be measured either as a count of workers or as a count of jobs. In the former case, an employed worker is counted only once; in the latter case, all jobs held by the worker are counted. The county employment estimates are a count of the number of jobs, so that, as with the earnings estimates, a worker's activity in each industry and location of employment is reflected in the measure. See http://www.remi.com/wp-content/uploads/2017/10/Data-Sources-and-Estimation-Procedures-v2_1.pdf, page 40. In Connecticut, the difference between workers and jobs is about 700,000 with about 1.62 million workers employed.

2025 when it again accelerates and combines with the other economic drivers that are accelerating as well (electricity sales, fossil fuel savings and remediation costs). Total employment averages 500 (0.02%) more jobs each year than the baseline forecast, while state GDP averages $134 million (0.03%) more than the baseline forecast each year.

Figure 9 shows the fiscal impact (changes from the baseline business-as-usual forecast) of the transportation strategy to reduce GHG emissions for the *45% case*. We show total state revenues (from all sources) and total state expenditure (for all uses). We do not force the budget to balance and therefore we see that there is a growing relative budget deficit in nominal terms after 2020 as a result of the economic activity described above for the transportation sector GHG reduction strategy. State revenue steadily declines from -$0.44 million (or -0.002%) to -$30 million (or -0.085%) relative to the baseline forecast in 2030, while state expenditure peaks at $7 million (or 0.023%) above the baseline forecast in 2030. State revenue averages $9.8 million (-0.03%) below the baseline forecast while state expenditure averages $2.9 million (0.01%) above the baseline forecast over the analysis timeframe. The relative revenue decline is primarily due to the relative decline in sales and use taxes from motor vehicle fuels and related retail sales, while the relative increase in state expenditure is primarily due to the relative increase in education spending. These fiscal changes are driven by the decline in retail and wholesale trade and the small increase in relatively low-wage construction jobs as well as projected population growth and migrants seeking employment opportunities that increase public spending. Keep in mind these are very small changes in state revenue and spending that result from the significant offsets to positive impacts as described above.

Figure 9: Fiscal Impact of Transportation Strategy, *45% Case*



Building Sector Assumptions

Thermal energy consumptions in commercial, industrial and residential buildings account for about 31 percent of Connecticut's GHG emissions. Mitigation strategies include replacing existing oil- and gas-fired heating appliances with electric heat pumps that both heat and cool spaces more efficiently. For this sector, we assume increased electricity demand is met with regional supply including imports and will be increasingly supplied by renewable sources. In addition to switching to more efficient heating and cooling technologies, building envelopes will become more efficient through installing improved insulation, and energy-efficient doors and windows. As a consequence of the deployment of these strategies, there will be less demand for heating oil and natural gas, and some suppliers of these and complementary products and services will exit the market. There will be a corresponding increase in the demand for electricity (offset by improvements in energy efficiency).

Heat Pump Deployment

We assume the investment in electric heat pumps is net new and there is no state incentive to induce the switch from oil- and gas-fired heating systems (there may be a federal tax credit for this purpose) and is entirely privately funded. The *45% case* separated the uptake of heat pumps for the residential and commercial sectors, which allows us to separate the changes in demand for different energy sources. We assume that commercial establishments and residential households increase their demand for electricity and reduce their demand for natural gas and fuel oil as heat pumps deploy.

Figure 10 shows the changes in demand for electricity, natural gas and fuel oil as well as the net energy savings households realize for the *45% case*. The savings in each case offset the investment households make; however, the cost of heat pumps greatly exceeds their energy savings. In the absence of incentives, we assume households finance heat pump installation by borrowing in the capital markets and do not alter their current modes of spending and consumption.[12] The increased borrowing to finance heat pump deployment as we imagine it benefits the banking sector and we do not account for this benefit.

[12] We assume households and businesses invest in heat pumps because they can obtain the needed capital from the Green Bank at 1% interest. Households and businesses recognize the discounted future costs of climate change outweigh the current costs of reducing GHG by using heat pumps for heating and cooling. This is a heroic assumption because realistically, significant incentives will likely be needed to achieve the deployment trajectory envisioned here.

Figure 10: Residential Demand Changes for Electricity, Natural Gas and Fuel Oil and Net Savings (Millions of Current Dollars), *45% Case*

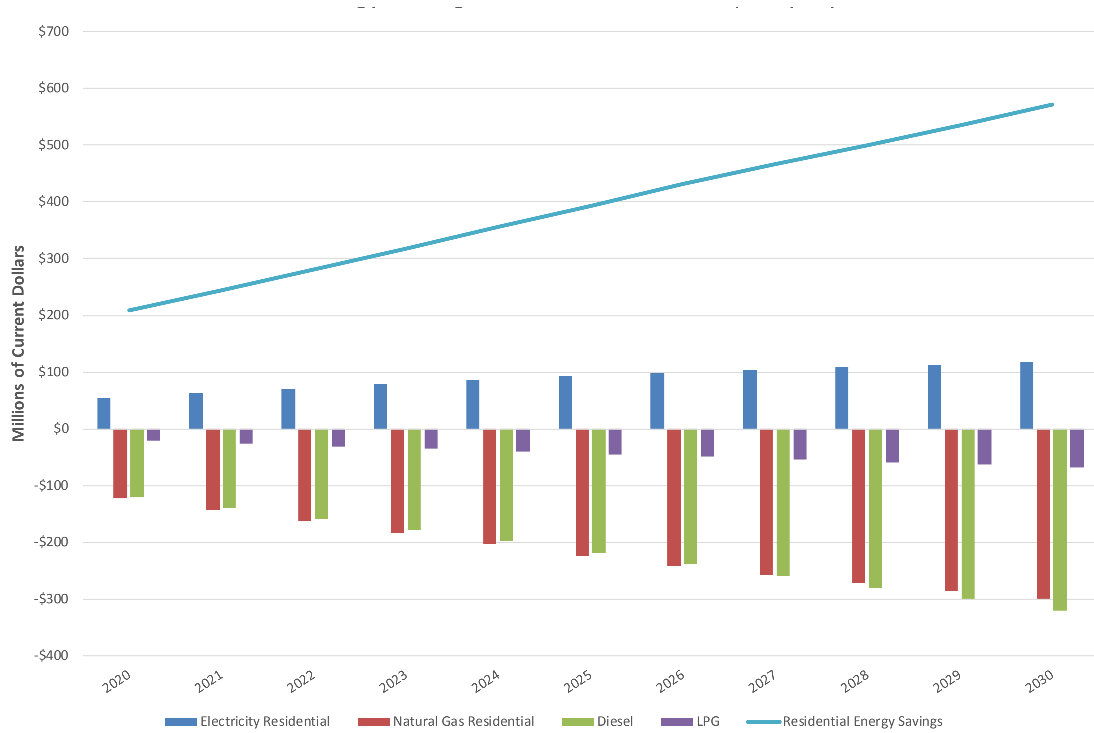


Figure 11 shows the changes in demand for electricity and natural gas and the net energy savings commercial establishments realize for the *45% case*. The savings in each case offset the investment in heat pumps businesses make. However, the cost of heat pumps greatly exceeds the energy savings. In the absence of incentives, we assume businesses finance heat pump installation by borrowing in the capital markets and do not alter their current modes of spending and consumption.[13] The increased borrowing to finance heat pump deployment as we imagine it benefits the banking sector and we do not account for this benefit.

[13] We assume households and businesses invest in heat pumps because they can obtain the needed capital from the Green Bank at 1% interest. Households and businesses recognize the discounted future costs of climate change outweigh the current costs of reducing GHG by using heat pumps for heating and cooling. This is a heroic assumption because realistically, significant incentives will likely be needed to achieve the deployment trajectory envisioned here.

Figure 11: Commercial Establishment Demand Changes for Electricity and Natural Gas and Net Savings (Millions of Current Dollars), 45% Case

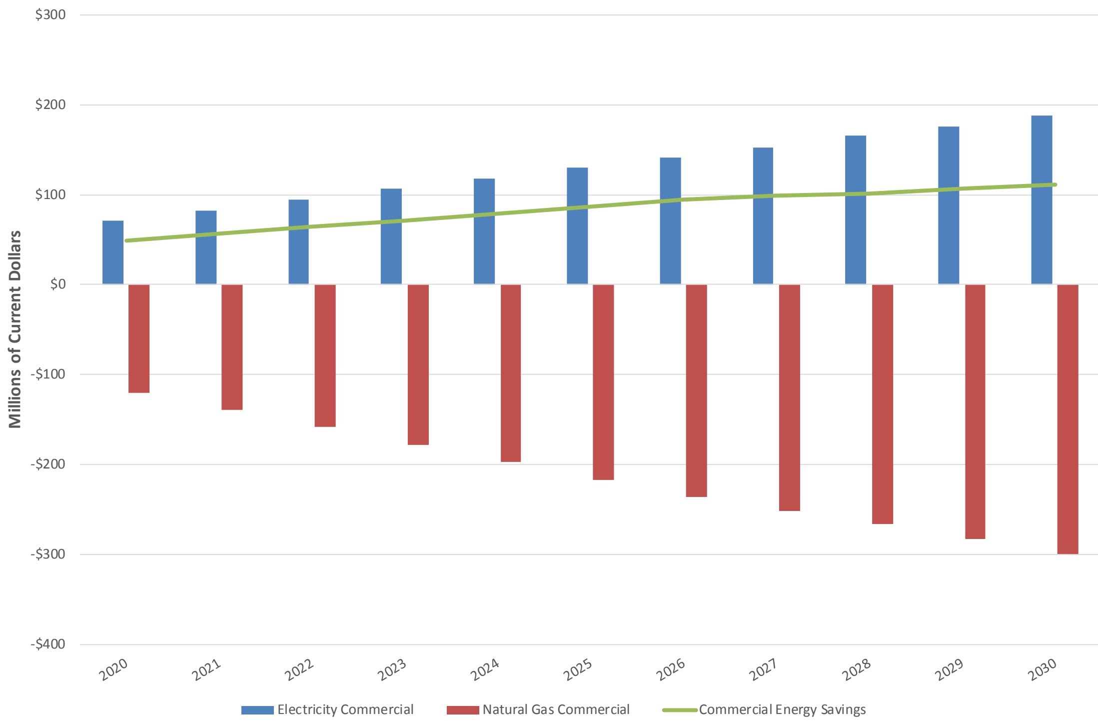
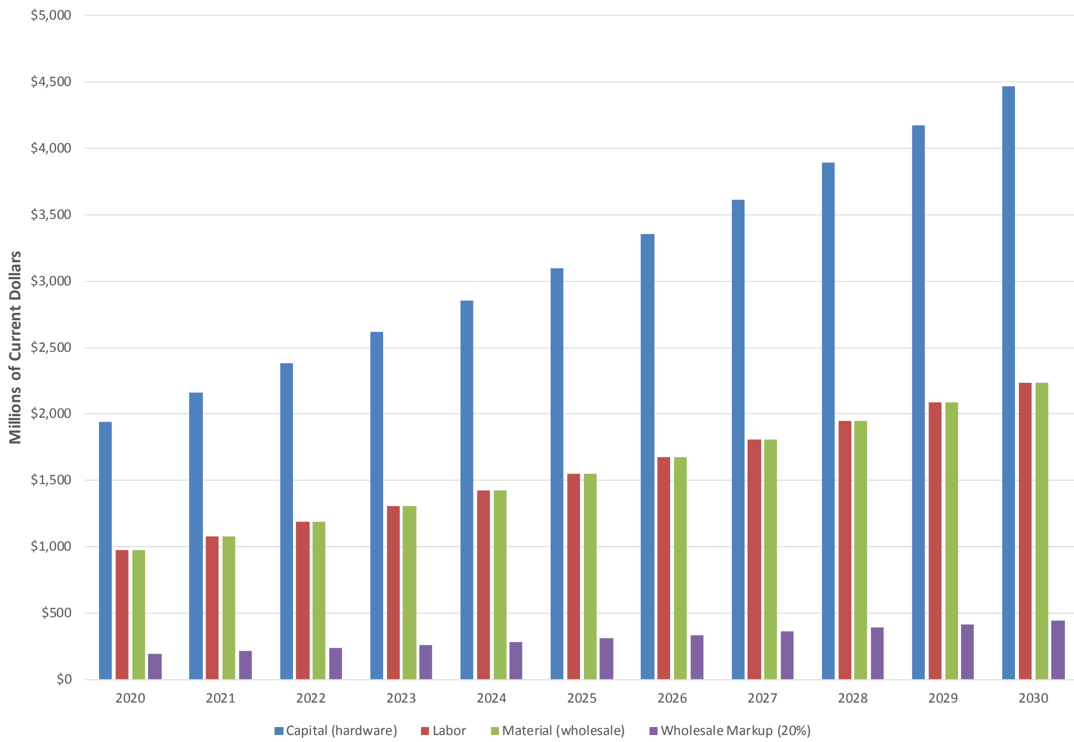


Figure 12 shows the combined residential and commercial net new (relative to the reference case) investment in heat pump capital equipment, labor and wholesale materials (recall wholesale enters as a 20% markup in REMI) for the *45% case*. We estimate the combined residential and commercial investment to be $8.93 billion in 2030 (add the largest bars in Figure 12).

