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BETTER TRAVEL, STRONGER GRID.

Full Market Vehicle Electrification In New Jersey

The *Opportunities, Impacts, and Net Benefits For* Light-, Medium-, and Heavy-Duty Electric Vehicles

Prepared For ChargEVC By Gabel Associates, Inc.

October 7, 2020

Acknowledgements

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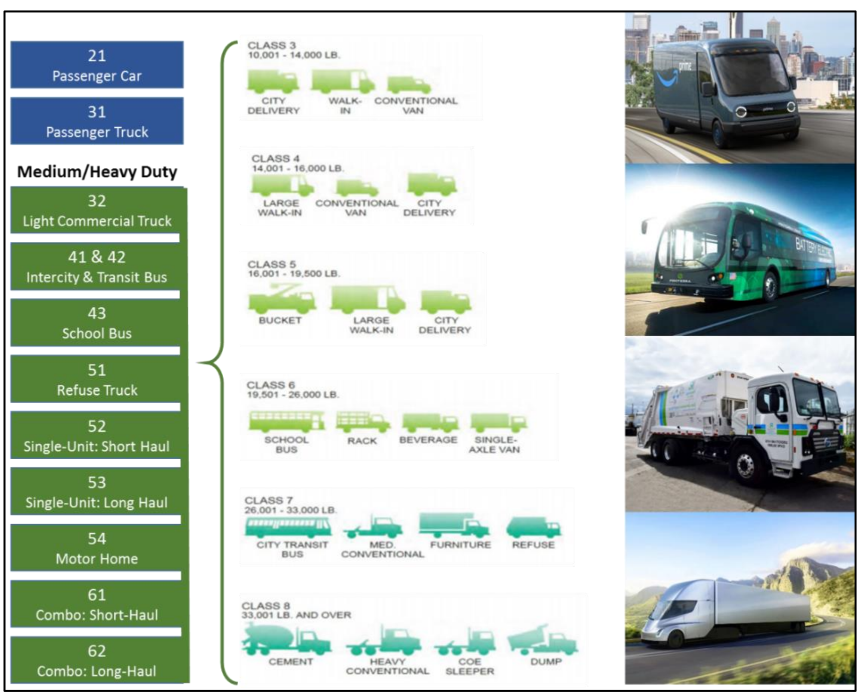
Acknowledgments: This report benefited greatly from the input, guidance, and active collaboration from many parties, especially members of ChargEVC, subject matter experts at New Jersey state agencies, and numerous other stakeholders and colleagues.

1 Executive Summary

New Jersey has adopted aggressive goals to improve the quality of life for its citizens through reduced air emissions of all types. These plans include reductions in greenhouse gases (GHG) to mitigate Climate Change impacts, and initiatives to reduce the emission of criteria pollutants that have a profound impact on public and personal health. Transportation is widely recognized as a primary source for these emissions, especially since vehicles create this pollution in high population density areas along roadways and in the communities where people live. The emergence of Plug-In Electric Vehicle (PEV) technology represents a profound opportunity to replace internal combustion engine (ICE) vehicles with advanced new alternatives that reduce transportation-related pollution and also change where those emissions take place. At the same time, PEVs bring other benefits through reduced operating costs, an enjoyable driving experience, and the potential for reduced electricity costs for all ratepayers.

This report summarizes the results of a new study that considers the market-wide potential for vehicle electrification in New Jersey, including projections of potential adoption rates, quantification of a diverse range of transition costs and benefits, and recommendations to inform the design of market development policies. This study considers both light duty vehicles (LDVs), and the full range of medium and heavy-duty diesel vehicles (MHDVs) that contribute especially to criteria pollutants such as Nitrogen Dioxide (NO2) and fine Particulate Matter (PM2.5).

Figure Exec_Sum - 1: Scope of The Electrification Study

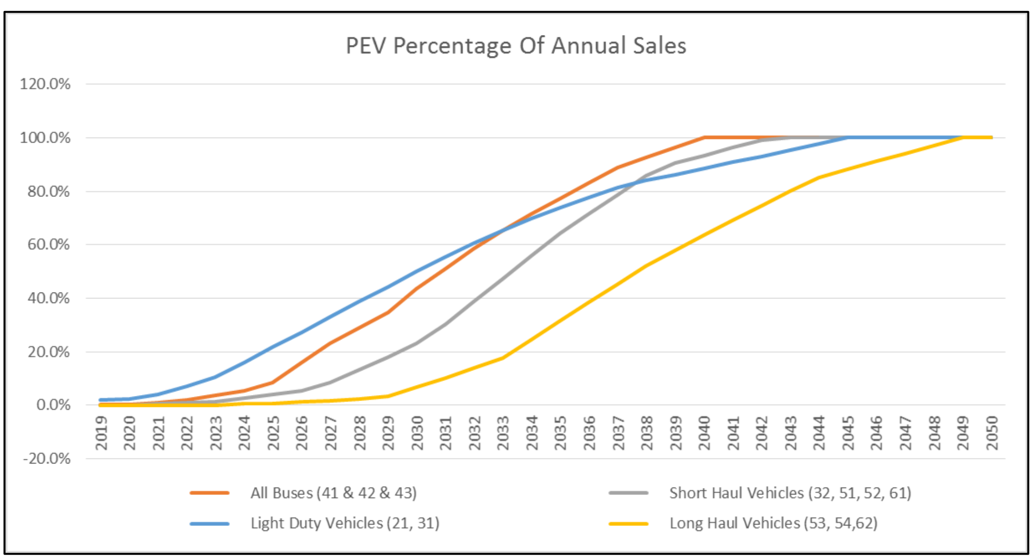


This study was commissioned by ChargEVC, a not-for-profit coalition of automotive retailers, utilities, technology companies, original equipment manufacturers (OEMs), local governments, environmental, community, labor advocates and others working to accelerate the transition to electrically fueled transportation in New Jersey. The study was conducted for ChargEVC by Gabel Associates, a consulting firm with well-established expertise in energy, environmental, utility, and policy research and analysis.

The study provides a statewide perspective on the potential benefits and challenges of electrification of the full market – from small passenger vehicles to buses, delivery trucks, and heavy-duty tractor-trailers. The study identifies a feasible schedule for each vehicle class, quantifies the technical potential for electrification of all types of vehicles, and assesses the net-benefit of a transition of the full on-road vehicle market to plug-in electric vehicles. The study provides projections through 2050, considers the need for new charging infrastructure and the associated grid impacts, and explores the synergy of increased use of renewable energy in the generation power mix with widespread vehicle electrification. The study identifies benefits related to savings in vehicle operating costs, reduced GHG and criteria pollutant emissions (especially in overburdened communities), and the potential for downward pressure on electricity costs that benefits all ratepayers. The study also identifies challenges associated with consumer adoption barriers, the need for vehicle charging infrastructure, and potential impact on the public grid and ways those impacts can be mitigated.

The study includes a detailed assessment of market readiness in all vehicle classes (both LDV and MHDVs), which was combined with a specialized technology dispersion model to determine a realistic vehicle adoption schedule. That schedule, quantified in terms of the percentage of new sales that are electrified each year, is summarized in the chart below.

Figure Exec_Sum – 2: Full Market Vehicle Electrification Schedule for New Jersey



Based on this electrification schedule, the study identifies impacts, opportunities, and challenges. The following highlights summarize the key findings and recommendations:

1) **Electrifying all cars and trucks in New Jersey is a big win:** Based on a comprehensive inventory of both benefits and costs for the full market, the study projects that widespread vehicle electrification (including LDVs and MHDVs) is strongly beneficial through 2050. The state would be justified in pursuing electrification of the full market – including diesel vehicles, as an expansion of existing efforts for LDVs.

2) **There is a strong synergy between vehicle electrification, increased renewable energy use, and proactive management of grid impacts:** The best-case scenario is when managed charging is widely deployed, and vehicle electrification is coupled with increased renewable energy ("RE") use. **In that case, benefits exceed costs by a factor of 4.12 through 2050, and electrification delivers nearly $100B in net benefit to New Jersey residents after considering costs.**

3) **The benefits from vehicle electrification are substantial, and impact everybody:** Electrification benefits include savings from reduced operating expenses for PEV owners, reduced GHG and criteria pollutant emissions (especially in the high-RE case), and downward pressure on electricity rates for all ratepayers when grid impacts are managed proactively. **Vehicle electrification creates substantial benefits for numerous stakeholders – including New Jersey residents that do not own a PEV, and especially overburdened communities that will benefit from cleaner air.**

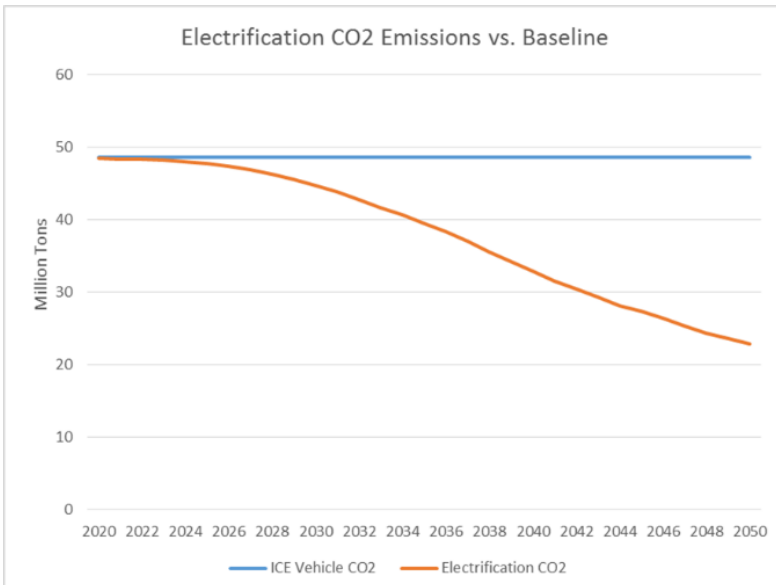
4) **The transition to plug-in electric vehicles cost less than the continued use of traditional vehicles.** The vehicle-oriented costs of the electrification are a critical factor. Focusing on the costs of vehicle purchases, fueling, and maintenance, the vehicle electrification scenario is less expensive (on both a nominal sum and net present value basis) than the continued purchase and use of traditional ICE vehicles – by nearly $140B (nominal sum).

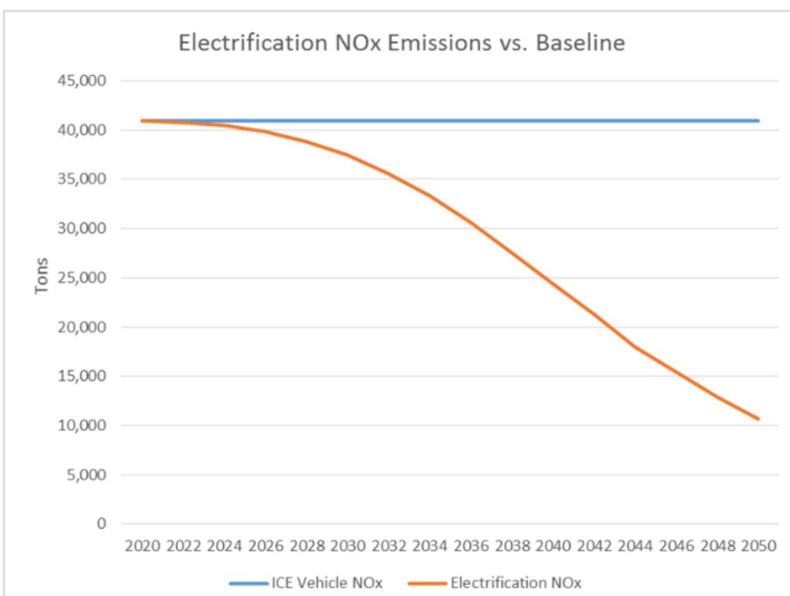
5) **The MHDV segments are extremely diverse, and goal setting and planning is best pursued at a granular "vehicle class" level. Some types of vehicles are ready to electrify relatively quickly – with local delivery vehicles, refuse trucks, and non-school buses being primary opportunities. Other segments, especially school buses and long-haul vehicles, will require targeted market development support to electrify rapidly.**

6) **Both LDVs and MHDVs reduce toxic emissions across-the-board, but in different ways.** LDVs generate the majority of GHG reductions, fuel cost savings, and downward pressure on rates. Electrified MHDVs also reduced GHG emissions, but have the largest impact on the reduction of criteria pollutants near travel zones. The study clarifies that vehicle electrification is justified as both a GHG reduction program and a public health initiative for which there are significant equity

considerations. These improvements are amplified when vehicle electrification is coupled with increased renewable energy use. **Toxic vehicle-induced emissions in urban areas and along roadways will be virtually eliminated on an absolute basis, especially for overburdened communities.** In all cases, even when considering net emission changes on a regional basis (i.e. after accounting for emission increases at power plants), Carbon Dioxide (CO_2) drops by 74% and Nitrogen Oxide (NOx) drops by 85% (for the high renewable energy scenario).

Figure Exec_Sum – 3: Net Emission Reductions from Full Market Vehicle Electrification





7) **Vehicle electrification presents huge opportunities for the grid, but also significant challenges that need to be addressed proactively.** At high levels of electrification, as much as 30% of all electricity use will be for charging vehicles. This new load will have a transformative impact on the grid and represents an opportunity to optimize overall loading since PEV charging can be a "dispatchable load" in some segments. Without proactive planning and impact mitigation, however, vehicle electrification could force significant grid reinforcement and increased electricity costs for all ratepayers.

8) **LDVs and MHDVs will impact the grid in very different ways.** LDVs will create a large number of small charging loads (increasing average residential consumption by about 50%), the impact of which will be significant unless mitigated proactively through a combination of technology and rate design solutions under managed charging programs. The charging impacts from MHDVs are potentially very large (due to the need for very high-power infrastructure for some vehicle classes, especially long-haul), but those load points are relatively small in number and therefore more manageable. Several mitigation strategies exist for those MHDV vehicle classes, including integrated storage, smart charge scheduling, and en-route charging where applicable. High power DCFC (150 – 350 KW) chargers are especially valuable because they can serve the needs of both the LDV and some MHDV segments (i.e. dual use infrastructure).

9) **Electricity pricing, and the structure of that pricing, has a strong impact on vehicle charging and infrastructure investment behaviors.** Existing tariff designs may be missing desired inducements, or may create barriers to charging infrastructure investment. Commonly used residential tariffs typically don't encourage the off-peak charging that is most optimal. The demand charges associated multi-family, workplace, fleet, and public charging applications can make investment economics challenging, especially during early market phases when utilization is lower. Those impacts will be even more impactful for the higher-powered charging solutions that will be needed by many MHDVs. At the same time, serving these new charging-induced loads could change the cost of service for utilities providing that power, which needs to be a consideration in the allocation of costs and overall rate design. **Balancing the needs of the PEV market for supportive rate designs (and other economic incentives) with the needs for fair cost allocation and recovery will be a key policy priority as the market matures.**

10) **The study identified key barriers to electrification of the full market and proposed a next generation plan that focuses on top priorities.** The analysis included the identification of key adoption barriers, and those barriers vary significantly by vehicle class. A next generation "market development plan" has been developed to identify the priorities of greatest need, and to provide detailed "working assumptions" about electrification costs. The net benefits noted above include the potential costs of those potential market development initiative. Priorities for this next generation program include (some of these already exist, some are new):

1. **Electric School Bus Program** – to improve equitable access to PEV benefits by addressing first-cost barriers, especially in overburdened communities.

2. **NJ Transit** – to address charging infrastructure needs in support of the electrification goals established in New Jersey's January 2020 EV law (P.L. 2019. C.362).

3. **LDV Rebate Program** – to address first-cost issues in the LDV segment, and to ensure attainment of the vehicle adoption goals established in the EV law.

4. **Charging Infrastructure -** a package of initiatives that provide the charging infrastructure needed across multiple segments, with a priority on new programs for diesel displacement opportunities:
    a) Residential managed charging initiative (to mitigate grid impacts).
    b) LDV high power public charging initiative (to increase LDV adoption).
    c) Multi-family EV access program (to ensure equitable access).
    d) Commercial charger program (workplace and fleet, including MH-duty).
    e) High power charging for long haul segments (at truck stops).
    f) Consumer education and awareness campaign.

2 Introduction

New Jersey has adopted aggressive goals to improve the quality of life for its citizens through reduced air emissions of all types. These plans include reductions in greenhouse gases (GHG) to mitigate Climate Change impacts, and initiatives to reduce the emission of criteria pollutants that have a profound impact on public and personal health. Transportation is widely recognized as a primary source for these emissions, especially since vehicles create this pollution in high population density areas along roadways and in the communities where people live. The emergence of Plug-In Electric Vehicle (PEV) technology represents a profound opportunity to replace internal combustion engine (ICE) vehicles with advanced new alternatives that reduce transportation-related pollution and also change where those emissions take place. At the same time, PEVs bring other benefits through reduced operating costs, an enjoyable driving experience, and the potential for reduced electricity costs for all ratepayers.

This report summarizes the results of a new study that considers the market-wide potential for vehicle electrification in New Jersey, including projections of potential adoption rates, quantification of a diverse range of transition costs and benefits, and recommendations to inform the development of market development policies. This study considers both light duty vehicles (LDVs), and the full range of medium and heavy-duty diesel vehicles (MHDVs) that contribute especially to criteria pollutants such as Nitrogen Dioxide (NO2) and fine Particulate Matter (PM2.5).

Terminology: The EV market includes pure Battery Electric Vehicles (BEVs) that do not have a petroleum fueled engine of any kind, and Plug-In Hybrid Electric Vehicles (PHEVs) that make use of both an electric motor and a fueled engine for motive power. Both vehicle types provide for charging of an on-board battery or similar storage device from primary energy sources external to the vehicle, and are collectively called Plug-In Electric Vehicles – i.e. all vehicles with a plug. **Throughout this document, the term Plug-In Electric Vehicles (PEVs) and Electric Vehicles (EVs) are used synonymously and interchangeably.** This vehicle group purposefully does not include traditional hybrid vehicles (without a plug for charging), or other alternative fuel vehicles such as compressed natural gas (CNG), hydrogen, or liquefied petroleum gas (LPG).

Please see Appendix A for a glossary of terms and acronyms.

2.1 Background

In January of 2018, ChargEVC published the first comprehensive study on the potential for vehicle electrification in New Jersey. That original study characterized the existing market, examined market barriers and the potential for electrification, and quantified the impacts that PEVs would have on fuel use, emissions, and electricity costs. Since that time, much has happened: the EV market has expanded rapidly due to increasing industry scale, lower costs, and the availability of new electric models, and New Jersey has established itself as a national leader in the development of its EV market.

Given those changes, the next generation of insights are needed to explore further opportunities for vehicle electrification in New Jersey, and to leverage new data sources, improved methodologies, and the involvement of numerous stakeholders and subject matter experts. While the first study focused primarily on LDV, the state is now considering new policies that will shape the emerging MDHV vehicle segments. The rapid evolution of market development policies in other states also provides new experience to inform New Jersey's thinking. This report summarizes the result of a new study that updates the first analysis with a significantly expanded scope and more advanced methodologies. Primary focus for this new study is to provide comprehensive perspective on the full market, including all types of on-road vehicles, and to provide the quantitative detail needed to inform the next phase of market development policy in New Jersey.

This updated study was also commissioned by ChargEVC, a not-for-profit coalition of automotive retailers, utilities, technology companies, original equipment manufacturers (OEMs), local governments, environmental, community, labor advocates and others working to accelerate the transition to electrically fueled transportation in New Jersey. Please see Appendix B for a list of ChargEVC members. The study team has benefited directly from collaboration and feedback from the diverse ChargEVC membership in the development of these results and conclusions. The study was conducted for ChargEVC by Gabel Associates, a consulting firm with well-established expertise in energy, environmental, utility, and policy research.

2.2 Objectives and Scope

The study provides a statewide perspective on the potential benefits and challenges of electrification of the full market – from small passenger vehicles to buses, delivery trucks, and heavy-duty tractor-trailers. The study identifies a feasible schedule for each vehicle class, quantifies the technical potential for electrification of all types of vehicles, and assesses the net-benefit of a transition of the full on-road vehicle market to plug-in electric vehicles. The study provides projections through 2050, considers the need for new charging infrastructure and the associated grid impacts, and explores the synergy of increased use of renewable energy in the generation power mix with widespread vehicle electrification. The study identifies benefits related to savings in vehicle operating costs, reduced GHG and criteria pollutant emissions (especially in overburdened communities), and the potential for downward pressure on electricity costs that benefits all ratepayers. The study also identifies challenges associated with consumer adoption barriers, the need for vehicle charging infrastructure, and potential impact on the public grid and ways those impacts can be mitigated.

This study has been guided by the following objectives:

- Help stakeholders and policy makers understand the technical potential for vehicle electrification in New Jersey – especially the question of "how fast could electrification happen". Provide the detail that allows for prioritization across different vehicle segments.

- Expand on the original study to consider the full market – both LDV and MHDV – and quantify the physical impacts and net benefits (after accounting for costs) from full market electrification.

- Explore market barriers to vehicle electrification by vehicle segment, and account for the costs of overcoming those barriers where feasible.

- Consider vehicle electrification in New Jersey in the context of other clean energy initiatives already underway within the state, especially significant efforts at grid supply de-carbonization.

The scope of the study was as follows:

- Consider both LDV and MHDV on-road vehicles, within the state of New Jersey, looking at conditions from 2019 through 2050.

- Include a comprehensive portfolio of both costs and benefits to determine net-benefit, including factors that are "externalized" or poorly economized. Focus on primary benefits such as reduced operating expenses for EV drivers, emission impacts, and potential impact on electricity rates. Consider a wide range of costs, including vehicle purchase premiums, investments for vehicle charging infrastructure, and potential grid reinforcement.

- Evaluate electrification recognizing that New Jersey is part of a larger power pool (PJM), and specifically is typically considered part of the RFC-East. Assess the impact of vehicle electrification happening in parallel with de-carbonization of the electricity supply.

- Align the study with various PEV related policies already established within the State.

2.3 What Is New In This Study

This study builds on the original research in 2018, but differs in several important ways:

- The study will consider the full EV market, including LDVs and the full range of MHDVs. This expands the scope of the model by nearly a factor of 10, and includes a highly granular vehicle segmentation structure that allows the unique details of different vehicle types to be considered independently.

- Along with including MH-duty (predominantly commercial diesel) vehicles, the study expanded the scope of emissions considered to include PM2.5, and more deeply considered the geographic implications of vehicle electrification and associated equity issues.

- New Jersey has made substantial commitments to increased use of (mostly in-state) renewable energy (RE), and attainment of high levels of carbon-free energy have been assumed in the BPU's recent Energy Master Plan[1] (EMP) and the Integrated Energy Plan[2] (IEP). There is a powerful synergy that emerges from simultaneous de-carbonization of the supply mix and widespread vehicle electrification. The new study examines impacts and net benefits from both a Business as Usual (BAU) supply mix scenario and a high-RE case.

- In addition to a multi-year quantification of both costs and benefits from vehicle electrification, the study also provides new tools that help clarify insights about the technical potential for electrification through "snapshot" models of market transformation.

- An essential issue for the study is determining how fast various segments can adopt new electric vehicle technology. A detailed technology dispersion model has been developed to quantify how evolving EV capabilities and natural consumer buying segments interact to affect the pace of electrification. This model considers a variety of gating factors, including cost-parity assessments. With the exception of LDVs and NJ Transit (which have adoption requirements set in law), this analysis was performed independent of policy-driven schedules under consideration (like the recent MHDV MOU) to allow for a market-based understanding of feasible electrification rates at the vehicle class level.

- The analysis has been aligned with EV policy efforts in New Jersey, especially the recently passed EV Law[3] that establishes formal state goals for the adoption of certain EVs and charging infrastructure. Focus is on a single set of vehicle adoption curves that (where applicable) align with law, rather than the hypothetical set of "what if" scenarios used in the first study.

- The geographical accounting policy associated with emissions has a very large impact on the results. For example, when calculating emissions from electricity generation should we consider the gross emissions from PJM overall, or should we focus on the State boundaries and the use of in-state generation? The study team has been coordinating with the DEP as they considered these issues, and we have aligned our emissions accounting policy with the emerging consensus within the DEP on this issue. In short, emissions accounting will be done considering New Jersey as part of the RFC-East sub-region[a]. All emissions accounting for the study has been done within those boundaries.

- The model developed for this study has benefited from extensive use in multiple states for EV impact modeling, especially regarding emissions, economics, and potential grid impact. These new modeling structures, and a much more robust set of data sources for inputs, have advanced the ability to characterize vehicle electrification significantly.

- This study benefited heavily from extensive input from, and collaboration with the ChargEVC members, industry subject matter experts, policy makers and electric utility program planners in multiple states, and state agencies in New Jersey.

2.4 Current Market Conditions

Electric Vehicles have been available for sale in New Jersey since 2008, with commercial availability of more mainstream options since 2010. Sales have grown steadily since that time, and the State has taken significant actions to accelerate EV adoption. Most recently, New Jersey has become a national leader through several key initiatives focused on development of the LDV market:

[a] This decision has a significant impact on the results. For example, even if there were carbon free generation assets within state boundaries to completely fulfill the state's load, the emissions accounting would not drop to zero.

- **EV Law:** In January of 2020, Governor Murphy signed a new landmark EV[4] law setting formal goals for vehicle electrification, and authorization policies and programs to achieve those goals. That law has since become the guiding framework for PEV policy development in the State.

- **Vehicle Rebate**: As authorized by the EV Law, the BPU now offers a $5,000 rebate when New Jersey residents buy an eligible LDV. This $300M fund addresses a key adoption barrier and helps make the aggressive adoption goals established in the EV law attainable.

- **Public Charging Infrastructure**: The EV Law also recognized that access to high power charging infrastructure was a key strategy for eliminating consumer concerns about range anxiety, and established a statewide initiative to build out the fast charging network needed to overcome those barriers. State agencies have started programs to build out this network, and other programs are under consideration.

- **Expanding Goals to include MHDV:** Also, as required in the new EV Law, the State is required to set formal goals for adoption in the "diesel displacement" segments, and those efforts are underway.

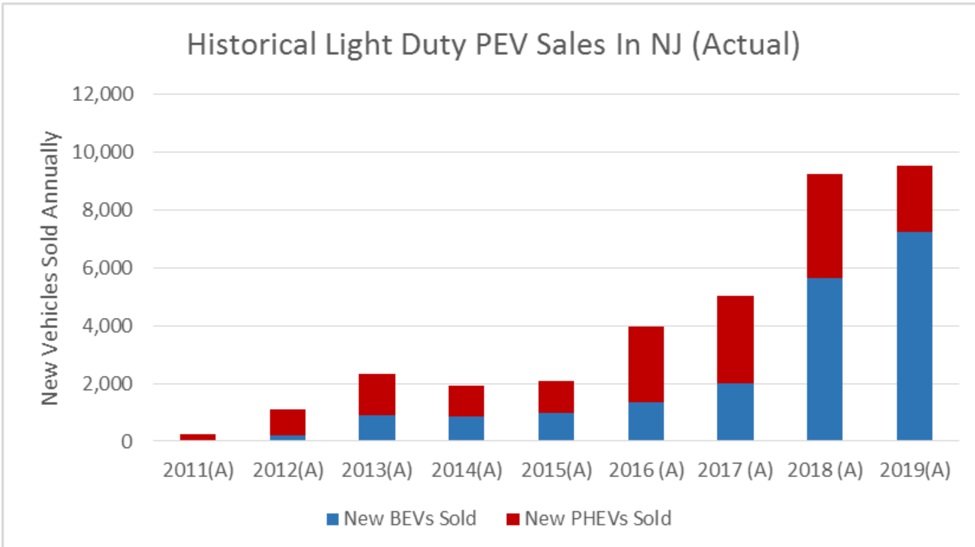
These initiatives explicitly target known consumer adoption barriers for LDVs and open the door for similar development across the full market (including MHDVs). Please refer to Appendix C for a more detailed summary of current PEV market conditions in New Jersey.

2.5 Historical EV Sales In New Jersey

This section summarizes key historical statistics that establish the quantitative baseline for the projection analysis. The following chart summarizes BEV and PHEV sales in New Jersey, from 2011 (the first year data is available) through year-end 2018.[b]

[b] https://autoalliance.org/energy-environment/advanced-technology-vehicle-sales-dashboard/, based on data extracted in September 2019.

Figure 2.0: Light Duty PEV Sales in New Jersey, Thru YE 2019



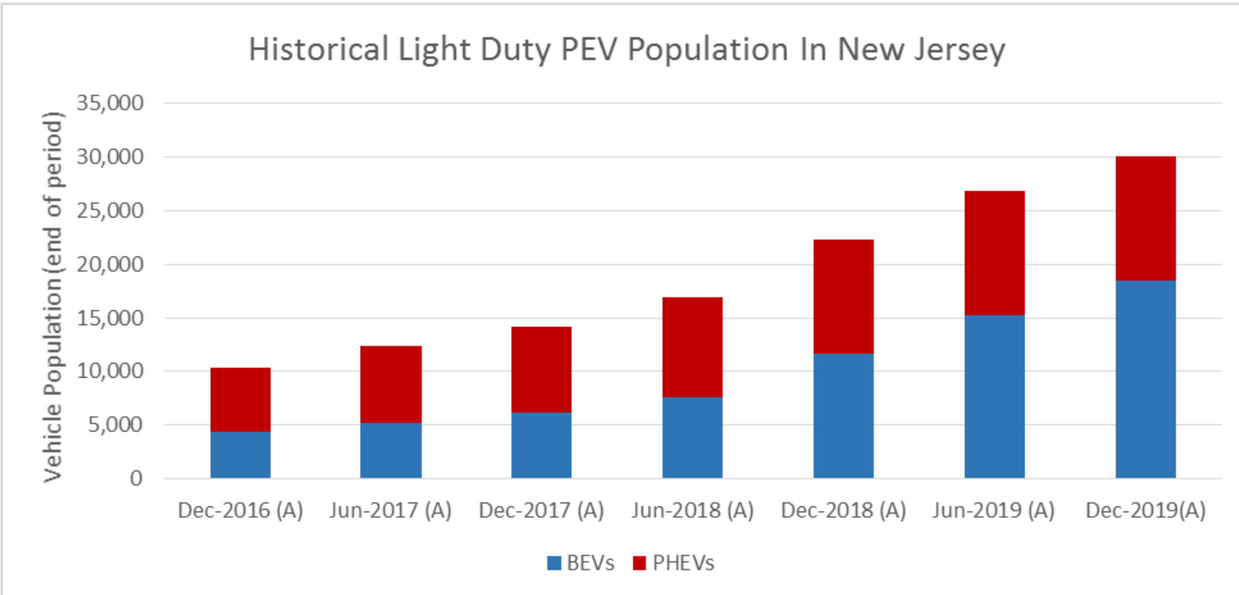
The above data covers only LDVs. The NJDEP VW Consent Order Program has encouraged deployment of a variety of electrified MHDVs, but other than these projects, there has been little development of the MHDV market in New Jersey.

These results represent year-over-year sales growth for PEVs of 89.9%, 26.5%, and 83.4% (for 2016, 2017, and 2018 respectively). Sales for the first half of 2019 demonstrated 55.4% growth over the same period in 2018, demonstrating strong growth but a slow-down compared with the average of the prior three years. This softening continued into the second half of 2019, mostly associated with supply slow-down.

These sales, after accounting for retirements and the net impact of vehicles entering or leaving the State, have resulted in substantial growth in the number of registered EVs on the road in New Jersey. That trend is summarized in the chart below, based on snapshots of vehicle registration data developed by the NJDEP[c] (year-end 2016 is the first year for which there is data available under the current methodology). Note that these numbers represent the PEV population, not annual sales.

[c] All NJDEP statistics in this report are based on an amended version of registration data issued by the NJDEP in August of 2019, reflecting corrections in minor prior-year methodology issues.

Figure 2.1: Light Duty PEV Population in New Jersey, Thru YE 2019



There are very few electric vehicles in the MH-duty segment on New Jersey roads as of the end of 2019, although a limited number of vehicles, especially buses, are entering the market in 2020, especially as part of the NJ DEP Consent Order Program.

2.6 Market Development Scorecard

Based on the recently passed EV Law, New Jersey has established a goal of 330K PEVs on the road in New Jersey by the end of 2025. Based on the most recent snapshot of vehicle registration data by the New Jersey DEP, 30,017 light duty PEVs are on the road in New Jersey as of the end of June 2019, net of retirements and changes due to used cars entering or leaving the state. **New Jersey has therefore achieved 9.1% of its 2025 goal**, a significant improvement over the 6.7% attainment achieved by the end of December 2018.

The EV Law has also established a goal for construction of at least 75 high power corridor charging locations, and DEP has estimated that approximately 118 such locations will be required to satisfy the EV Law's geographic density requirements. The DEP reports that 6 compliant locations are currently in operation as of the end of September 2020. **That means the state has attained between 5% and 8% of its corridor charging market development goal.** The EV Law also establishes goals for development of community fast chargers, but they have not yet published an assessment of the number of compliant community chargers. The study team estimates that roughly 10 such locations are currently in operation today.

3 Methodology Overview

The study team has developed a comprehensive set of models that capture relevant research data for use as NJ-tuned inputs, and methods for modeling physical impacts, economic impacts, and the net-benefit of those impacts. The following sections provide an overview of the key concepts, the modeling system, and critical assumptions.