Figure 12: Combined Residential and Commercial Net New Heat Pump Investment, *45% Case* (Millions of Current Dollars)



To illustrate the residential and commercial investment undertaken relative to the excess of heat pump spending over energy savings, Figures 13 and 14 display the trends for the *45% case* as we assume that the annual energy savings offsets the interest payments on borrowed funds but does not nearly cover the investment required to build out the heat pump penetration needed to satisfy the 45 percent midterm reduction target.

Figure 13: Residential Heat Pump Investment Relative to Net Excess Expenditure, *45% Case*

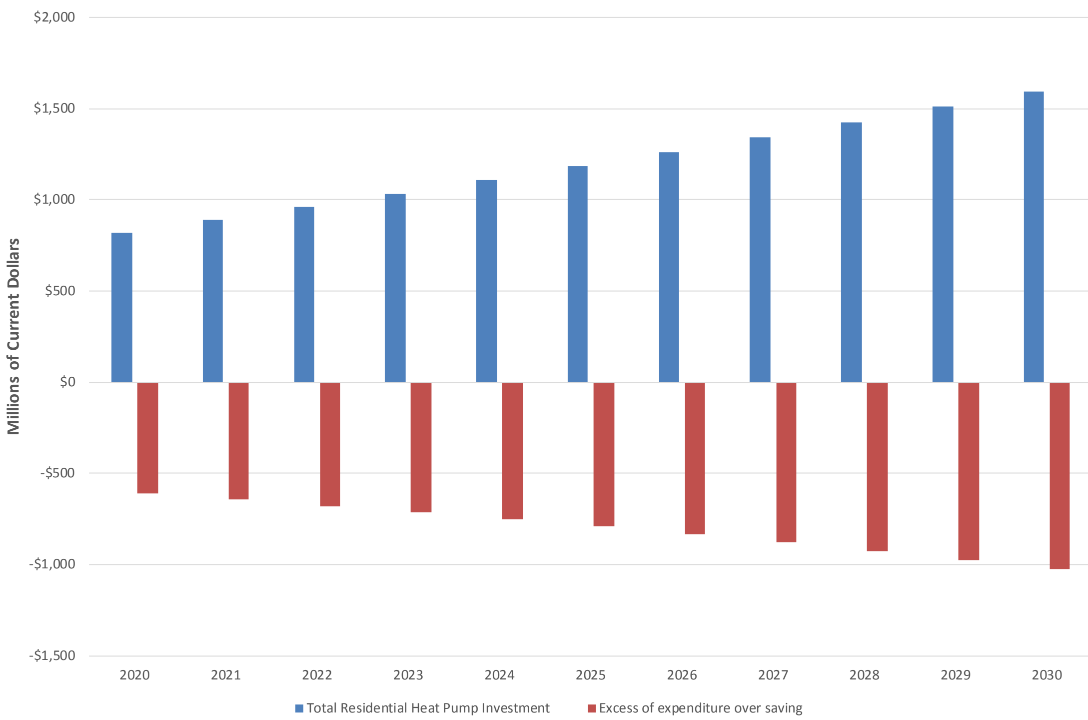
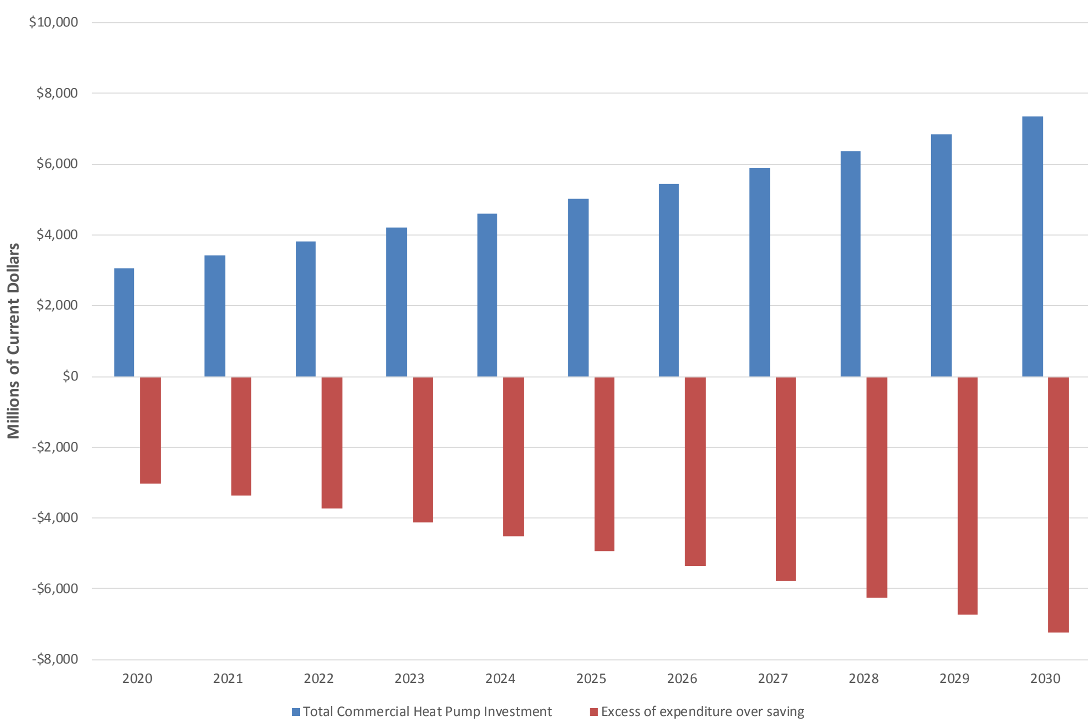


Figure 14: Commercial Heat Pump Investment Relative to Net Excess Expenditure, *45% Case*



Energy Efficiency Investments

Figure 15 shows the energy savings households realize excluding spending on efficiency improvements while Figure 16 shows the savings commercial establishments realize excluding spending on efficiency improvements for the *45% case*.

Figure 15: Residential Savings from Energy Efficiency Improvements Excluding Costs (Millions of Current Dollars), *45% Case*

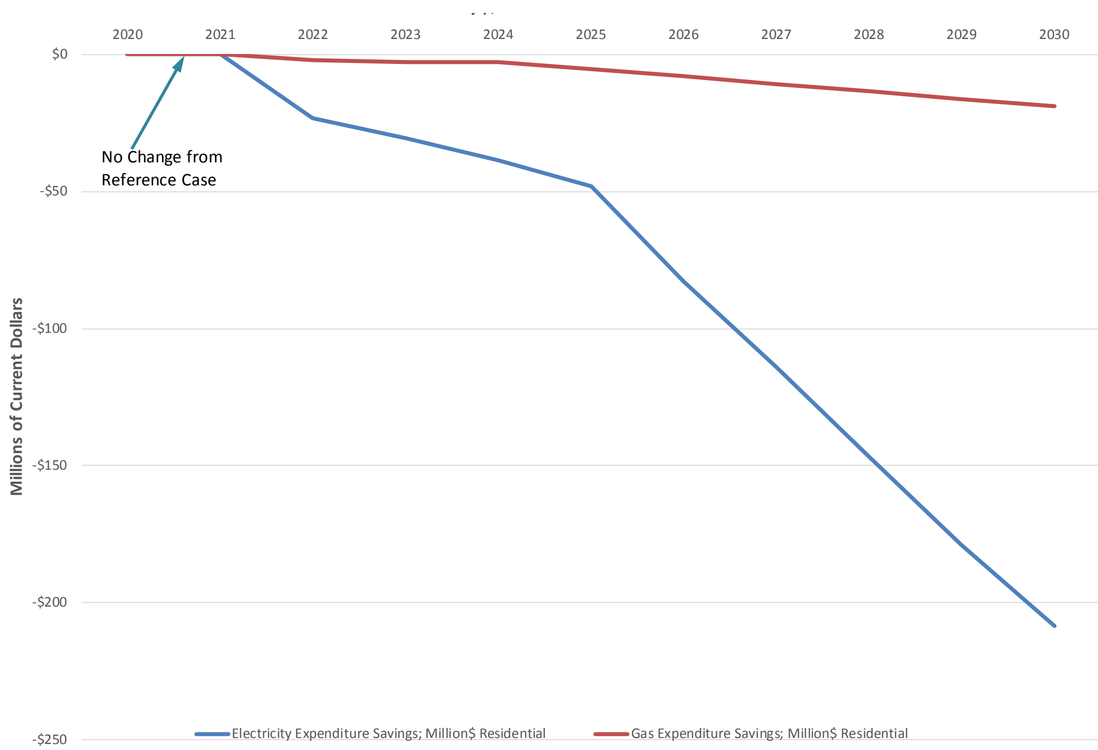


Figure 16: Commercial Savings from Energy Efficiency Improvements Excluding Costs (Millions of Current Dollars)

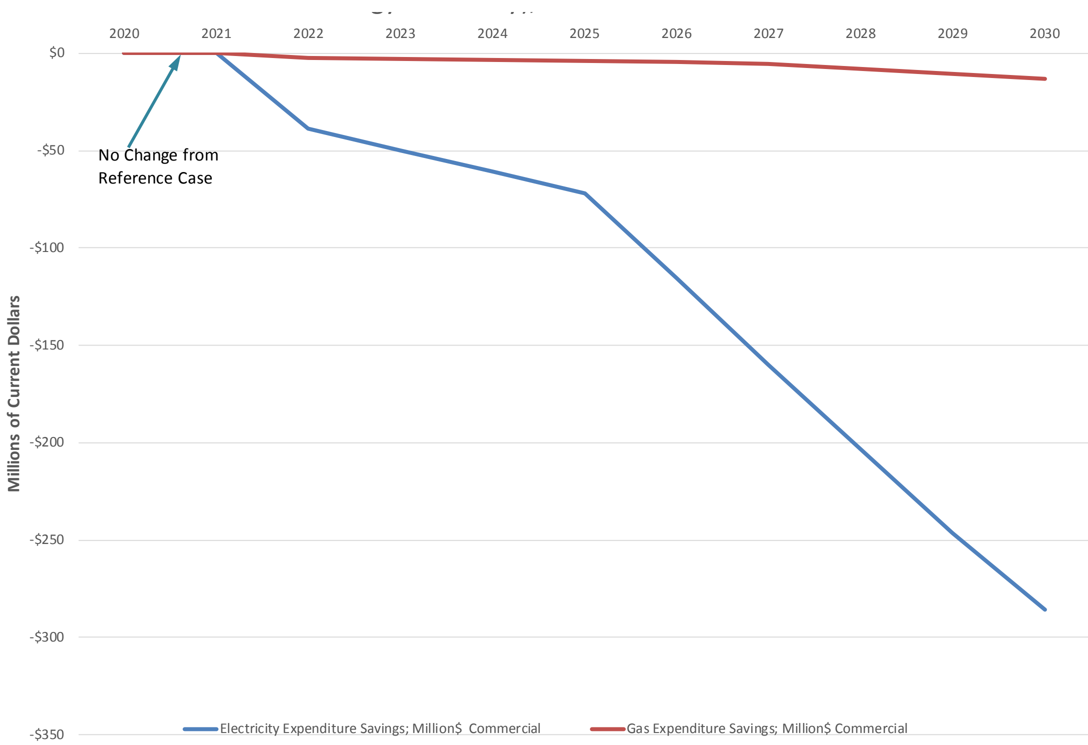


Figure 17 shows the combined residential, commercial and institutional spending on energy efficiency products and services including building audits, engineering services, insulation, and window and door installations among other efficiency improvements such as building energy management systems. The largest average expenditure between 2020 and 2030 is for construction services ($115 million); the second largest average expenditure is for technical and professional services ($24 million); the third largest average expenditure is for retail goods ($18 million); and the fourth largest average expenditure is for utilities ($16 million). We assume energy efficiency improvements are funded in part by the Connecticut Energy Efficiency Fund (CEEF) and the excess over this funding source is supplied by households and businesses.[14]

[14] The CEEF is funded from the system benefit charge on ratepayers' electric utility bills.

Figure 17: Combined Residential, Commercial and Institutional Energy Efficiency Spending (Millions of Current Dollars)

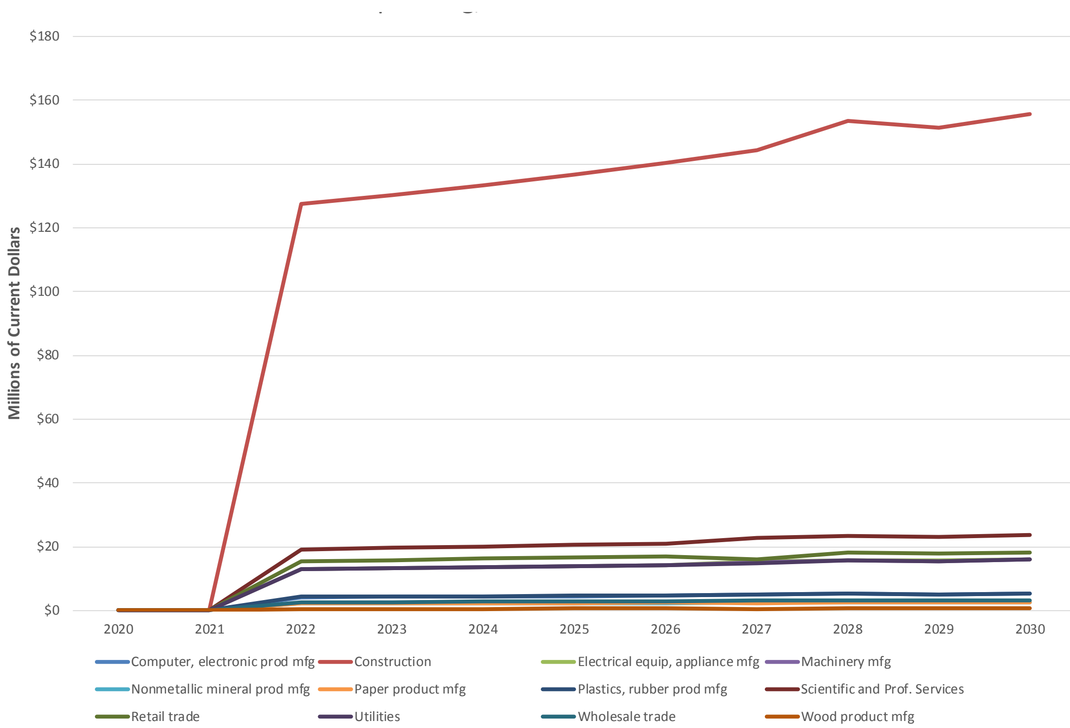


Figure 18 shows the net savings from annual energy efficiency spending for households and commercial establishments. This is the difference between the annual savings in Figures 15 and 16 and the annual spending in Figure 18. We assume that households and businesses pay out-of-pocket for energy efficiency improvements in excess of CEEF offsets and that households spend their savings on other goods and services while commercial establishments invest in additional plant and equipment. Note that before 2026, commercial establishments spend more than they save and before 2027, households spend more than they save. Beyond these dates, both commercial establishments and households realize annual net savings for their energy efficiency investments and these savings accumulate over time. In Figure 18, we superimpose total combined spending for energy efficiency improvements on the net savings trends.

Figure 18: Net Saving from Energy Efficiency Spending (Millions of Current Dollars)

Building Sector REMI Results

Figure 19 shows the trajectories of the level changes in total employment (as total jobs) and gross state (in millions of current dollars) from 2020 through 2030 for the 45 percent midterm target relative to the baseline forecast. Total jobs increase by 22,900 or 0.86% in 2030 relative to the reference case and average 21,000 (0.86%) more jobs relative to the reference case over the period. Gross state product peaks at $3.16 billion (0.67%) higher than the reference case in 2030 and averages $2.55 billion (0.67%) higher than the reference case from 2020 through 2030.

Figure 19: Building Sector Economic Impact, 45% Case

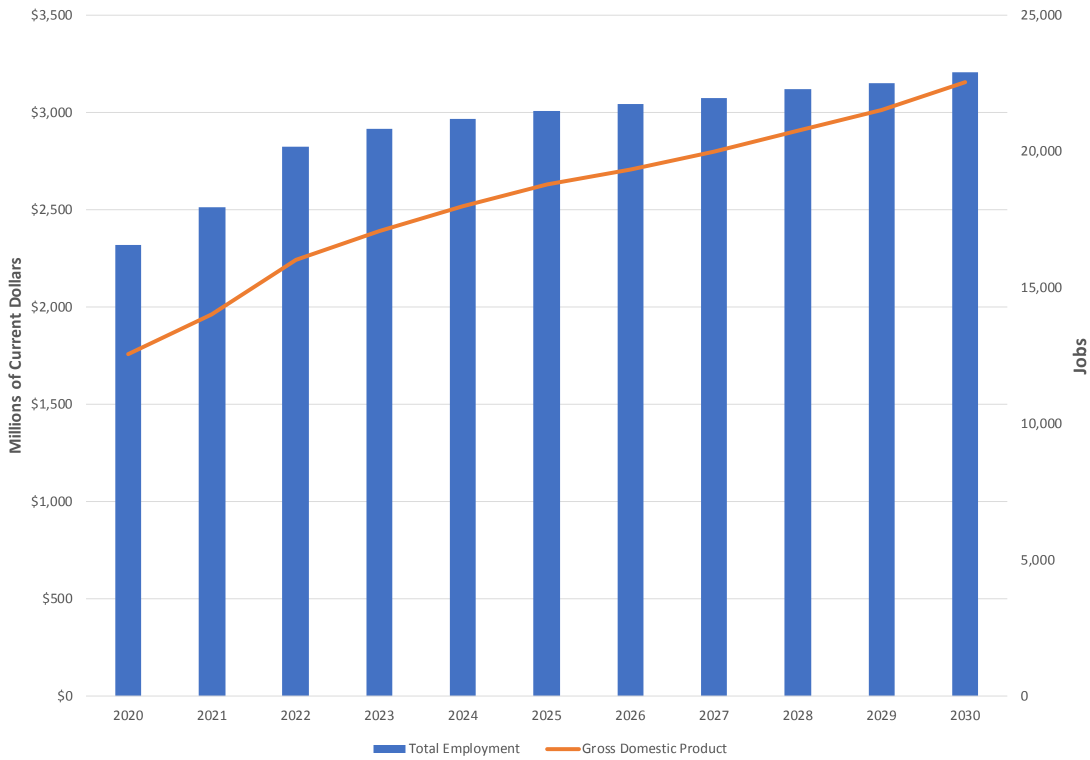
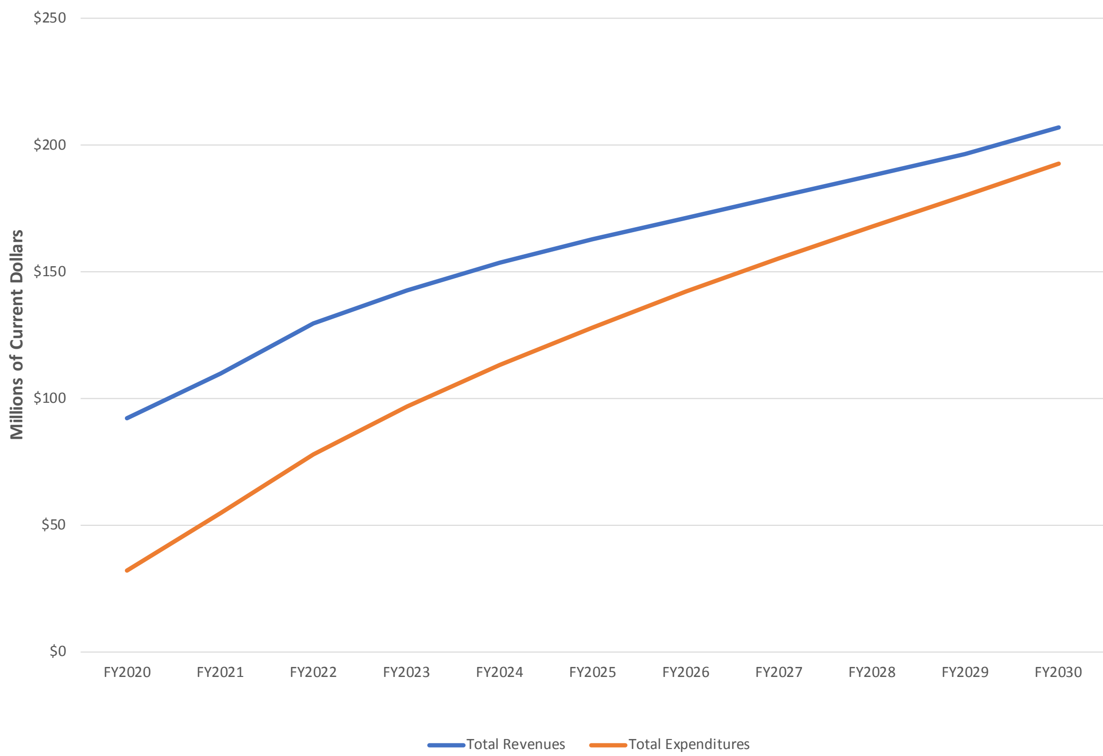


Figure 20 shows the trajectories of state revenue and spending for the *45% case*. State revenue peaks at $207 million (0.59%) higher than the reference case in fiscal year 2030. State expenditure peaks in fiscal year (FY) 2030 at $193 million (0.64%) higher than the reference case. State expenditure averages $122 million (0.46%) and state revenue averages $158 million (0.54%) higher than the baseline forecast between FY 2020 and FY 2030. Note again that there is a small budget surplus over the forecast period.

Figure 20: Building Sector Fiscal Impact, *45% Case*



Electric Sector Assumptions

The electric sector accounted for about 23 percent of Connecticut's GHG emissions in 2014. Decarbonizing the electric sector requires switching from fossil fuel electricity generation to zero carbon resources such as wind, solar, biomass, hydro and fuel cells. For modeling purposes, we assume grid-scale investment includes annual capital expenditure as well as cumulative fixed and variable operating and maintenance expenditure and cumulative fuel costs less the cumulative savings from burning less natural gas. We aggregate the net (for solar, wind, biomass and fuel cell) investment under investment for 'electrical transmission, distribution, and industrial apparatus' sector in the economic model.

We assume grid-scale investment is financed with 20-year bonds earning a return to investment of 7 percent. A tranche of bonds is issued each year as new investment funds are needed to continue the buildout of wind, solar, biomass and fuel cells. Annual, net amortized grid-scale investment is offset by an annual increase in electricity costs to businesses and households. The average cost per kilowatt hour (kWh) increase is roughly constant because each year the additional tranche of bonds to finance additional wind, solar, biomass and fuel cell generation is spread over accumulating renewable generation. We assume households and businesses bear the increased costs of electricity without offsetting incentives because they recognize the importance of reducing GHG emissions as a hedge against the costs of climate change. Similarly, we assume utilities undertake the investment in solar, wind, biomass, and fuel cells without offsetting incentives because they recognize the importance of reducing GHG as a hedge against the costs of climate change. Without incentives, these are heroic assumptions.

We model behind-the-meter (BTM) investment as a household maintenance expenditure as we imagine the residential installation of solar comes from the household's budget for maintenance as it might for a new furnace or air-conditioning unit. We assume such expenditure may be financed by a home equity loan or one from the Green Bank.[15] We assume businesses finance their solar and fuel cell installations through capital expenditure financed perhaps by borrowing in the capital market or from retained earnings. We model business BTM investment as occurring in the 'electrical equipment not-elsewhere-classified (nec)' sector.[16]

Households and businesses that install BTM solar, small hydro and fuel cells realize a reduction in their electric bills that reduces revenue to the electric utilities. This in turn increases the rates of all users. We do not capture the increased rates accruing to all ratepayers as a result of the uptake of BTM solar because rates differ across classes of users and they have several choices of electricity suppliers whose rates differ. Further, the increased rates benefit BTM users because their credit is at the retail rate. The net effect of rate increases is difficult to allocate to different users and therefore to a net aggregate effect without additional research. Our modeling approach simply accounts for the reduction in the utilities' demand for natural gas as the buildout of BTM and grid-scale renewable generation proceeds. The reduction in natural gas demand offsets the utilities' investment in grid-scale renewable generation and BTM savings so there is no effective reduction in revenue to the utilities from BTM production (via net metering). We assume households spend their BTM savings on additional goods and services, while businesses invest their excess BTM savings in new plant and equipment.