3.1 Vehicle Segmentation and Nomenclature

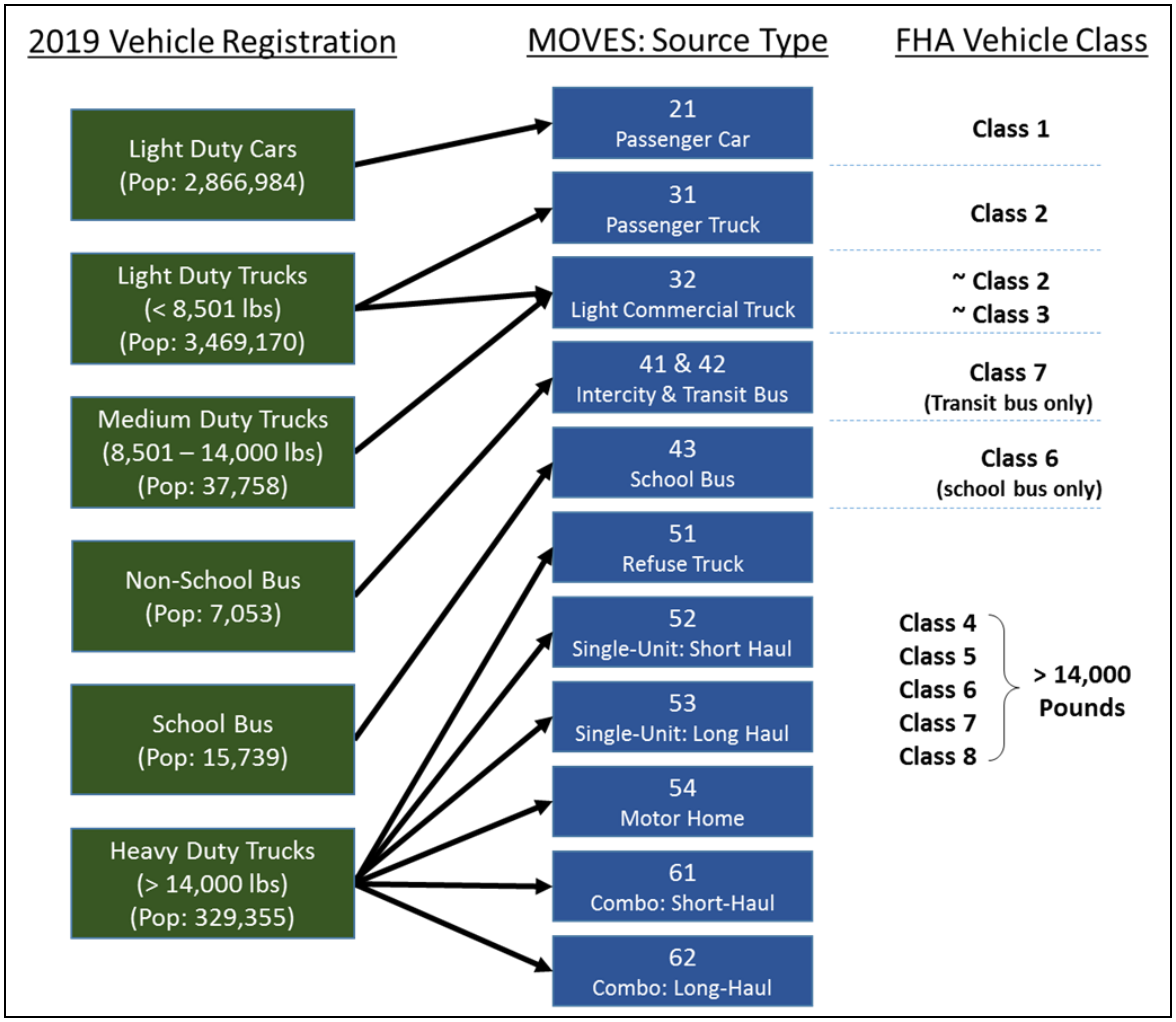
A primary consideration in the design of the study was how to organize the on-road vehicle landscape. There are a variety of segmentation methods in wide use, many of them managed by the federal government as part of various regulatory frameworks. The goal was to make use of a segmentation model that was granular enough to allow the unique characteristics of diverse segments to be quantified, but not so detailed that results and conclusions become fragmented. After considering a variety of methods, the study adopted a framework based on the EPA MOVES modeling system. That framework assigns vehicles to different classes (called "Source Types" (ST) based on their size, weight, and typical use, as follows:

Figure 3.0: MOVES Vehicle Classifications

Source Types	Description
21	Passenger cars (light duty)
31	Light duty passenger trucks (SUVs, pick-ups, mini-vans)
32	Light commercial trucks (medium duty, both gas and diesel variations)
42 & 42	Intercity and transit buses
43	School buses (typically K-12)
51	Refuse Truck (typically short haul)
52	Single-Unit, Short Haul
53	Single-Unit, Long Haul
54	Motor Home
61	Combo: Short Haul
62	Combo: Long Haul

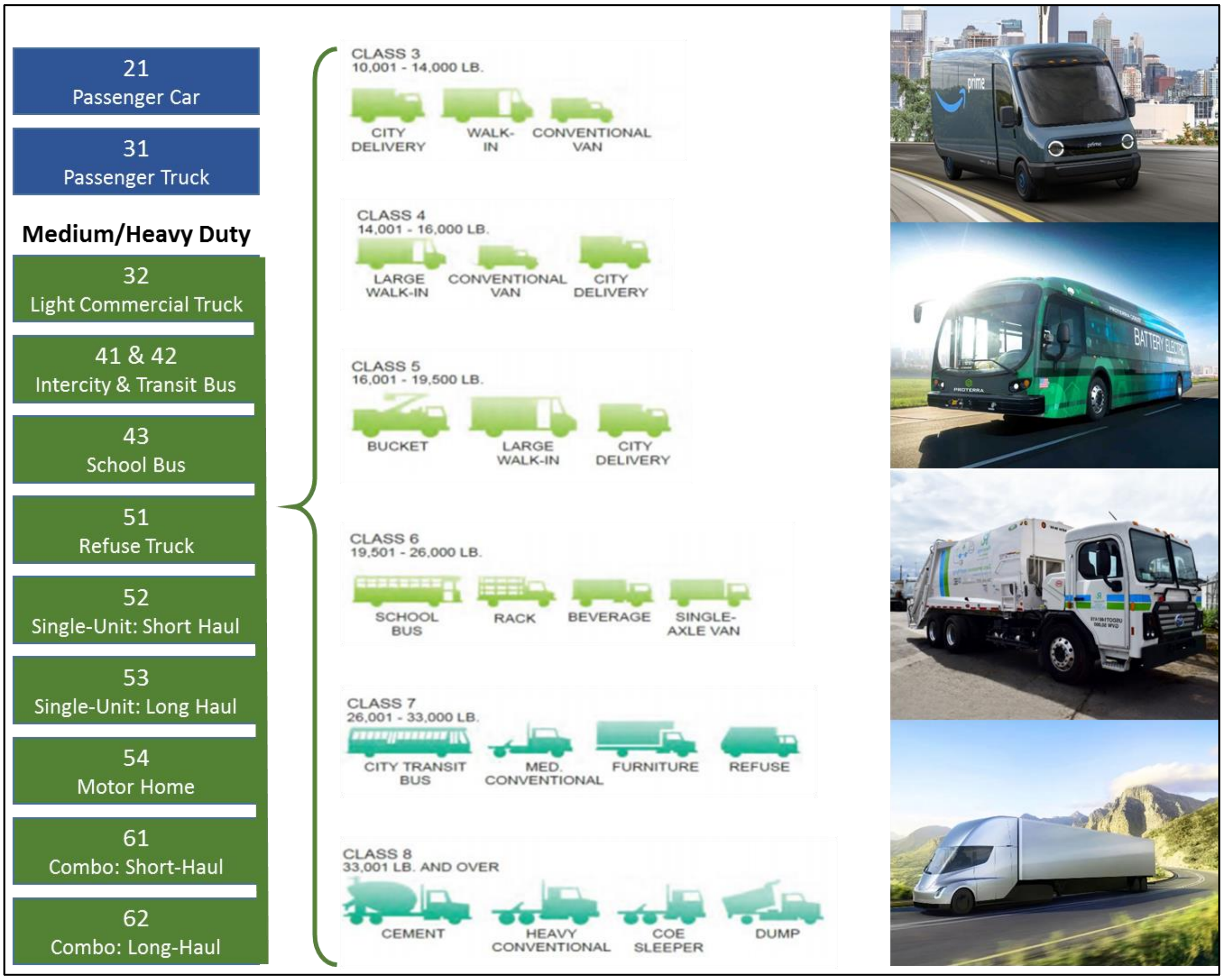
Adopting any one framework, however, introduces challenges since the different paradigms in place do not map easily to each other. The following diagram illustrates how the MOVES categories used in the study map to data collection segments used by the DEP (for registration data) and the federal weight Federal Highway Administration (FHA) weight class system.

Figure 3.1: Mapping Between Classification Systems



The following infographic provides a "silhouette-style" guide to various vehicle types and how they map to the federal system, and based on the mapping above, to the MOVES segmentation structure.

Figure 3.2: Real World Examples Of Vehicle Classes Considered In Study



3.2 Modeling Approach

The primary focus of the study was development of a quantitative model, including the inputs required by that model, to project impacts of vehicle electrification across multiple vehicle segments over time. The model included several elements that are used together to generation the reported results:

- **Vehicle Modeling Framework:** The entire model is organized around a granular segmentation model described in Section 3.1 above. Most data inputs, calculations, and results are done on a per vehicle class basis.

- **Data Aggregation:** the study consolidates data from a wide variety of sources to use as inputs. Parameters such as vehicle efficiencies, fuel costs, vehicle pricing, electricity costs, etc, are all aggregated in a single place so that change control can be maintained, units harmonized, and to provide a single reference point for other modules.

- **2019 Snapshot:** a specialized model quantifies the full transportation market in 2019 based on vehicle registration data and estimates how key benchmarks change under a hypothetical scenario where 80% electrification is attained. This tool is useful for understanding the technical potential for electrification, without the need for numerous projections about future factors. The 2019 Snapshot and the associated results are provided in Section 6.

- **Vehicle Cost Snapshot:** Hard costs associated with vehicle purchase and operation is a primary consideration in transformation of the market. This tool focuses on just direct vehicle costs in the case where the market continues to purchase and use ICE vehicles, and an alternative scenario in which the market electrifies according to the electrification schedule (see below). The Vehicle Cost Snapshot and the associated results are provided in Section 6.

- **Electrification Schedule:** One of the most important considerations in the study was the rate at which difference vehicle classes can feasibly electrify. The electrification schedule is a function of PEV availability within each segment, but also natural customer adoption rates and potential gating factors (such as charging infrastructure availability). This part of the model includes economic "cost per mile" analysis to determine when basic levels of parity are attained in each segment and applies a customized technology diffusion model to determine vehicle sales rates over time. Each vehicle class is modeled separately. This adoption model is described in more detail in Section 4.

- **Infrastructure Requirements:** The cost of vehicle charging infrastructure is a primary consideration, and this model translates projected vehicle sales into a detailed plan for the number of chargers required each year. This infrastructure plan is used to determine infrastructure costs and is summarized in Section 5.

- **Electricity Market Impact Models:** Once the electrification schedule is established, information about how vehicle charge (in different ecosystem segments) is combined with estimated vehicle travel statistics to project charging requirements and load curves. These load curves are used to compute how the wholesale market is reshaped due to vehicle charging, the associated wholesale costs, and emissions associated with the necessary dispatch. The electrification schedule is described in detail in Section 4.

- **Net Benefit Model:** Outputs from all the above modules are integrated to estimate physical and economic impacts over a multi-year period, including a comprehensive inventory of benefits and costs. These factors are combined to estimate net-benefit through a benefit/cost ration. Various charging scenarios, and both business-as-usual and high renewable energy supply mixes are considered. These results are summarized in Sections 7 – 10.

Please refer to Appendix D for more details on the modeling approach and data sources.

3.3 Key Assumptions

Within the model structure and key concepts outlined above, there are a variety of key assumptions and boundary conditions that determine the scope of the model and its results, as described below:

1. The study considers a single-year snapshot for 2019, and multi-year scenarios from 2021 through 2050. All analysis is focused on vehicle registered in, and used within, New Jersey.

2. All types of on-road LDVs and MHDVs are included in the analysis.

3. The size of the vehicle population is always changing, and accounting for those variations can obscure market changes that result from electrification. The study therefore considers a "fixed world" in which the vehicle population, annual sales, and vehicle efficiencies are fixed over time. The only exceptions are a) efficiency of ICE vehicles change over time due to the CAFÉ standards (which slowly drive mpg-efficiency up), and b) the clear shift in consumer buying preferences for light duty trucks (typically SUVs) over traditional "cars". This approach allows almost all change in market characteristics to be attributed exclusively to electrification impacts.

4. The study assumes that driver travel patterns do not change as the result of using a PEV rather than a traditional fueled vehicle. In particular, annual miles traveled per vehicle remain the same between traditional vehicles and PEVs.

5. The electric market quantification is based on a detailed hour-by-hour simulation of dispatch for the entire PJM wholesale generation fleet, using known run-prioritization rules, heat rate factors, marginal costs, emission rates, etc. Emission factors are based on RFC-East, consistent with emerging DEP guidance on emission accounting methodology. Outputs from the simulation include wholesale energy costs, physical emission rates, and wholesale generation capacity build requirements.

6. As part of assessing potential vehicle adoption schedules, the study team identified key adoption barriers in each vehicle segment. A potential market development program that would address these barriers was defined, with a focus on the most impactful and strategic initiatives. The team defined these programs (nine in all), covering the LDV market as well as the MH-duty segments. The electrification schedule assumed that these barriers were addressed in New Jersey, and the estimated costs for those programs are included as a cost in the net benefit analysis. These program definitions should be considered working assumptions for potential costs, included in the spirit of taking a comprehensive approach to cost accounting.

7. The study included consideration of potential grid reinforcement costs, based on engineering parameters developed from detailed studies in other utility territories.

Please refer to additional details in Appendix D.

4 Vehicle Adoption Schedule

Everything in the impact assessment depends on projections about how fast electric vehicles will displace traditional ICE vehicles. The vehicle market is turning over all the time, and the majority of the fleet is naturally replaced every 12 to 15 years. The essential question is at what rate those natural purchase decisions transition to adoption of a plug-in vehicle, rather than perpetuation of the inertial ICE decision. This question about the "electrification schedule" is one of the most critical parts of the study. The study identified key barriers that influence the pace of adoption in each vehicle class, completed a detailed market readiness assessment within each vehicle class, and developed a customized technology diffusion model to quantify a realistic schedule for PEV adoption rates in all segments. These individual adoption rates are then combined to project the *rate* of electrification transformation.

The critical distinction is that this schedule development reflects not just technical readiness – many studies have attempted to quantify when PEVs will achieve "parity" in certain segments. That information, by itself, is not sufficient to develop an electrification schedule. For example, if the perfect vehicle, with both a cost of ownership and first cost advantage were available in a particular segment in a given year, 100% of the buyers that year would not begin buying that vehicle. Once certain criteria were met, adoption grows within a segment based on expanding customer acceptance. The electrification schedule proposed below was developed based on considering the interaction between improving market readiness and natural technology diffusion through successive cohorts of customers over time[d].

4.1 The Technology Diffusion Model

New technology adoption, especially when a new solution is displacing a well-established incumbent, progresses at a rate that is a function of two things: a) a maturing product and increasing "market fit" (product features, price points, the commercial ecosystem, etc), and b) the willingness of successive segments of customers to adopt the new technology over time. It is the intersection of these two considerations that determine the rate of adoption. The latter component is especially critical – not all customers are equally willing to accept new technology, even if it is a good match with their needs. Some customers are natural innovators and will be the first to change their traditional vehicle purchase decision once certain basic criteria are satisfied. Other customers will only adopt after nearly every other customer has "made the leap". The study team developed the electrification schedule based on assessing both product maturity and "market readiness", as well as a customized technology diffusion model that accounts for how successive segments of customers adopt the new technology over time.

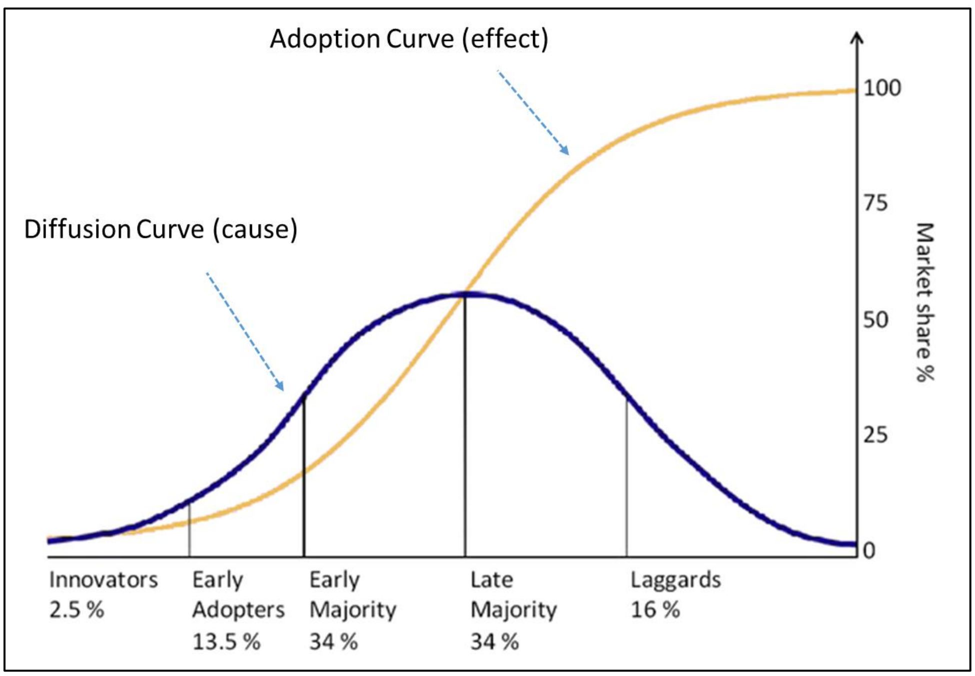
These considerations were applied to each vehicle class separately, and there were different factors involved in most vehicle segments. In short, based on characteristics of the vehicles themselves combined

[d] In parallel with this study, the State of New Jersey signed on to a regional MHDV MOU that established very high level goals for MDHV electrification in time. This study is focused on answering the question – independent of any policy goals that are being established – what the electrification rate *could* be based on market factors (with the exception of LDVs and NJ Transit, which are already established in law). This analysis can help confirm the feasibility of the MOU goals, and also allow translation of those very high level objectives into more specific adoption goals per vehicle class. The study team therefore intends this analysis to be complementary with high level MOU goal setting.

with the natural pace of adoption by the customer base within a segment, electrification schedules were developed for each vehicle class. This electrification schedule is ultimately quantified as a percentage of new sales each year that could be electrified.

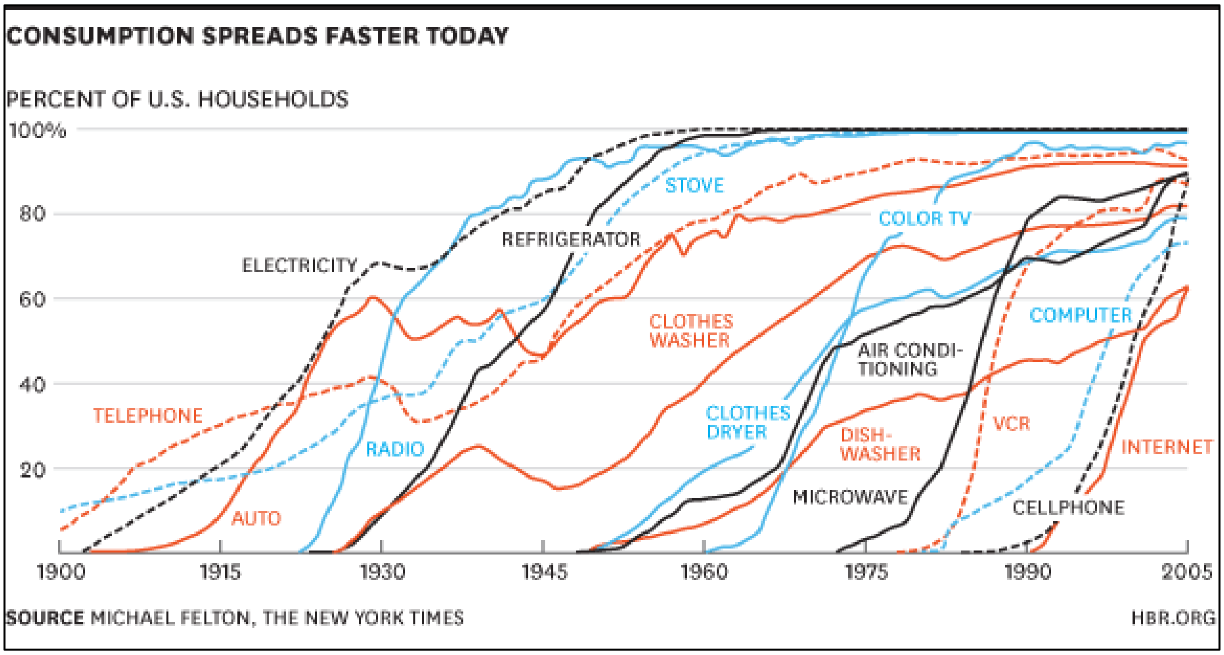
The following diagram illustrates a classic "technology diffusion" model for new technology. The blue curve represents a normal distribution that describes different phases of customer acceptance – from the eager innovators in the early stages of the market, to the highly resistant laggards that are the last to "make the switch". This customer adoption profile can be applied to any technology, and the study team has adopted a customized version specific to the EV market in New Jersey. The yellow curve represents the increasing penetration that results (in the overall vehicle population) as a result of growing levels of consumer adoption . The blue diffusion curve is essentially the "cause", and the yellow adoption curve is the resulting "effect". Knowing the details of the diffusion curve for each vehicle segment allows a projection of the rate of vehicle adoption over time.

Figure 4.0: Generic Technology Diffusion Model



While most technologies exhibit penetration over time in successive segments of customer acceptance, and the general shape of both curves are similar across diverse products and markets, the exact shape of the curves vary. Some products can attain "full saturation" in a few years, while others may take several decades to attain the same level of penetration. Some technologies are novel –e.g. inventions such as television were not replacing an existing incumbent product. In contrast, vehicle electrification needs to be considered as a displacement decision. This means that adoption depends on when the new technology achieves parity (and advantage) over an established solution whose characteristics are well known by the consumer. This adoption diversity is evident in the following diagram, which illustrates how penetration has progressed over time for a variety of different technologies.

Figure 4.1: Market Adoption of Example Technologies

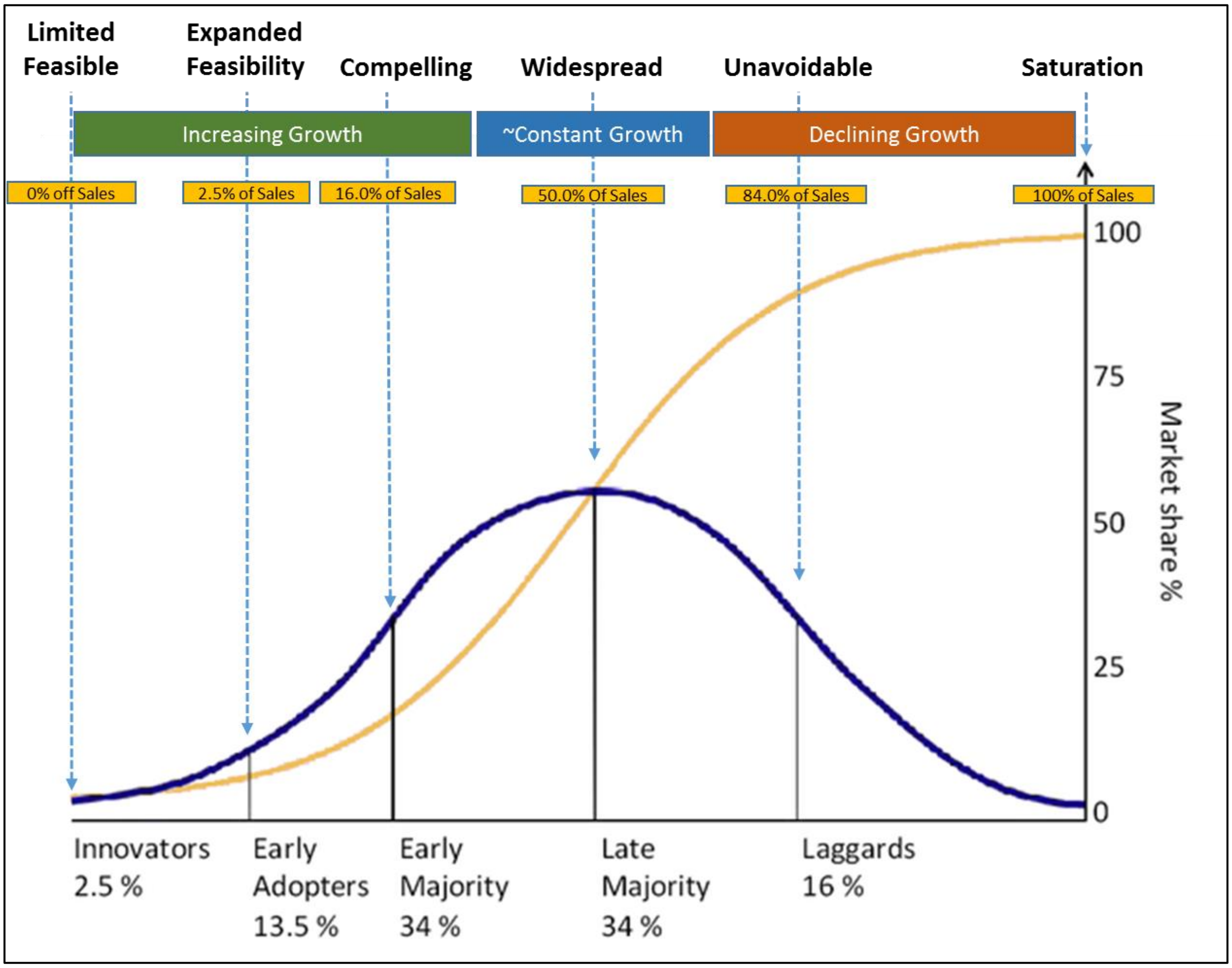


The essential characteristic of the diffusion curve is that each customer segment (or cohort) is a certain size, meaning that a certain fraction of consumers will be amenable to PEV adoption when the market is "in that phase" of adoption. Setting the date for each transition threshold between these natural segments is based on finding when the product has evolved to the point that a certain fraction of consumers would make that adoption choice. For example, to determine the "expanded feasibility" threshold, what year would at least 16% of consumers find PEVs to be the preferable alternative? Once the market has entered a given phase (between two thresholds), the annual percentage of adoption increases linearly from that at the beginning of the phase to that at the end of the phase (e.g. 16 – 50%). While the size of each segment is pre-determined based on the characteristics of the normal distribution, the shape of the diffusion curve can be set by establishing "anchors in time" for each transition threshold.

The challenge of determining an electrification schedule therefore reduces to quantifying the shape of each diffusion curve in time, per vehicle segment. If we know a) when adoption can begin based on key criteria being satisfied, and b) the duration of each threshold from one adoption segment to the next, the shape (and timing) of diffusion curve can the determined for each vehicle class.

The following diagram illustrates how this general technology diffusion model has been adapted to characteristics associated with PEV adoption as a displacement of existing technology.

Figure 4.2: Technology Diffusion Model For PEV Technology



The key parameters that set the adoption shape is the timing of when each threshold is traversed. The study team has defined six thresholds to define PEV adoption, reflecting a product displacement scenario:

- **Limited Feasibility:** A few PEVs available that meet requirements for some applications but no EV alternatives for most applications, limited number of brands/options available, and limited commercial availability. Limited decision maker awareness. PEV alternatives not economic from any perspective in almost all cases. Most adoption by technology innovators and in early stage pilots.

- **Expanded Feasibility:** Multiple PEVs available for many applications (but not longer range scenarios), strong match with consumer requirements in many cases, but commercial availability somewhat limited. Economic on a cost-per-mile basis for some applications, but in most cases not at price parity (without incentives). Modest decision maker awareness, but limited operational history available for most applications. PEVs have become a viable option in many cases, especially where longer range is less critical, and where there are no limitations on charging infrastructure availability.

- **Compelling:** Multiple PEVs available for most applications with competitive options from multiple trusted brands. PEVs are economic on a cost-per-mile basis, and near price parity in many cases without incentives, and advantageous with incentives. Widespread commercial availability, with strong support from the entire ecosystem (financing, repair, insurance, etc). Widespread decision maker awareness, and well established operational record for PEVs in many applications. Longer range segments becoming viable, and charging infrastructure availability not a constraint except in some long haul applications.

- **Widespread:** PEVs are competitive with traditional vehicles for almost all applications when considering the number of models available, match with application requirements, options from multiple trusted brands, and nationwide availability. Economic in almost all segments on a price parity basis, with a strong cost-per-mile advantage. Widespread decision maker awareness, well established operational record for PEVs in most applications, and fully developed sales and support ecosystem. PEVs become the preferred option in most cases, and strongly advantageous over traditional options in most applications, with few limits on the availability of charging infrastructure. Traditional vehicle options beginning to decline.

- **Unavoidable:** Purchase of a tradition vehicle becomes difficult due to limited product options, declining commercial support (leasing, repair), fuel costs and availability.

- **Saturation:** PEVs are the only option for the mainstream market, sales of traditional vehicles very limited.

Determining the timing of these thresholds, and the associated duration of each phase, allows for the determination of the diffusion curve shape. The following sections summarize how market readiness was assessed to determine the timing of these adoption thresholds, resulting in a detailed electrification schedule expressed as a percentage of PEV adoption (in each vehicle class) per year over time.

4.1.1 Market Readiness and the Cost Per Mile Indicator

There are a large number of factors that determine whether a new technology is attractive to successive waves of more demanding customers. Many of them, such as consumer awareness or familiarity with operating history (which is critical for some fleet segments), are hard to quantify objectively, and/or there is very limited data available to use for that characterization. After exploring a wide variety of criteria, the study team settled on four factors that can be used to determine threshold timing:

- Basic product availability and rudimentary “feature parity” with existing vehicles. These criteria are used to estimate when the first threshold (limited feasibility) is crossed.

- An economic indicator that quantifies the value of the PEV compared with existing vehicles, expressed as an amortized "cost per mile" factor. This criteria is used to estimate when the second threshold (expanded feasibility) is crossed.

- The natural "rate of retirement" associated with different vehicle segments, which influences how long the market takes to progress through successive adoption phases. Segments that turn over the vehicle population more quickly, and/or which are more sensitive to cost competitiveness, would take less time to move through a given phase. This criteria – which is more qualitative in nature – is used to estimate the duration of the latter phases. But generally latter phases are longer in duration than earlier phases, since that class of customers are less receptive to innovation.

- Gating factors that may delay progress through the phases even if other criteria are satisfied were also considered. For example, even if a perfect BEV semi-trailer were available tomorrow, most long haul fleet operators would not seriously consider it until fast charging is available at a critical mass of truck stops along their routes. That same trailer, however, might see adoption in short haul applications (such as drayage) where en-route charging is not necessary. Other gating factors considered include established operating track record which is essential in segments like schools, or standards compliance in markets regulatory factors apply.

Of these factors, one of the most important is the economic indicator associated with amortized cost per mile. This criteria determines the threshold when more widespread adoption begins, and is also one of the most quantitative of the criteria. Doing a detailed Total Cost of Ownership (TCO) model for each vehicle segment, especially given the range of vehicle involved in the MH-duty space, is beyond the scope of this study. However it has been studied in depth by others[5] [6] [7] [8], and the study team developed a "cost per mile" indicator that provides a similar measure.

The Cost Per Mile (CPM-I) combines initial cost, the cost of routing charging infrastructure (as paid for by the vehicle owner), the cost of fuel, and the cost of maintenance, over typical vehicle life for each vehicle class. This approach brings in differences in vehicle efficiency (mpg vs kwhr/mile) that delivers operational savings that offset higher initial costs. This total cost is amortized over the total lifetime miles. In this case, the full range of vehicle travel, not just the travel in New Jersey, is used as the basis for comparison. A CPM-I is computed for existing ICE vehicles in each vehicle class, which establishes a parity benchmark. Once PEVs have attained an equivalent level of CPM-I performance, the threshold criteria is considered satisfied.

In some vehicle segments, the CPM-I parity benchmark has already been surpassed – in these segments, PEVs are already attractive to early stage customers – even if first cost parity has not been fully attained. For the segments where the PEV alternatives are not yet at CPM-I parity, iterations were performed to determine the vehicle cost that would deliver the required CPM-I parity. By comparing that vehicle price point with expected PEV vehicle pricing changes over time, a date for attainment of CPM-I parity can be estimated. The following chart summarizes the result of this CPM-I analysis for each vehicle class:

Figure 4.3: Cost Per Mile Indicators Per Vehicle Class

	$/Mile Indicator	
Source Types	**ICE**	**EV**
21 - Light Duty - Passenger Car (BEV)	$0.2605	$0.2545
21 - Light Duty - Passenger Car (PHEV)	$0.2605	$0.2581
31 - Light Duty - Truck (BEV)	$0.3286	$0.2745
31 - Light Duty - Truck (PHEV)	$0.3286	$0.2666
32 - Medium-Duty Commercial Truck (gas)	$0.4913	$0.4753
32 - Medium-Duty Commercial Truck (diesel)	$0.4593	$0.4657
41 & 42 - Inter-City and Transit Buses	$2.3273	$2.1237
43 - School Bus	$2.1707	$3.4906
51 - Refuse Truck	$4.8823	$4.0470
52 - Single-Unit - Short Haul	$0.6726	$0.4484
53 - Single-Unit - Long Haul	$0.7007	$0.4231
54 - Motor Home	$1.6615	$1.9640
61 - Combination - Short Haul	$0.8981	$1.0222
62 - Combination - Long Haul	$0.8382	$0.9318

The segments shaded in green already have CPM-Is that are lower than the ICE benchmark. Others are not yet at parity, but are close. The cap in CPM-I parity can be used to estimate when the "expanded feasibility" threshold might be attained.

4.1.2 Market Evolution Thresholds

Based on consideration of the market factors outlined above, and especially the more quantitative indicator associated with amortized CPM-I parity, the study team estimated when each threshold would be reached in time for each vehicle segment. The "anchors in time" allow the shape of each adoption curve to be established. At each threshold, a certain percentage of the consumer population becomes amendable to the PEV value proposition. During that phase, the percentage of customers in that cohort increases linearly to the adoption percentage associated with the next threshold. Moving the threshold anchors in time determines the shape of the adoption curve in terms of PEV percentage of new sales each year.

The following chart summarizes the dates estimated for each of the adoption thresholds, for each of the vehicle segments. Note: the timing of thresholds for LDV and NJ Transit were set to be aligned with the new EV Law. All the other segments were characterized using the criteria defined above.

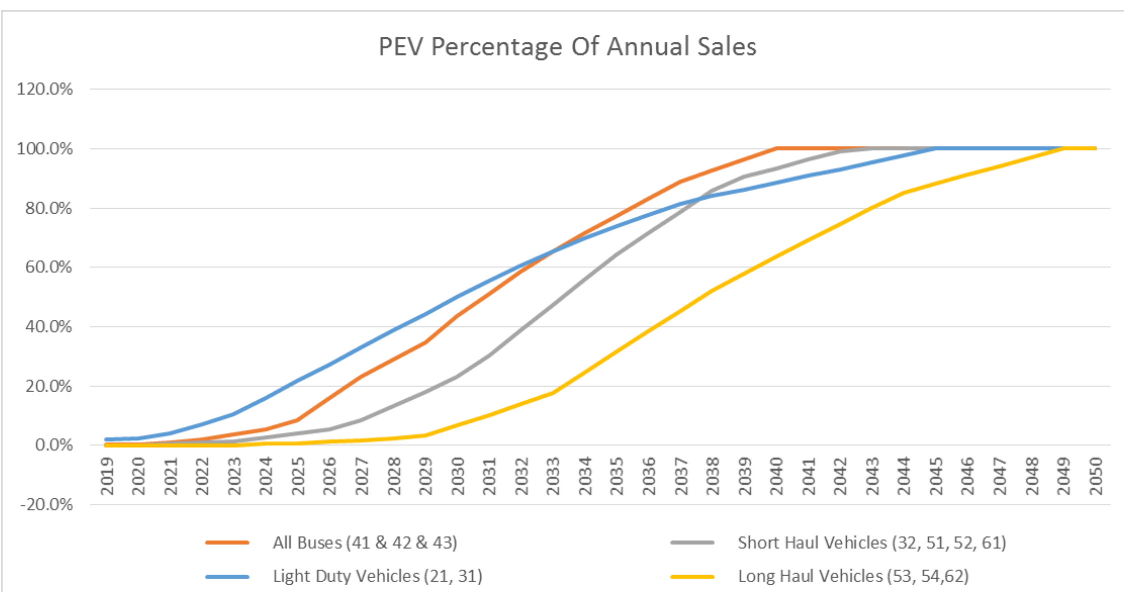
Figure 4.4: Dates For Each Adoption Threshold

	Limited Feasibility	Expanded Feasibility	Compelling	Widespread	Unavoidable	Saturation
% of sales when threshold is achieved	0.0%	2.5%	16.0%	50.0%	84.0%	100.0%
Source Type						
21 - Light Duty - Passenger Car (BEV)		2020	2024	2030	2038	2045
21 - Light Duty - Passenger Car (PHEV)		2021	2024	2030	2038	2045
31 - Light Duty - Truck (BEV)		2020	2024	2030	2038	2045
31 - Light Duty - Truck (PHEV)		2021	2024	2030	2038	2045
32 - Medium-Duty Commercial Truck (gas)		2026	2030	2034	2038	2042
32 - Medium-Duty Commercial Truck (diesel)		2027	2031	2035	2039	2043
41 & 42 - NJ Transit Buses		2021	2024	2026	2029	2032
41 & 42 - All Other Non-School Buses		2022	2025	2027	2030	2033
43 - School Bus		2025	2029	2033	2037	2040
51 - Refuse Truck		2021	2025	2029	2033	2037
52 - Single-Unit - Short Haul		2023	2027	2031	2035	2039
53 - Single-Unit - Long Haul		2024	2028	2032	2036	2040
54 - Motor Home		2027	2031	3035	2039	2043
61 - Combination - Short Haul		2026	2030	2034	2038	2042
62 - Combination - Long Haul		2029	2033	2038	2044	2049

4.1.3 The Vehicle Adoption Schedule

Based on the threshold "anchors in time" established for each vehicle class as summarized above, the shape of each adoption profile can be determined. This adoption curve is quantified at the percentage of new sales that are electrified, per year, in each vehicle class. The following chart summarizes the resulting adoption profiles for groups of vehicles with similar profiles.

Figure 4.5: Electrification Schedule (in similar-vehicle groups)



5 Vehicle Charging Infrastructure

Vehicle charging represents the connection between PEV use and the electricity system. The availability of vehicle charging is also an essential factor in the adoption of PEVs – if the right kind of charging infrastructure is not available, in the right places, in the right quantity, consumers simply won't make the PEV transition. The study therefore included a detailed investigation of vehicle charging needs in New Jersey, its costs, its impact on the grid, the interplay between charging infrastructure availability and adoption. This section explores the framework used to model infrastructure and its impacts on the electricity system. The needs of LDVs and MHDVs are considered separately.

Some of the following information represents general background about PEV charging, and is not really a finding of the study. But it is provided for purposes of completeness, and to represent the charging infrastructure context that informed development of the infrastructure modeling framework.

5.1 The Charging Ecosystem For Light-Duty Vehicles

LDV – predominantly for personal use – will be charged through an ecosystem that allows those vehicles to be charged in a variety of ways in a range of settings. Building on work from the original ChargEVC study in 2018, the study team has developed a detailed model of this ecosystem, considering differences in application settings, technology, power levels, use cases, operating profiles, and other factors.

There are two types of charging connectors on a modern EV: an Alternative Current (AC) plug which supports low and medium power charging, and a Direct Current (DC) connection for higher power charges. Almost all PEVs will have an AC connector, and many will also have a DC connector as well. Multiple charging technologies are therefore provided the charging ecosystem, offering different plug-standards and power levels to serve a broad range of vehicle needs:

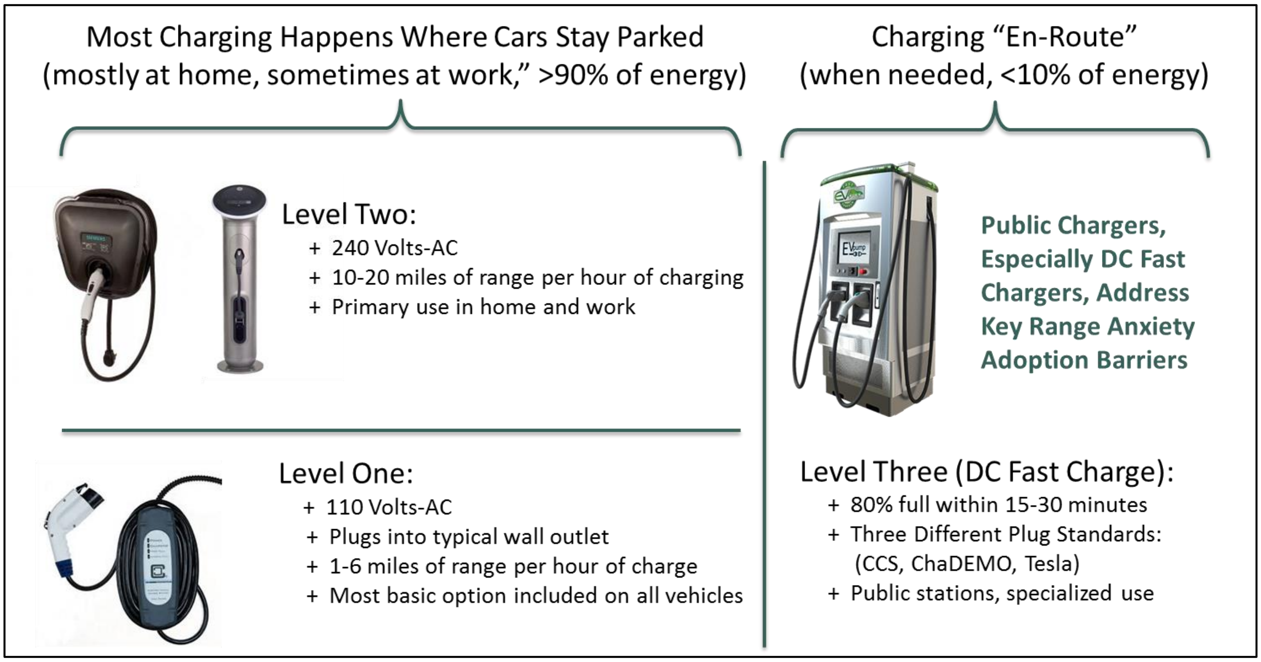
- **Level 1 (L1):** the lowest power "trickle chargers" that are powered through a typical 110V residential outlet. These chargers are suitable for PHEVs, or BEVs with more limited travel profiles. These chargers typically provide 1.4KW of charging AC charging power.

- **Level 2 (L2):** medium power chargers that are based on a 240V circuit (similar to an electric oven), and which are able to charge even the largest batteries from empty to full in 10-12 hours (usually overnight). These chargers are most common for longer range BEVs, and can deliver either 3.6 or 7.2 KW of AC charging power, but could support as high as nearly 20KW.

- **Direct Current Fast Charger (DCFC):** High power chargers that connect to the DC connector on the PEV. These chargers are sometimes called "Level 3 DC", and can deliver much higher power than the ACE chargers - with the range being from ~25KW to ~350KW. For vehicles that can accept higher power levels, an empty battery can be recharged to 80% of full in 15 - 30 minutes, and many recently announced announce PEVs are supporting higher DCFC charging power (100KWdc or above). Three different plug types are present in the market: The Combined Charging System standard (CCS), the "Charge de Move" (CHAdeMO) standard, and a specialized plug that can be used only by Tesla vehicles.

The following diagram illustrates the different charger types and their application.

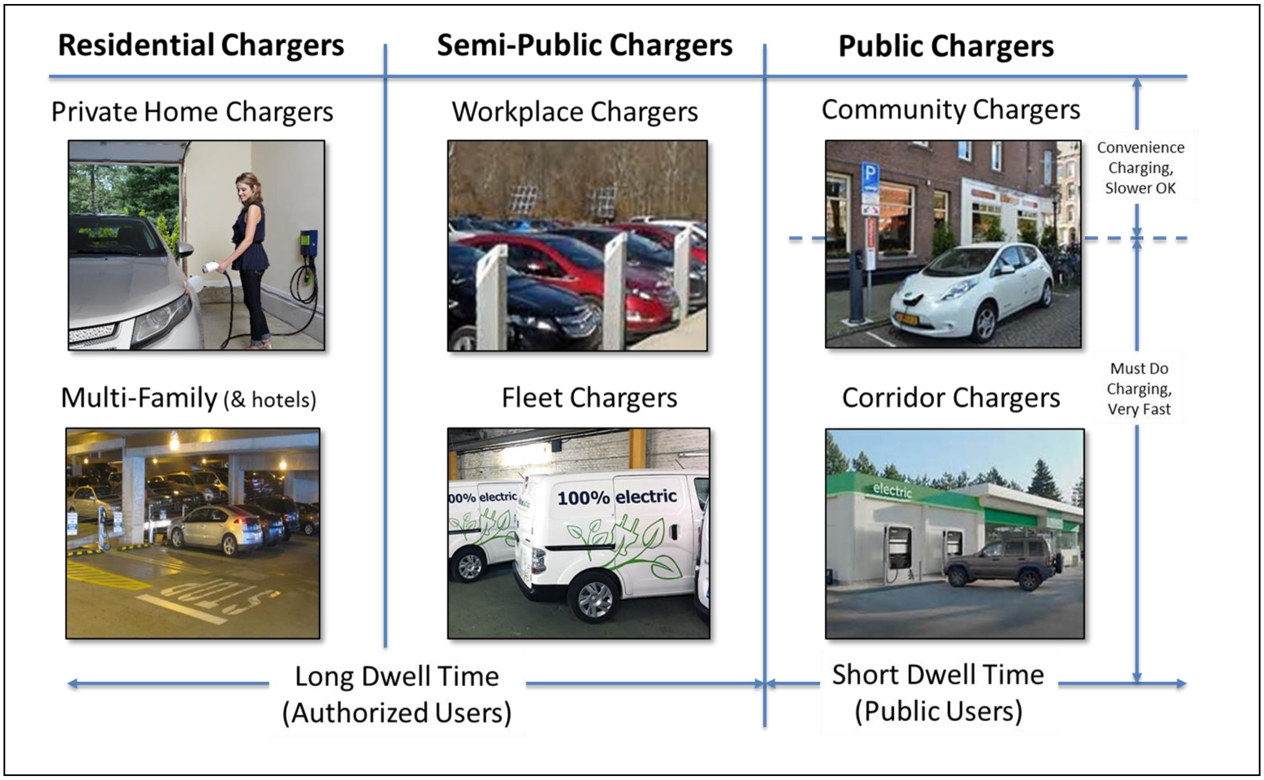
Figure 5.0: Different Types of Vehicle Chargers



A key characteristic of all chargers is the degree of network connectivity they support. Some chargers (mostly L1, but some L2 as well) are completely non-networked, and have no data connectivity other than with the PEV plugged into it. Other chargers allow for sophisticated network connectivity, with the vehicle operator (typically through a smart phone), and through a "charging network cloud". This connectivity allows the charger to report transaction (or session) data, support point-of-sale transactions (i.e. user authentication, credit card purchase, etc), and to accept instructions about when and how to charge. Many L2 chargers can be networked, and almost all DCFC chargers are networked. L2 chargers that support a robust networking interface are typically called "smart chargers".

In addition to consideration of power level, plug standard, and networking capability, chargers are deployed in a variety of settings based on which users they serve, use cases, and operating profiles. Key charging segments in this "charging ecosystem" framework are represented in the diagram below.

Figure 5.1: Vehicle Charging Ecosystem For LDV



The LDV charging ecosystem includes six segments organized into three groups (residential, semi-public, and public):

- **Residential: Private Chargers:** L1 and L2 chargers used at home, typically in free-standing (detached) home, or homes that dedicated parting area.

- **Residential Shared Chargers (multi-family):** L1, but more typically, networked L2 chargers, that are used in multi-family settings (apartments, condominiums, etc), either in shared lots, decks, or street-side parking. These chargers may be dedicated to a particular user, or shared among multiple residents. Chargers at overnight establishments (hotels, etc) are included in this segment since they have a very similar operating profile.

- **Workplace Chargers:** L1, but more commonly networked L2 chargers for use by employees while at work. These chargers serve a variety of roles in the ecosystem, including being the primary charging resource for some multi-family residents, but also serving as "back up" for employees that have chargers at home (forgot to charge overnight, need to handle an unplanned trip, etc). Workplace chargers have also been shown to significantly increase consumer awareness and adoption. Typically, these chargers are located on private commercial property, and only authorized users can make use of them.

- **Fleet Chargers:** Usually L2 chargers that provide the "routine charging" for commercial LDVs, usually at a commercial location. Typically these chargers are sited on private commercial property, and are often dedicated for use by authorized fleet vehicles only.

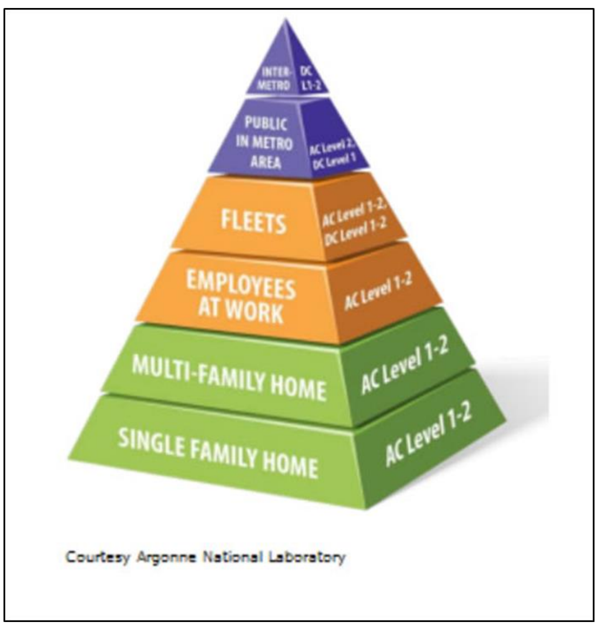
- **Corridor Public[e] Chargers:** High powered DCFC located along major travel corridors, serving the needs of long distance PEV drives, as well as the "must charge" needs of local drivers. The primary consideration for these applications is the shortest possible charge time, and higher powered chargers are becoming common in these settings.

- **Community Public Chargers:** Medium – to high powered chargers for public use, located near where people live and work. Both "public L2" and medium powered (25KW – 50KW) chargers are typical in these installations. These facilities are often located near retail or entertainment sites so that PEV drivers can combine with vehicle charging with other activities (e.g. shopping).

Please see Appendix E for more details on this LDV charging ecosystem framework.

A key characteristic of LDV charging is that *most* drivers will leave home (or their fleet home-base) with a "full charge" on *most* days. People will charge their PEVs the same way their charge their cell phones, and most charging will begin at the end of the workday and be complete in time for daily travel the following morning. This means that the majority of the electricity used for vehicle charging (70% - 80%) will be delivered through those routine home-base chargers. The following diagram illustrates the relative fraction of electricity delivered through chargers of different types.

Figure 5.2: Relative Electricity Consumption In Different Charging Segments (for LDVs)



[e] The term "public" in this case means "for public use", not a reference to a "public entity" like a municipality.

A recent study in Maryland[9] quantified what the natural load profile looks like across several of these key charging segments. As expected, the majority of electricity is delivered at home, typically during peak times (for the *natural* charging case, see below).

Figure 5.3: Natural Charging In Different LDV Charging Segments

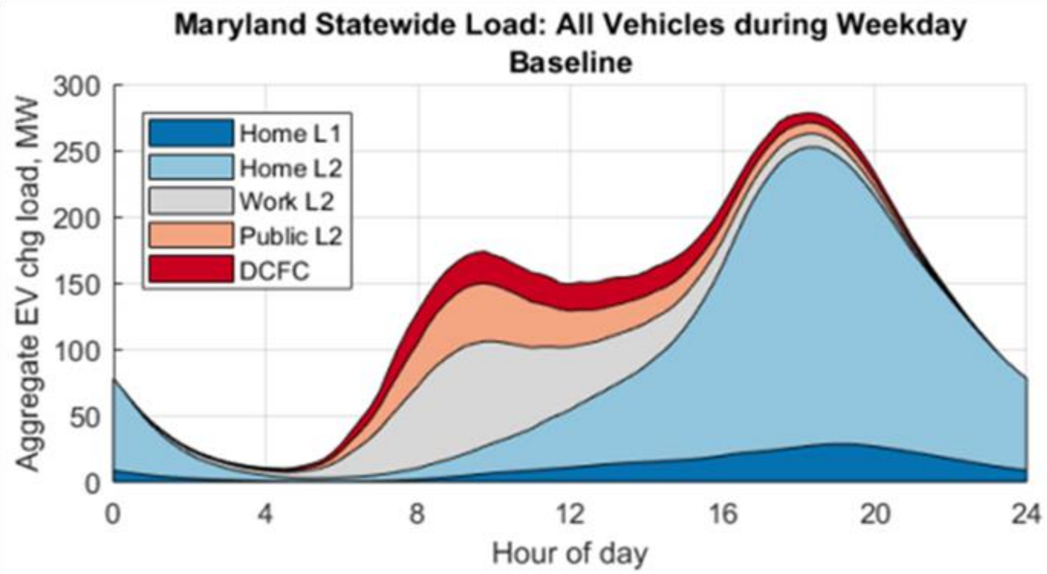


Figure 14. Aggregate statewide load profiles for a weekday, baseline

The NJ study model allocates the fraction of LDV charging electricity required in each of the six segments defined in the ecosystem, with separate time-of-day profiles for each segment, covering both "natural" and "managed" charging scenarios. Natural charging represents the timing that PEV drivers exhibit when there are no incentives in place to encourage a change in charging behavior.

For residential charging (where most charging electricity is delivered), this profile has some baseline charging throughout the day, but most of it takes place in the few hours when most PEV drivers get home from work and "plug in" for an overnight charge. As illustrated in the figure above, the peak of natural residential charging coincides with peak loading on the public grid (typically around hour-18).

The potential impact of residential charging on the public grid is profound: at high levels of penetration, as many as six million vehicles will be "charging at home", many at peak times. This could add several GWs of additional load at a time when the grid is already at peak load. Fortunately, unlike most electric loads, *when* vehicles charge at home is relatively flexible – charging can happen in any way overnight as long as the charge transaction completes before the workday begins the following morning. It is therefore worthwhile to think of residential EV charging as a "dispatchable load" that can be shifted not only to avoid additional peak impact, but also to distribute load so as to optimize grid utilization overall. Residential charging therefore represents a significant risk to the public grid through significant additional load, but if proactive steps are taken, an unprecedented opportunity to achieve more optimized loading on the grid overall. The subject of "managed charging" is about influencing when residential charging happens to mitigate grid impact, as described in Section 5.2 below.

The impacts on the grid vary significantly depending on whether natural or managed charging becomes dominant in the residential sector. If natural charging emerges, that will likely increase capacity and transmission costs, induce the use of more expensive generation, and potentially (longer term) for significant grid reinforcement. By contrast, if managed charging becomes dominant than those additional costs can be avoided, grid reinforcement may be deferred or eliminated (or reduced in scope), and the use of PEV charging as a "dispatchable load" can be used to create more optimal loading on the grid overall, with benefits for all ratepayers. The study models both the natural and managed charging scenarios for all net-benefit calculations, which quantifies the differences in grid impact from each case. Note that these scenarios represent "boundary condition cases", either cases of "mostly natural charging" or "mostly managed charging". Real-world results are likely to be between these two extremes based on the degree of use and efficacy of managed charging solutions.

5.2 Residential Managed Charging

Residential managed charging is a strategic opportunity to mitigate potential grid impacts from vehicle charging short term, and to make EVs an "interactive" distributed-energy-resource (DER) longer term. As the nomenclature introduced above implies, managed charging does not happen on its own – it has to be created, promoted, and incentivized. Otherwise, PEV drivers will default to their "natural" charging behavior. At its heart, managed charging is a solution that modified natural consumer charging behavior proactively, with the goal of "flattening the curve" of charging impact on the grid.

As conceptualized in this study, managed charging is an umbrella term that captures a full spectrum of solutions ranging from very simple (and only modestly impactful) to very sophisticated. Across all these solutions, managed charging always includes a *technology component* and a behavior modifying *incentive component*. The incentive component is often conceptualized as an issue of "rate design", but there re multiple ways to deliver an incentive that modifies customer behavior. In most cases, offering one without the other will minimize the beneficial impact the solution could otherwise have. For example, deploying incentives for residential chargers, without coupling them with participation in an "off peak charging" incentive of some type, will have little value as a grid impact mitigation strategy. Similarly, deploying economic incentives to encourage off-peak charging will be either more difficult, and/or less impactful than if coupled with an appropriate networked charging component.

These components can be deployed in various combination, with a range of sophistication from simple to complex. At a high level, the study team expects that the industry will evolve from more simple solutions shorter term, evolving to more sophisticated solutions longer term. But a key element in this transition is the "Smart Charger" – a networked L2 charger that a) meets the at-home charging needs for most customers (even those with larger BEV batteries), and b) provides the networking functionality needed to enable and deliver a managed charging solutions. Most Smart Chargers are capable of supporting basic functions now, but can also support more advanced solutions later as the "charging cloud" matures.

The residential managed charging framework used in this study covers the following range of permutations (from simple to complex):

- **Voluntary Charge Scheduling:** A basic, typically non-networked charger, coupled with a simple time-of-use incentive for off-peak charging. These configurations usually require a whole-house tariff (of which vehicle charging is a part), or a dedicated second meter for the EV charger with a special tariff for that use. The EV owner needs to determine how to charge their vehicle so as to realize benefit under this structure, usually by using the "charge programming" capabilities of the PEV itself.

- **Passive Smart Charging:** A networked charger, or functionally equivalent connector interface device, combined with an economic incentive. In this case, the charger can provide the charge transaction data (i.e. the "metering function" for EV charging) to be used as the basis for delivering the incentive. This approach eliminates the need for a second meter, and introduces a much more robust data exchange as part of EV charge management (either with the PEV drivers, the utility, or other third parties through a "charging network" cloud)[f]. Typically, the EV owners has the freedom to charge whenever they want, but they realize economic benefit from charging during preferred (usually off-peak) times. As with the Voluntary Charge Scheduling scenario described above, the EV owner needs to determine how to charge their vehicle so as to realize benefit under this structure, either by using charge scheduling features of the PEV or typically web-based scheduling features enabled by the networked charger.

- **Active Smart Charging:** Physically similar to the Passive Smart Charging program defined above, except that the "charging cloud" provides coordination signals that influence when charging happens. These signals could dynamically set "preferred charging windows", allocate a preferred charging start time to the charger, or recommend a preferred charging power. The combination of these signals can be used to a) minimize the local grid impact (down to the transformer), and to c) create a desired "load profile" at the aggregate level (feeder, substation, and above). Under this program, users would "opt in" to the managed charging program, perhaps set a default charging schedule, but otherwise allow charging to take place as coordinated by signaling from the charging network cloud. This solution makes EV charging more adaptive and allows EV charging scheduling to reflect real time conditions. This smart charging platform must be combined with a properly structured economic incentive that rewards EV drives participation.

[f] As an example, the PSC in Maryland has approved the use of certain networked chargers to use "embedded metrology" as the basis for rating EV-charge usage and determining incentive delivery. This approach allows the charger to "serve as its own meter", and enables a new EV-specific data stream for the utility.

- **Active Smart Charging,** With Demand Response: This solution can either be a simplified version of the "Active Smart Charging" solution described above (i.e. one which only responds to demand reduction signals), or one which also responds to demand response signals in addition to charge coordination signaling. In addition to more generic value of charge coordination that happens daily, this functionality makes PEVs "demand response" resources that can be signaled to curtail charging at times of peak grid loading. As with all solutions presented here, a demand response solution needs to include an economic incentive to encourage the desired customer participation.

- **Grid Interactive Charging:** this solution takes the Smart Charging platform one step further and allows electricity to flow in both directions. All the configurations defined above are based on electricity flowing one way – from the grid into the vehicle. Vehicle-to-Grid (V2Grid) chargers are now being developed that would allow the charge transaction to be bi-directional – traditional charging from the grid to the PEV battery, *and* the reverse where electricity stored in the battery flows back onto the grid. In this scenario, the BEV becomes a fully-formed distributed energy resource (DER) that can be used to reduce local or aggregate loading conditions.

- **Resiliency Functionality:** There is a special case of the "grid interactive charging" solution described above, which is allowing the home to operate in "island mode" with the PEV battery being used as a source of AC electricity to power the home. Once this capability becomes widespread, every home with a PEV now has the ability to run independently for a period of time (usually several days) when the public grid. In this way, widespread PEV adoption could significantly increase resiliency at the residential level by using the PEV as a personal back-up supply option.

It is important to note that the functions defined above can be provided by a variety of market participants. The charge coordination intelligence could exist in a variety of entities (third party network operator, electricity utilities, etc), and various approaches are being tried in the market. In most cases, however, the key attributes of an advanced managed charging solution is an offering that tightly-couples a smart charger with an economic incentive that encourages participation in the program and modification of the natural charging behavior.

The economic incentive provided to modify customer behavior may evolve over time. Many utilities, for example, begin with simple time-of-use tariffs that reward off-peak charging and/or punish on-peak charging. Even in the "voluntary" or "passive" cases, in the early stages of market development when adoption is still modest, those approaches are effective and valuable. At higher levels of adoption, the more advanced program become preferable because the need is to a) defer the start of charging until an off-peak time *and* b) spread that charge out over as many hours as possible. The duration of an average residential charge is about 2 hours, yet those vehicles typically stay plugged in (at home) 8-10 hours. A simple time-of-use tariff general just moves the typical charging start from the natural time to whenever the off-peak window opens. A more active managed charging program defers the charging start and spreads it out over an extended interval which has greater mitigation value.

As noted above, the study model considers both natural and managed charging for the residential segments. The model is relatively agnostic on exactly how managed charging is delivered, but as noted above, a) the market may evolve from simple charging solutions short term, to more advanced solutions longer term (as the charging cloud matures), and b) many networked chargers can be used in various modes, from simple to complex. There is merit to being proactive in encouraging the use of networked chargers that can deliver the spectrum of functionality outlined above.

The study quantified the potential impact of natural residential charging, and the significant mitigating impact that managed charging (when fully deployed) can have. This load mitigation effect avoids increased capacity and transmission costs, and reduces, defers, or avoids potential grid reinforcement costs longer term. These impacts emerge relatively soon in the adoption schedule, and become more significant at higher levels of electrification. In 2035, the LDV private residential charging load is 1.2GW under natural charging (at hr18), but that load is reduced to 120MW with high levels of managed charging. But 2050, the residential EV charging load (at hr 18) increases to 2.8GW in the natural case, but only 281MWs in the managed charging case. These differences in load impact have significant implications for the grid – but the prospect of managed charging, if pursued as a strategic priority pro-actively, represents an opportunity to avoid the resulting costs for all rate payers.

This section focused on *residential* managed charging, but there are similar opportunities associated with how PEVs connected to a commercial building (as part of workplace or fleet charger use) could be used to reduce building load (as seen by the grid). That technology may become more critical as the fraction of solar in the supply mix increases, and peak-solar-generation power can be absorbed by workplace and fleet connected PEVs.

5.3 Public Charging For Light-Duty Vehicles

For LDV owners especially (and some MHDV owners too), "range anxiety" is a primary barrier to adoption. An Eagleton poll[10] of NJ residents in 2019 found that concerns about "running out of charge while on the road" was the top concern for mainstream vehicle buyers – 56% of respondents noted it as a major concern, while another 17% listed it as a minor concern. Now that relatively long range BEVs (i.e. range over 200 miles on a single charge, far more than most people drive in a single day) are readily available, the issue is really consumer concerns about the lack of public charging. The barrier in the current market is therefore more about "charge anxiety", and increasing the availability of public fast charging is a primary strategy for addressing this dominant consumer barrier.

The study team explored the topic of public fast charging in depth, especially given the goals recently established in the NJ PEV Law[11]. Quantification of public fast charging needs was needed to allow estimates of the cost of that infrastructure as part of the net benefit determination, but also because it is tightly coupled with adoption.

5.3.1 Current State of Public Charging in New Jersey

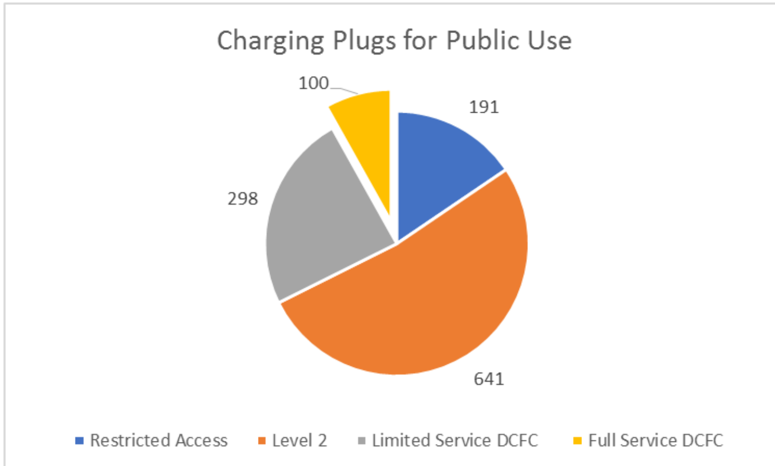
Public fast chargers are developed are developed by a variety of private entities in the market today, including dedicated "charging network operators" that develop, own, and operate public fast charging facilities on a for-profit basis.

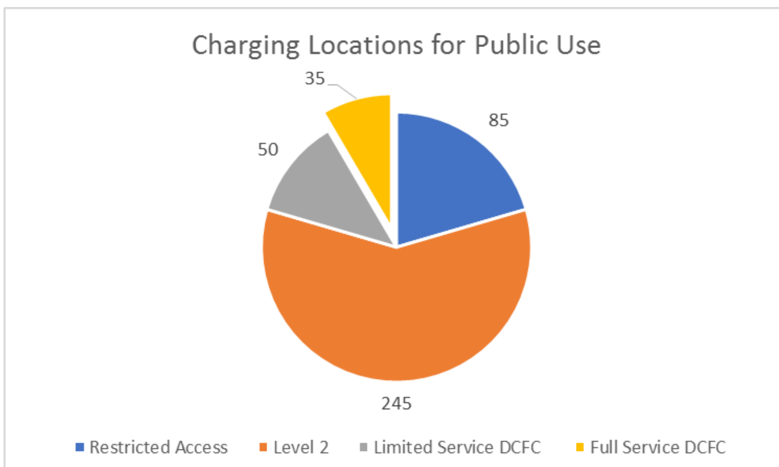
These public chargers are inventoried in a database maintained by the US DOE through the National Renewable Energy Laboratory (NREL), called the Alternative Fuels Data Center (AFDC). As of the beginning of September, the AFDC documented a total of 1,230 plugs ats 415 locations. After scrubbing this data to eliminate duplicates or other data issues, and extracting only those that are fully available for public use, the public charging count stands at 591 L2 plugs at 245 L2-only locations, and 398 DCFC plugs at 85 locations (which also include an additional 50 L2 plugs at 18 of those locations). A large fraction of these DCFC facilities can only by used by Tesla vehicles, and don't help address the charge-anxiety concerns of prospective non-Tesla customers. Focusing on the fraction of the DCFC market that can serve all vehicles (including Teslas), there are 129 CCS or CHAdeMO plugs at 56 locations, but only 35 locations (and 100 plugs) in the state offer both. This level of public charging represents significant growth over the last few years, but has not yet assuaged consumer concerns about charge anxiety (i.e. it is still cited as a primary adoption barrier by many prospective buyers).

When considering range anxiety (or charge anxiety), the market is moving toward a preference for public fast charging. While public L2 still has a role in many scenarios – wherever the vehicle has a long dwell time – for mainstream consumers where convenience is a priority, fast charging offers significant advantage. Whether for long distance drivers or for local drivers that need a "top off" to get home, quick charging (through a higher powered DCFC charger) is the preferred solution. Many of the leading PEV-adoption markets are focusing on build out of public fast charging as a way to eliminate the range anxiety (or charge anxiety) barrier.

The following two pie charts summarize the segmentation of the AFDC data for New Jersey (as of Sept 1, 2020). The yellow sections represent "full service" locations that can provide fast charging services for all vehicles on the road.

Figure 5.4: Public Charging In New Jersey (as of Sept 1, 2020)





The NJ DEP is responsible for tracking deployment of public fast charging as specified in the NJ EV Law, including determination of which locations are compliant with technical requirements established in the legislation.

5.3.2 Public Fast Charging Planning Framework

A key question in both long term electrification cost planning and also barriers to adoption (related to range anxiety), a key question is "how much public charging is needed" over time? When considering this question for public fast charging, there are two very distinct aspects to consider:

- **Geographic Distribution:** how widely distributed public fast chargers are deployed. There may be a concentration of charging location in high travel density areas, but then limited (or non-existent) availability in more remote locations – i.e. "charging deserts". Consumer perceptions about "charge anxiety" are very sensitive to not just the number of chargers, but how widely available charging locations are along their daily travel route. In short, consumers need to see enough locations that they are comfortable that they won't have trouble getting a charge conveniently when needed. This factor is more concerned with the number of locations, not just the number of chargers.

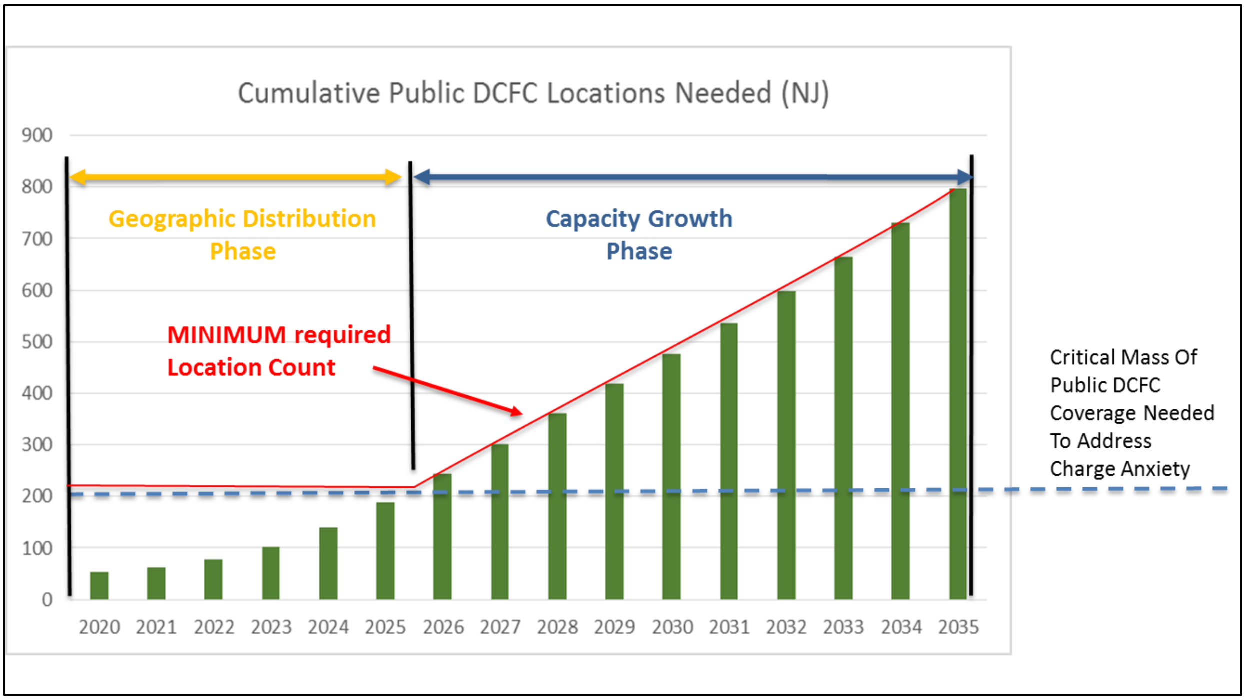
- **Charging Capacity Requirements:** The number of chargers needed to serve the required number of public DCFC charging sessions required per day, which scales with the number of BEVs on the road. This factor is derived from traffic engineering analysis and consideration of congestion timing, and is focused on the number of plugs, regardless of the number of locations (roughly).