Digression on REMI

In the economic model (REMI), there is no job accounting metric for technology groups such as:

- # of jobs/megawatt for renewable energy technology deployment (solar, wind, small hydro);
- # of jobs per megawatt reduced for energy efficiency; or,
- # of jobs per traditional power plant/combined natural gas fired power plant.

This is because REMI and other input-output impact analysis programs such as IMPLAN use a sales-to-employment ratio to count jobs. For example, if Pratt hired 600 workers, that is direct employment that converts to a proportional sales increase in the industry in which Pratt is located (aerospace). The direct employment increase and the proportional increase in sales cause two additional effects. The indirect effect is the business-to-business (B2B) effect where Pratt buys additional goods and services from Connecticut businesses. The induced effect measures new workers spending their wages, which in turn stimulates businesses. The total effect is the sum of the three effects which is what we report as total employment or total sales. The value added is calculated from the payments to all factors of production as well and represents the increase to state GDP.

The translation to job changes is more involved when we increase production costs due to higher electricity costs. As electricity costs increase with other costs unchanged, there is reduced output because the increased production costs reflect in increased prices and reduced profit that in turn reduce competitiveness relative to regions that have not changed electricity costs. Households experience lower real wages as their electricity bills are higher (there is an income and substitution effect). The result without any offset is an out migration over time of businesses and households to areas with lower relative costs (although other areas presumably would be experiencing changes in production costs from their own GHG mitigation efforts to address a global problem).

There is insufficient granularity in REMI to differentiate among various types of power plant jobs; the jobs are in the utility sector or more precisely, the electricity generation, transmission and distribution sector. Inputs to REMI (such as changes in employment or sales) are by industry at the 3-digit NAICS (see note 12) level at best and most are at the 2-digit level, which is more highly aggregated (has less industry detail) than the 3-digit level.

[15] Other financing options such as leasing exist as well.

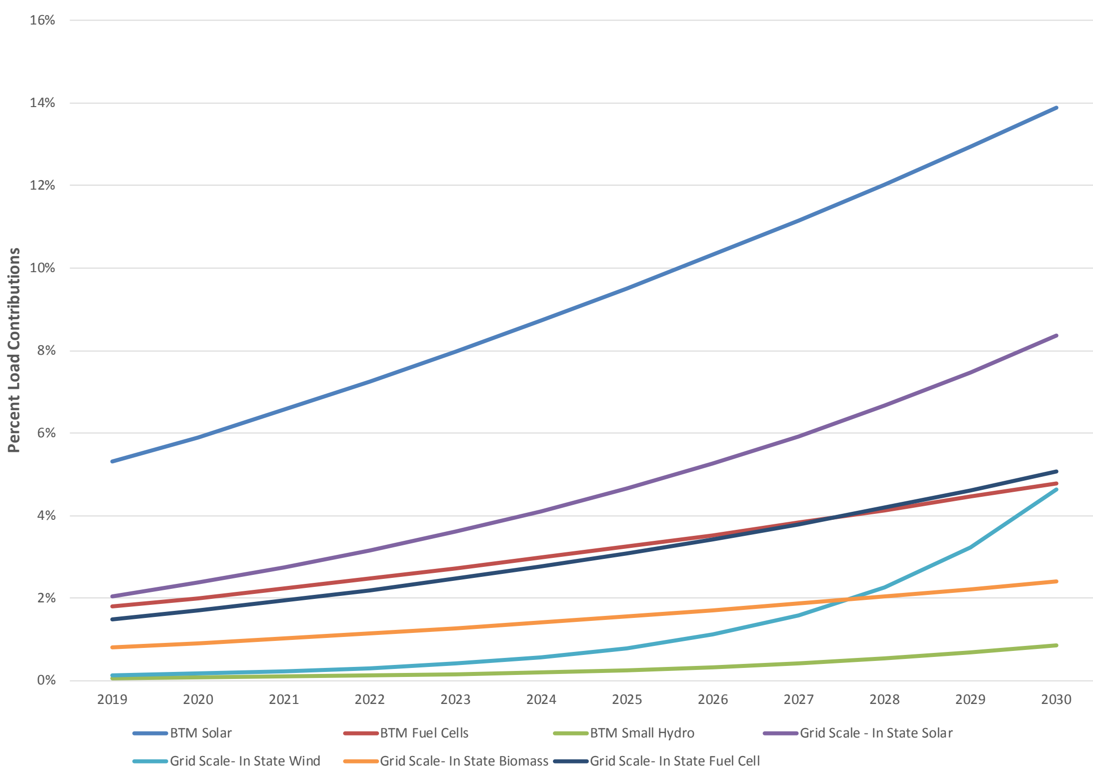
[16] Industrial sectors in North America are defined in the North American Industrial Classification System or NAICS for purposes of accounting for sales and employment of the industries in Canada, Mexico and the Unites States as part of their national income accounting.

Inputs to REMI describe changes in direct employment, direct sales or production costs, capital investment, and productivity as well as demographic effects such as labor force participation (not by industry; this is a labor supply issue that affects wage rates). For investment REMI input, we can be more specific if we know what kinds of plant and equipment is purchased.

Renewable Energy Generation

The LEAP model uses a forecast of Connecticut's electricity load and the buildout of grid-scale renewable and BTM generation that satisfies an increasing portion of the projected load. We establish the expected load in 2019 as a base year by assuming it is the same as in 2020. DEEP provided the annual fractions of BTM solar, fuel cells and small hydro as well as grid-scale solar, wind, biomass and fuel cells that we assumed to contribute annually to the state's electricity load and reduce natural gas generation.[17] The geometric mean growth rate of these contributions over the forecast period scales the 2020 percent contributions back to 2019.[18] Figure 21 shows the percent contributions to the state's renewable portfolio from BTM and grid-scale generation sources including for the year 2019.

Figure 21: Renewable Contributions to Connecticut Electricity Load



The total renewable contribution from BTM sources is 8 percent in 2020 and 19.5 percent in 2030, while the total contribution from grid-scale renewable sources is 5.1 percent in 2020 and 20.5 percent in 2030 leading to a 2030 combined renewable contribution of 40 percent in 2030.

[17] Some of this data comes from https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf.

[18] The geometric mean is a better than the arithmetic when there is exponential growth, especially as exhibited by BTM small hydro and grid-scale wind.

The annual contribution of renewable electricity begins with the fraction of electricity supplied by each renewable source in 2019 and annually subtracting the cumulative amount supplied by each source from the fraction of load satisfied by that source. This yields new renewable generation each year by source.

Figure 22 shows the state's projected electricity load between 2020 and 2030 and the amount of new renewable energy generation added each year without accumulation.[19] The green bars are the amount of new renewable energy generation added only in that particular year. The red bars contain the pre-existing generation mix of nuclear, gas and other generation sources for each individual year. The height of the red and green bars represents the total annual projected load.

Figure 22: Annual Projected Connecticut Electricity Load and New Renewables Contribution, 45% Case

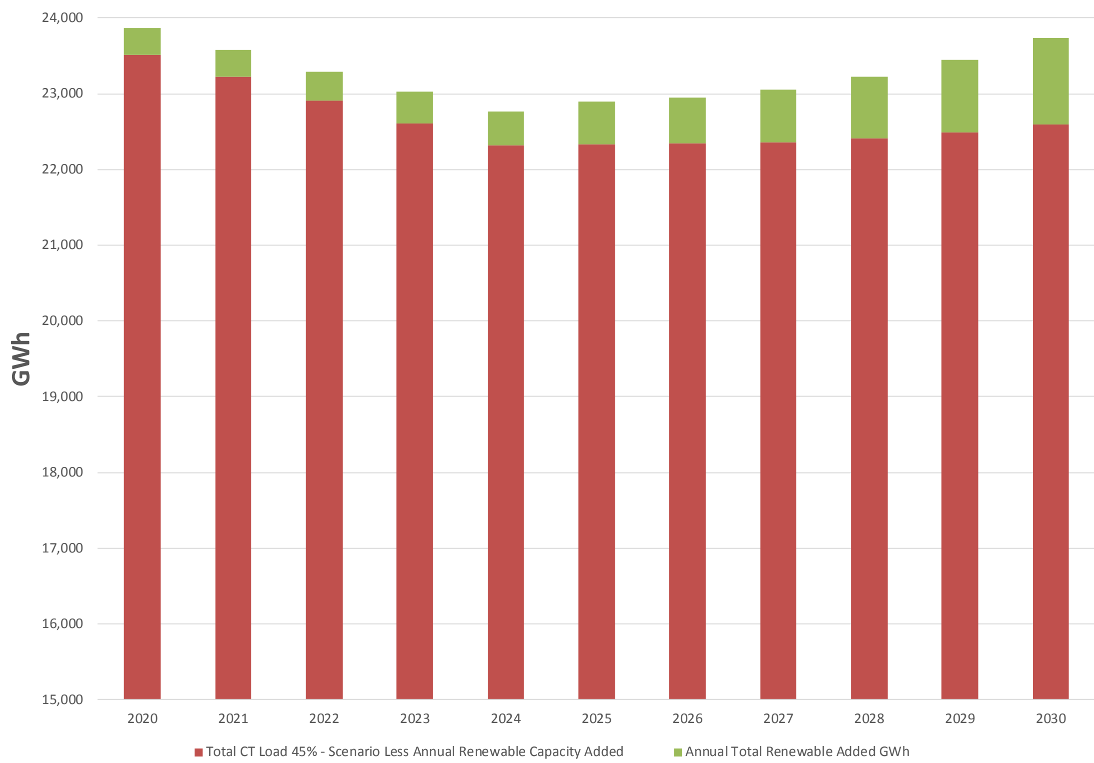


Figure 23 shows the portion of the state's load satisfied by the accumulating new renewable sources. This is the actual effect of the *45% case* renewable buildout on the state's electricity load. In contrast to Figure 22, the green bars represent the annually accumulating renewable sources since 2020 that offset the current mix (assumed to offset existing natural gas generating plants), while the red bars represent the current generation mix for each individual year less the accumulated renewable energy sources added since 2020. The height of the red and green bars again represents the total annual projected load.

[19] We assume additional renewables consist only of new grid-scale solar, wind, biomass and fuel cell sources as well as all BTM. Existing nuclear and other renewable sources are in the baseline mix.