Projecting long term public charging need is not just a question of how many, but also of where. To illustrate that distinction, consider the following thought-experiment: if there were 1000 BEVs on the road, there would need to be between two and five DCFC plugs available to serve the necessary charging sessions (depending on capacity and congestion factors used). That number of plugs would be sufficient to fully serve the vehicle population with all the public fast charging sessions required. But even if those five plugs were distributed at individual locations across the state, most mainstream consumers would agree that five locations does not provide the needed geographic coverage to address their range anxiety (or charge anxiety) concerns. With only five charging locations in the state, few mainstream consumers would adopt, even though those locations provided enough charging capacity. When the goal is eliminating consumer charging concerns, both geographic distribution and capacity need to be considered separately.

Given that reality, the study team adopted a two phase planning framework, based on recognizing that the public DCFC market will go through two phases of development: a first phase focused on attaining the geographic distribution needed to address range anxiety concerns, and then once that threshold is attained, a second phase during which additional capacity is added as dictated by additional demand (i.e. more BEVs on the road). The first phase is focused on how a critical mass of locations is geographically dispersed, while the second phase is based on keeping charging supply in step with increasing demand. The first phase is policy driven, based on the market development goal of reducing range anxiety as early in the schedule as possible to accelerate LDV electrification.

The following figure this two-phase approach to planning for public DCFC development goals. The first phase is policy driven- focused on attaining the geographic distribution desired. The second phase starts after that geographic distribution threshold is attained, and tracks with additional BEV adoption and the associated increases in charging demand. The green bars represent the number of DCFC locations needed to support the required capacity, while the dotted blue horizontal line represents the critical bass of locations associated with the desired level of geographic dispersion (assumed to be 200 locations for this example, see further discussion below). The red line represents the desired number of public charging locations – driven by the critical mass requirement in phase one, and transitioning to track the capacity requirement in phase two.

Figure 5.5: Public Charging In New Jersey (as of Sept 1, 2020)



The recent PEV Law enshrined this approach to public DCFC planning in the following ways:

1. Distinguishing between CORRIDOR and COMMUNITY chargers, consistent with the definitions provided in introduction to Section 5.1.

2. Establishes goals for each of these segments:
   - At least 200 public DCFC locations total by 2025
   - Of 200 total required, at least 75 Corridor locations, along major travel arteries (as defined by the DEP), with no more than 25 miles between these locations
   - The Corridor locations must be within 1 mile of the major road they serve, and include at least two chargers supporting at least 150KW, supporting CCS and CHAdeMO plugs
   - Of the 200 total required, at least 100 Community locations, supporting at least 50KW (higher preferred), also supporting at least two chargers per location with CCS and CHAdeMO plugs

3. It is important to note that these goals are intended to represent the crucial mass needed to eliminate consumer concerns about range anxiety, and that once this capacity is installed, installation growth would continue as driven by additional demand, resulting in either additional locations, or additional chargers at existing locations.

4. The DEP has identified the forty-two federal and state roads that count as major travel arteries (for corridor chargers), and identified the need for 118 locations to satisfy the 25 mile

requirement[12]. This is not inconsistent with the goals summarized above, since the requirement in law as *at least* 75 corridor locations, with an implication that at least 100 would be desired to meet the 200 charger total.

The study team adopted this two-phase approach to setting the goals for public DCFC development in New Jersey, and used the 200-location goal in the EV law as the target for the critical mass necessary to address range anxiety concerns. It is worth noting that the infrastructure model (see below) estimates the need for 189 locations (both corridor and community) by 2025 to support the goal of 330K PEVs – very close to the 200 location goal established in law. So the development curve rationalizes with the goals in law – building out 200 locations creates a critical mass of locations short term (through 2025), but is well aligned with the number of locations that will be needed (from a capacity perspective) at that point in time. This approach is reinforced by the fact that many consumers will want to see the charging locations available *before* they would seriously consider PEV adoption, and so public charging location development (for the phase one critical mass) should lead the desired vehicle adoption requirement.

Since the law specifies specific requirements as to what counts as a "corridor" or "community" location, the DEP periodically publishes maps that document attainment of those goals. As of the publication of this study, there are six compliant corridor locations. An attainment map for community locations has not yet been published.

To help inform continued development of the market, with a focus on whether the required number of locations *per road* is being attained, ChargEVC has developed the following attainment map. This map focuses on corridor locations, the goal of 118 locations allocated per DEP-identified travel corridor road, and the 25-mile separation goal. The attainment map was created using the following rules:

1) Each compliant DCFC location is aligned with a single "served road".

2) For any road that has NO compliant DCFC location, the whole length is colored red.

3) For any PLANNED charger location, the "served road" is colored yellow for 12.5 miles in either direction of the charger, in cases where traffic in both directions can access the charger.

4) For any EXISTING charger location, the "served road" is colored green for 12.5 miles in either direction of the charger, in cases where traffic in both directions can access the charger.

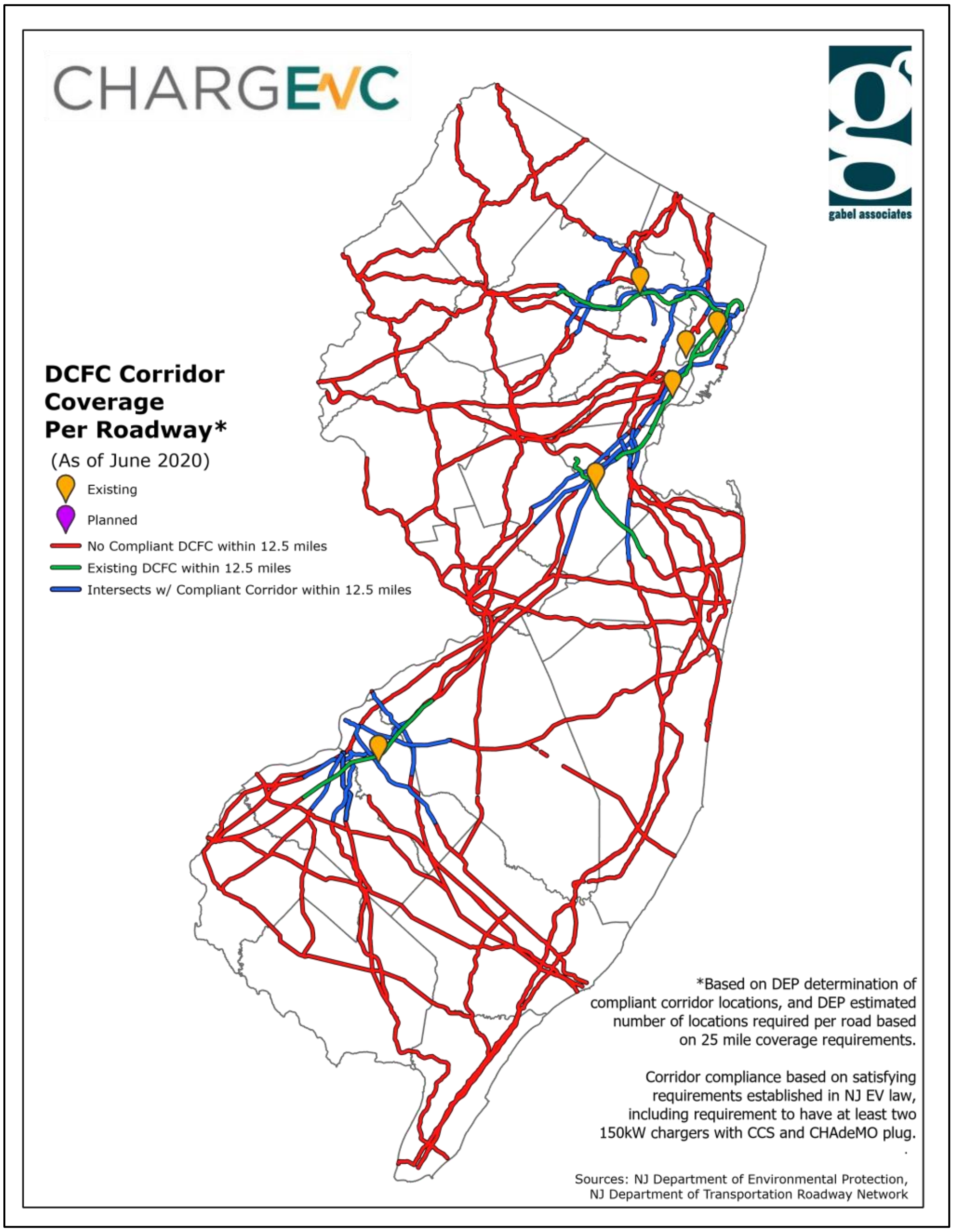
5) For any roads that intersect with a "served road", and which are within 12.5 miles of a compliant location (either PLANNED or EXISTING), the intersecting road is colored blue for X miles in either direction of the intersection, where X = 12.5 minus the distance of the intersection to the charger location.

6) Colors are layered in the following order: red, purple, yellow, green (with red on the bottom, green on the top).

This analysis is performed only for the corridor roads, and for corridor-compliant locations (as defined in law), since the intention of this map is to visually represent progress towards compliance with the corridor guidelines in law. The map don't show impacts on non-corridor roads, or the implications of nearby non-corridor chargers on non-corridor roads that may intersect with a corridor road in question.

Given this methodology, this map will visually track with program toward attainment of 118 well distributed DCFC charger locations. On the day that the all 118 locations are in service, *and* the 25 mile separation condition is satisfied, the map would turn all green.

Figure 5.6: A "Road-By-Road" View Of Goal Attainment For Corridor Locations in New Jersey



5.4 Charging For Medium and Heavy-Duty Vehicles

Just as there is a full ecosystem of charging infrastructure to serve LDVs, there is a similar (but different) ecosystem of charging infrastructure required for MHDVs. The MHDV environment is much more complex, however, due to the broader range of charging power required, and the extreme diversity of operating profiles and use cases. There is no single answer to the question "What kinds of chargers are needed for the MHDV segment?" Other studies have explored MHDV charging requirements in detail, and that information was used to inform the modeling of the MHDV segments in the study[13] [14] [15]. Substantial input has been provided by ChargEVC members that helped develop the MDHV charging infrastructure assumptions for this study.

The charging for some MHDVs resemble the technology and operating profile of an LDV fleet. For example, a medium-duty truck with a relatively short range duty cycle that can charge in the depot overnight for deliveries during the day. Other MHDVs, such as Class 8 tractors in long-haul applications, require very high power charging at specialized "on the road" locations (such as truck stops) in addition to specialized depot charging facilities. Some vehicles – like buses with certain route characteristics or some drayage vehicles may require charging overnight *and* multiple high-power charging cycles during the day. Fire trucks charge differently than school buses, which are different than dump trucks, transit buses, and tow trucks. After assessing a wide array of use case and operating profiles for the MHDV segments, and to make statewide infrastructure modeling manageable for the scope of this study, the following simplifying assumptions were made:

1. All MHDVs are assumed to have a "depot-style" home base that they return to frequently.

2. All MHD vehicles can charge at this depot during an off-duty period, and this charging cycle can provide at a substantial part of charging needed in some (but not all) vehicle classes. A fraction of this depot infrastructure can be lower powered AC charging (50KW or less) consistent with longer duration charge opportunities during the off-duty period.

3. Some vehicle classes will require additional "as needed" charging during the day, away from the depot, but they can use standards-based high power DCFC being developed for LDVs (150 – 350KW DCFC).

4. These higher powered public DCFC are highly valuable because they provide "dual service" to both LDV and MHDV segments.

5. Some MHDV classes will require very high power charging both at the depot (such as for longer range buses), and very high power charging en-route (especially for long haul vehicles). Other MHDV classes will require high power charging sessions during the daily use patter, but located at the depot (some buses and drayage trucks are a good example). Specialized infrastructure development will be needed to support these vehicle classes, both to enable electrification in those segments (i.e. without the charging infrastructure, the vehicles can't electrify), and b) to mitigate the impact of that infrastructure on the grid (or grid reinforcement where needed).

6. There can be substantial sharing of charging infrastructure in some vehicle classes, while others will require dedicated charging infrastructure per vehicle.

7. The scheduling of most LDV charging is somewhat flexible, but MHDV charging can be more constrained in many cases due to fixed commercial use patterns. At the same time, the travel patterns of many fleet vehicles are highly predicable, which make charge planning more feasible.

Under this simplified model, estimating the charging infrastructure requirements reduces to a) projecting the off-duty depot-charging needs for each vehicle class, which will provide much of the charging needed for some vehicle classes, and most of the charging needed for other vehicle classes, b) assuming some reuse of high power DCFC also used by LDVs for en-route charging (150 – 350KW chargers) in some vehicle classes (like local delivery vehicles), and c) characterizing the specialized very high power chargers needed for certain vehicle classes (especially long haul, at truck-stop style facilities). Focus in this study was on "en route" high power fast charging, not specialized very high powered DCFC charging at depots. The characteristics of these needs were captured as a market-wide average, recognizing that actual charging installed could be lower-power or higher-power than the average. Please see the methodology details in Appendix D for details about the MHDV charging infrastructure requirements, including assumptions related to time-of-day charging distribution per vehicle class.

5.5 A Charging Infrastructure Plan For New Jersey

The need to construct significant new charging infrastructure, and the cost of that infrastructure, is a critical element of determining the costs of overall vehicle electrification. The study included development of a detailed model that predicts the amount of charging infrastructure needed as a function of PEV sales. The model projects the infrastructure needed in all six LDV charging ecosystem segments, and the depot and "en route" infrastructure needed for MHDVs.

5.5.1 Charging Infrastructure Modeling Framework and Nomenclature

The nomenclature associated with charging infrastructure is diverse and inconsistent, and some parts of the industry use the same word to mean different things. For clarity, the infrastructure model used in this study is based on the following framework and nomenclature:

1. A **location** is a physical place where charging takes place. The location includes space for the chargers, parking spaces for vehicles while they charge, lighting, signage, and ideally access to nearby amenities. For public charging, the number of locations is a critical factor in achieving a critical mass of geographic distribution to address consumer range anxiety (or charge anxiety) concerns.

2. A **charger** is the physical device that delivers the charging service, frequently referred to as Electric Vehicle Service Equipment (EVSE). There are often multiple chargers per location.

3. A **port** is the connector that physically interfaces with the PEV to deliver the charging services. A port is synonymous with a "plug". There are often multiple ports per charger – for example, a particular charger/EVSE may have two cables – one for CCS and one for CHAdeMO. In the infrastructure model of this study, only independently operable ports are counted – for example, if a charger has two cables, but only one can be used at a time, is counted as a single port.

4. The infrastructure model translates the new PEV sales each year into the number of new ports needed to deliver the required charging services across the ecosystem. The projection of ports is translated into the required number of chargers. In the case of public DCFC, the required number of chargers is also translated into a projection of the number of locations.

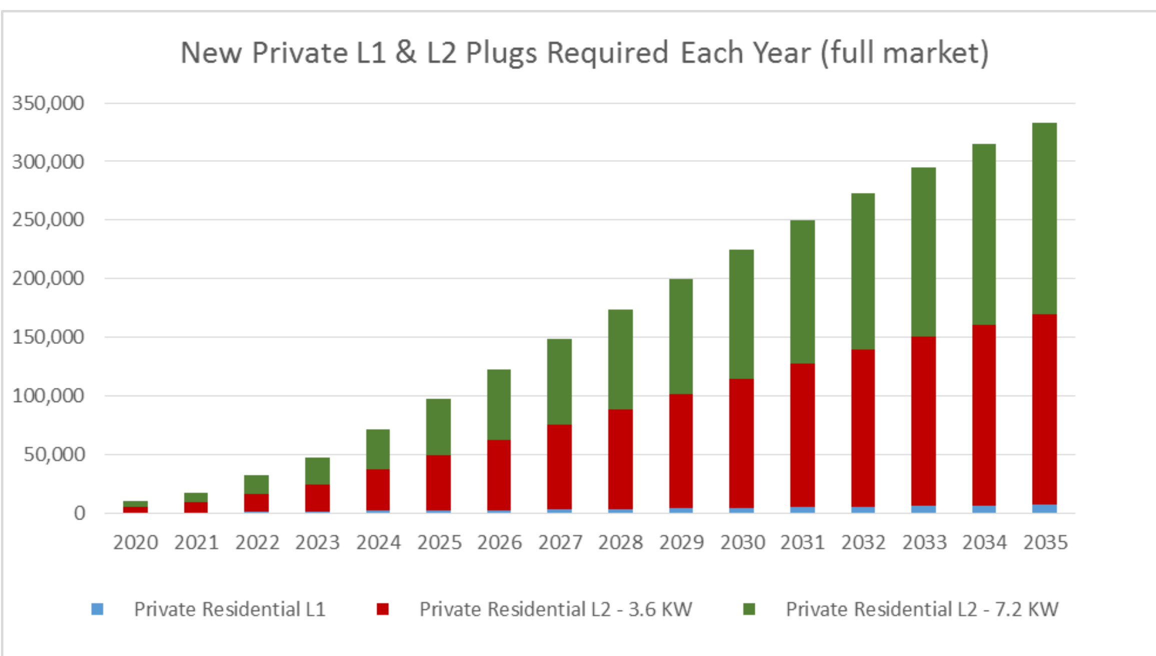
5. Please see the methodology detailed in Appendix D for assumptions associated with the infrastructure model.

5.5.2 LDV Charging Infrastructure Requirements

The infrastructure model estimates the number of chargers, ports, and (for public chargers) the number of locations required to support the growing number of PEVs represented in the electrification schedule. For clarity, the following charts summarize the infrastructure requirements through 2035, but the model makes estimates through 2050.

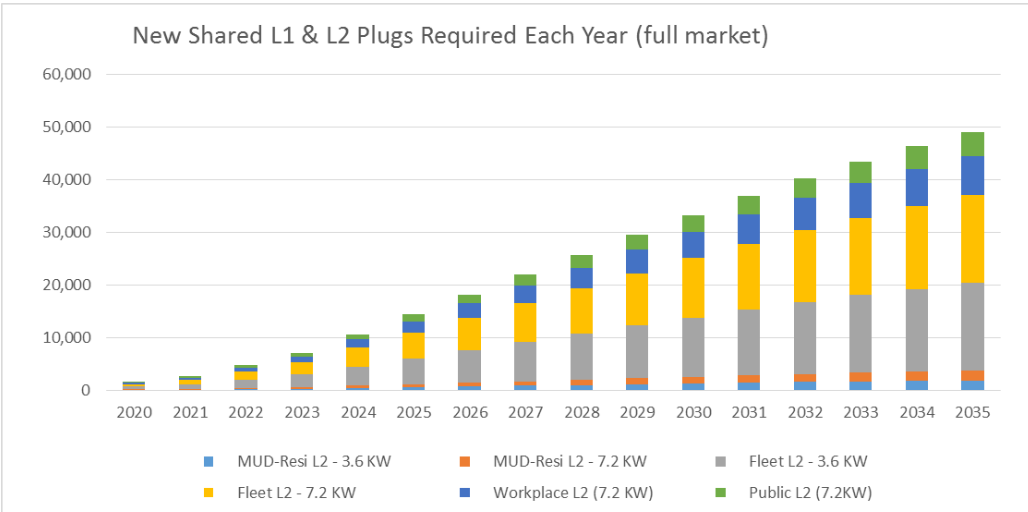
The number of plugs required in the private residential sector are summarized in the following graph, showing L1, low power L2 (3.6KW), and high power L2 (7.2 KW).

Figure 5.7: Private Residential Charging Infrastructure



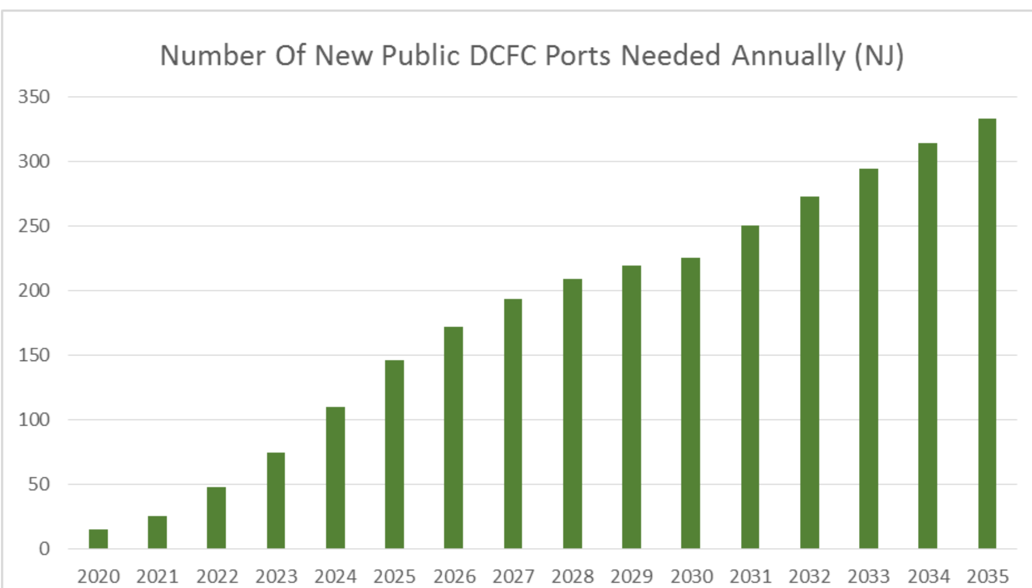
The number of shared plugs in the multi-family, workplace, fleet, and public L2 sectors are summarized in the following graph. In the case of fleet, this represent LDV requirements (see section below for MHDV).

Figure 5.8: Shared L2 Charging Infrastructure



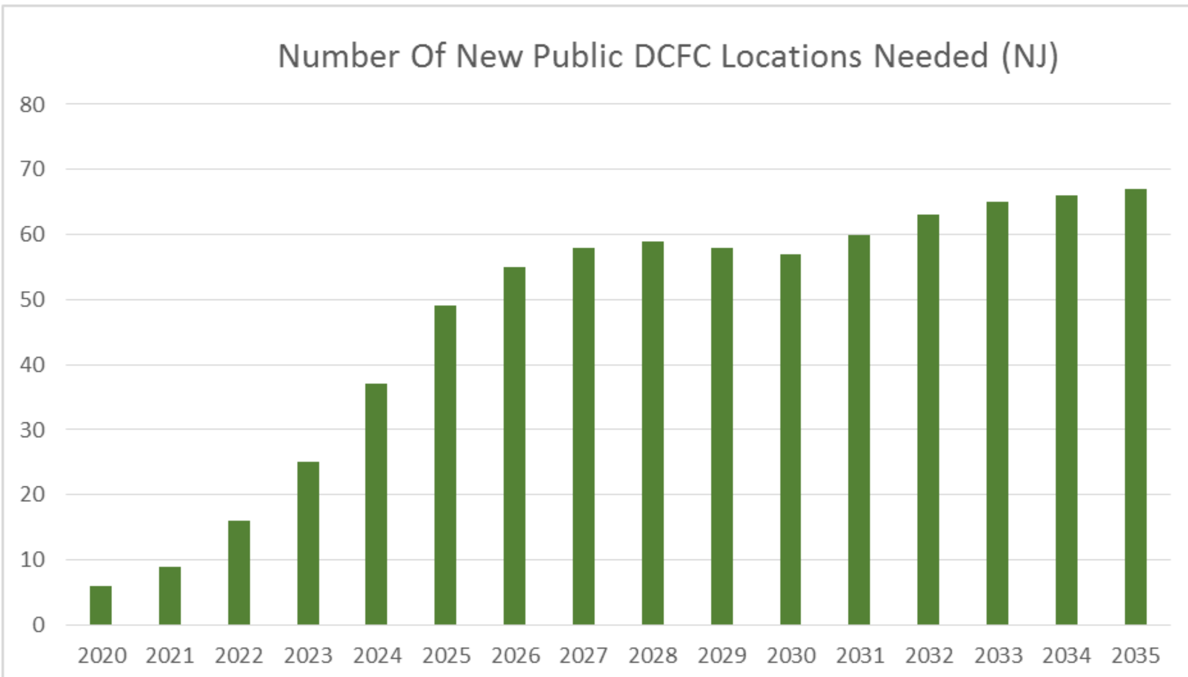
The number of public DCFC ports required to support the LDV electrification schedule.

Figure 5.9: Shared L2 Charging Infrastructure



The number of new DCFC locations required each year is summarized in the graph below. As discussed in Section 3.5.2, this graph represents the locations needed based on the number of charging transactions that must be served each day, as driven by the number of BEVs on the road. In the early years, through 2025, there is a legislative goal to develop a critical mass of at least 200 compliant DCFC locations for LDV use.

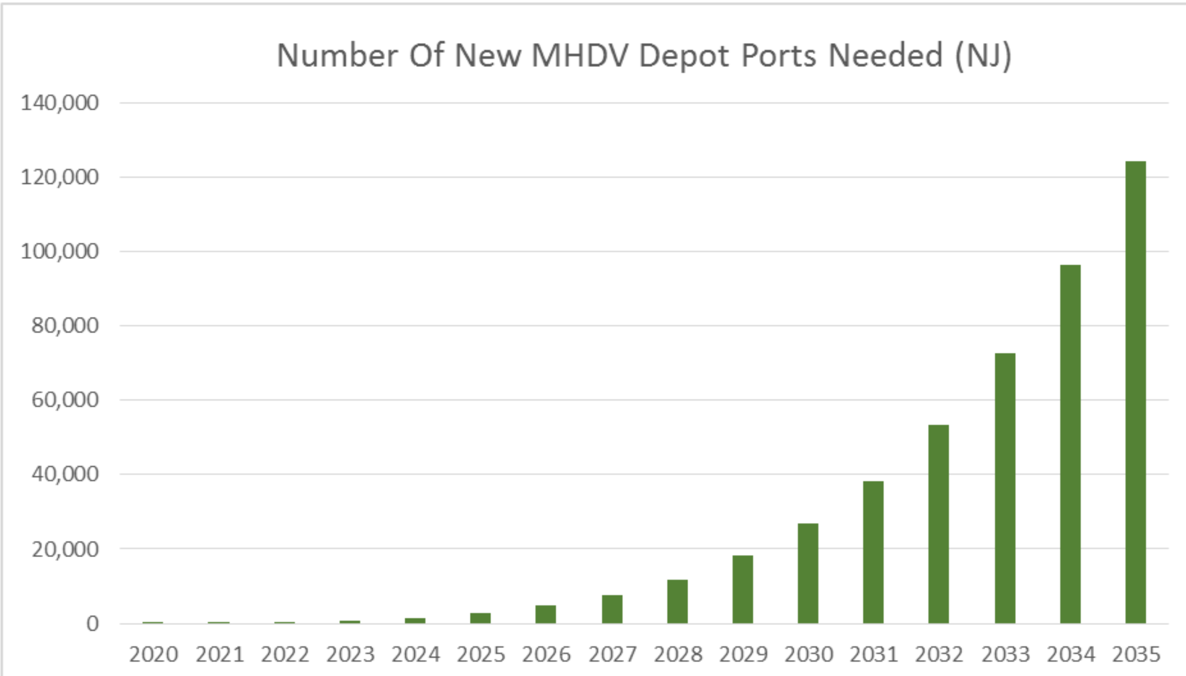
Figure 5.10: New DCFC Locations Needed Annually



5.5.3 MHDV Charging Infrastructure Requirements

MHDVs are expected to require a "home base" depot-style charger, with some sharing of those ports among MDHVs. These ports are expected to average 50KW, acknowledging that some may be lower power (even 7.2KW L2 chargers), and some may be higher[16]. The following figure summarizes the MHDV depot charger locations needed in New Jersey through 2035, consistent with the electrification schedule developed as part of the study.

Figure 5.11: New MHDV Depot Ports Needed In New Jersey (through 2035)



To augment these depot-style long-duration chargers, some vehicle classes are expected to share the high power public DCFC facilities developed for LDVs – especially local delivery medium-duty vehicles. In addition, long haul vehicles will only electrify if there are sufficient "en route" charging infrastructure available. There are approximately 100 truck stops in New Jersey[17] [18], and the study assumes that there are very high power DCFC developed at these locations to achieve the critical mass of fast charging infrastructure needed to enable long haul electrification in New Jersey.

5.5.4 Rate Design Considerations

Electricity pricing, and the structure of that pricing, has a strong impact on market development for multiple reasons. Existing tariff designs may be missing desired charging-behavior-modification inducements, or may create barriers to charging infrastructure investment. For example, commonly used residential tariffs typically don't encourage the off-peak charging that is most optimal. The demand charges associated multi-family, workplace, fleet, and public charging applications can make investment economics challenging, especially during early market phases when utilization is lower. Those impacts will be even more impactful for the higher-powered charging solutions that will be needed by many MHDVs.

At the same time, serving these new charging-induced loads could change the cost of service for utilities providing that power, which needs to be a consideration in the allocation of costs and overall rate design. Balancing the needs of the PEV market for supportive rate designs (and other economic incentives) with the needs for fair cost allocation and recovery will be a key policy priority as the market matures.

6 Understanding the Potential of Vehicle Electrification

As covered in subsequent sections, vehicle electrification is a complex process that involves numerous factors, projections depend on assumptions about market evolution over time, and models must account for interactions between a diverse set of market elements. This complexity can make it difficult for policy makers and stakeholders to understand what changes can be clearly attributed to vehicle electrification rather than other "moving parts". The essential need is to quantify in a clear and un-cluttered way what the impact of vehicle electrification is, without the influence of numerous other confounding factors.

The study team has developed two "snapshot" tools that allow for understanding the impact of vehicle electrification in a simple but highly representative way:

- **2019 Snapshot:** This retrospective analysis quantifies a thought-experiment in which the year 2019 attains 80% vehicle electrification. This detailed model compares key parameters (i.e. fuel costs, emissions, etc) about 2019 as it really happened with an alternative scenario where there is a high level of vehicle electrification in place across all segments.

- **Vehicle Cost Snapshot:** A primary consideration in the vehicle electrification transformation is what it is going to cost. When considering the statewide adoption schedule through 2050 (as described in Section 4), how much will consumers spend on vehicle purchases, fueling, and maintenance? That analysis has been performed assuming that the market continues to use ICE vehicles exclusively, and compares it with a scenario in which EV adoption becomes widespread over time. Quantifying a simple model of total vehicle costs over time – with and without EVs – provides a clear perspective on this especially critical question.

The following sections summarize the results of the 2019 Snapshot and the Vehicle Cost Snapshot.

6.1 2019 Snapshot

We can gain a clear perspective on the *technical potential* of vehicle electrification by conducting a thought experiment that retroactively examines the year 2019 in the scenario in which 80% vehicle electrification had been attained. Details about the year 2019 are well known, and it is not necessary to speculate about future costs, adoption rates, vehicle efficiencies or numerous other factors. The 2019 snapshot provides two perspectives: a way to characterize the vehicle market as it exists today, and an alternative view of how key market parameters change under high levels of vehicle electrification. This retrospective is very tangible, because we are making hypothetical changes to a known and well understood baseline with a minimal number of assumptions. The 2019 snapshot therefore provides a detailed baseline, as well a clear quantification of the technical potential that can eventually be realized through vehicle electrification over time. The 2019 Snapshot considers both the Business-As-Usual (BAU) scenario where the power generation mix is the known market today, and a "high Renewable Energy" (HI-RE) scenario.

6.1.1 Characterizing the New Jersey Vehicle Market

Based on data provided by DEP based on actual vehicle registration data as of the end of 2019, we can characterize the full on-road transportation sector in detail. Most of the assumptions associated with this model are based on actual parameters such as the cost of fuel or electricity. The 2019 Snapshot characterizes the current market through consideration of the following parameters:

- Vehicle population, broken out as defined in Section 3.1.
- The miles traveled by all vehicle types (commonly known as Vehicle Miles Traveled, or VMT).
- The amount of gasoline and diesel fuel used by those ICE vehicles.
- The cost to purchase those fuels.
- The amount of energy, expressed in BTUs, used by all types of vehicles. This metric is useful for understanding the relative activity of different vehicle classes, normalized to account for the energy content of different fuels and different vehicle efficiencies.
- The transportation induced emissions for the year, considering CO2, NOx, SO2, and PM2.5.
- The fuel taxes collected.

The following sections summarize the baseline results of the 2019 Snapshot, with virtually no PEVs active in the market. For convenience, most of the following data is reported in composite categories (see Section 3.1 for details): light duty cars, light duty trucks, medium-duty commercial vehicles, school buses, all other non-school buses, and all other heavy-duty vehicles (both short haul and long haul). In most cases, the data for the heavy-duty segment is broken out into its component vehicle categories.

1.1.1.1 Vehicle Population

There were approximately 6.7M on-road vehicles registered in New Jersey at the end of 2019. The following charts summarize how that population is distributed across vehicle classes. Note that LDVs – mostly cars and SUVs – make up nearly 90% of the vehicle population.

Figure 6.0: Vehicle Population in New Jersey, YE 2019

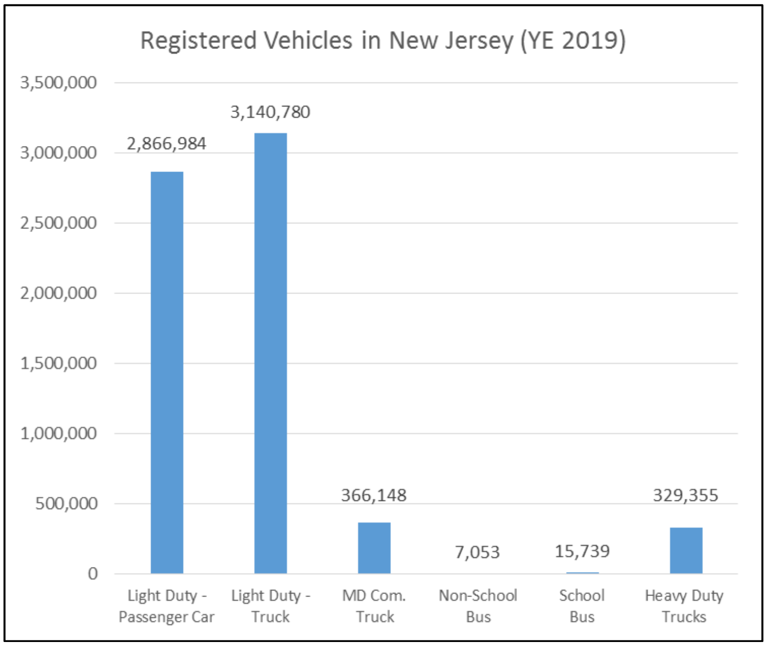
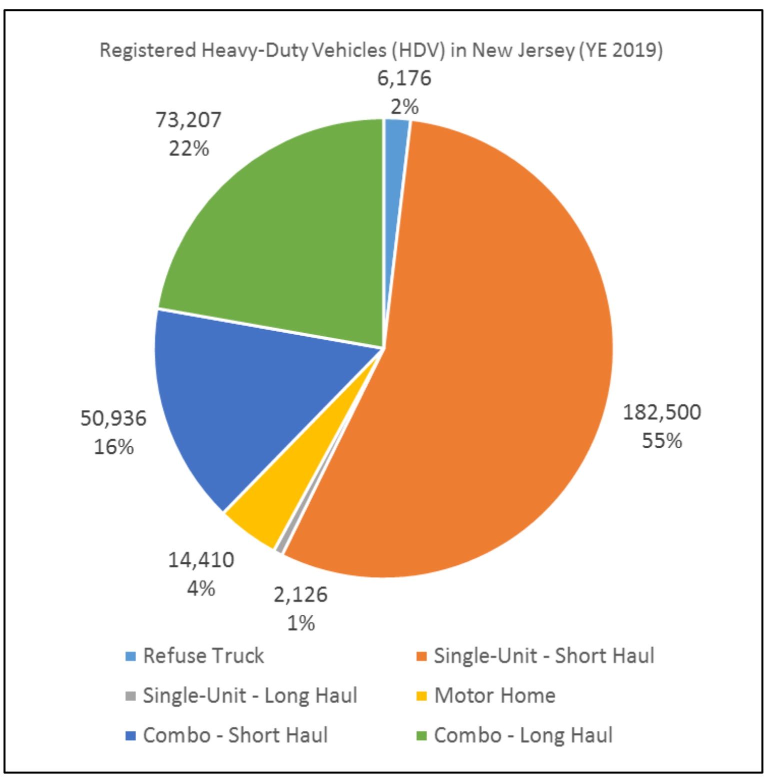


Figure 6.1: Break-Out of the Heavy Duty Vehicle Population in New Jersey, YE 2019



The single-unit short haul segment includes a wide variety of vehicle types, from firetrucks to street-sweepers to armored cars. But a large fraction of this segment are expected to be local delivery trucks, which represent a particularly large segment for rapid electrification. The Combo short haul segment includes the drayage vehicles that operate in and around New Jersey ports, with an especially large impact on over-burdened communities along those routes.

1.1.1.2 Vehicle Miles Traveled

Vehicles in different classes exhibit a diverse range of usage profiles and travel patterns. In particular, each vehicle class has an "average miles travelled per year", which when applied to the vehicle population, estimates the total VMT for the state. The total VMT for New Jersey in 2019 was ~76.4B vehicle miles travelled. Note that this covers only the miles travelled by vehicles within State boundaries. This is especially relevant for long-haul vehicles that travel extensively outside New Jersey.

Figure 6.2: Vehicle Miles Travelled in New Jersey, YE 2019

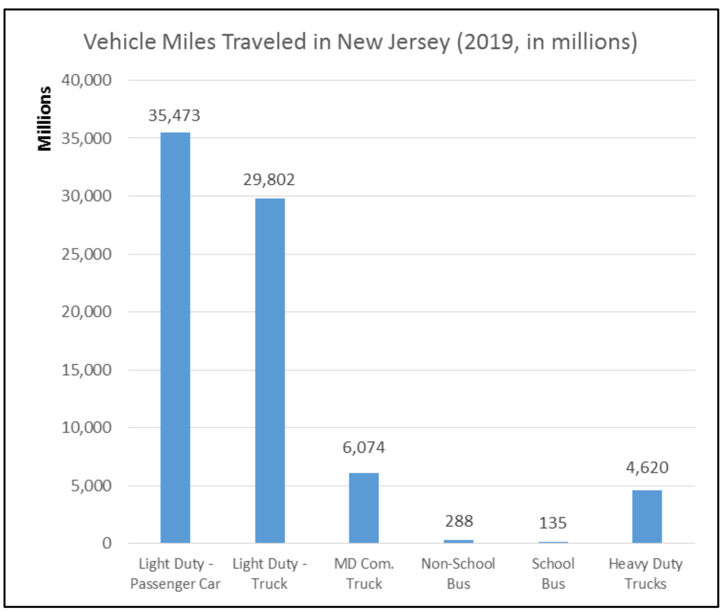
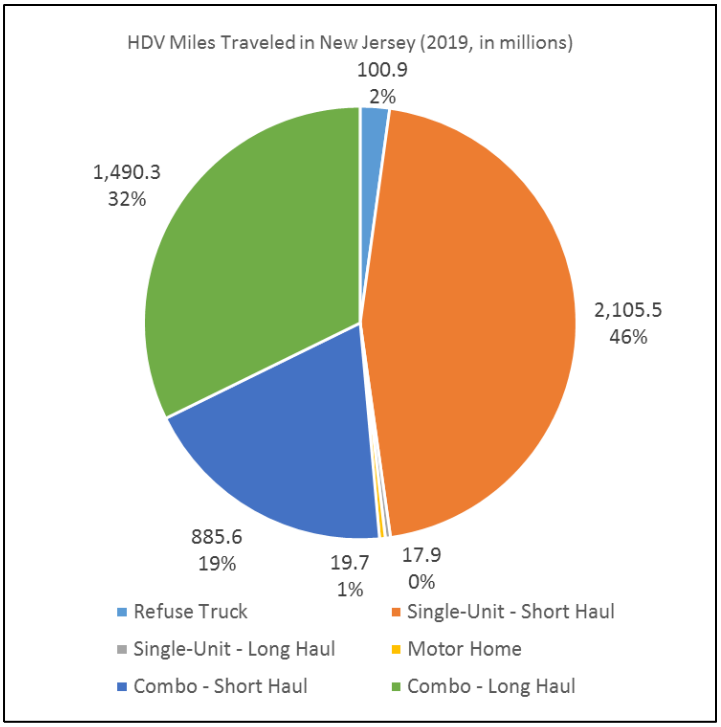


Figure 6.3: Break-Out of the Heavy Duty Vehicle VMT in New Jersey, YE 2019



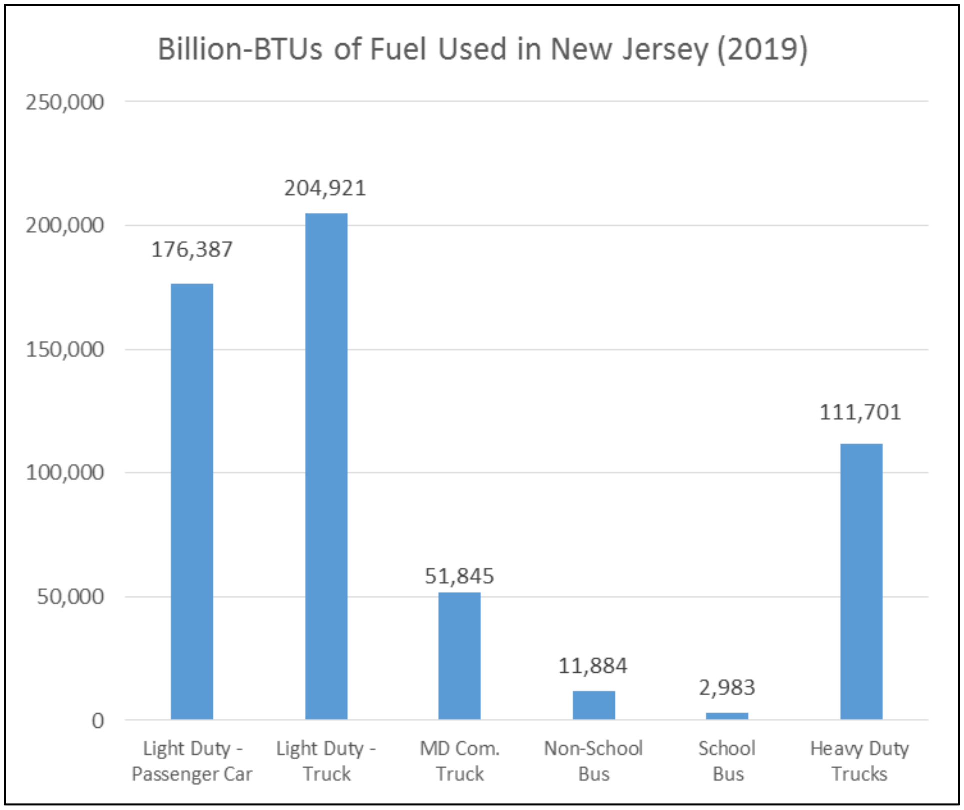
Even though many of the heavy duty vehicles have longer average annual mileage, the VMT associated with LDV dominate since those vehicles account for 90% of the vehicles on the road.

1.1.1.3 Fuel Use

Gasoline and Diesel fuel each have different energy content, and it is therefore not meaningful to compare vehicle classes based on gallons used. In addition, normalizing energy use based on a consistent unit (such as British Thermal Units (BTUs)) allows for consideration of vehicles as part of the energy-use landscape. The following charts summarize fuel use – in BTUs – for different vehicle classes after accounting for differences in the energy content of different fuels, and various vehicle efficiencies.

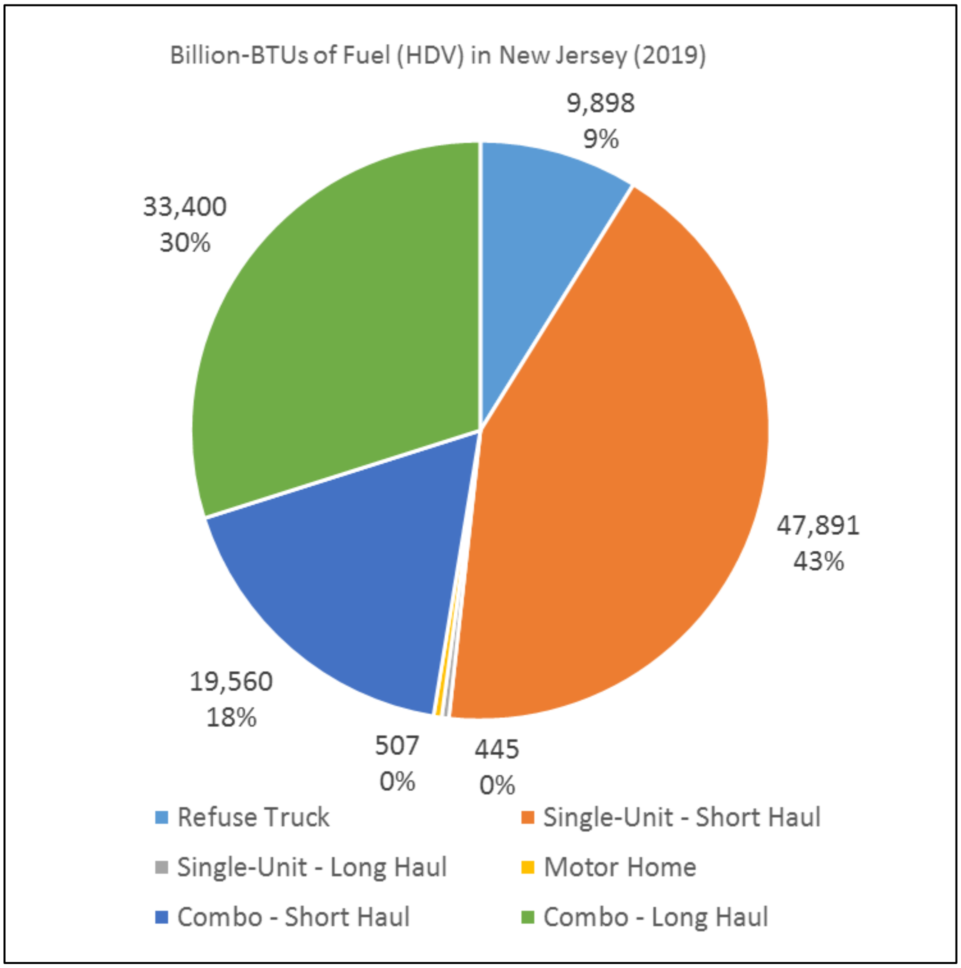
Vehicles in New Jersey used ~560 trillion BTUs in 2019. To put that in perspective, the electricity consumed in the State in 2019 represents ~253 trillion BTUs of electricity. New Jersey vehicles use more than twice as much energy moving around (with ICE vehicles) as the entire state consumes in electricity. As noted in more detail below, however, the amount of energy that will be required at high levels of PEV penetration is far less because electric vehicles are far more efficient than ICE vehicles.

Figure 6.4: Fuel Use By Vehicles in New Jersey, YE 2019



Diesel vehicles, especially in the Heavy-duty segments, are proportionally larger consumers of fuel since most have a relatively low efficiency (i.e. miles/gallon) rating. For example, a typical light duty car gets about 24.2 miles/gallon of gasoline (average for the vehicle population). An urban bus gets about 3.3 miles per gallon of diesel, and a long-haul tractor gets around 6.1 miles/gallon (of diesel in both cases). This lower efficiency results in greater fuel use per mile travelled. The following chart breaks out fuel use within the Heavy-duty category in more detail.

Figure 6.5: Break-Out of the Heavy Duty Fuel Use in New Jersey, YE 2019



The Single-unit short haul category is the largest fraction of fuel use within this category, many of which are expected to be local delivery vehicles. Combination long-haul tractors (mostly on interstate travel arteries) also account for a large fraction of fuel. Drayage vehicles, in the combination short-haul segment account for a large fraction of vehicle use, which is disproportionally large given the relatively small number of vehicles involved. The combination of low mpg-efficiency and larger average annual mileage account for this larger energy use in those segments.

1.1.1.4 Vehicle Emissions

Greater fuel use leads to greater air emissions, including the greenhouse gas CO2, and criteria pollutants such as NOx, SO2, and PM2.5. MHDVs account for a larger share of these pollutants since diesel is generally a dirtier fuel, and the mpg-efficiency of those vehicles is typically lower than LDV. While CO2 is a more regional emission that disperses widely (even globally), the criteria pollutants tend to “settle” and directly affect the communities in the urban core and along major travel arteries. Many of these impacted residents are already low-income or otherwise overburdened locations, with air quality being a major public health issue in those areas. The following charts summarize the break-out for each pollutant across vehicle classes associated with VMT in the State in 2019. All the following statistics are in short tons, and can be compared directly (on a mass basis).

Figure 6.6: CO_2 Emissions Induced By On-Road Vehicles in New Jersey, YE 2019

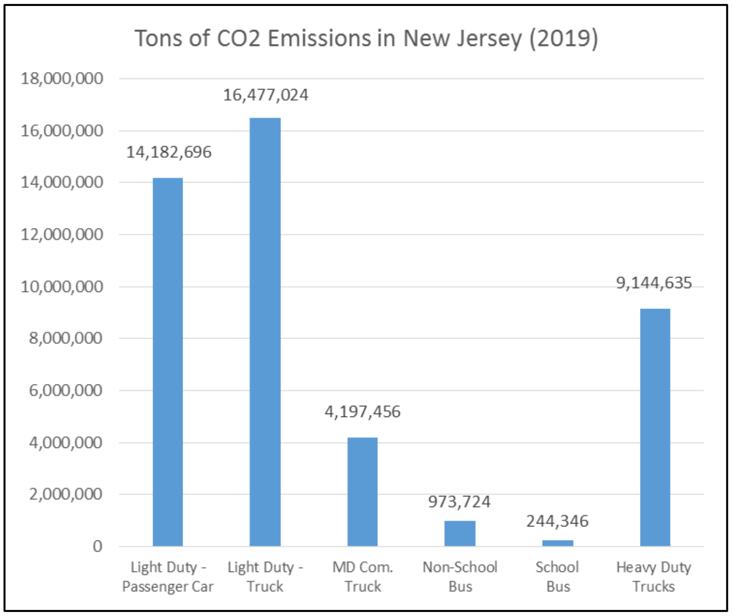


Figure 6.7: NO_x Emissions Induced By On-Road Vehicles in New Jersey, YE 2019

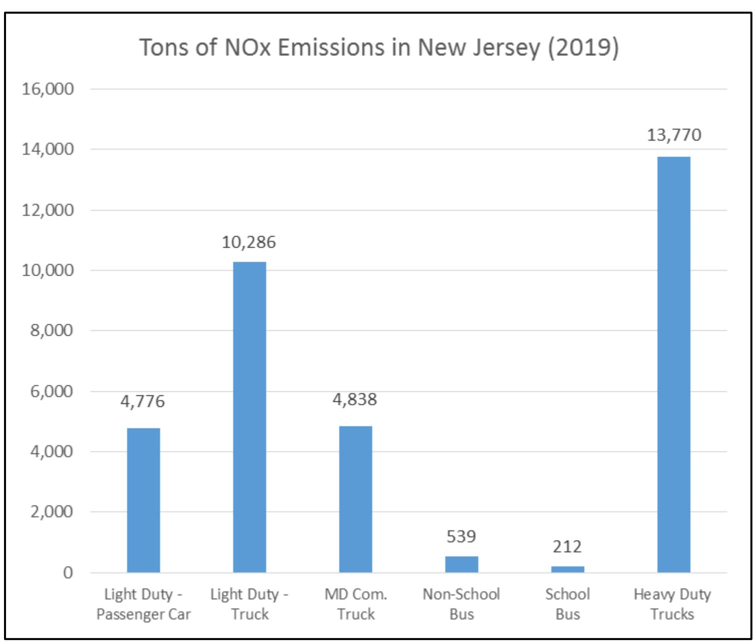


Figure 6.8: SO2 Emissions Induced By On-Road Vehicles in New Jersey, YE 2019

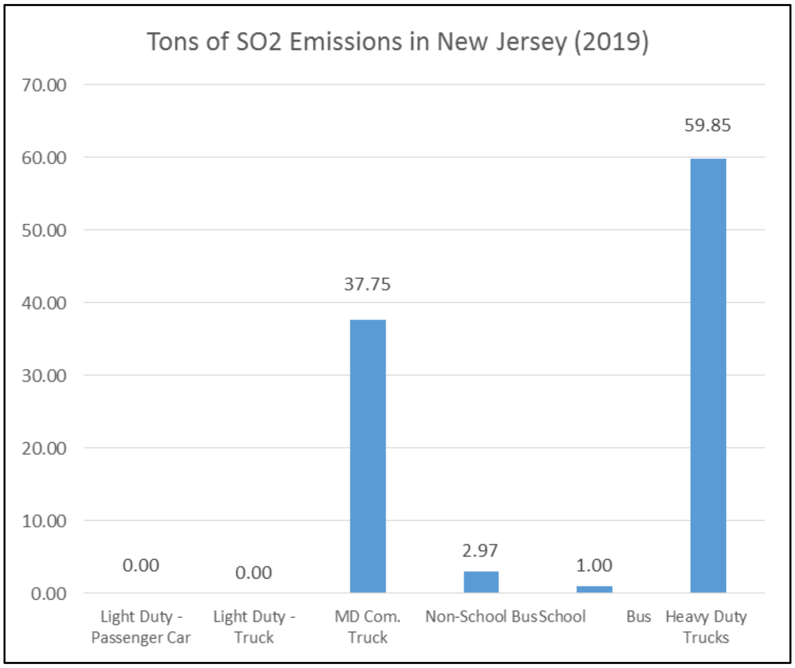
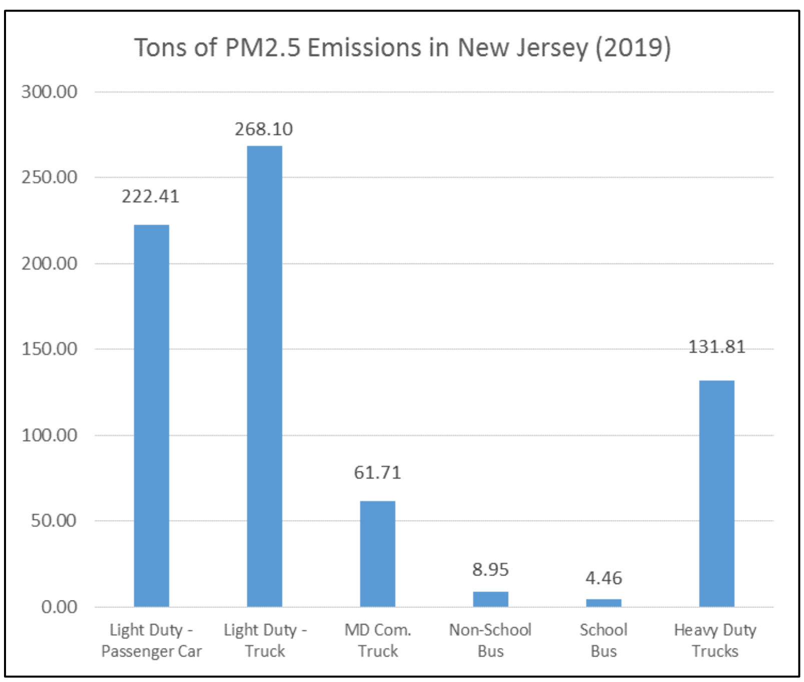


Figure 6.9: PM2.5 Emissions Induced By On-Road Vehicles in New Jersey, YE 2019



Note that Heavy-duty vehicles, which only account for ~10% of the vehicles on the road, account for around 40% of the NOx emissions, and 60% of the SO2 – both of which directly impact public health.

1.1.1.5 Economic Impact Of Vehicle Emissions

Vehicle emissions (especially CO2) contribute to climate change, as well as public health (NOx, SO2, and PM2.5), all of which have significant economic consequences. These emissions can be translated to costs which are carried by both society at large, as well as individuals. Using standardized factors that consider both the social cost of carbon and public health consequence, the emissions quantified above can be translated to dollars.

These economic impacts totaled ~$3.5B for air pollutants emitted from on-road vehicles in New Jersey in 2019. The following chart illustrates the break-out of these economic impacts (both public health and environmental consequences) across different vehicle classes. These figures represent the net present value of the pollutant-lifetime of impact from a ton of emissions in a given year.

Figure 6.10: Economic Impact of Emissions Induced By On-Road Vehicles in New Jersey, YE 2019

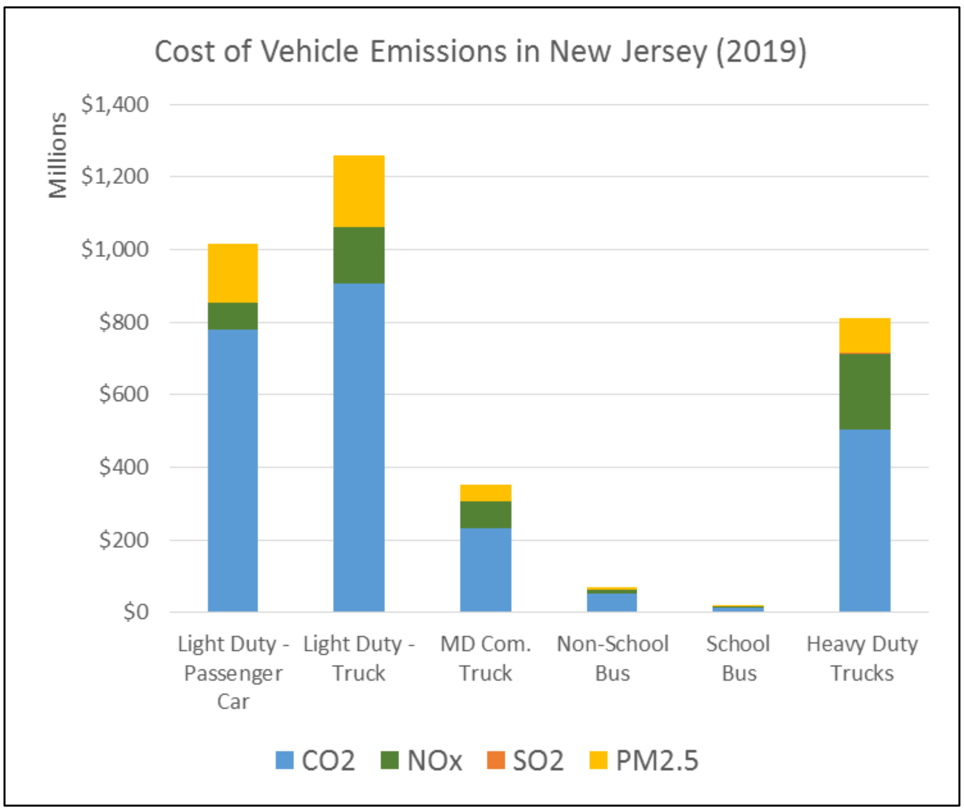
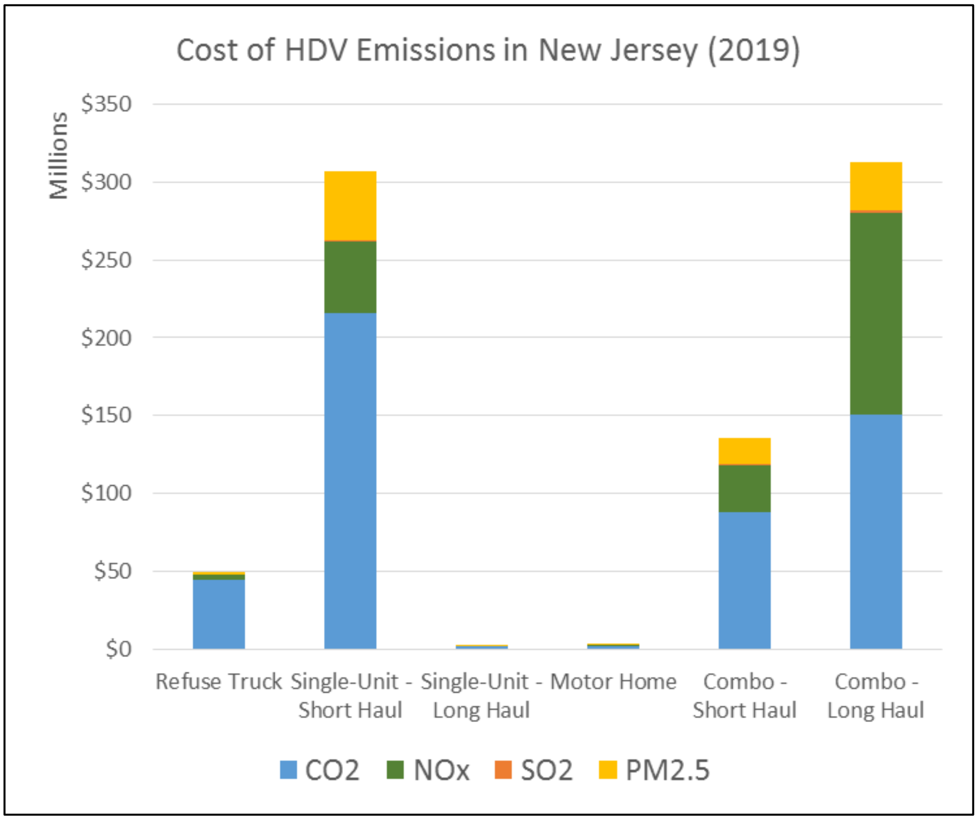


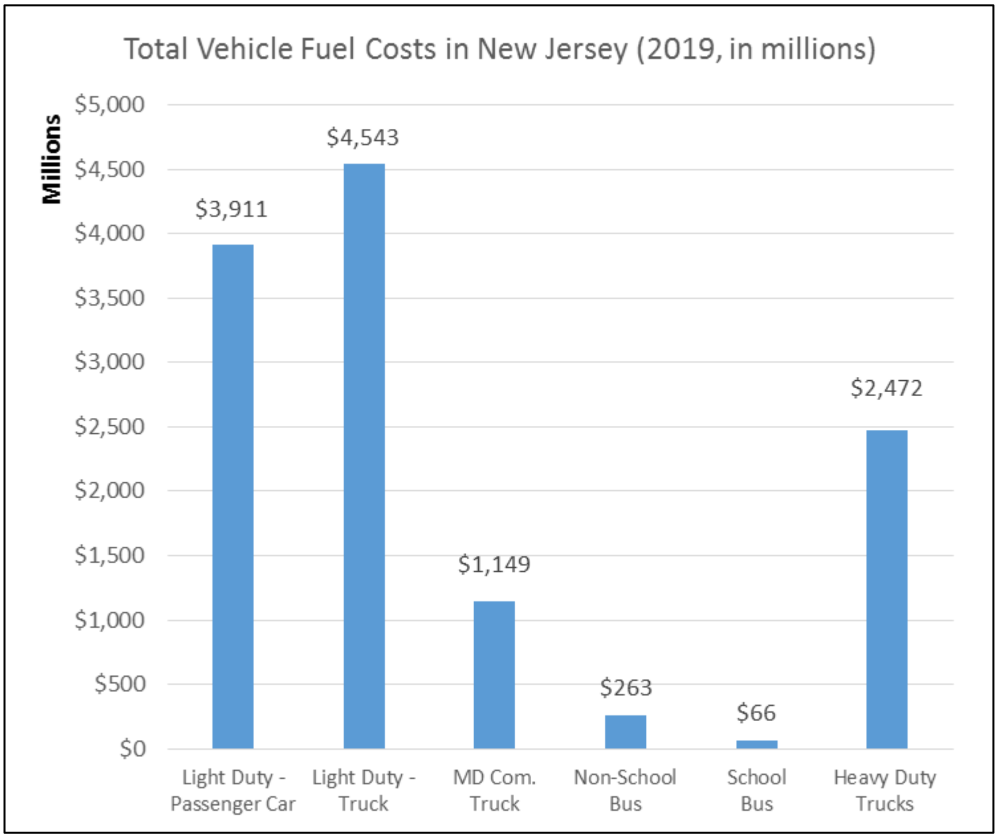
Figure 6.11: Economic Impact of Emissions Induced By Heavy-Duty Vehicles in New Jersey, YE 2019



1.1.1.6 *Expenditures on Fuel*

Vehicles on New Jersey roads accounted for approximately $12.4B in fuel expenditures in 2019[g], including both gasoline and diesel fuel.

Figure 6.12: Fuel Expenditures by Vehicles in New Jersey, YE 2019



The above figures includes both federal and state fuel taxes which break out as follows.

Figure 6.13: Fuel Tax Expenditures for Vehicles in New Jersey, YE 2019

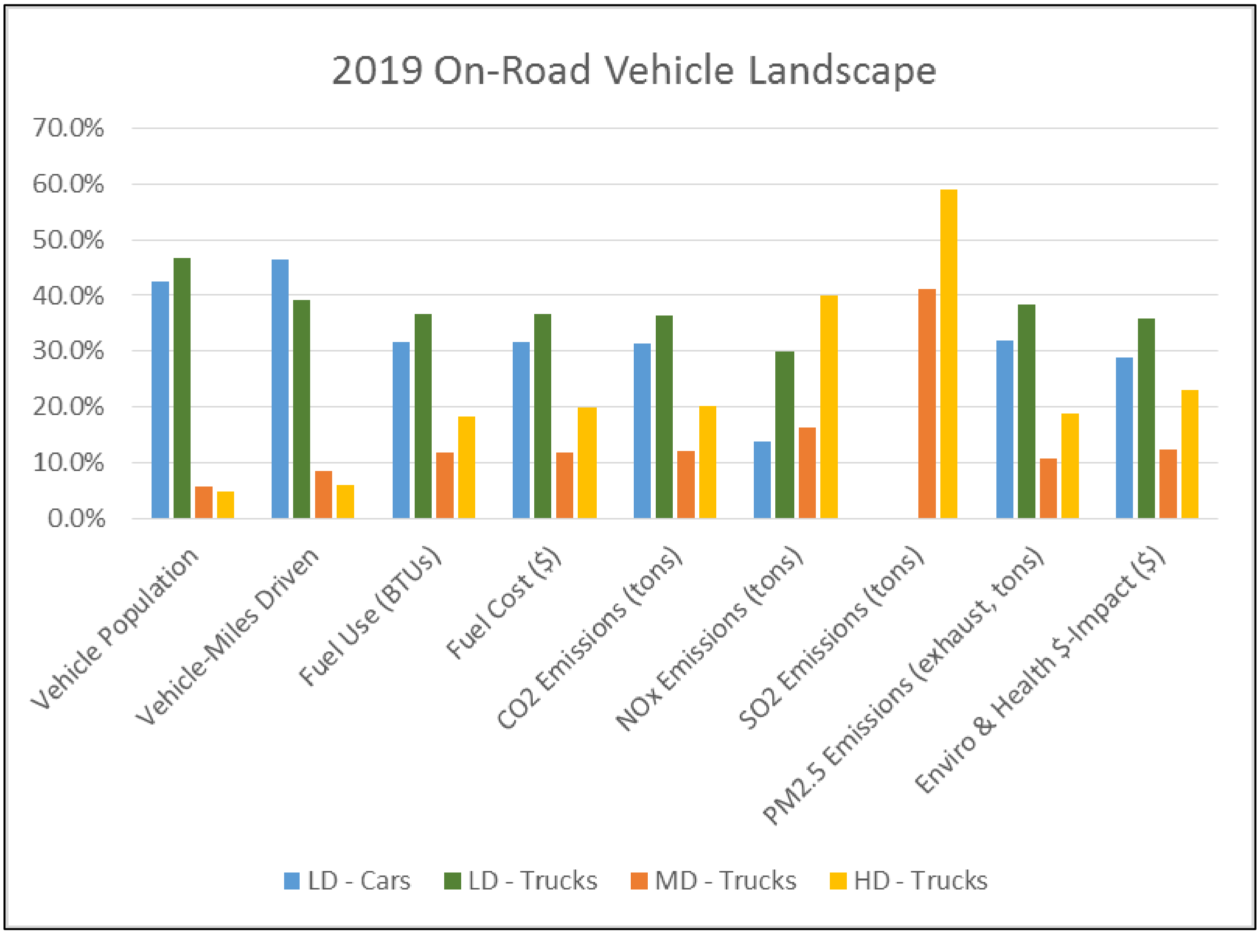
Fuel Type	State	Federal	Total Fuel Tax
Gasoline	$1,424,065,482	$632,917,992	$2,056,983,474
Diesel	$514,733,012	$258,958,464	$773,691,476
Total:	**$1,938,798,494**	**$891,876,456**	**$2,830,674,950**

[g] This figure represents the cost of fuel that accounts for the VMT on roads within the state, which is not the same thing as the retail value of fuel purchased within the State.

1.1.1.7 A Composite View Of 2019

The statistics provided in the sections above provide a detailed view about the on-road vehicle landscape in New Jersey in 2019. The following chart provide a composite view that illustrates how each vehicle cohort accounts for the impacts in different metrics of interest.

Figure 6.14: Composite View Of Impacts From Vehicles in New Jersey, YE 2019



This analysis suggests several observations about on-road vehicles in New Jersey in 2019:

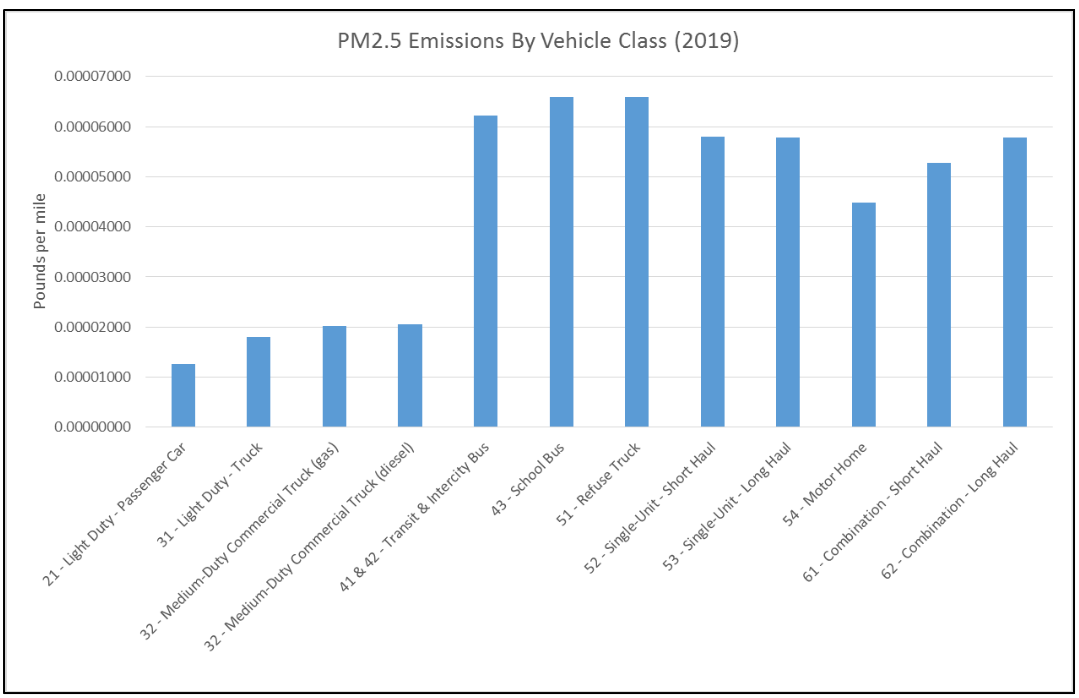
- LDVs (both cars and light trucks such as SUVs) account for the majority of vehicles on the road (89%) and vehicle miles traveled (VMT, 85%) in the State.