Figure 23: Annual Projected Connecticut Electricity Load and Cumulative New Renewables Contribution, *45% Case*

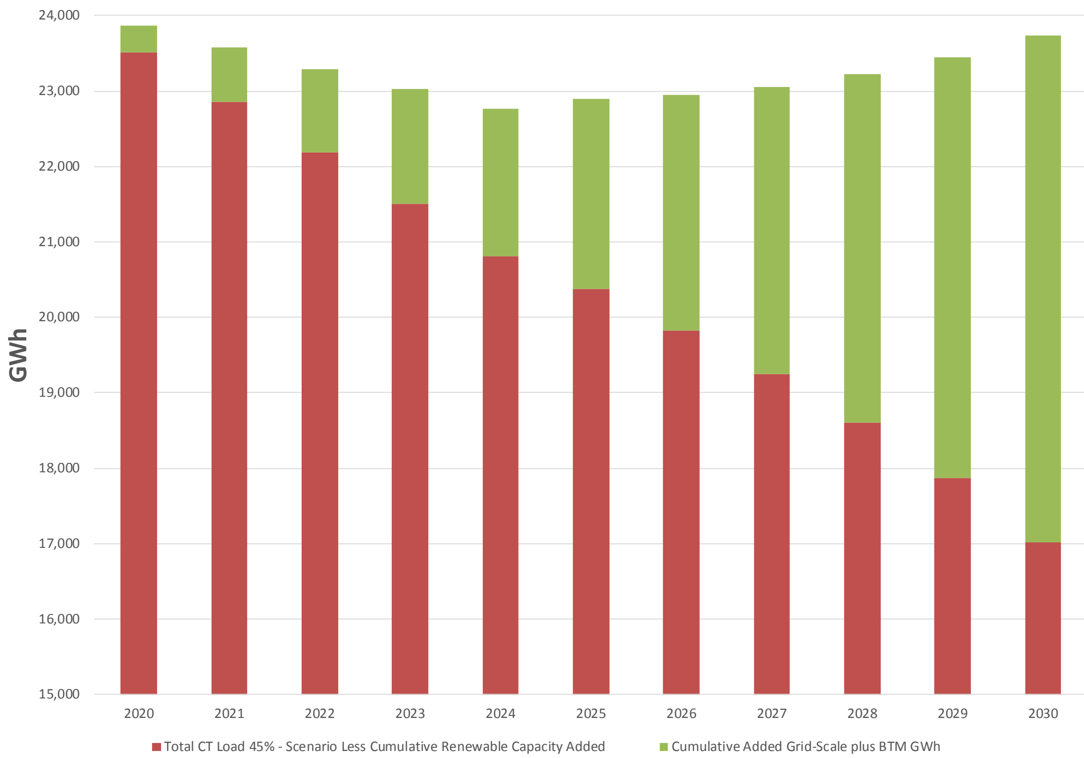


Figure 24 shows the percentage of cumulative, new Class I renewables added between 2020 and 2030 that satisfy the state's projected electricity load. In 2020, new Class I renewables added that year satisfy 1.5 percent of total load, with additions in the following years gradually increasing to satisfy 28.3 percent of total load in 2030. The percent of total load satisfied by Class I renewables in 2030 is 40 percent when adding the additional 11.7 percent of Class I renewables already existing as part of the current generation mix (i.e., current renewables included in the red bars).

Figure 24: Projected Connecticut Load Satisfied by Cumulative, New Renewable Sources, *45% Case*

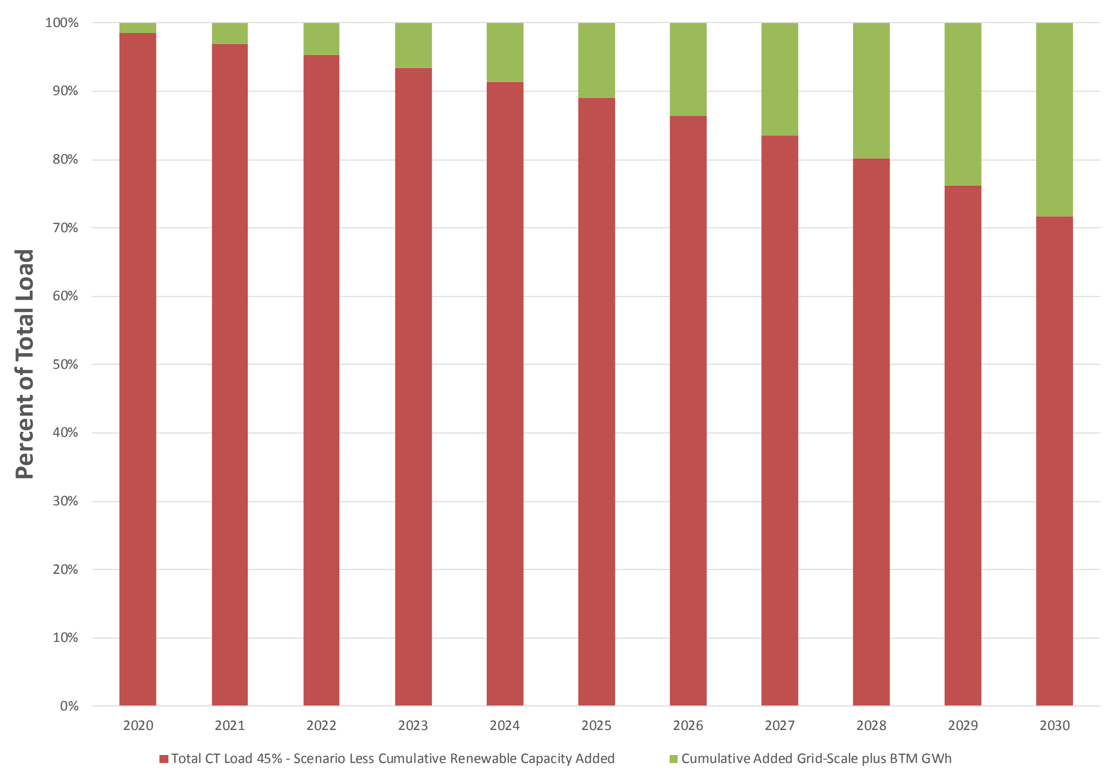
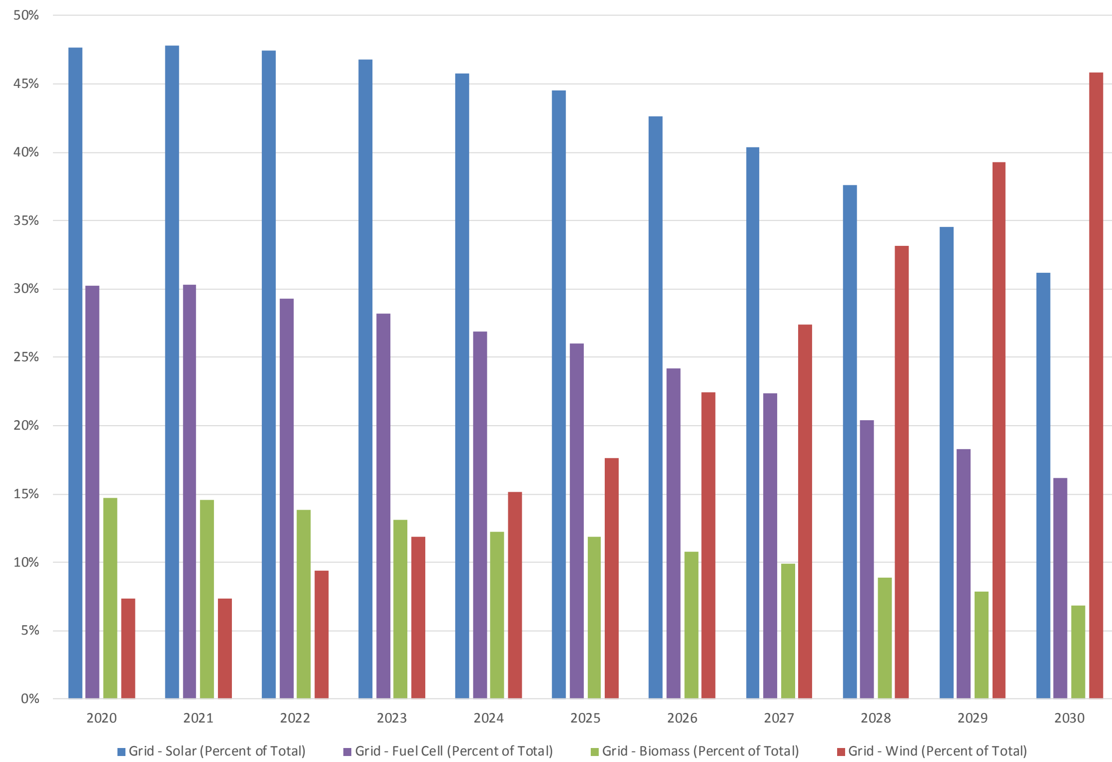


Figure 25 shows the allocation of grid-scale generation added among solar, wind, biomass, and fuel cells as a percent of total generation in gigawatt hours added. Grid-scale solar adds most of the new generation throughout the 2020 to 2030 period starting at 47.7 percent in 2020 and declining to 31.2 percent in 2030. Note that wind-generated electricity rises from 7.4 percent in 2020 to 48.9 percent of total renewable generation added and surpasses fuel cells and biomass in 2027. In addition, fuel cells and biomass represent declining shares of new renewable generation added.

Figure 25: Grid-Scale Generation Added as a Percent of Total GWh Added

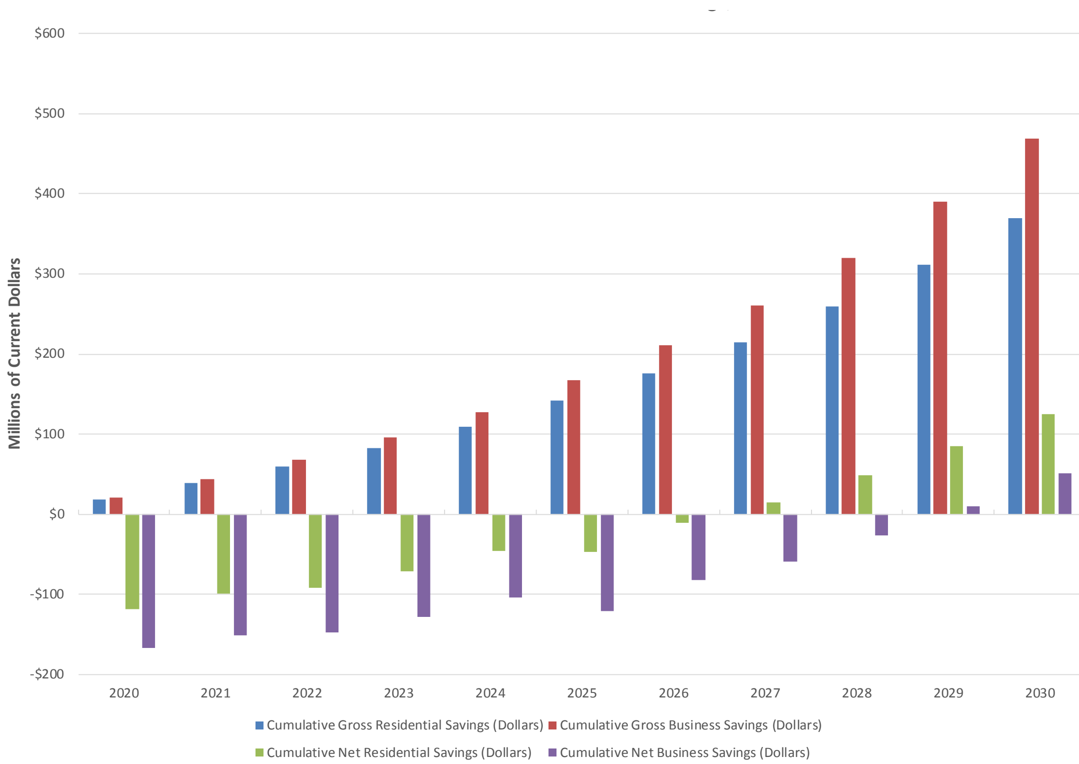


We assume that as new renewable generation contributes to total load, it displaces natural gas. Figure 26 shows the cost savings to utilities in terms of (forgone) cumulative natural gas fixed and variable fixed operating and maintenance (O & M) and fuel costs (the sum of the negative bars). The natural gas cost savings to the utilities does not offset the lost revenue from BTM production and this counts as reduced revenue to the utilities. The positive bars in Figure 26 represent the net saving for households and businesses (their gross BTM savings less their capital, fixed and variable O & M and fuel costs). The lost revenue to utilities appears in Figure 27 and is the gross savings households and business realize from BTM production. For reference, the annual and cumulative Gigawatt hour (GWh) of natural gas displacement appears on the right-hand scale in Figure 26.

Figure 26: Cumulative Cost and GWh of Displaced Grid Gas, *45% Case*

So, while utilities realize reduced capital costs through savings on natural gas, they also lose revenue from BTM production. Figure 27 shows the net savings to households and business as their gross saving from producing their own electricity less their capital and O & M costs (there are no variable O & M or fuel costs associated with solar or hydro). Total gross cumulative savings (the red and blue bars) for households and businesses represents reduced revenue to the utilities. The proportion of total savings allocated to households hovers around 45 percent and for businesses around 55 percent for the forecast period based on LEAP's allocation of fuel shares.

Figure 27: Gross and Net Household and Business Saving from BTM Production, *45% Case*



Because we assume households borrow at very low rates or lease to obtain BTM solar (we assume households do not purchase fuel cells), we assume they spend their gross BTM electricity savings on other goods and services even though their net BTM saving is negative from 2020 through 2026 and positive thereafter. As mentioned above, we model household expenditure for solar and small hydro as household maintenance expenditure, which drives economic impact. Businesses realize a positive net saving from BTM investment in 2029 and 2030, which they invest during that period and which contributes to economic impact. Between 2020 and 2028 inclusive, we assume businesses invest in BTM solar and fuel cells with retained earnings or by going to the capital market to obtain needed funds.