- LDVs also account for the majority of the fuel use (68% of BTUs) and fuel expenditure (68%), as well as the majority of the CO2 emissions (68%). Compared to their relatively small fraction of the population, however, MHDV have a dis-proportionally large impact on those factors due to their use of diesel fuel and lower mpg-efficiencies (i.e. 11% of the vehicle population accounts for ~32% of the fuel use, fuel expenditure, and CO2 emissions).

- Heavy-duty vehicles are approximately eight times "dirtier" than LDV when it comes to NOx and SOx emissions. In this case, ~5% of the vehicles on the road account for 42% of the NOx emissions, and 63% of the SO2. Many of these emissions represent public health burdens, since they accumulate near travel zones where these commercial vehicles frequently travel. The emissions are therefore much more concentrated, and therefore more harmful, than the emissions of more widely-travelled LDV.

- PM2.5 emissions are more complicated. They are one of the most harmful of the criteria pollutants on public health (especially in overburdened communities). On a per-mile basis, Heavy-duty diesel vehicles such as refuse trucks, drayage vehicles, buses, and long-haul tractors are about five times dirtier. However, the LDV contribute a large fraction of PM2.5 emissions as well because they dominate the VMT. However, as noted above with NOx, and SO2, emissions by commercial Heavy-duty vehicles tend to be more concentrated along travel corridors, while LDV are more distributed. Both impact modes are detrimental, but in different ways. The following chart illustrates the relative emissions rate of PM2.5 by vehicle class.

Figure 6.15: Relative PM2.5 Emissions (per mile) by Vehicle Class, YE 2019



- **These trends suggest different motivations and benefit strategies for different vehicle classes. Electrification of LDV represents transformation of over 6 million vehicles, accounting for the majority of the VMT. That change brings significant benefits in reduced fuel expenditure and**

lower CO_2 emissions. Electrification of MHDV trucks, especially buses, local delivery, and drayage vehicles, represent an opportunity to improve public health by substantially reducing criteria pollutants, especially where they are in more concentrated zones. This air quality improvement is especially impactful for low income and environmental justice communities that are typically near these zones.

6.1.2 The Potential Impact of Vehicle Electrification In New Jersey

The Snapshot quantified above characterizes the on-road vehicle landscape in New Jersey in 2019. To understand the technical potential of widespread vehicle electrification, it is also useful to explore what the year 2019 would have looked like across all the same benchmarks at 80% electrification. The 80% attainment level was selected since that is the level of electrification realized in 2050 according to the electrification schedule developed for the study (see Section 4). This approach avoids the need to make numerous assumptions about *future* conditions, since we know many details about the world of 2019. This electrification Snapshot therefore provides a clear perspective on the impacts when high levels of PEV use has been attained over time[h].

The 2019 Snapshot only assumes that current ICE vehicles are displaced by PEVs with known (i.e. as existing in 2019) characteristics. The number of vehicles on the road, the distribution by vehicle segment, and the aggregate VMT per segment all remains the same. The Snapshot considers two variations: the case where the electric power mix is as it really existed in 2019, and also a high Renewable Energy scenario that would exist when New Jersey achieves its grid de-carbonization goals.

For both the BAU and Hi-RE scenarios:

- Gasoline consumption reduces by 2.8 billion gallons, while diesel consumption reduces by 849 million gallons. Consistent with the level of electrification attained, that represents a reduction in fuel use of just under 80%.

- Electricity consumption increases by 25.8 billion kwhrs due to vehicle charging, which is about a 35% increase in the electricity use compared with the actual consumption in 2019. In that case, about 26% of the electricity consumed is going into vehicle charging. This increased vehicle use will dilute electric utility distribution requirements for all ratepayers, driving rates down. This downward impact on rates has been quantified in other similar studies[19] [20].

- Vehicle owners will spend about $9.9B less on fuel, but about $4B more for electricity, for a net savings on "fuel" costs of $5.9B. That is an annual savings that will accrue for each year of PEV life, and represents a 47% reduction in those costs.

- That reduced fuel use impacts the collection of fuel taxes, as summarized below.

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[h] The comprehensive net-benefit model described in Section 7 through 10 below quantify the total impact of market-wide vehicle electrification over a multi-year period.

Figure 6.16: Estimated Reduction In Fuel Tax Revenues, 80% Electrification (2019)

Changes In Fuel Tax Collected (minus number means a reduction in revenue)			
Fuel	**State**	**Federal**	**Total Fuel Tax**
Gasoline	-$1,139,252,379	-$506,334,391	-$1,645,586,770
Diesel	-$411,786,408	-$207,166,770	-$618,953,178
	-$1,551,038,787	**-$713,501,161**	**-$2,264,539,947**

The following summarizes the key changes in energy usage (fuel and KWHrs) associated with 80% electrification in 2019.

Figure 6.17: Changes in Fuel and Electricity Use Resulting From 80% Electrification (2019)

	Num. PEV	Num ICE	Fuel Savings ($)	Fuel Savings (%)	MWHr Used
21 - Light Duty - Passenger Car	2,293,587	573,397	-$1,834,198,631	-46.9%	8,201,852
31 - Light Duty - Truck	2,512,624	628,156	-$2,309,833,372	-50.8%	8,394,839
32 - Medium Duty Commercial Truck (gas)	169,893	42,473	-$315,988,559	-43.7%	1,662,723
32 - Medium Duty Commercial Truck (diesel)	123,026	30,756	-$150,513,560	-35.4%	1,204,041
41 & 42 - Transit & Inter-City Bus	5,642	1,411	-$143,278,945	-54.5%	425,168
43 - School Bus	12,591	3,148	-$30,947,676	-46.9%	138,519
51 - Refuse Truck	4,941	1,235	-$140,616,491	-64.2%	219,276
52 - Single-Unit - Short Haul	146,000	36,500	-$636,657,162	-60.1%	1,337,903
53 - Single-Unit - Long Haul	1,701	425	-$6,090,032	-61.8%	11,371
54 - Motor Home	11,528	2,882	-$7,000,112	-62.4%	12,524
61 - Combination - Short Haul	40,749	10,187	-$129,597,312	-29.9%	1,372,996
62 - Combination - Long Haul	58,566	14,641	-$135,720,585	-18.4%	2,886,847
Total	**5,380,847**	**1,345,212**	**-$5,840,442,437**	**-47.1%**	**25,868,060**

When considering the impact of vehicle electrification on emissions, it is important to recognize several separate changes that happen simultaneously:

- In all cases, emissions from the tailpipe are reduced to zero for all pollutants along the travel route. For PM2.5, brake wear (which is part of PM2.5 emissions) is also reduced by half due to the use of regenerative braking[21].

- The total quantity of emissions – considering the reduction by the vehicle net of increases at the power plant – will change. The net production of CO_2 goes down dramatically, and so does NO_x. The impacts on SO_2 and PM2.5 vary depending on the power mix, as noted in more detail below.

- Vehicle emissions are displaced geographically through electrification: the amount of emissions changes, but *where* the emissions take place also changes, shifting from the travel route to the power plant. This geographic displacement is a significant component of the electrification impact.

- For this one-year snapshot under the BAU-electrification scenario, 2019 emissions change as follows:

  a) Emissions of both CO_2 and criteria pollutants are virtually eliminated in travel zones.
  b) On a regional net basis (considering both tailpipe reductions and power plant increases), net CO_2 emissions reduce by 60%, and NO_x reduces by 68% under BAU generation.
  c) Regional net SO_2 increases substantially regionally, from 102 tons in the 2019 baseline case to 6,301 tons from electrification (BAU generation).
  d) Net regional PM2.5 increases slightly, by ~5% under BAU generation.
  e) The net regional increase of SO_2 and PM2.5 emissions are potential negative consequences of vehicle electrification, but that outcome is very dependent on the electricity supply mix (and emission accounting policy). As generation becomes cleaner, that negative outcome fades. For the hi-RE power mix, net regional PM2.5 emissions reduce significantly, similar to the extent of reduction seen by CO_2 and NO_x.
  f) Electrification introduces significant geographic shifts in emissions: in all cases, the emissions *along the travel route*, which is typically near heavily populated areas, is reduced to zero. The model accounts for the fact that the economic impact in a dense population center is different than the impact near a power plant (see Section 3 for more details). The following table summarizes the net-regional emission changes associated with the BAU case, and the associated changes in the economic impact of those emissions. A negative number means a reduction in absolute emissions or economic impact (i.e. savings).

Figure 6.18: Summary Of Emission Changes Under BAU Generation (New Jersey, 2019)

	CO2	NOx	SO2	PM2.5	ENV SAVINGS
21 - Light Duty - Passenger Car	-59.5%	-51.6%	N/A	4.6%	-$438,801,025
31 - Light Duty - Truck	-61.9%	-66.5%	N/A	-8.2%	-$624,687,330
32 - Medium Duty Commercial Truck (gas)	-57.5%	-63.5%	1635.9%	27.2%	-$81,521,148
32 - Medium Duty Commercial Truck (diesel)	-52.9%	-73.7%	2066.9%	25.6%	-$68,890,678
41 & 42 - Transit & Inter-City Bus	-64.5%	-67.0%	3450.5%	29.0%	-$35,394,550
43 - School Bus	-59.9%	-69.2%	3322.2%	-8.7%	-$9,660,412
51 - Refuse Truck	-70.4%	-62.3%	3787.3%	71.4%	-$30,138,757
52 - Single-Unit - Short Haul	-67.9%	-72.7%	1795.2%	-29.8%	-$184,513,651
53 - Single-Unit - Long Haul	-68.9%	-72.3%	1929.5%	-29.5%	-$1,691,138
54 - Motor Home	-69.3%	-73.0%	1799.0%	-14.9%	-$1,879,412
61 - Combination - Short Haul	-49.6%	-68.5%	2293.0%	54.8%	-$46,112,243
62 - Combination - Long Haul	-42.6%	-74.4%	2631.4%	73.8%	-$118,860,440
Total	**-59.7%**	**-67.6%**	**6203.6%**	**5.1%**	**-$1,642,150,782**

- For the Hi-RE case, simulating the case where New Jersey attains its renewable energy goals in 2019, the emission reductions from electrification improves on a net basis regionally. CO_2 emissions reduce by 30 million tons (67%), NO_x emissions drop by 24 thousand tons (71%), and PM2.5 drops by 274 tons (39%). SO_2 emissions are still elevated compared with the nonelectrified baseline, increasing by about 4 thousand tons[i], but that increase is less than in the BAU case. The following table summarizes the changes in net regional emissions the Hi-RE case per vehicle class. As with the chart above, negative numbers represent a reduction in absolute emissions or economic impact.

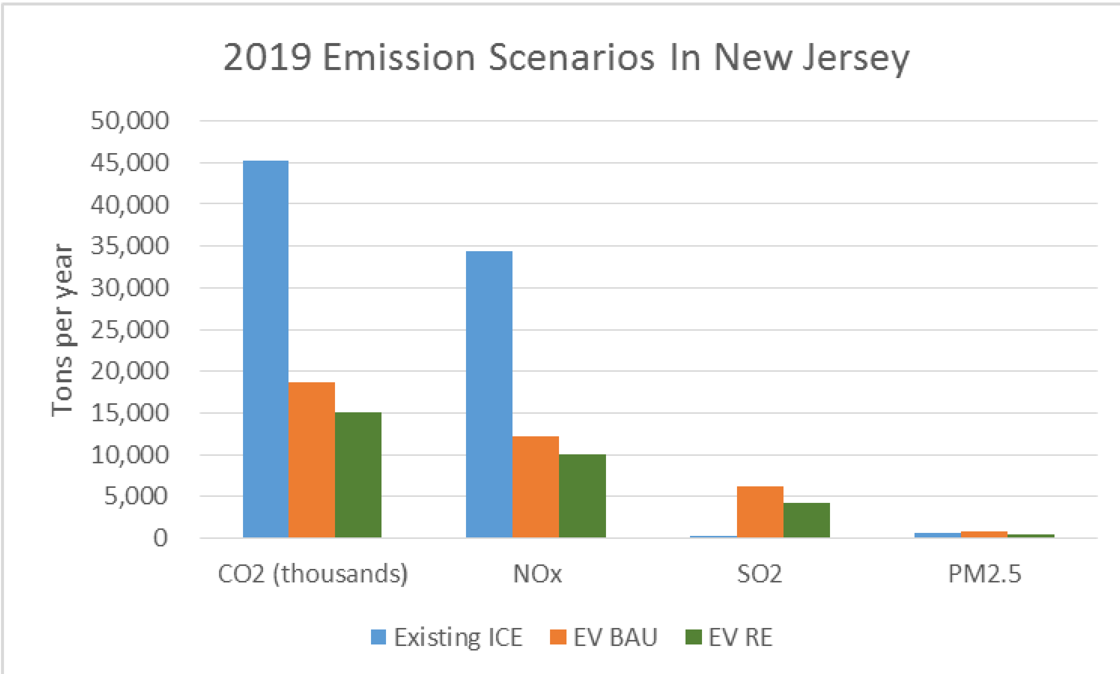
Figure 6.19: Summary Of Emission Changes Under Hi-RE Generation (New Jersey, 2019)

	CO2	NOx	SO2	PM2.5	ENV SAVINGS
21 - Light Duty - Passenger Car	-67.9%	-66.8%	N/A	-40.5%	-$588,534,463
31 - Light Duty - Truck	-69.3%	-73.7%	N/A	-46.5%	-$777,943,941
32 - Medium Duty Commercial Truck (gas)	-66.7%	-72.3%	1059.1%	-29.9%	-$111,875,906
32 - Medium Duty Commercial Truck (diesel)	-64.0%	-77.1%	1345.2%	-30.7%	-$90,871,710
41 & 42 - Transit & Inter-City Bus	-70.9%	-73.9%	2263.7%	-29.1%	-$43,156,446
43 - School Bus	-68.1%	-75.0%	2178.5%	-46.7%	-$12,189,229
51 - Refuse Truck	-74.3%	-71.7%	2487.3%	-9.3%	-$34,141,866
52 - Single-Unit - Short Haul	-72.8%	-76.6%	1164.9%	-56.6%	-$208,938,477
53 - Single-Unit - Long Haul	-73.5%	-76.4%	1254.0%	-56.4%	-$1,898,735
54 - Motor Home	-73.7%	-76.7%	1167.4%	-49.6%	-$2,108,055
61 - Combination - Short Haul	-62.0%	-74.6%	1495.3%	-17.0%	-$71,177,723
62 - Combination - Long Haul	-57.9%	-77.4%	1720.0%	-8.2%	-$171,562,869
Total	-68.0%	-74.2%	4091.4%	-40.3%	-$2,114,399,421

- The 2019 Snapshot allows us to consider the overall impact of electrification on emissions in a year for which many details are known. As summarized in detail above, these impacts vary significantly between the BAU and Hi-RE generation scenarios. The following graph illustrates the differences between the no-EV baseline and those two generation alternatives.

[i] The outcomes for both SO2 and PM2.5 are very sensitive to the emissions accounting boundaries. This analysis, in alignment with DEP direction, is based on RFC-East which – even when New Jersey decarbonizes its in-state supply – still contains a substantial amount of fossil fuel generation (including coal).

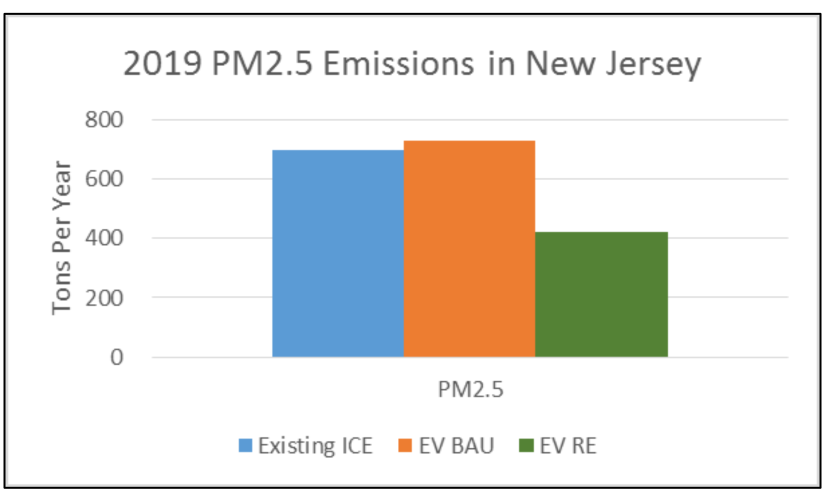
Figure 6.20: Emissions For Three Scenarios In New Jersey, 2019



NOTE: in the above chart, **the CO_2 figures are THOUSANDs of tons**, to avoid visually swamping the other pollutants. CO_2 emissions are larger than the other pollutants, on a mass basis, by factor of at least 1000.

- As noted above, PM2.5 increases slightly due to electrification with the BAU supply mix, but declines significantly in the Hi-RE case. The following chart illustrates the relative magnitude of that change.

Figure 6.21: PM2.5 Emissions For Three Scenarios In New Jersey, 2019



- The 2019 Snapshot also quantifies the inherent improvement in *efficiency* realized by widespread vehicle electrification. The following chart illustrates the change in BTUs/mile realized by vehicles in 2019, depending on whether they were an ICE vehicle running on fuel, or a PEV running on electricity[j].

Figure 6.22: BTUs Per Mile By Vehicle Class, 2019

Vehicle Class	ICE BTUs/Mile	PEV BTUs/Mile
21 - Light Duty - Passenger Car	4,972	986
31 - Light Duty - Truck	6,876	1,201
32 - Medium Duty Commercial Truck (gas)	9,256	2,013
32 - Medium Duty Commercial Truck (diesel)	7,540	2,013
41 & 42 - Transit & Inter-City Bus	41,256	6,295
43 - School Bus	22,087	4,374
51 - Refuse Truck	98,129	9,272
52 - Single-Unit - Short Haul	22,745	2,710
53 - Single-Unit - Long Haul	24,888	2,710
54 - Motor Home	25,727	2,710
61 - Combination - Short Haul	22,087	6,612
62 - Combination - Long Haul	22,411	8,262
Market-Wide Average:	**7,327**	**1,444**

The 2019 Snapshot illustrates that on almost every benchmark of interest, a high level of electrification delivers significant benefit. This outcome can be determined with relatively few assumptions when considered in retrospect, drawing primarily on the real-world conditions known to exist in 2019. This Snapshot quantifies significant savings on fuel costs, increases in electricity that dilute utility distribution revenue requirements for all ratepayers, and significant reductions in emissions – especially CO_2 and NOx. The multi-year model presented in Section 7 – 10 below complements this one-year Snapshot, and quantifies similar impacts based on how key parameters (fuel costs, vehicle efficiencies, etc) are expected to change over time, and in proportion to the rate of electrification attained over time.

6.2 Vehicle Cost Snapshot

Cost is a primary consideration for the transformation of the on-road vehicle market through electrification. In a scenario where PEVs don't exist, vehicle owners would continue to buy new ICE vehicles each year, and pay for fuel and maintenance – a total of about $39B in 2019 alone. Under the proposed electrification schedule (see Section 3), an increasing fraction of EV drivers will choose to buy a

[j] The energy content illustrated for PEVs is the BTU equivalent of the electricity used for charging, not the primary source of energy used to create the electricity.

PEV rather than a traditional ICE vehicle. They will then pay for electricity rather than fuel, and benefit from lower maintenance costs.

The Vehicle Cost Snapshot captures this dynamic over time (from 2021 through 2050), and compares the total costs carried by New Jersey vehicle owners in the case where ICE ownership continues without change with the costs associated with electrification under the proposed schedule. The total number of vehicles on the road, the number of new vehicles purchased each year (under the natural retirement rate per class), and the number of miles driven every year remains constant. The distribution of vehicles by class stays mostly the same over time, with the only exception being the shift of LDV sales from cars to SUVs consistent with current market trends. Vehicle efficiencies are mostly constant, with the exception of increased MPG-efficiency for LDV consistent with CAFÉ standards. Inflation factors are applied equally across all cost parameters, including projected increases in the cost of fuel and the cost of electricity. ICE vehicle prices are essentially constant in current dollars, but PEVs are projected to decline in price consistent with current trends for reduced battery costs. All dollars used below are in nominal dollars.

These two scenarios can be quantified as follows:

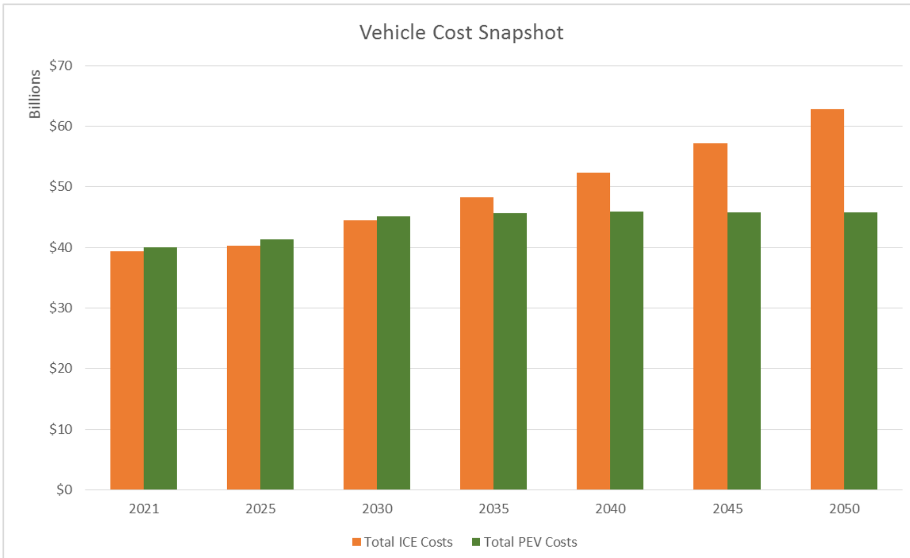
- In the ICE-only baseline, vehicle owners (across all classes) will spend about $39.4B on new vehicle purchases, fuel, and maintenance in 2021. This increases to about $62.8B in 2050 as a combination of inflation and increased fuel costs.

- In the PEV-adoption scenario, leading to 80% electrification by 2050, total costs are slightly higher in 2021 ($40.0B), due mostly to the purchase premium for the modest number of PEVs purchased in that year. The total figure for vehicle purchase, electricity, and maintenance grows to about $45.7B in 2050, reflecting substantial savings in operational expense (fueling with electricity and maintenance) for a large number of vehicles in all classes.

- Aggregating the impact of this transition from 2021 through 2050, the total costs for the 80% electrification case is lower than the ICE-only case by 9.4% ($139B, nominal sum). This outcome is a result of reducing PEV purchase premiums over time, and the significant operating-expense savings realized by PEVs. **Widespread vehicle electrification is a lower cost option compared with a market that continues to purchase and use only ICE vehicles thru 2050.**

- The following chart summarizes how total costs (purchase, fuel or electricity, maintenance) change in the ICE or PEV-adoption scenario changes for representative years.

Figure 6.23: Total Vehicle Market Costs, ICE-only vs PEV adoption, 2021 – 2050



This is a striking conclusion, since it quantifies an unexpected outcome: the market overall will spend less (on a nominal sum basis) pursuing electrification than if they "did nothing" and continued with traditional vehicle choices over time.

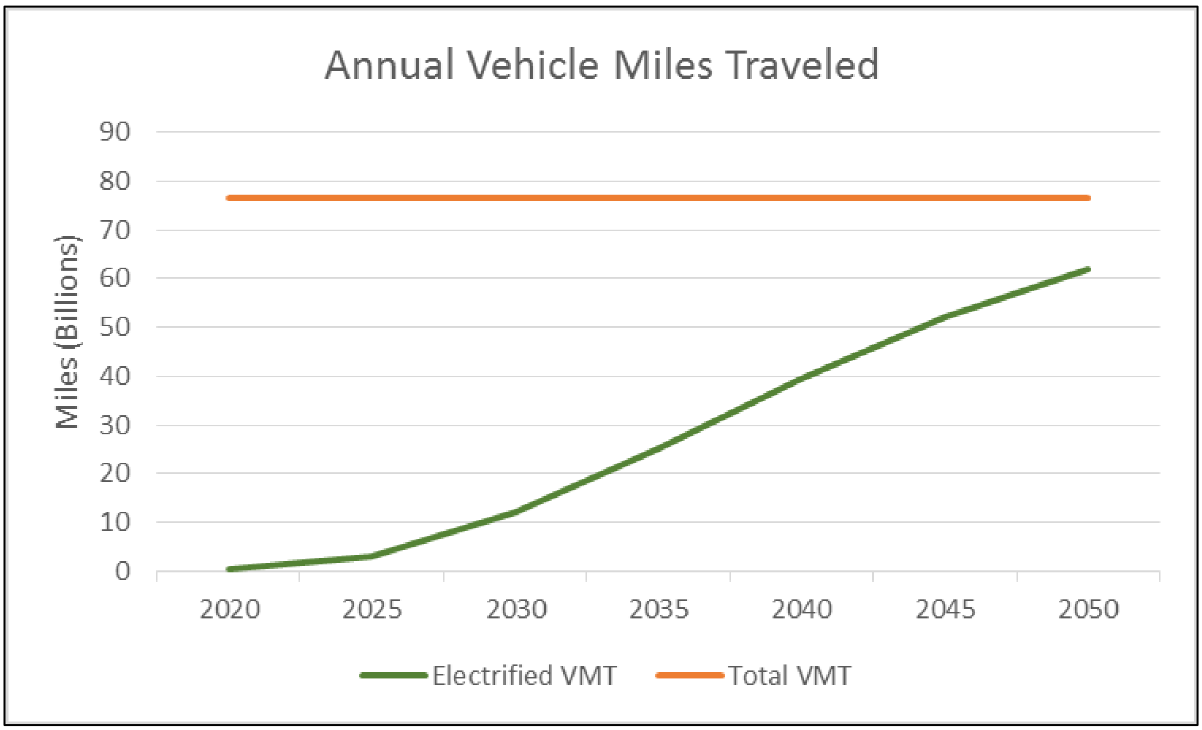
7 Physical Impacts Of Electrification Through 2050

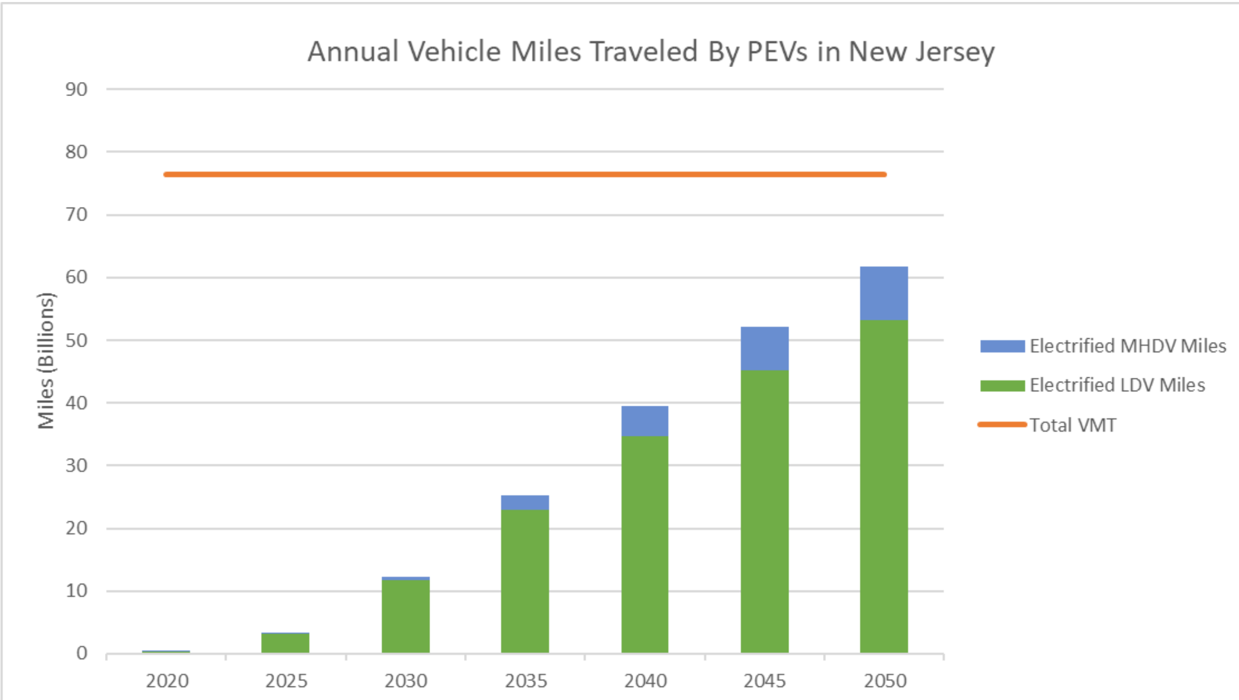
The impact model starts with the electrification schedule described above and applies key parameters about travel statistics, vehicle efficiency, and charging behaviors to compute the physical characteristics of both a no-EV baseline case, and quantification of the same parameters under the EV adoption scenarios. Both BAU and Hi-RE cases are considered. The quantification of these physical impacts provides the foundation for the economic and other impacts that go into cost and benefit modeling as described in subsequent sections.

All the following results characterize the physical impacts of the fraction of the full market that has electrified, which is increasing over time according to the electrification schedule.

As the number of PEVs on the road increases, the fraction of electrified miles increases in proportion. The growth of electrified miles resulting from the electrification schedule is summarized in the chart below.

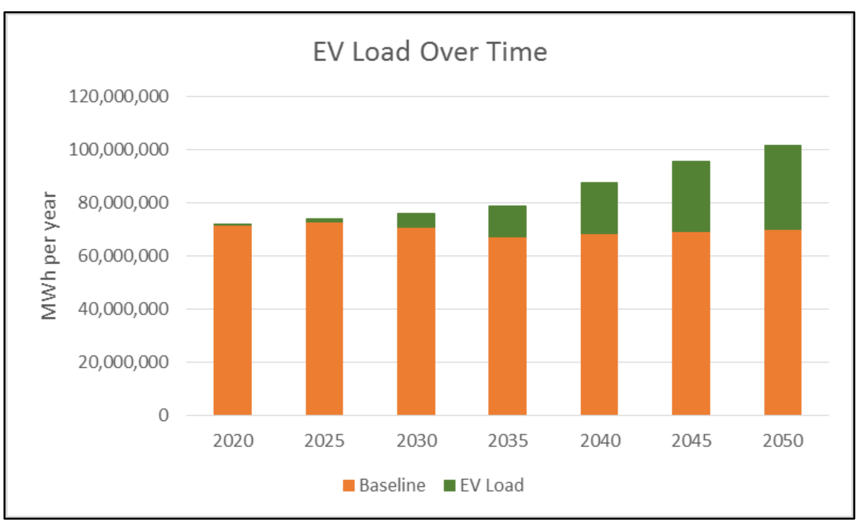
Figure 7.0: Electrification of Vehicle Miles Traveled In New Jersey





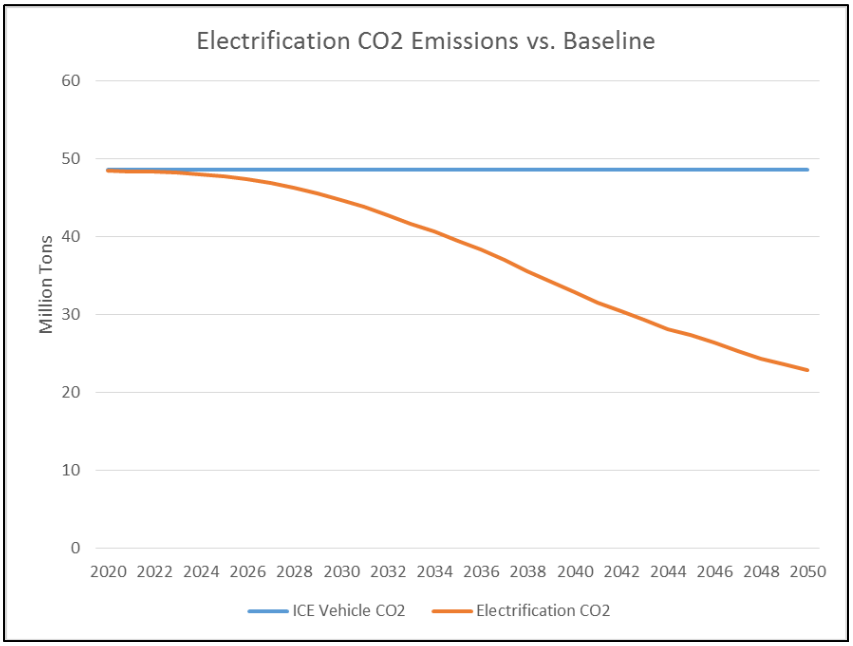
When fuel is displaced by electricity for most on-road travel, vehicle charging becomes a significant fraction of electricity consumption. This new load will have profound implications for electricity markets, generation, transmission, distribution, and the utilities. The following graph summarizes the degree of increasing electricity use over time compared with the projected baseline.

Figure 7.1: Vehicle Charging Load Compared With Baseline (New Jersey)



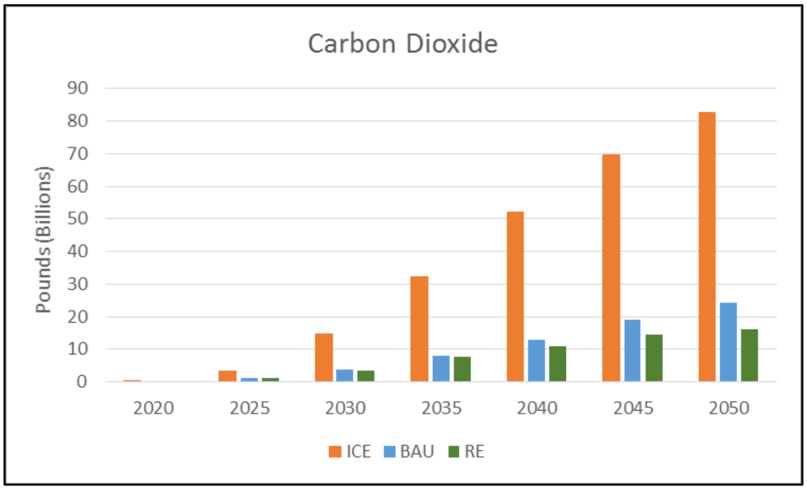
Traditional ICE vehicles emit a massive amount of CO2, a primary greenhouse gas that contributes directly to climate change. Vehicle electrification results in a large net reduction in CO2 emissions, even when considering the net impact of reductions at the PEV tailpipe and increases in emissions at the power plant. The following graph shows how CO2 emissions in the state will decrease over time as the degree of electrification increases.