Figure 28 shows the annual gross investment for residential and commercial and industrial BTM solar, fuel cells and small hydro and net (incorporating natural gas savings) grid-scale investment in solar, wind, biomass and fuel cell electricity generation for the *45% case*. These annual, net investments (not the net amortized costs in Figure 29) drive the economic and fiscal impact.

Figure 28: Annual Net Electricity Sector Investment, *45% Case*

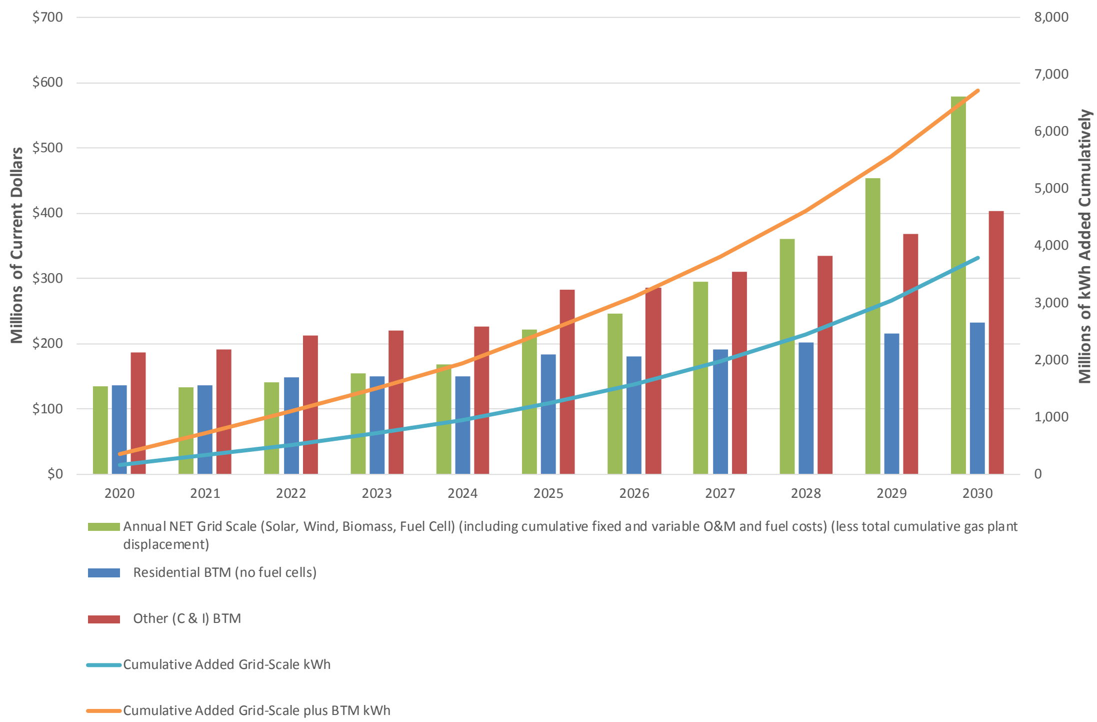
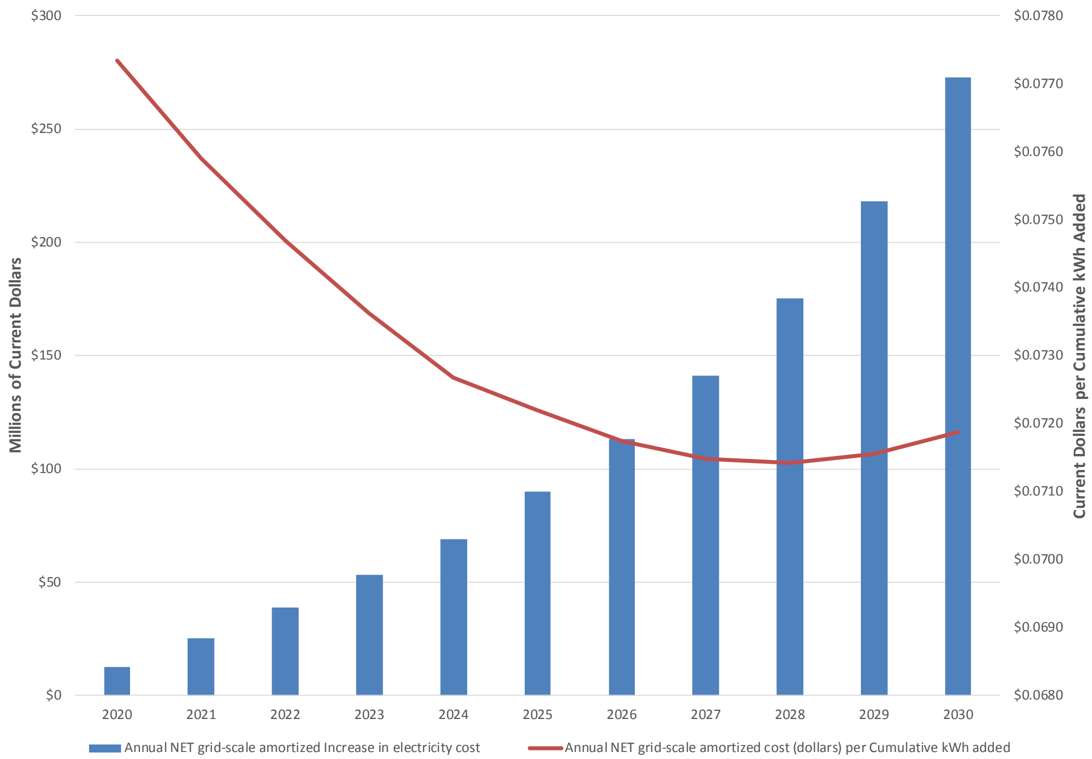


Figure 28 also shows the cumulative grid-scale and total renewable generation in kWh added each year. By 2030, there will be 6.7 billion kWh of renewable generation added that has presumably displaced an equivalent quantity of fossil fuel-generated electricity (we assume it is natural gas).

We assume the grid-scale investment is amortized over 20 years and a smaller 'mortgaged' amount represents the aggregate annual electricity cost increase to households and businesses, while the average amortized cost per kWh is spread out over accumulating generation. Figure 29 shows the amortized grid-scale cost and average annual cost per kWh relative to cumulative renewable generation added. These costs range from 7.7 cents per kWh in 2020 to 7.2 cents per kWh in 2030. Keep in mind that bonds issued in 2030 have debt service until 2050 and that grid-scale investment is likely to continue until or beyond 2050, so debt service will continue to increase until bond tranches are no longer issued. However, as above, the average cost per kWh may be roughly constant as the increasing cost of debt is spread over accumulating renewable generation.

Figure 29: Amortized Grid-Scale Electricity Investment and Cost per kWh of New Generation, *45% Case*



Finally, we do not consider the decommissioning costs of fossil fuel or nuclear power plants as renewable sources displace them. These costs would likely be borne by investors and not affect rates beyond those necessary to build out the decarbonized grid.

Electricity Sector REMI Results

Figure 30 shows the response of the state economy to BTM and net grid-scale investment as well as the savings (modeled as increased household spending and business investment and reduced utility revenue) from BTM investment and the increase in amortized electricity cost to pay for grid-scale solar, wind, biomass, and fuel cell buildout for the *45% case*. Jobs increase by 2,146 (0.09%) and GDP increases by $109 million (0.036%) above the baseline forecast in 2020 and both decline steadily thereafter as the buildout of renewables proceeds. This is due to the accumulating savings to BTM users which is less than offset by the accumulating savings from reduced natural gas consumption and represents a net reduction of revenue to the utilities. Net job creation (above the baseline forecast) averages 448 jobs (or 0.02%) each year over the period 2020 to 2030, while state GDP averages $344 million (or -0.08%) each year over the period less than the baseline forecast.

Figure 30: Electricity Sector Economic Impact, *45% Case*

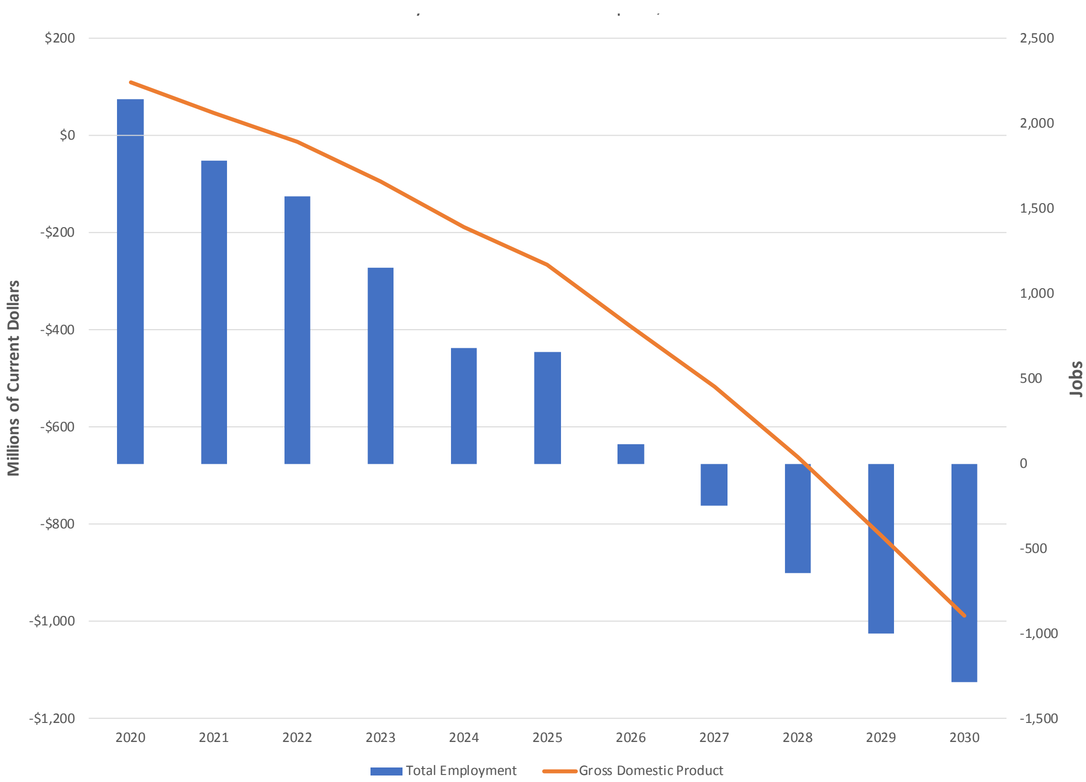
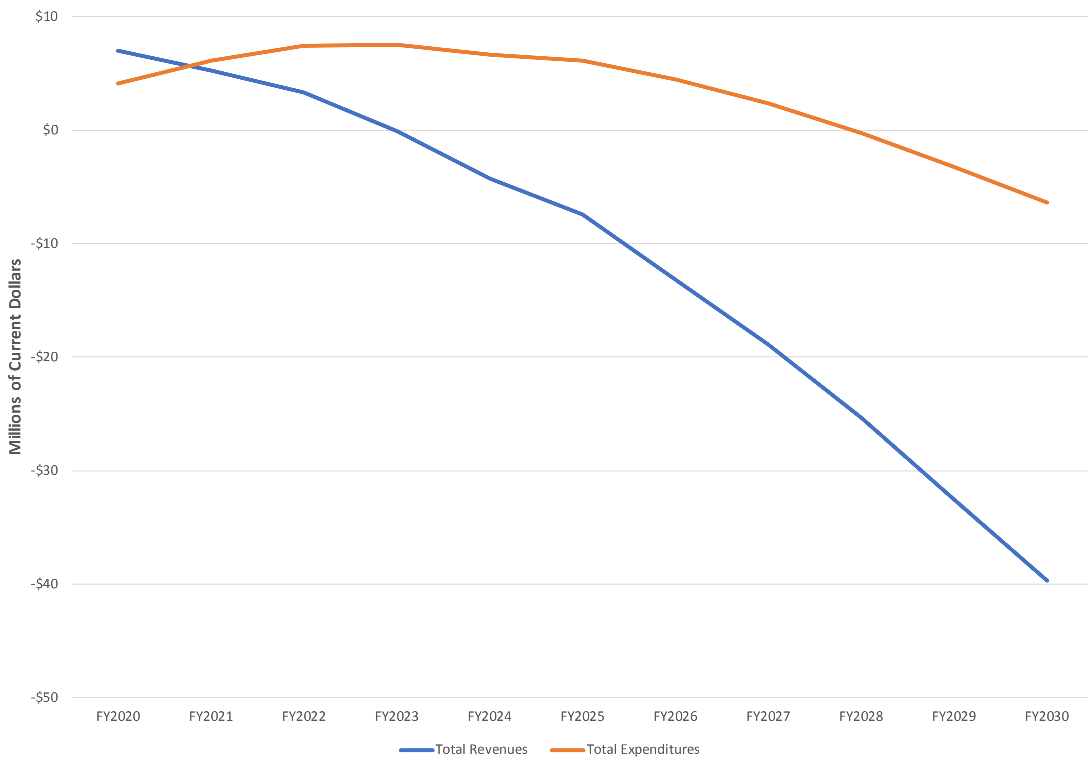


Figure 31 shows the response of state revenue and expenditure to the grid-scale and BTM investment as well as the commercial and residential savings from BTM investment and the increase in electricity cost to pay for grid-scale solar and wind buildout for the *45% case*. Significant in this fiscal response is the reduced revenue to the utilities from BTM generation. State revenues exceed state expenditures relative to the baseline forecast yielding a small budget surplus in 2020 and a budget deficit from 2021 through 2030. Net state revenue averages $11 million (0.03%) lower than the baseline forecast each year over the period, while net state expenditure averages $3.2 million higher than the baseline (0.014%) each year over the period 2020 through 2030.

Figure 31: Electricity Sector Fiscal Impact, *45% Case*



Combined Sector REMI Results

The 45 percent midterm GHG reduction strategies within the transportation, building and electricity sectors described above do not occur in isolation. Rather, they occur together over time as households and businesses add BTM solar, replace oil- and gas-fired heating systems with heat pumps, add building energy management systems and improve the efficiency of their building envelopes. Further, the displacement of gasoline- and diesel-powered vehicles with EVs and FCEVs changes the wholesale and retail landscape for the fueling and maintenance of these vehicles. Electric generators replaces gas- and oil-fired power plants with solar, wind, hydro, and fuel cell power sources. There are costs and benefits to the changing landscape as described above and in the economic results that follow, we show the combined, net economic impacts of the three sectors' GHG reduction strategies. One must keep in mind that the assumptions underpinning the economic analysis here are optimistic. Without significant incentives, some of these strategies will not materialize. Whatever incentives may be implemented, they will offset the benefits as they entail additional costs (for example, tolling, a carbon tax, grants and loans financed by an increased system benefits charge, net-zero building codes, among other GHG-reducing requirements). Further, the positive co-benefits of improved health and averted environmental damage are not considered in this analysis.

Figure 32 shows the net economic effect of the three sectors combined. Net new job creation averages 22,000 jobs (or 0.9%) more than the baseline forecast each year over the period 2020 to 2030, while net new state GDP averages $2.34 billion higher than the baseline forecast (or 0.62%) each year over the period 2020 through 2030. The 19,200 net new jobs created in 2020 represent 0.8 percent of the state's workforce, while net new state GDP in 2020 is $1.91 billion and represents 0.62 percent of state GDP. In 2030, 22,540 net new jobs (0.91%) are added relative to the baseline forecast, while net new state GDP increases by $2.54 billion (0.54%) relative to the baseline forecast.

This pattern of economic and fiscal change arises from the offsetting positive and negative economic activities occurring in the state as it transitions from a fossil fuel-based economy to a significantly reduced carbon economy envisioned in the of goal of reducing carbon emissions in the state by 45 percent below 2001 levels by 2030. The employment gains are primarily in the construction industry, wholesale trade, waste and remediation services and the professional and technical services sector. The employment losses are primarily in the retail sectors of the Connecticut economy.

Figure 32: Combined Sectors Economic Impact, *45% Case*

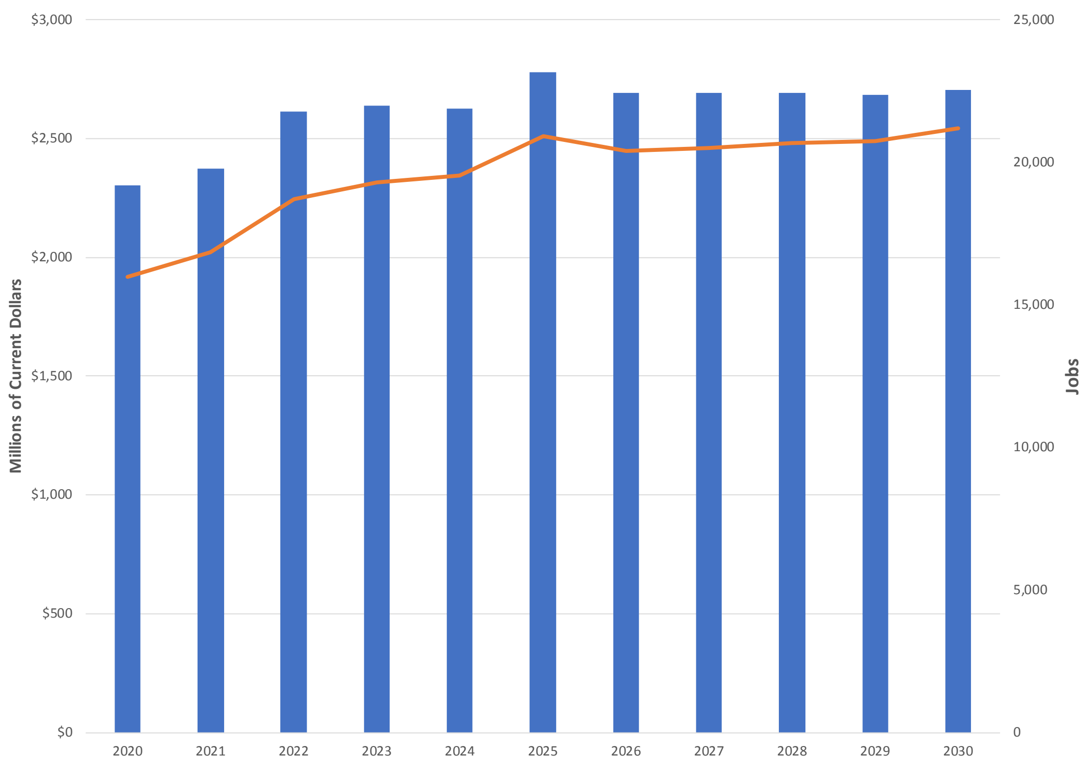


Figure 33 shows the net fiscal impact of the combined sector strategies. Net new state revenue averages a gain of $136 million (0.47%) each year over the period relative to the baseline forecast, while net state expenditure averages a gain of $128 million (0.48%) each year over the period relative to the baseline. Over the period 2020 through 2030, state revenues exceed state spending by about $91 million[20] or roughly 0.3 percent of the estimated budget during that period.

The primary contributors to the decline in revenue are the reductions in the sales and use tax, while the largest contributors to expenditure increases are education and health and human services. These changes are due to the increases in relatively low-wage construction jobs on the one hand and the loss of jobs in the retail sector on the other.

[20] The area between the revenue and expenditure curves up to FY 2028 less the area between these curves from FY 2029 through FY 2030.

Figure 33: Combined Sector Fiscal Impact, *45% Case*

Summary and Conclusions

Without incentives or accounting for policy costs or health and environmental co-benefits, the net economic and fiscal impacts of the individual and combined sectors' GHG reduction strategies are summarized in the tables below.

Transportation Sector Economic & Fiscal Impact (2020 – 2030)	
	45% Midterm Target
Economic or Fiscal Variable	Average Annual Change from Ref. Level & Percent
Total Employment (Jobs)	500, 0.02%
State GDP (millions of current $)	$134, 0.03%
State Revenue (millions of current $)	$-10, 0.03%
State Expenditure (millions of current $)	$2.88, 0.01%

Building Sector Economic & Fiscal Impact (2020 – 2030)	
	45% Midterm Target
Economic or Fiscal Variable	Average Annual Change from Ref. Level & Percent
Total Employment (Jobs)	21,000, 0.9%
State GDP (billions of current $)	$2.55, 0.7%
State Revenue (millions of current $)	$158, 0.54%
State Expenditure (millions of current $)	$122, 0.46%

Electricity Sector Economic & Fiscal Impact (2020 – 2030)	
	45% Midterm Target
Economic or Fiscal Variable	Average Annual Change from Ref. Level & Percent
Total Employment (Jobs)	448, 0.02%
State GDP (millions current $)	-$344, -0.08%
State Revenue (millions current $)	-$11, -0.03%
State Expenditure (millions current $)	$3.2, 0.014%

Combined Sector Economic & Fiscal Impact (2020 – 2030)	
	45% Midterm Target
Economic or Fiscal Variable	Average Annual Change from Ref. Level & Percent
Total Employment (Jobs)	22,000, 0.9%
State GDP (billions current $)	$234, 0.62%
State Revenue (millions current $)	$136, 0.47%
State Expenditure (millions current $)	$128, 0.48%

We assume Connecticut's GHG reduction strategies occur in isolation (i.e., other states are not implementing their own GHG strategies) such that modeling the transition to a greener, healthier Connecticut economy occurs in the absence of similar changes in other states' economies. When viewed in isolation, some households and businesses may migrate to lower cost regions in the modeling exercise, but such an inducement to move may diminish if all areas were similarly addressing the global problem of climate change. Also keep in mind we have not modeled the health or other co-benefits from reducing GHG emissions that would positively affect these results or the costs of incentives or policies that are necessary to induce the transition envisioned in this analysis that would negatively affect these results. Until these offsetting effects are modeled, the results presented here are preliminary.

Appendices

Appendix A: Key Assumptions and Inputs to REMI for 45% 2030 Mid-Term Target

Measure	Consideration	Value Description	Description of Rationale	Source
Transit Bus Electrification	Costs associated with the electrification of the states transit bus fleet.	**Number of buses:** 618 **Age of fleet:** 7-9 years **Vehicle life:** 12 years **Annual VMT:** 27,000 **Diesel bus:** 3.26 MPGe **BEB:** 2.15 Kwh/ mile **Maintenance:** $.16/ mile electric, $.18/ mile diesel **Buses per charger:** 12:1 **Charger cost:** $350k/unit **Installation:** $150k/unit **Charger maintenance:** 3% of hardware annually	There are ~ 618 busses operating in the urban areas of Hartford, New Britain/Bristol, New Haven, Stamford, Waterbury, Bridgeport, and Norwalk. It more likely that electrification of transit buses will occur in Urban/ Metropolitan areas. For the purposes of the REMI analysis all 618 buses will be replaced with electric buses. The number of buses replaced in each year will be determined using CT DOT data on the current age of individual buses within the states fleet. For this analysis it is assumed that there will not be any significant increase in the size of the state's bus fleet. Annual VMT was calculated using a report from CT DOT. An analysis by The National Renewable Energy Laboratory (NREL) found that over the course of nearly 400,000 miles the average energy efficiency of an electric bus was 2.15 kWh per mile, equating to 15.67 MPGe (gallon gasoline equivalent). The fuel economy of a diesel transit bus is ~ 3.26 MPGe. The costs of gasoline and electricity are based off of EIA data. For this analysis a ratio of 12 buses to 1 500kW fast charger was applied. This is a conservative estimate based on existing research. It is	National Renewable Energy Laboratory (NREL) "Foothill Transit Battery Electric Bus Demonstration Results" January 2016 Columbia University "Electric Bus Analysis for New York City Transit" May 2016 http://www.afdc.energy.gov/data/10310 U.S. Energy Information Administration: Energy Prices Transportation Motor Gasoline Online Conversion Tool: http://www.mpgtokpl.net/calculator/kwh100-miles-kilowatt-hour-100-miles-mpge-mpg-equivalent-calculator CT DOT "Existing Conditions: Connecticut Statewide Bus study" September 2016 CT DOT "Connecticut on the Move, Transportation Fast Facts" 2015 CT DOT data request 2/3/2017

			assumed that supporting infrastructure will be fully built out after 5 years and will not require replacement. The cost of charging infrastructure was determined using the report from NREL.	
Zero-Emission Vehicles	Light-duty passenger car and truck electrification	Vehicle Count ~20% of on-road light-duty vehicle fleet in 2030 is BEVs/PHEVs.	Vehicle shares are based on battery and plug-in hybrid electric light-duty cars and trucks coupled with 66% zero-carbon generation grid in 2030 projected in LEAP that would be needed to meet a 45% GHG reduction mid-term target.	Transportation fuel costs from AEO 2015 Vehicle technology costs from California PATHWAYS v.2.3.1 (2015), https://ethree.com/public_projects/energy_principles_study.php, file name: CA_Pathways_DemandSide_inputs
	Hydrogen Fuel Cell Electric Vehicles (FCEVs) and their supporting infrastructure.	Vehicle Count 945 FCEVs in Connecticut starting in 2028. The annual growth rate of Battery Electric Vehicles was applied to FCEVs for this analysis. Fueling Stations 1 fueling station for every 160 FCEVs. The cost per fueling station is $200k.	The vehicle counts are based on projected deployment numbers in CA for 2018 and have been scaled to reflect the difference in population size. The vehicle count begins in 2028 to account for a 10-year lag in deployment of this technology in CT. The ratio of fueling stations to vehicles is based on current and projected deployment rates in CA. The cost of the fueling infrastructure was calculated based on the number of publicly funded fueling stations in CA, and the level of funding that was required to support their deployment.	*California Environmental Protection Agency, Air Resources Board " 2015 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development" July 2015* *U.S Census Bureau - State Data Center* *CT DEEP, Air Bureau, Mobile Sources Unit*