Figure 7.2: CO2 Emission Reductions Due To Electrification (full vehicle population, New Jersey)



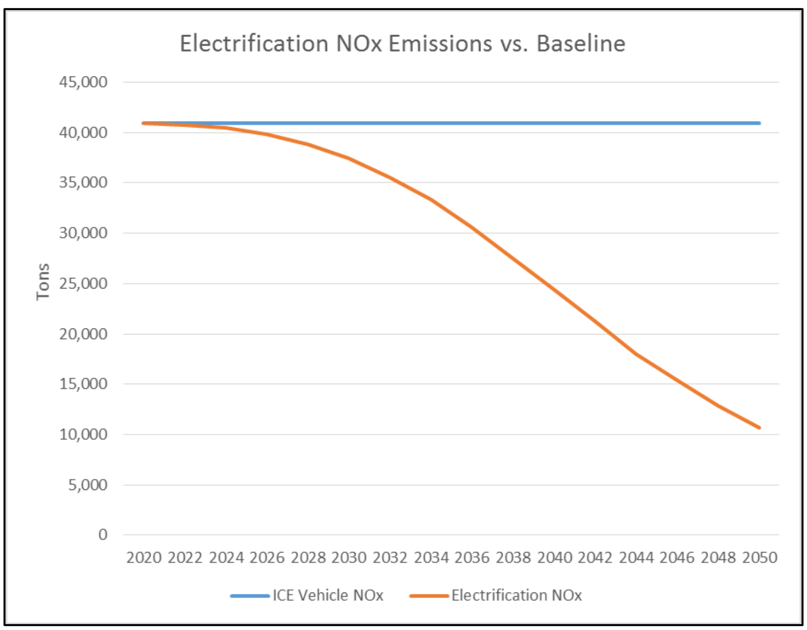
The emission reductions are substantial even in the BAU case, but reductions improve in the Hi-RE generation scenario. The following chart compare the emissions for the sub-group of vehicle that have been electrified between an ICE baseline, and BAU or hi-RE electrification scenarios. Note that the numbers in the following chart are in *billions* of pounds emitted annually,

Figure 7.3: CO2 Emissions Induced By Electrified Vehicles (New Jersey)



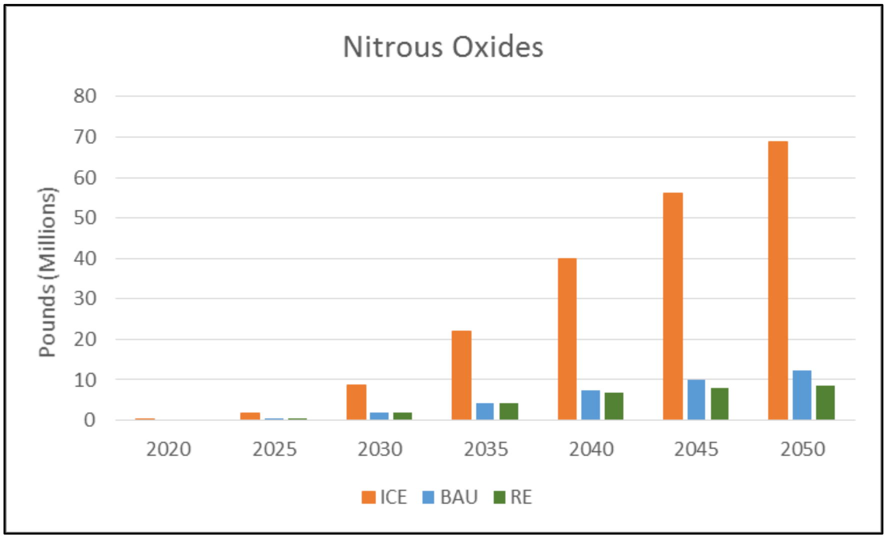
NO2, is a significant criteria pollutant that affects public, personal, and environmental health directly. Traditional vehicles emit a large volume of NOx, typically in high population density areas. Vehicle electrification reduces the absolute amount of NOx emissions (even when the regional net impact is considered), reduces those emissions to zero in travel zones, and displaces those emissions geographically. The following graph shows the reduction in total NOx emissions as electrification increases over time.

Figure 7.4: NOx Emission Reductions Due To Electrification (full vehicle population, New Jersey)



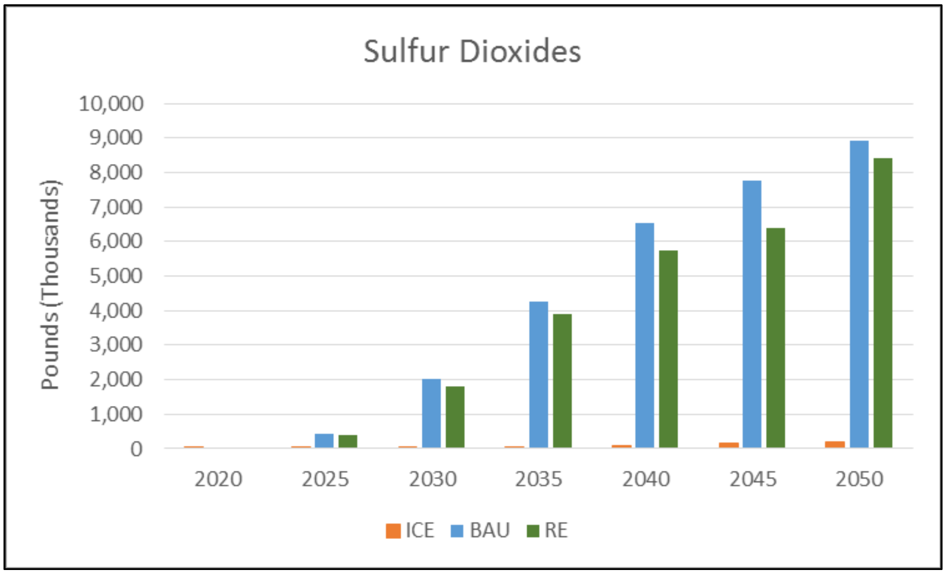
The following graph shows how NOx is reduced between the ICE baseline, BAU, and Hi-RE cases for the subset of vehicles that have been electrified. As with CO2, reductions are enhanced with the supply mix include higher levels of RE.

Figure 7.5: NOx Emissions Induced By Electric Vehicles (New Jersey)



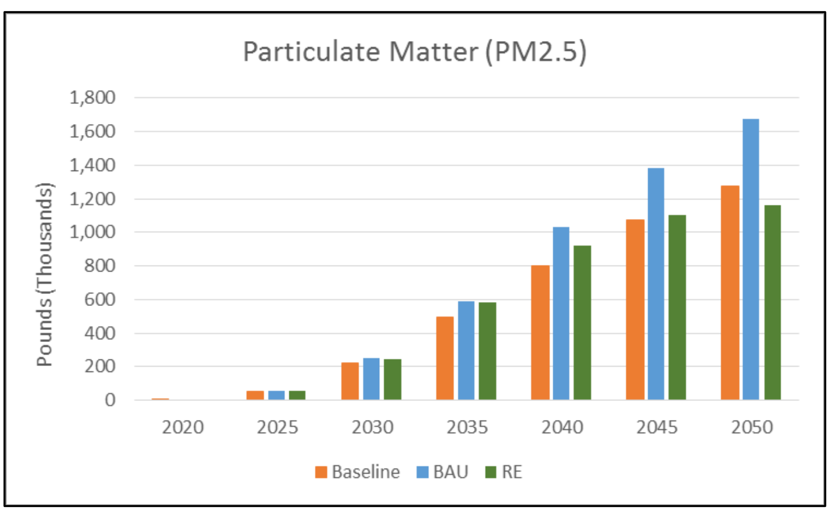
SO2 is an area where vehicle electrification is not beneficial on a regional net basis, especially under current BAU conditions, but it reduces SO2 significantly in travel zones for MHDVs. The primary reason is because LDVs emit virtually no SO2, and they account for the overwhelming majority of VMT (see the 2019 Snapshot). Electricity generation generates SO2, especially in the RFC-east zone (which is the emission accounting policy boundary for this analysis), especially given a significantly amount of coal generation in that zone. Net regional SO2 emissions therefore increase substantially with vehicle electrification in the BAU scenario, but the increase is smaller with higher levels of RE generation. The following graph summarizes how SO2 emission changes for the group of vehicles that have been electrified over time.

Figure 7.6: SO2 Emissions Induced By Vehicle Electrification (New Jersey)



Vehicle electrification results in the elimination of PM2.5 near the travel zones, but displaces it with an increase in the net absolute quantity of emissions at the power plant in the BAU case. The PM2.5 outcome improves significantly with an increased RE supply mix, resulting in both displacement of emissions from travel zones *and* a net reduction in absolute emissions compared with the ICE baseline case.

Figure 7.7: PM2.5 Emissions Induced By Vehicle Electrification (New Jersey)



These results highlight the synergy possible between vehicle electrification and supply de-carbonization.

- CO_2 emissions are reduced massively in the BAU case.
- NO_x is also reduced by a significant degree in the BAU case, in addition to displacement of those harmful emissions from high population density travel zones.
- PM2.5, which has a very large impact on public and personal health and is displaced from the (typically) high population density travel zone in the BAU scenario, *but* the absolute quantity of PM2.5 emissions increases on a regional net basis.
- All three – CO_2, NO_x, and PM2.5 – recognize displacement and absolute reductions in emission quantity at higher levels of RE supply mix.
- SO_2 is displaced from the travel zone, but the absolute quantity of SO_2 emissions increases substantially in all scenarios, but less so with Hi-Re supply.

8 Vehicle Electrification Benefits Through 2050

The study team developed a net benefit model that takes a comprehensive approach to quantifying both benefits and costs. Building on the physical and economic impacts outlined in the sections above, the following benefits were captured in the net benefit model:

- Beneficial changes in the cost of electricity as realized (on their utility bill) directly by all ratepayers, not just EV owners. These benefits result from a) the dilution of utility distribution revenue requirements due to increased electricity consumption induced by vehicle charging, and b) re-shaping of the wholesale supply curve to procure a greater share of energy during less expensive off-peak periods.

- Reductions in vehicle operating expense, due to a) reduced costs associated with charging with electricity compared with fueling with gasoline, and b) reduced maintenance expense. These savings accrue to EV owners as a real cash flow savings.

- The economic value of reduced emissions, including both public health and environmental impact. This part of the model translates net emission reductions into dollar impact using established "cost of emission" factors (see Appendix D on methodology). This calculation is done on a regional net-reduction basis – and probably understates the full benefit since it doesn't directly quantify the fact that emissions are reduced directly in travel zones.

- Many EV drivers also benefit from significant federal tax incentives associated with their vehicle purchase.

These benefits vary between the BAU and high-RE cases, since that affects the degree of emission reductions. They also vary slightly under natural and managed charging scenarios, since that affects the wholesale shaping (although the effect is small). The following four charts summarize the NPV of benefits over the period in all four cases (BAU and RE, natural and managed charging).

Figure 8.0: Summary of Vehicle Electrification Benefits (2021 – 2050)

Benefits	BAU Nat	BAU Man	RE Nat	RE Man
Electricity Cost Savings	$6,581,992,414	$7,592,069,200	$6,489,661,258	$7,265,333,635
PEV Operating Cost Savings	$90,640,730,524	$90,640,730,524	$90,640,730,524	$90,640,730,524
Emission Reduction Savings	$30,206,113,344	$30,206,113,344	$31,564,098,060	$31,564,098,060
Federal Tax Incentives	$1,310,421,272	$1,310,421,272	$1,310,421,272	$1,310,421,272

The most valuable scenario – when considered as an absolute benefit - is widespread penetration of managed charging coupled with simultaneous de-carbonization of the electricity supply (I.e. higher levels of RE). This benefit portfolio is combined with costs (as described in the following section) to determine the net-benefit in each scenario (see Section 10).

9 Vehicle Electrification Costs Through 2050

The net benefit model also captures a comprehensive portfolio of costs associated with the transformation that results from vehicle electrification. All these costs are quantified as the NPV of investments or expenses over the period (from 2021 to 2050). As with benefits, there are BAU, Hi-RE, and Natural charging/Managed charging permutations. The differences between natural and managed charging are most evident in costs, since managed charging avoids both increased capacity and transmission costs (that would otherwise result from additional peaking loads), and the potential need for grid reinforcement longer term.

9.1 Vehicle Electrification Costs

The following costs are included in the model:

- Electricity cost increases associated with increased loading at peak time due to vehicle charging.
- The cost of installing vehicle charging infrastructure.
- The cost premium associated with PEV purchases in all vehicle classes, which declines over time but is significant in the short term.
- The potential need for grid reinforcement, especially replacement or upgrade of secondary single phase transformers.
- The potential cost of a market development program, organized into four categories: the LDV vehicle rebate program, incentives to enable the widespread adoption of Electric School Buses, especially in overburdened communities, charging to enable NJ Transit to attain the electrification goals established in law, and a package of investments related to charging infrastructure. Please see the following section for details on the working assumptions associated with this Market Development Plan.

Figure 9.0: NPV of Vehicle Electrification Benefits: BAU under Natural Charging (2021 – 2050)

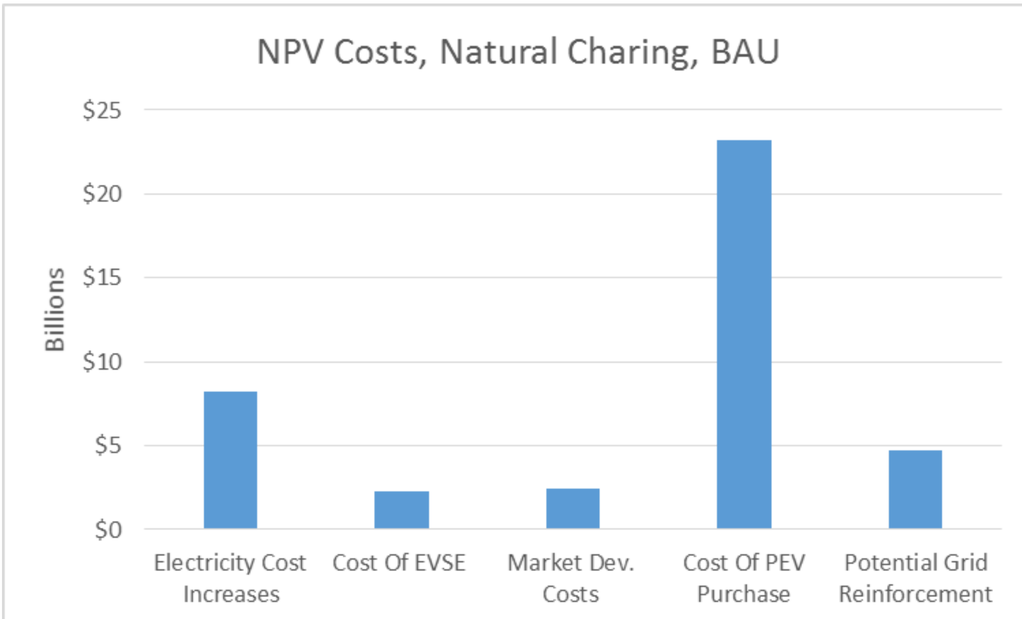


Figure 9.1: NPV of Vehicle Electrification Costs: BAU under Managed Charging (2021 – 2050)

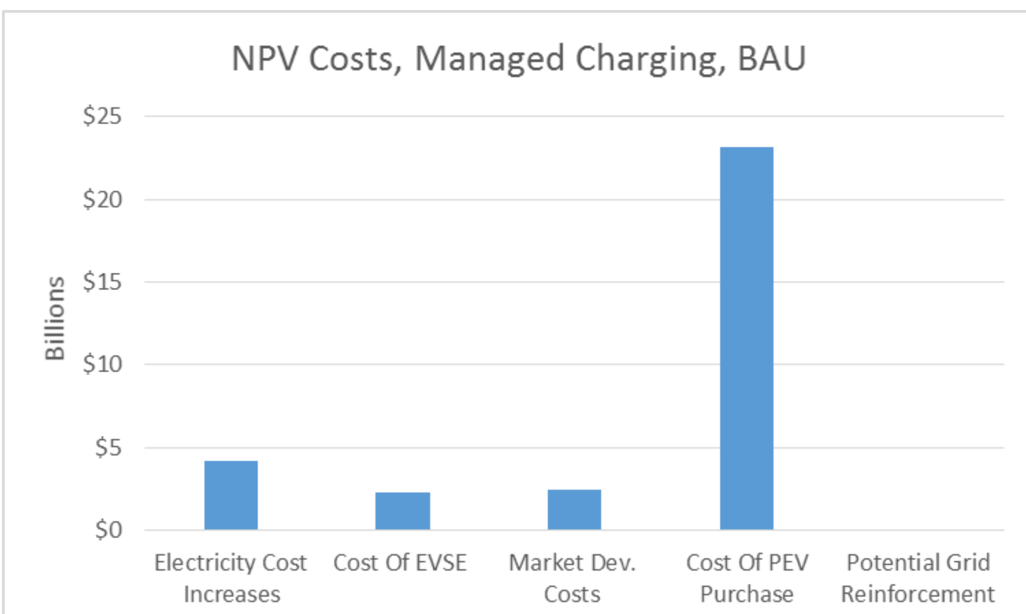


Figure 9.2: NPV of Vehicle Electrification Costs: Hi-RE under Natural Charging (2021 – 2050)

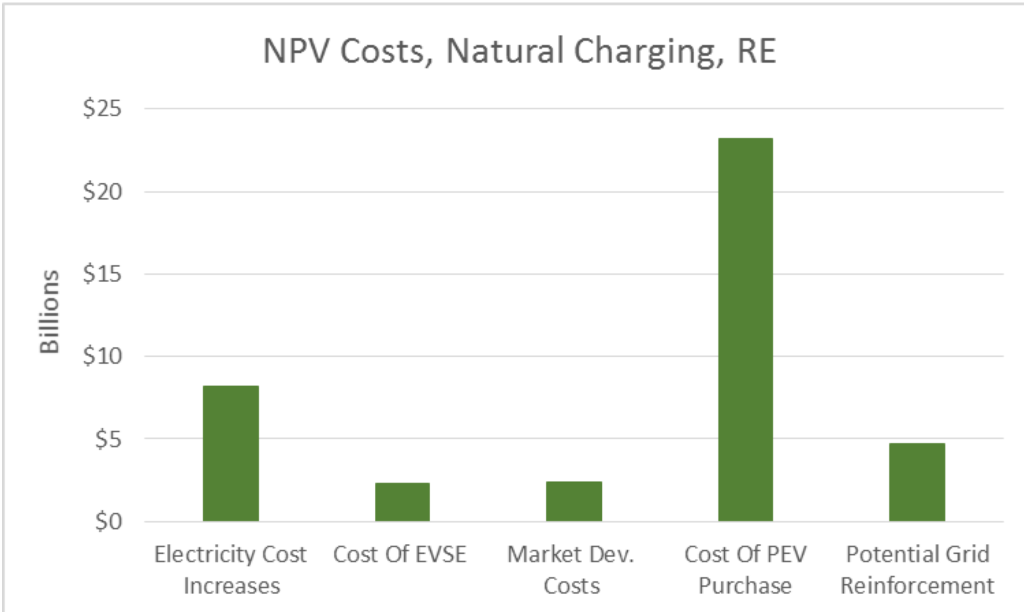
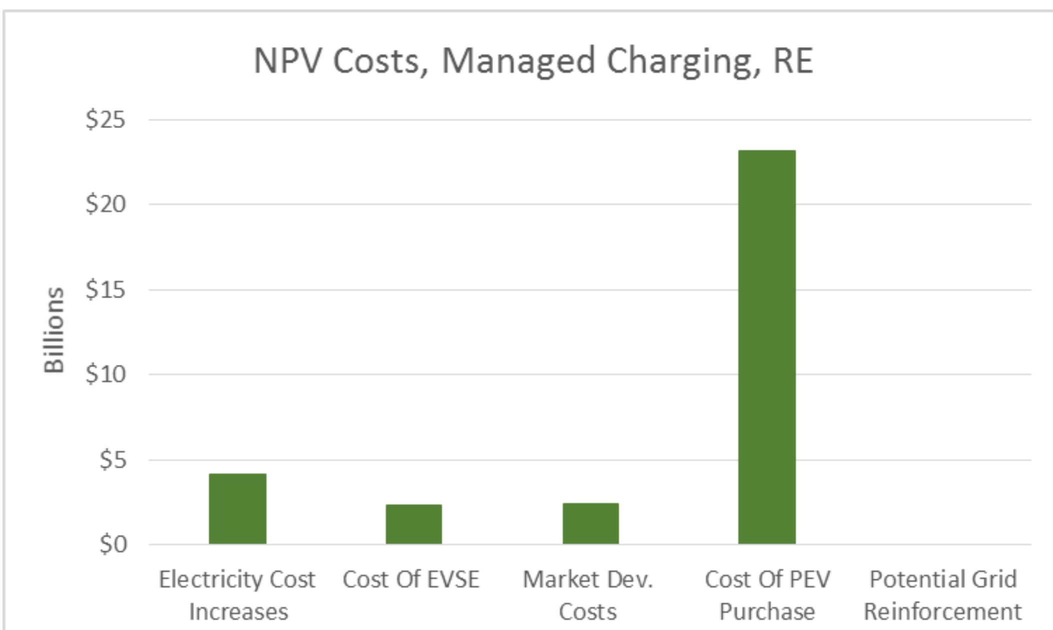


Figure 9.3: NPV of Vehicle Electrification Costs: HI-RE under Managed Charging (2021 – 2050)



9.2 Potential Market Development Program (Working Assumptions)

The study identified a variety of market barriers that could limit the rate of electrification across the full market, especially in some important but challenged vehicle classes. Key barriers identified in the study include:

1. **For LDVs (cars and trucks for personal use) -** Identified barriers are consistent with the challenges identified in the original ChargEVC study:
    - First cost affordability – may LDVs have a purchase price that is $10K-$15K higher their existing ICE equivalents. That is a primary barrier for most mainstream buyers.
    - Range (charge) anxiety – concerns about limited range of a PEV (that concern is fading with more recent models), and also concerns that there are not enough public charging facilities across the state to avoid "getting study" with a discharged battery and no place to charge. A primary strategy for addressing this barrier is accelerated build-out of a critical mass of public fast charging.
    - Consumer awareness – the majority of the LDV market has very limited awareness of PEV availability, their benefits, and the extent of public charging available. There are also a large number of false perceptions that dampen adoption interest.
    - Grid impact mitigation – although this is not an adoption barrier, increased PEV use will bring increased loading on the grid. Programs that help mitigate this impact (such as managed charging programs) have the greatest impact if they are deployed proactively when the market is beginning to grow and consumer behaviors are being established.

2. **School buses** – Electric school buses currently cost two to three times more than their ICE equivalent. There is also very limited "shared operating experience" about these vehicle among the K-12 fleet management community, which is seen as a significant risk factor.

3. **NJ Transit** – Electric buses suitable for transit or inter-city routes are becoming available, and the total cost of ownership is approaching ICE-parity (or in some cases advantageous already). A primary barrier, however, is the charging infrastructure that will be required for these vehicles, especially given that very high power equipment may be necessary. Beyond the cost of the equipment itself, multiple high-power chargers could force major new service upgrades for the depot, and potentially significant local grid reinforcement. Transitioning to an electric fleet is further complicated by the need to sustain operations even when the public grid is down. In short, the equipment, service upgrade, and engineering costs of charging infrastructure are a primary barrier to rapid electrification in this segment.

4. **Long Haul** – Electric versions of Class 8 (or similar) trailers are expected on the market over the next two years, and fleet operators in this segment are very receptive to the reductions in operating expense PEVs can deliver. From that perspective, electrification in this segment could be relatively rapid. However, the long haul segment will require not only depot-based charging but also availability of very high power (200KW – 2,000KW) DCFC along the travel route (i.e. at "truck stops"). The limited number of PEVs on the road in this segment today make private

investment very difficult, and there is very limited ultra-high power fast charging being developed yet. This issue is especially challenging since a long haul route needs charging support along the entire route – and "charging deserts" potentially make the entire route infeasible. Short-haul PEVs (especially drayage applications) may be more feasible short term, but long-haul applications will depend on robust build-out of the very high-power charging infrastructure needed.

5. **Multi-Family** – although the charging technology for this segment is very common (a standard L2 charger), this segment has been very slow to provide the solutions needed by residents living in multi-family settings. Landlords are generally unwilling to make specialized investments of this type, especially since only a few residents may benefit, and the installations can be very expensive (trenching through parking lots, etc). Structurally, this segment suffers from the fact that the person making the investment (the landlord) is different than the person receiving the benefit (the PEV owner). This economic barrier has limited charging infrastructure investment in this segment, which in turn has severely limited PEV adoption.

6. **Commercial Charging** – there are several application scenarios on commercial properties, including chargers for use by employees, chargers for LDV fleet vehicles, and higher-powered "depot-style" chargers for fleets MHDVs.

To address these barriers, the following "next generation" market development program was included as a working assumption for the study. Please note that this a set of assumptions for purposes of providing a comprehensive view on electrification costs, and in some cases should be viewed as initial proposals that would require significant additional socialization and refinement. This program augments some of the recommendations contained in the original study, and has been expanded to include the needs of MHDVs. Some of the initiatives noted are already underway (at least in part):

1. **For LDVs (cars and trucks for personal use):**
    - **LDV purchase rebate** ($30M/year for 10 years): As authorized in law, and already being implemented by the BPU.
    - **Residential Smart Charging Program** ($157M over 10 years): This program is intended to encourage off-peak charging and to establish a foundation for broader managed charging programs. It includes a smart charger incentive (assumed to be $500 each for 150,000 customers), plus an off-peak incentive (assumed to be equivalent to 5 cents/kwhr from 2021 – 2025, and 3 cents/kwhr from 2025 – 2030).
    - **LDV public fast charging** ($77.3M from 2021 thru 2030) – a program to build out the critical mass of compliant public DCFC authorized in law, including a) a capital buy-down component ($200K per corridor location, $150K per community location), b) a make-ready ($100K per location), and c) a demand charge offset ($20K per operating location through 2030).
    - **Consumer Awareness Campaign** ($1M/yr from 2021 thru 2025)

2. **School buses:** A capital grant program supporting 12,000 school buses (out of ~15,000 currently in service), with a priority on over-burdened communities. The grant is designed to cover the

incremental cost of an electric school bus over the cost of an ICE equivalent, starting at $150K per bus in the first year, declining linearly to $100K per bus by 2030.

3. **Charging For NJ Transit:** An initiative to support the purchase of medium and high-power charging systems, including design and construction, totaling $10M for each of 16 current NJ Transit bus depots.

4. **Long Haul:** A focused initiative to build at least four very high powered DCFC at each of 100 truck stops (or similar locations) in New Jersey. Include funding for the charger ($200K per charger), and $250K per location for the make-ready.

5. **Multi-Family:** Funding for the charger ($5K each, for 4,000 chargers total), and the required make-ready ($50K per location, 1000 locations).

6. **Commercial Charging (LDV and MHDV):** Incentives to enable Workplace, L2 Fleet, MHDV Fleet installations. Key assumptions include $30K per site for 4 dual-port L2 chargers at 4,000 commercial sites (for workplace and LDV fleet applications), and 4,000 50KW (average) chargers for depot-style MHDV charging ($25K per charger, covering half the cost).

As noted above, this preliminary market development program is used within the study as a set of working assumptions to allow a comprehensive accounting for potential costs, including new initiatives associated with the MHDV segments. Developing a "Full Market Development Roadmap" will require significant further socialization, cost refinement, and prioritization.

10 Net Benefits Of Vehicle Electrification

The net-benefit model computes a net benefit ratio, quantified as the Net-Present-Value (NPV) of the expected benefits (described in Section 8) divided by the NPV of the projected costs (described in Section 9). When that ratio is above 1.0, the overall program can be considered beneficial since benefits exceed costs. The use of NPV accounts for the fact that the benefits and costs vary over time.

The portfolio of benefits and costs is very broad, and it considers impacts on EV owners, utility ratepayers, and society at large. As with the benefits and costs summarized above, there are four variations of the net benefit test, with permutations based on BAU and RE power mix, and natural and managed charging scenarios. Those four permutations are illustrated in the charts below.

All scenarios are beneficial, with a benefit/cost ratio greater than 1.0. The greatest benefit is realized in the case where a Hi-RE power mix is coupled with widespread managed charging, especially for utility ratepayers.

Figure 10.0: Net-Benefit of Vehicle Electrification: BAU under Natural Charging (2021 – 2050)

2050 Costs and Benefits, Natural Charging, BAU	Benefit	Cost
Benefit: Electricity Cost Reductions	$6,581,992,414	0
Benefit: PEV OpEx	$90,640,730,524	0
Benefit: Emission Reductions	$30,206,113,344	0
Benefit: Federal Tax Incentives	$1,310,421,272	0
Cost: Electricity Cost Increases	$0	$8,205,793,374
Cost: Private EVSE Investment	$0	$2,305,202,365
Cost: Utility Incentives	$0	$2,080,583,882
Cost: Incremental PEV Costs	$0	$23,211,430,150
Cost: Potential Grid Reinforcement	$0	$4,724,988,015
Total:	**$128,739,257,554**	**$40,527,997,787**
Benefit To Cost Ratio:	**3.18**	
NPV of Net Benefits:	**$88,211,259,767**	

Figure 10.1: NPV of Vehicle Electrification Benefits: BAU under Managed Charging (2021 – 2050)

2050 Costs and Benefits, Managed Charging, BAU	Benefit	Cost
Benefit: Electricity Cost Reductions	$7,592,069,200	0
Benefit: PEV OpEx	$90,640,730,524	0
Benefit: Emission Reductions	$30,206,113,344	0
Benefit: Federal Tax Incentives	$1,310,421,272	0
Cost: Electricity Cost Increases	$0	$4,164,364,790
Cost: Private EVSE Investment	$0	$2,305,202,365
Cost: Utility Incentives	$0	$2,080,583,882
Cost: Incremental PEV Costs	$0	$23,211,430,150
Cost: Potential Grid Reinforcement	$0	$0
Total:	**$129,749,334,341**	**$31,761,581,187**
Benefit To Cost Ratio:	**4.09**	
NPV of Net Benefits:	**$97,987,753,153**	

Figure 10.2: NPV of Vehicle Electrification Benefits: Hi-RE under Natural Charging (2021 – 2050)

2050 Costs and Benefits, Natural Charging, RE	Benefit	Cost
Benefit: Electricity Cost Reductions	$6,489,661,258	0
Benefit: PEV OpEx	$90,640,730,524	0
Benefit: Emission Reductions	$31,564,098,060	0
Benefit: Federal Tax Incentives	$1,310,421,272	0
Cost: Electricity Cost Increases	$0	$8,205,793,374
Cost: Private EVSE Investment	$0	$2,305,202,365
Cost: Utility Incentives	$0	$2,080,583,882
Cost: Incremental PEV Costs	$0	$23,211,430,150
Cost: Potential Grid Reinforcement	$0	$4,724,988,015
Total:	**$130,004,911,114**	**$40,527,997,787**
Benefit To Cost Ratio:	**3.21**	
NPV of Net Benefits:	**$89,476,913,327**	

Figure 10.3: NPV of Vehicle Electrification Benefits: HI-RE under Managed Charging (2021 – 2050)

2050 Costs and Benefits, Managed Charging, RE	Benefit	Cost
Benefit: Electricity Cost Reductions	$7,265,333,635	0
Benefit: PEV OpEx	$90,640,730,524	0
Benefit: Emission Reductions	$31,564,098,060	0
Benefit: Federal Tax Incentives	$1,310,421,272	0
Cost: Electricity Cost Increases	$0	$4,164,364,790
Cost: Private EVSE Investment	0	$2,305,202,365
Cost: Utility Incentives	0	$2,080,583,882
Cost: Incremental PEV Costs	0	$23,211,430,150
Cost: Potential Grid Reinforcement	0	$0
Total:	**$130,780,583,491**	**$31,761,581,187**
Benefit To Cost Ratio:	**4.12**	
NPV of Net Benefits:	**$99,019,002,304**	

11 Conclusions and Recommendations

The study included a deep look at a real-world schedule for electrification across vehicle classes, a Snapshot of what 80% electrification would look like if applied as a thought-experiment to 2019, a multi-year estimate of key vehicle cost differences during the electrification transition, and a detailed multi-year model that quantifies market-wide physical impacts, benefits, costs, and net-benefits. This analysis illuminated both opportunities and challenges associated with attaining a high level of electrification, as summarized in the Findings and Recommendations sections below.

11.1 Summary Of Key Findings

The study quantified the impacts of electrification of both LDV and MHDV, while considering both the opportunities and challenges associated with that electrification. Key insights from that analysis are as follows:

- When considering *net* benefits in a comprehensive way over the transformation period (2021 – 2050), electrification delivers strong advantages. **In the best case, when managed charging and increased renewable use are widespread, benefits exceed costs by approximately a factor of four.**

- The study provides insight on the ultimate technical opportunity associated with widespread vehicle electrification. **Market-wide electrification (including diesel vehicle classes) delivers substantial benefits in operational expense savings (cost of fueling and maintenance), emission reductions for key pollutants (especially as renewable energy becomes more prevalent), and downward pressure on electricity rates for all ratepayers.** Petroleum use is displaced by an increase in electricity use, and at 80% electrification about 30% of electricity will be used for vehicle charging.

- A detailed multi-year analysis of direct vehicle expenditures (new vehicle purchases, fueling, and maintenance) from 2021 through 2050, based on the electrification schedule developed in the study for all vehicle classes, indicates that New Jersey vehicle owners will spend less in the electrification scenario than if they continued purchasing and using ICE vehicles. **Electrification is a lower cost option compared with the no-EV baseline, saving 9% (nominal sum) over the period, or approximately $140B.**

- A high level of electrification, up to 80% by 2050, is attainable in most segments based on a detailed assessment of vehicle availability, cost effectiveness, and market readiness. The electrification schedule analysis also considered the natural retirement rates of different vehicle classes, and the rate at which different segments of customers (innovators, mainstream, etc) will adopt the new PEV technology over time. **Some vehicle classes are far more ready for rapid adoption than others, and several segments face unique challenges.**

- Although some MHDV segments are poised for growth in New Jersey, there has been little deployment in those segments other than through the DEP Consent Order Program. **Several**

vehicle classes are particularly strategic for accelerated development either because of their large potential impact, and/or because they are especially competitive with traditional ICE vehicles today and less constrained by market barriers. Those segments include medium-duty local delivery vehicles, refuse trucks, non-school-buses, and short-haul applications (especially drayage). Electrification in those segments are likely much more feasible than is widely recognized. **Although these segments are well suited for more rapid electrification, market development is needed to address key barriers, primarily regarding charging infrastructure.**

- **Two MHDV classes are highly strategic, but are particularly challenging: School buses and Long Haul vehicles.** School buses should be a top priority since it directly affects the health of K-12 school children and the communities in which they live. Yet our analysis indicates that the school bus segment is extremely challenging economically (and in other ways), especially for budget-constrained local school districts. School buses therefore represent one of the most strategic electrification priorities, but one of the lowest levels of "market readiness" for rapid electrification. That segment is unlikely to transition to electric vehicles without significant subsidization. The other key segment is long haul vehicles (such as tractor-trailers moving freight), which account for a large fraction of NOx and SO2 emissions. Although PEV tractors are quickly moving into the market, and are likely to be economically competitive (given the high sensitivity of that segment to fuel-cost and maintenance savings), that segment is heavily constrained by the current lack of very high powered fast charging along long haul routes. Until a high level of fast charging is available at truck stops and similar sites, including development of *regional* fast charging corridors, fleet operators won't electrify for long haul applications. **Both of these segments would benefit from specialized market development programs to overcome these significant market barriers.**

- **LDV and MHDV both deliver benefits from electrification, but in different ways.** LDV electrification is the primary driver of fuel cost savings, lower electricity rates, and lower GHG gases. The MD-duty segments also reduce GHG emissions, but play an even larger role delivering improvements in public health, especially for overburdened communities along travel routes where harmful air emissions are concentrated. There are therefore significant equity dimensions to MH-duty electrification. **Distinguishing these different electrification motivations is critical to creating a policy framework that is well aligned with various strategic goals.**

- **Emissions of all types – including criteria pollutants that impact public health – are reduced dramatically in the travel zones.** On a regional net basis (after accounting for increased emission at the power plant), there are still large reductions in CO2 and NOx, and those reductions are larger when the generation mix shifts to high levels of renewable energy. PM2.5 net-emissions increase slightly in the case of BAU generation, but decline significantly in the Hi-RE case. Although electrification decreases SO2 emissions in the travel zones, there is a substantial net increase in all cases regionally. **The "geographic displacement" that results from electrification is significant, in addition to the absolute reduction of emissions that occurs for several key pollutants.**

- Access to vehicle charging infrastructure is an especially critical consideration in the MHDV segments, potentially representing more of a barrier than in the LDV segments. At the same time, charging for MH-duty vehicles – either at depots or at public charging stations – could potentially have much higher grid impacts due to the need for much faster charging (50KW or above in many cases, up to several MW per charger). **Both LDV and MH-duty segments represent significant grid integration implications – but for different reasons.** LDVs impose a very large number of relatively small charging loads (i.e., ~6 million 3-7KW chargers), whereas the MH-duty vehicles will require a relatively small number of relatively high-powered chargers in many case (about 300K 50KW (average) chargers, plus ultra-high chargers at truck depots and other similar settings). **For these MH-duty segments, the charger implications are significant, but may be easier to deal with since those fleet vehicles are served at a relatively small number of locations.**

- Managed charging is a strategic priority in anticipation of higher levels of electrification, especially in the residential charging segment. Managed charging – through a combination of technology and economic incentives - can mitigate the impact of vehicle charging on the grid substantially. **In general, managed charging reduces grid impact by a factor of 3 – 4, depending on the extent of program adoption and its efficacy.** This pre-emptive approach to load mitigation brings advantages in terms of avoided capacity and transmission costs, and deferred or avoided grid reinforcement. This outcome is evident in the difference in the net-benefit outcomes between the natural and managed cases: the benefit/cost ratio (in the BAU case) is 3.18 in the natural charging case, compared with 4.09 when managed charging is dominant.