	Charging station infrastructure deployment rate	Based on ~20% BEV/PHEV fleet mix in 2030	The deployment rate is based on the ratio of different types of charging stations required to support the number of EVs in the 45% by 2030 reduction scenario. The ratios are based on findings from a literature review, current levels of EVSE deployment, and expert industry opinion. <u>EVSE per # of EVs:</u> Level 1 Station- 1:500 Level 2 Residential- 1:3 Level 2 Public- 1:8 Level 3 DC- 1:1000	*Informal discussion with an industry expert at Eversource*. *C2ES, NASEO, Clean Cities "Strategic Planning to Implement Publically Available EV Charging Stations: A Guide for Businesses and Policymakers." July 2015*
	Electric Vehicle Purchase Incentive	Rebate amounts are set maintain the current rebates for Connecticut Hydrogen and Electric Automobile Purchase Rebate (CHEAPR) which are based on vehicle battery capacity and range from $750 to $5,000 per vehicle. The program has been averaging 600 vehicles and $1.5 million per year. The Federal tax credit of $2,500 to $7,500, depending on the size of the battery in the car is utilized. The incentive begins	To ease the price gap between electric and internal-combustion models the current rebate is extended an additional 5 years. The extension of the program will help increase the overall adoption rate of electric vehicles to a level that will help stabilize the EV market.	"CHEAPR" website: http://www.ct.gov/deep/cwp/view.asp?a=2684&q=564768&deepNav_GID=2183

		phasing out after an automaker sells 200,000 vehicles that are eligible for the credit.		
	Heavy-duty vehicle electrification	Vehicle Count 30% light commercial trucks and transit busses electrified by 2030 30% school busses and refuse trucks electrified by 2030 35% single unit short haul trucks electrified by 2030	Vehicle shares are based on battery electric light-duty cars and trucks coupled with ~66% zero-carbon generation grid in 2030 projected in LEAP that would be needed to meet a 45% GHG reduction mid-term target.	Transportation fuel costs from AEO 2015 Vehicle technology costs from California PATHWAYS v.2.3.1 (2015), https://ethree.com/public_projects/energy_principles_study.php, file name: CA_Pathways_DemandSide_inputs
	Impact of declining gasoline/diesel fuel consumption in CT as a result of greater EV deployment.	Annual transportation fuel taxes revenues in the reference case fall 18% from 2016 to 2050. From 2016 to 2050, annual fuel tax revenues are down 55% in the 45% scenario. From the reference case the cumulative fuel tax revenues are down 23% in the 45% scenario.	As standard passenger vehicles & light duty truck markets transition to electric, a decline in the use of petroleum-based fuels decreases. This in turn leads to a fall in fuel tax revenues. Applied CT tax rates (from OPM) to gallons and unit prices to generate annual tax revenues on gasoline, diesel, and ethanol fuels. With guidance from DOT, a 3.5% annual average growth rate was assumed to maintain transportation infrastructure and will be used to estimate the revenue shortfall.	Used "https://www.quora.com/What-is-the-sales-ratio-of-premium-to-mid-grade-to-regular-gasoline" to get relative shares of Reg-Mid-Premium for average gasoline prices. Standard conversion factors were used to convert BTUs to gallons.
Passenger &	Electrify	45% of passenger &	Assumed increased rate of rail energy	This is a minor measure in LEAP, and

Freight Rail Electrification	passenger & freight rail	freight rail energy use from electricity by 2030	consumption in CT provided by electricity on path to achieve 95% electrification by 2050	costs were not included in REMI analysis.
Commercial & Residential Renewable Thermal	Electrification of thermal demand in residential and commercial buildings	Residential & Commercial Renewable Thermal • Air source heat pumps ~ 90% • Ground source heat pumps ~ 10%	26% residential thermal load from air/ground source heat pumps in 2030 20% commercial heated sq. ft. provided by air/ground source heat pumps Breakout of total investment between capital, labor and material • Capital -50% • Labor – 25% • Materials – 25%	*Economic Impact Analysis of Clean Energy Development in North Carolina*—2014 Update, Appendix A.
Electric & Gas Energy Efficiency	Energy and monetary savings from electric and gas efficiency	Breakout of total investment into more detailed industries See table 1 and table 2	Projected savings per dollar spent based on publicly reported program results from CT Statewide Energy Efficiency Dashboard. Electric efficiency measures assumed 12-year lifetime; thermal efficiency measures assumed 15 year lifetime. Measure cost escalation factor capped at 12% per CT DEEP. Program spending increased to remain a constant share of CT GDP through 2050 starting from 2014-2016 levels.	Electricity and natural gas demand based on AEO 2015 reference case end use technology characterizations. CT Statewide Energy Efficiency Dashboard https://www.energizect.com/connecticut-energy-efficiency-board/statewide-energy-efficiency-dashboard
Vehicle Miles Travelled (VMT) Reductions	Reduction in VMT by passenger cars and trucks	Projected 3% VMT reduction in 2050 relative to Reference Case	Assumed 3% VMT reduction for only passenger cars and trucks. Specific measures and costs not identified.	Assumption provided by CT DEEP
Electric Power Generation[21]	Increased shares of electricity	40% CT RPS Class I renewables	Zero-carbon generation shares in 2030:	All renewable technology costs and capacity factors from Lazard's

[21] Note that the 45% LEAP scenario projected a ~66% zero-carbon generation mix in 2030 comprised of 34% Class I renewables, 22% nuclear, 10% hydro, and a remaining balance of largely natural gas (31%), biomass (2%), coal (1%), and oil (<1%). After completion of the LEAP scenario analysis in late 2017, Connecticut released its Comprehensive Energy Strategy (Feb. 8, 2018) that included an increase in the State's Renewable Portfolio Standard to 40% by 2030 (Class I renewables). While this occurred after we completed the LEAP analysis, we were able to scale the Class I renewables share to meet the 40% RPS target for input into REMI. As a practical impact, this would result in a small extra GHG reduction beyond the 2030 45% mid-term target in LEAP, and at an additional cost. Overall costs in REMI, however, remain small relative to Gross State Product, and this increase in renewables does not change the REMI conclusions.

	generation from zero-carbon generation	generation by 2030	40% renewables (defined as CT Class I resources) 22% nuclear 10% hydro Remaining balance largely natural gas (25%), biomass (2%), coal (1%), and oil (<1%)	Levelized Cost of Energy Analysis, v. 11.0 (Nov. 2017), https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf, with the following exceptions: Residential solar PV costs provided by CT DEEP based on in-state program data for purchased and leased PV systems. Small hydro data from Maine Governor's Energy Office, *Maine Hydropower Study*, Feb. 2015 (page 2-6); http://www.maine.gov/energy/publications_information/001%20ME%20GEO%20Rpt%2002-04-15.pdf

Table A1 – Electric Energy Efficiency Industry Breakout

	Residential	Commercial
Computer, electronic prod mfg	1%	3%
Construction	63%	54%
Electrical equip, appliance mfg	2%	10%
Machinery mfg	3%	8%
Nonmetallic mineral prod mfg	1%	1%
Paper product mfg	2%	0%
Plastics, rubber prod mfg	2%	2%
Scientific and Prof. Services	4%	14%
Retail trade	15%	0%
Utilities	6%	6%
Wholesale trade	1%	2%
Wood product mfg	1%	0%

Table A2 – Gas Energy Efficiency Industry Breakout

	Residential	Commercial
Computer, electronic prod mfg	1%	3%
Construction	63%	54%
Electrical equip, appliance mfg	5%	5%
Machinery mfg	5%	13%
Nonmetallic mineral prod mfg	1%	1%
Paper product mfg	2%	0%
Plastics, rubber prod mfg	2%	2%
Scientific and Prof. Services	4%	14%
Retail trade	10%	0%
Utilities	6%	6%
Wholesale trade	1%	2%
Wood product mfg	1%	0%

Appendix B: Assumptions for BEV Charging Stations

Table B1: Assumptions for BEV Charging Stations

Type of Charger	Average Hardware Cost	Average Installation Cost	Annual Maintenance (3% of hardware value)	Average Total Cost (does not include maintenance) *	EVSE to BEV Ratio	Comments
Level 1 outlet (standard 120v)	$0	$0	$0	$0	1:1	It is highly likely that BEV owners will have access to a standard outlet without incurring additional costs. Each vehicle comes with a charging cord, hence a 1:1 ratio. Maintenance on a standard outlet is assumed to be infrequent and costs would be negligible and unplanned.
Level 1 station	$460	$825	$14	$1,285	1:500	Hardware cost was calculated by averaging cost from the Chicago study, Energize CT study, and the DOE report. The $1500 hardware cost from the DOE was omitted as it is more than double the next highest price and does not seem reasonable. The installation cost was calculated by averaging costs from the Energize CT report and the Chicago report. The DOE costs were omitted for installation as they would be viewed as extreme outliers. An industry expert confirmed that the Energize CT total average cost of $900 was on the low side. There are currently ~4600 BEV and PHEV (ZEV Sales Dashboard) in CT and 14 public and private L1 stations giving a ratio of ~1:330. This does not include residential charging. It is likely that homeowners will install level 2 stations rather than spend money on a level 1 station as a regular 120v outlet is sufficient. The ratio was moved to 1:500 as it is likely that new installations will be Level 2 and 3, however, level 1 stations may continue to be deployed at workplaces and other long-dwell sites.

Level 2 home	$650	$1,255	$20	$1,905	1:3	The install price is the average price of installations from the INL study. The hardware cost represents the low-end figures from the RMI, Chicago, Energize CT, and US DOE reports. The high-end price was included from the Energize CT report to account for EV drivers who opt for a more expensive model. The low-end prices carry more weight in this average as it is likely that most BEV drivers will opt for the less expensive model. Based on searches of retailers the average price of $650 appears to be reasonable. The ratio of 1 home charger to every 3 vehicles is because not every BEV owner will have a home charging station and households with more than 1 BEV will most likely only have 1 charger. The ratio of 1:3 was confirmed as reasonable by an industry expert.
Level 2 public	$3,480	$5,430	$104	$8,910	1:8	The install price and the hardware price were averaged using RMI, Chicago, Energize CT, and US DOE reports. The prices for hardware and installation of this EVSE vary widely so a large sample was used. Per a conversation with an industry expert aggressive deployment is a ratio of 1:4. It was suggested that a 1:8 ratio be used.
DC fast charger level 3	$37,500	$44,100	$1,125	$81,600	1:1000	Calculated using the high-end data from the RMI, Chicago, Energize CT, and DOE reports. High end data was used because these stations often incur high costs for installation that vary greatly from site to site. The ratio of DC fast chargers to EVSE was estimated in a 2013 report by the National Research Council. The top 10 BEV markets in the country have much lower ratios of DC fast to BEV; however, one may infer that the stations are not being fully utilized. It is likely that these chargers will be placed on major roadways and interstates so the ratio of 1:1000 appears to be reasonable.

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