- **Electricity pricing, and the structure of that pricing, has a strong impact on vehicle charging and infrastructure investment behaviors.** Existing tariff designs may be missing desired inducements, or may create barriers to charging infrastructure investment. Commonly used residential tariffs typically don't encourage the off-peak charging that is most optimal. The demand charges associated multi-family, workplace, fleet, and public charging applications can make investment economics challenging, especially during early market phases when utilization is lower. Those impacts will be even more impactful for the higher-powered charging solutions that will be needed by many MHDVs. At the same time, serving these new charging-induced loads could change the cost of service for utilities providing that power, which needs to be a consideration in the allocation of costs and overall rate design.

- **The quantification of emissions associated with vehicle electrification is very dependent on the choice of accounting methodology.** This study is aligned with emerging guidance from the DEP on that methodology, based on considering emissions for New Jersey within the RFC-East region. Alternative accounting scenarios would produce different electrification impact results, with particular implications for how higher levels of renewable energy synergize with PEV use. Establishing formal policy regarding those accounting methods, and alignment of those methods with State goal attainment measurement, will facilitate policy analysis associated with vehicle electrification.

11.2 Policy Implications and Recommendations

Given the key findings noted above, the study team highlights several market development policy implications and associated recommendations.

1. Sustained high adoption levels in the LDV segments is critical to attaining the goals already established for the State but are also attainable. Existing programs to address known barriers should be continued and strengthened where possible, including the LDV vehicle rebate program, the initiative to achieve geographic density of fast public chargers, and marketing efforts to improve consumer awareness.

2. Residential managed charging is a strategic priority, and policy development and supporting programs have not yet been established in New Jersey. Without pro-active programs to encourage and guide changes in consumer charging behavior, managed charging is unlikely to emerge. The study team recommends focused prioritization of policies and programs associated with residential managed charging, including consideration of both the technology and economic incentive components that are required. Similar programs in commercial sectors may eventually be needed as well, especially as solar generation becomes more dominant (with a high level of daytime generation).

3. Balancing the needs of the PEV market for supportive rate designs (and other economic incentives) with the needs for fair cost allocation and recovery will be a key policy priority as the market matures. These considerations apply in multiple segments, including residential (to encourage off-peak charging), and C&I rates for workplace, fleet, and public charging applications.

4. The research highlighted how diverse different vehicle classes are, especially within the diesel displacement segments. Market development planning would benefit from goal-setting and development priorities on a per vehicle-class basis.

5. Increasing EV adoption, while simultaneously changing the supply mix to include higher levels of clean energy, is highly synergistic. All the benefits associated with vehicle electrification, as quantified in this study, are amplified when combined with a high-RE power mix.

6. Several diesel segments are especially ripe for electrification, but would benefit from policy support associated with vehicle charging in particular. Those segments include medium-duty local delivery vehicles, refuse trucks, non-school-buses (including NJ Transit, where charging infrastructure is a key barrier), and short-haul drayage. The readiness of these segments make it possible to accelerate diesel displacement short term.

7. Two other segments will likely only electrify if supported by strong policies: school buses – where vehicle first cost is the primary barrier, and long haul tractors – where widespread availability of high powered chargers at truck stops and similar locations is needed.

8. Charging infrastructure is a particularly difficult issue for MHDV segments, more so than for LDV. Programs to address those barriers, potentially with the close involvement of the electric utilities so that grid integration issues can be considered and dealt with based on emerging best practices, will be critical to success in those segments.

9. The study team has developed working assumptions for a four-part market development initiative, including new programs to support electric school bus adoption, charging infrastructure for NJ Transit, the LDV vehicle purchase rebate, and a variety of other programs associated mostly with charging infrastructure for the diesel segments. Even when including the costs for these programs as part of the market-wide net-benefit analysis, vehicle electrification is still strongly positive. The team proposes the following portfolio of initiatives as a starting point for a comprehensive, statewide program to encourage electrification across all vehicle classes (some of these programs are already underway or proposed in some form).

    - **Electric School Bus Program** – to improve equitable access to PEV benefits by addressing first-cost barriers.

    - **Charging For NJ Transit** – to address charging infrastructure needs in support of the electrification goals established in law.

    - **LDV Rebate Program** – to address first cost issues in the LDV segment, and to ensure attainment of the vehicle adoption goals established in law.

    - A package of initiatives that address **charging infrastructure** needs across all segments, including new programs for diesel displacement opportunities:
        a) Residential managed charging initiative
        b) LDV high power public charging initiative
        c) Multi-family EV access program
        d) Commercial charger program (workplace and fleet, including MH-duty)
        e) High power charging for long haul segments (at truck stops)
        f) Market awareness campaign

11.3 Areas For Further Study

Throughout the study process, several opportunities for expanded investigation were identified, including:

1. Socialization, right-sizing, cost-refinement, and prioritization of the market development working assumptions, leading to development of a consensus Full-Market Development Roadmap.

2. With the addition of MHDVs to the project scope, criteria pollutants become much more significant, and the public health value of electrification comes into focus. Many of these pollutants have geographic dimensions – i.e. they tend to settle near the point of emission. The

study could be expanded to consider the geographic aspects of emission displacement, especially regarding the impact on overburdened populations near heavy travel zones. These emission reductions could be translated to specific public health change metrics.

3. More detailed consideration of the synergy between RE and EV adoption, including evaluation of a) coincidence in timing, and b) incremental costs of RE.

4. Given the scope feasible within this study, a relatively simple model for MHDV charging was developed to allow statewide assessment of the charging needs (and costs) for those segments. The model could be easily extended to define a MHDV charging ecosystem, similar to what was developed for the LDV market. That extension would allow for more a more granular assessment of costs and potential grid impacts.

5. Explore the use of Vehicle-To-Grid (V2G) technology to shave peak, in addition to using EVs to increase loading during the "trough times" overnight. This development has a close linkage with modeling of renewable energy supply, since solar and wind each have very different time-of-day profiles.

6. There are a wide variety of broader benefits that have been identified qualitatively but which have not been factored into the benefit portfolio. Examples include benefits that might accrue to sites that host public charging infrastructure (more customers), the benefits to non-EV drivers of softening petroleum demand and lower gasoline prices, how load optimization might lower prices for PJM customers outside of New Jersey, more detailed quantification of potential grid reinforcement costs (as impacted by managed charging programs), etc.

Appendix A: Glossary of Terms and Acronyms

Battery Electric Vehicles (BEV) – a vehicle that operates exclusively on electricity from a source external to the vehicle; these vehicles are powered by a rechargeable battery and do not have a traditional gasoline or diesel engine

British Thermal Unit (BTU) –the amount of energy required to increase the temperature of one pound of water by one degree Fahrenheit.

Business-As-Usual Case (BAU) – assumes that the mix of resources used to generate electricity continues under known changes (plant retirements) and the existing Renewable Portfolio Standard(s) (RPS). It does not include renewable energy use beyond what is required in the RPS.

CCS – a global industry standard for fast charging up to 350 kilowatts; supported by many EV models from many countries (BMW, Daimler, Ford, Volkswagen, etc.)

CHAdeMO – the first fast-charging platform for electric vehicles; a global industry standard for fast charging typically compatible with Japanese EV models (Toyota, Nissan, Mitsubishi, etc.)

Direct Current Fast Charger (DCFC) – typically a 3-phase 480-volt AC device that delivers DC current directly to the battery; this fast charging charges vehicle batteries much more quickly, and is essential for long-distance traveling or large fleets.

Global Warming Response Act (GWRA) – signed in 2007, the GWRA calls for reducing greenhouse gas emissions to 1990 levels by 2020 and 80% below 2006 levels by 2050

Heavy- Duty Vehicles (HDV) – vehicles weighing over 26,001 pounds; this class includes refuse trucks, semi tractors, dump trucks, etc.

High-Renewable Energy Case (RE) – assumes that over time the power mix shifts to an increased fraction of electricity coming from renewable energy sources such as solar and wind.

Internal Combustion Engine (ICE) – an engine that burns fossil fuels (usually gasoline or diesel) to produce thermal energy and move the vehicle.

Level 1 Charger (L1) - provides charging through a 120V AC current (a standard household outlet); a relatively low powered charging option typically used for longer charging sessions and overnight sessions, especially for vehicles with smaller batteries.

Level 2 Charger (L2) – supplies an electric vehicle with 240V AC current; typically used for longer charging sessions and overnight sessions, these chargers are well suited to vehicles with larger batteries, and can be found in residential, commercial, and public use segments.

Light-duty Car (LDC) – passenger cars; cars with a maximum Gross Vehicle Weight Rating (GVWR) less than 8,500 pounds

Light-duty Truck (LDT) - passenger trucks; trucks with a maximum Gross Vehicle Weight Rating (GVWR) less than 8,500 pounds; this classification includes SUV's, crossovers, minivans, most pick-up trucks, etc.

Light-Duty Vehicle (LDV) – vehicles with a maximum Gross Vehicle Weight Rating (GVWR) less than 8,500 pounds, and is an umbrella term that includes both LDCs and LDTs.

Medium-Duty Vehicles (MDV) – vehicles weighing between 8,501 pounds and 26,000 pounds; class includes delivery trucks, large pick-up trucks, box trucks, utility vehicles, etc.

Medium- and Heavy-Duty (MHDV) Vehicles – A collective term that includes both MDVs and HDVs.

New Jersey Board of Public Utilities (BPU) – the regulatory authority that oversees New Jersey's regulated utilities (natural gas, electricity, water, telecommunications, and cable television).

New Jersey Department of Environmental Protection (DEP) – state government agency tasked with addressing environmental issues (air quality, water monitoring and standards, waste management, site remediation, etc.) and managing natural resources (land use, forest management, fish and wildlife management, etc.).

New Jersey Energy Master Plan (EMP) - a plan issued by the BPU, which aims to move New Jersey towards 100% "clean" energy by 2050; focuses include 100% carbon-neutral electricity generation; "greener" buildings and transportation; increased deployment of renewable energy; maximizing efficiency; decreasing peak demand; modernizing energy systems; and other key goals and strategies

New Jersey Integrated Energy Plan (IEP) – informs New Jersey's Energy Master Plan (EMP) by modeling the simultaneous transition of energy use in multiple segments (transportation, building energy use, electricity generation) in an integrated way; models the most cost-effective strategies to meet targets and goals while still providing enough energy to support the state's economy.

Pennsylvania-New Jersey-Maryland Interconnection (PJM) – a regional transmission organization (RTO) that coordinates, controls and monitors the regional electric grid that serves Pennsylvania, New Jersey, Maryland, Delaware, Virginia, West Virginia, Ohio Washington DC, and parts of Illinois, Indiana, Tennessee and Kentucky.

Plug-In Electric Vehicle (PEV) – any vehicle that plugs in to charge a battery to either fully or partially operate; this designation is made up of all Battery Electric Vehicles (BEV) and Plug-In Hybrid Electric Vehicles (PHEV).

Plug-In Hybrid Electric Vehicle (PHEV) – a vehicle that can operate, for a limited range, using only a rechargeable battery, but can also function using a traditional gasoline or diesel engine to recharge the battery or power the vehicle directly.

Source Type (ST) – vehicle classification segments used in the EPA's Motor Vehicle Emission Simulator (MOVES) and throughout this report, similar to a vehicle segment.

United States Energy Information Administration (EIA) – a statistical agency of the Department of Energy; collects, analyzes, and disseminates energy information to promote sound policymaking, efficient markets, and public understanding

United States Environmental Protection Agency (EPA) – an independent executive agency of the united states government that sets and enforces national pollution-control standards and is tasked with the protection of human health and the environment

Vehicle Miles Traveled (VMT) –the total number of miles traveled by a group or class of vehicles; this statistic considers the overall VMT of vehicles registered in New Jersey as well as the VMT of those vehicles operating within the State's geographic borders. VMT is affected by both the number of vehicles on the roads, and the average number of miles each vehicle travels each year.

Appendix B: ChargEVC Members

The following list summarizes all ChargEVC members as of the date of this study. Please go to www.chargevc.org for more details.

1. Arrival
2. Association of NJ Environmental Coalitions (ANJEC)
3. Atlantic City Electric
4. BYD
5. Climate Change Mitigation Technologies
6. Center for Sustainable Energy
7. Clearview Energy
8. Environment New Jersey
9. Environmental Defense Fund
10. EvBox
11. EVgo
12. Fuel Force/Multiforce Systems Corp
13. Greenfaith
14. Greenlots
15. Independent Energy Producers of NJ (IEPNJ)
16. Isles, Inc.
17. Jersey Central Power & Light
18. Natural Resources Defense Council
19. New Jersey Coalition of Automotive Retailers
20. New Jersey Clean Cities Coalition
21. New Jersey League of Conservation Voters
22. New Jersey State Electrical Workers Association/International Brotherhood of Electrical Workers
23. NJR Clean Energy Ventures
24. Plug-In America
25. Proterra
26. PSE&G
27. Rockland Electric
28. Sierra Club NJ Chapter
29. Sussex Rural Electric Cooperative
30. Tesla
31. Union of Concerned Scientists
32. Work Environmental Council

Appendix C: Current New Jersey Market Conditions

PEVs have been available in New Jersey since the introduction of first-generation vehicles in 2010, and those sales have generally increased year-over-year. The state has been actively developing policies, programs, and market development initiatives. This section outlines New Jersey's market conditions at the current time:

- **The ZEV MOU and State Goals:** Many of the "Section 177" states developed and signed on to a regional Memorandum of Understanding (MOU). This MOU outlined a variety of EV market development policies and programs intended to encourage accelerated adoption of EVs in the participating states. Primary elements of the MOU include a commitment to certain levels of EV penetration (approximately 5% of the LDV population by 2025), and development of the infrastructure necessary to support those vehicles. Governor Murphy committed New Jersey to this multi-state MOU in April of 2018.[k] Like the Section 177 opt-in, participation in this initiative positions New Jersey as a market leader, helps attract EV inventory to the state, and stimulates the programs necessary to achieve the stated goals. Consistent with the MOU, the State has communicated a goal of 330K EVs on New Jersey roads by 2025. This objective is consistent with the short-term goals identified in the ChargEVC roadmap. In 2018, the participating states released an updated "ZEV Task Force Multi-State ZEV Action Plan" that lays out priority strategies and actions for the Task Force to take, a summarization of the Task Force's work since the initial 2014 plan, and provides recommendations for automakers, utilities, dealers and other key stakeholders to effectively collaborate and support the continued adoption of electric vehicles.[l]

- **New Jersey's "EV Law":** On January 17, 2020, Governor Murphy signed Senate Bill S-2252 into law (P.L. 2019, c. 362) creating one of the most comprehensive and progressive set of electric vehicle policies in the country. The law establishes a number of formal state goals for vehicle adoption and infrastructure development including:

    a) 300,000 LDV-PEV's registered in New Jersey by 2025;
    b) Two million LDV-PEV's registered in New Jersey by 2035;
    c) PEV's are 85% of LDV-sales in NJ by 2040;
    d) At least 400 public DCFC at 200 locations, covering both corridor and community sites, with specific requirements on high power, open standards, and geographic density;
    e) 1,000 public L2 chargers;
    f) Increased access to L2 chargers for multi-family property residents (15% of properties by 2025, increasing to 30% by 2030);
    g) Increased access to L2 chargers for hotel guests (20% of hotels by 2025, increasing to 50% by 2030).

[k] https://www.nj.gov/governor/news/news/562018/approved/20180403b_emissions_standards.shtml

[l] 2018 ZEV Task Force, Multi-State ZEV Action Plan; http://www.nescaum.org/documents/2018-zev-action-plan.pdf

h) Electrification of the state fleet (25% of the non-emergency vehicles electrified by 20205 and 100% by 2035) and NJ Transit buses (gradually increasing to 100% of new purchases to be zero-emission by 2032).

The law empowers various agencies, especially the BPU and DEP, to take action to realize these goals through market tracking and compliance reporting, setting goals for diesel displacement, and implementing programs for consumer awareness building. The BPU is specifically authorized to implement "rules and regulations" required to realize the goals of the act which is intended to cover the rebate programs and consideration of utility infrastructure filings. The new law also establishes a cash-on-the-hood rebate program for the purchase or lease of a new PEV (BEV and PHEV initially, then BEV only after 2022). The rebate, which is deducted from the sale price by the dealer at a rate of $25/mile of electric range (up to $5,000 per vehicle) is currently funded at $30 million per year for ten years. Additionally, the BPU is authorized (but not required) to offer a rebate program for residential vehicle chargers up to a maximum of $500.

- **Inter-Agency Partnership (Partnership to Plug-In):** To facilitate realization of the MOU goals, and in support of broader vehicle electrification priorities being identified by the State, Governor Murphy announced a new inter-agency partnership in June of 2019.[m] The New Jersey Board of Public Utilities (NJBPU), the NJDEP, and the Economic Development Authority (EDA) have formed the "Partnership to Plug-In" to coordinate agency activities on EV market development, especially as it relates to charging infrastructure. The partnership is actively developing mapping to inform the most effective locations for publicly accessible charging locations, particularly DCFC locations on or near major traffic corridors.

- **Vehicle Electrification in the EMP and IEP:** As required by law, the State is required to periodically update its Energy Master Plan (EMP) and, this year, the Murphy administration released a comprehensive new plan that, for the first time in a New Jersey EMP, identifies vehicle electrification as a primary strategy for realizing GHG reductions, among other anticipated benefits. While the plan aims to move New Jersey towards 100% "clean" energy by 2020 (100% carbon-neutral electricity generation) through a variety of strategies, the plan recognizes the unique and potentially transformative potential of electrifying the transportation sector and the crucial importance of electrification in meeting state climate goals. The state's Integrated Energy Plan (IEP) informs the EMP by modeling the most cost-effective strategies to meet targets and goals whiles still meeting the needs of the state's economy. These activities are expected to significantly enhance the EV market conditions in New Jersey, and to accelerate EV adoption over time as a result.

- **Sales Tax Exemption:** The New Jersey legislature implemented a state sales tax exemption for Zero Emission Vehicles (ZEVs, N.J.S.A. 54:32B-8.55) as defined under the California Zero Emission Vehicle program. The incentive applies to any ZEV that is purchased, leased, or rented after May 1, 2004. This is a significant incentive that eliminates what would otherwise be several thousand dollars in tax for a purchased vehicle. The value of this incentive is captured at the point of sale

[m] https://www.nj.gov/governor/news/news/562019/approved/20190603b.shtml

if the customer supplies a “sales tax exemption waiver” (ST-4) form. The NJDEP maintains a list of vehicles that are eligible for earning the Sales Tax Exemption.

- **“Charge Up New Jersey”:** As part of the State budget, a $30M fund has been included to launch a new vehicle purchase rebate program – as authorized by the new law. Any New Jersey resident who purchased or leased an electric vehicle after January 17, 2020 is eligible to apply to receive an incentive amount equal to $25 per mile of electric range, up to $5,000. This program (along with the sales tax waiver, and the federal tax incentive (where applicable)) is expected to help shift electric vehicles closer to price parity with traditional ICE models and increase sales substantially.

- **It Pay$ to Plug In:** The NJ DEP has developed a program that provides grants to offset the purchase and installation costs of publicly available vehicle charging stations to reduce range anxiety and encourage the adoption of electric vehicles. The Department supported a special solicitation to provide grants for new Corridor DCFC projects that comply with the new EV Law.

- **Section 177 Waiver (ZEV Compliance Program):** As allowed under the federal Clean Air Act, New Jersey opted-in to the California Zero Emission Vehicle compliance program. New Jersey is one of ten states that have opted into that framework and is therefore referred to as a “Section 177” state in reference to the enabling Clean Air Act provision. This framework requires that large volume automobile manufacturers ensure that a certain percentage of new vehicle sales are based on zero emission vehicles (ZEVs, such as fuel cell or pure battery electric cars), or transition zero emission vehicles (TZEVs such as plug-in hybrids) each year. The percentage of ZEVs and TZEVs increases each year and is managed through a “credit” system. The NJDEP is responsible for tracking credit compliance and banking in the state. New Jersey’s participation in the ZEV program has a real and significant practical implication for the PEV market: automobile manufacturers prioritize the allocation of PEVs in “Section 177 states” like New Jersey, thereby making stronger PEV adoption feasible.

- **Utility Program Filings:** Two New Jersey electric utilities, Public Service Electric and Gas (PSE&G) and Atlantic City Electric (ACE), have submitted proposed PEV market development programs to the NJBPU. These programs, if approved, would provide substantial incentives that could grow EV adoption and use, including (among other efforts) expanded availability of public charging, help for new EV buyers that need a charger at home (including multi-family settings), incentives to encourage off-peak charging, as well as other incentives. The BPU recently published new EV policy guidelines for utility EV program offerings, based primarily on a “shared responsibility” approach to charging infrastructure development.

- **MHDV Vehicle Segments:** In July 2020, New Jersey joined 14 states and Washington D.C. by signing a Memorandum of Understanding, with the aim of collectively advancing the market for electric MHDV. The aim of the MOU is to reach 30% zero-emission vehicle sales by 2030, and eventually 100% by 2050. The new “EV Law” directs the Department of Environmental Protection and Board of Public Utilities to establish goals for the electrification of MHDV. In April of 2020, the state announced that it has allocated almost $45 million dollars from the national Volkswagen settlement to electrify heavy-duty vehicles in urban areas. This initiative puts a particular emphasis on alleviating the disproportionate burden faced by vulnerable environmental justice communities. Approximately $37.2 million of the allocated funds will be contributed to projects converting old diesel trucks, buses, and other heavy-duty vehicles to electric power with the remaining funds being invested in charging infrastructure throughout New Jersey. [n]

- **PEV Availability:** Vehicles are becoming more widely available in New Jersey, with manufacturers allocating PEV product to the state due to its increasing attractive market environment. Recent legislation authorizes Tesla to sell vehicles through its "factory direct" business model (i.e. not through independent retailers), but with limitations and requirements. For customers that prefe a PEV from an established manufacturer, NJ CAR (in partnership with ChargEVC and Plugin America) and is developing a dealer certification program that will help prepare, educate, and motivate traditional dealers to sell EVs. Sales are likely to be further encouraged by new vehicles expected to come onto the market in the near future. The compact/mid-sized SUV is the fastest growing vehicle segment in America and a number of fully electric crossovers/SUV's, such as the Hyundai Kona, Kia Niro, VW ID.4, Nissan Ariaya, Ford Mustang SUV, Tesla Model Y, Volvo XC40, and Audi Q4 are either available or expected to become available over the next year or so. This wide selection, which spans a healthy variety of price points in an extremely popular vehicle class, can dramatically impact the adoption rate of electric vehicles.

- **Market Planning and Development Efforts:** A variety of loosely coupled organizations have been working over the last decade to improve the EV market in New Jersey, including:

  - The NJ Clean Cities Coalition (led by Chuck Feinberg) has been active in the State for approximately a decade and published an EV infrastructure development plan in October 2011.

  - Several local environmental groups, especially Sierra Club, Environment NJ, and the Association of New Jersey Environmental Commissions (ANJEC) have been promoting PEVs over the last few years. Environment NJ published its "Driving Cleaner" report in June 2014, and a guide promoting "50 steps to carbon-free transportation" in the Fall of 2016.

  - The local metropolitan planning authorities, including the North Jersey Transportation Planning Authority (NJTPA) covering north Jersey and the Delaware Valley Regional Planning Commission (DVRPC) covering the New Jersey region around Philadelphia, have become active in PEV matters, and NJTPA recently sponsored an initiative focused on municipal EV readiness.

  - Sustainable Jersey, a not-for-profit organization focused on supporting schools and municipalities in sustainability advancements statewide, introduced PEV actions in 2014 which have helped socialize the potential for municipal support of PEV market development by local government units.

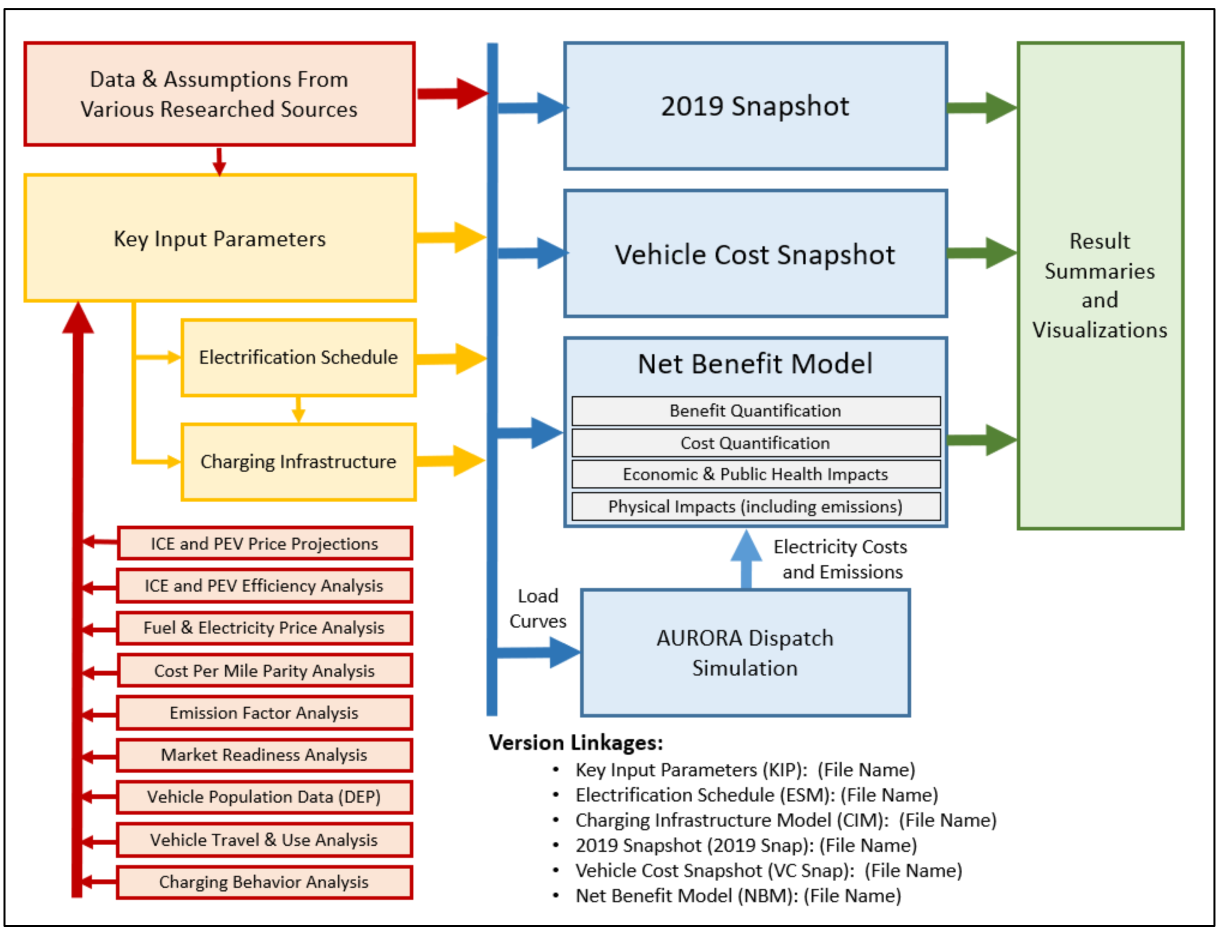
[n] NJ Spotlight; "State Commits $45M to Electrify Heavy-Duty Vehicles Used in Cities," April 23,2020

- Formed in 2016, ChargEVC is a coalition which focuses specifically on PEV market development in New Jersey. The ChargEVC coalition, based on consensus building within its diverse stakeholder membership, published a roadmap for New Jersey Plug-In Vehicle Market Development in September of 2017, and a market opportunity and benefit-cost study in January of 2018. ChargEVC commissioned and funded the research project upon which this updated projection report is based.

Appendix D: Methodology and Assumptions

The quantitative results of the study were developed through a set of interconnected models that, combined, provide a comprehensive view of vehicle electriciation impacts in New Jersey. In order to achieve the granularity required, most of the inputs and calculations in each of these models were imiplemente for each vehicle class in the Servcie Type (ST) structure established by MOVES. This provided insight to the study team not just at the state fleet level, but also for each ST individually. This ability to isolate specific classes throughout the models' structure allowed the team to account for class-specific nuances and better characterize the overall impacts with electrification of that class. Those results were then aggregated to characterize groups of vehicle classes or the state's vehicle population as a whole.

The diargam below is a representation of several specialized models that together provide the results required by the study.



Key Input Parameters (KIP)

Crucial data sets commonly used throughout the study were organized into the Key Input Parameters module to allow for a common point of reference of key inputs and for clear change control. The parameters were identified and gathered through a variety of means and many were used to perform a variety of functions across the other models that make up the total study.

- The Study Team worked with the New Jersey DEP to collect details about currently registered vehicles, and to allocate the population into the various vehicle segments used throughout the study.

- The DEP also provided crucial data regarding vehicle travel patterns, most especially the total VMT traveled within each class. This data was used directly in determining the energy requirements (for both fueled and electrified vehicles) throughout the various models that make up the study. Both average miles for the full range of the vehicle, and miles traveled on New Jersey roads were compiled.

- Average lifespan of vehicles in each class were obtained primarily from ICF's "*Comparison of Medium- and Heavy-Duty Technologies in California*" and, in some vehicle classes, supporting market research was necessary.

- Current vehicle prices and price projections for both ICE and EV MHDV were synthesized from ICF's "*Comparison of Medium- and Heavy-Duty Technologies in California*" and publicly available samples of pricing for current representative models. In order to project the price of electric school buses through 2050, the projected costs of batteries were factored into price projections as they are the costliest element of an electric vehicle and are expected to drop in price in the coming years significantly impacting vehicle price. LDV vehicle prices were interpolated from PEV purchase premiums projected by NREL in the 2020 AEO.

- Vehicle maintenance costs for ICE and PEV were provided by ICF's "*Comparison of Medium- and Heavy-Duty Technologies in California.*"

- The infrastructure costs for all MHDV was based on data provided by the International Council on Clean Transportation.

- The charger share factor was based on ICF's "*Comparison of Medium- and Heavy-Duty Technologies in California,*" which assumes that in many segments two MHDV will share one charger. The exception was NJ Transit, where one charger per bus is assumed to be required.

- ICE vehicle efficiencies (mpg) were determined by completing thorough market surveys and considering the impact of CAFE standards on projections of fleet ICE efficiency.

- PEV efficiencies were determined for each vehicle class based on average publicly available "mile per kwh" statistics, including vehicle manufacturers. This data was weighted based on the distribution of vehicle sales in New Jersey. If data was not available explicitly, the efficiency was calculated using the battery size and electric range of the vehicles.

- Current fuel prices and price projections are from EIA Advanced Energy Outlook 2020.

- State and Federal Gas tax were taken from the current data on the website of the American Petroleum Institute

- Current residential and commercial electricity prices were taken from *EIA Electric Power Monthly, September 2020* for New Jersey. Electricity prices were inflated at an annual rate of 0.76%, as advised by a New Jersey electric utility.

- Overall average electricity prices in New Jersey were determined by calculating a weighted average of each sectors average price using the annual revenue of each sector. All of this data was provided by EIA Electric Power Monthly, September 2020.

- The total electric delivery revenue for the state of New Jersey was calculated using EIA's "*Annual Electric Power Industry Report, Form EIA-861, Detailed Data Files 2018*" The sum of revenue for each of the states four major IOU's was inflated to nominal dollars for the period of 2019-2050.

- The study team used an analysis by Argonne National Labs, "*Updated Emission Factors of Air Pollutants from Vehicle Operations in GREET Using MOVES*," to average twelve years of mobile emissions data and determine the average rate for vehicles on the road today. Carbon dioxide emissions factor was reduced gradually over time to be proportional to the established increases in fuel efficiency.

- An AURORA simulation models determined the emission rates at generation sources for CO2, NOx, and SO2.

- For PM2.5 emission rates at generation sources were determined using *eGrid*, specifically for 2018 PM2.5 emissions induced by NJ load.

- The Interagency Working Group on Social Cost of Greenhouse Gases' "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis," (average of 3% case) was used to determine the economic impact of carbon dioxide emissions.

- The economic impacts of all other emissions were determined using conversion factors from the EPA's study, "Value of Emission Impacts 2018" (average of 3% case).

- The study team also had the benefit of experience examining the charging habits of electric vehicle owners. Having already developed models for natural and managed charging scenarios and models for charging distributions across different location types, the team was able to apply this knowledge to make informed assumptions about how, when, and where the drivers across these vehicle segments will charge.

- The general inflation factor to express projected values in nominal dollars was provided by the Organization for Economic Co-operation and Development.
- All general energy conversion rates for BTU calculations were taken from EIA's Energy Calculator.
- The discount factor for NPV calculations was set at 3%, consistent with NJ BPU guidelines for Energy Efficiency cost/benefit analysis.

Cost-Per-Mile Indicator (CPM)

As a preliminary effort to inform the Electrification Schedule Model (ESM), which forecasts the adoption of PEV (see section below), an analysis of the average cost per mile indicator (CPM-I) of each ICE and PEV class. The inputs for this analysis were imported from the KIP model.

- The numerator for each indicator was the vehicles initial purchase cost, plus the total lifetime fuel or electricity costs of the vehicle (individually calculated for each year of the vehicles life, then totaled), plus the total lifetime maintenance cost (individually calculated for each year of the vehicles life, then totaled).
- The denominator for each indicator was the full range miles traveled per year for each class multiplied by the typical service life of a vehicle in that class, or the vehicle's lifetime mileage (over its full range).
- The result was a specific "cost per mile" indicator for both the PEV and ICE vehicles in each class.
- The CPM-I for PEVs could be compared to the equivalent benchmark for ICE vehicles in each class to estimate when "operating cost" parity would be attained. Although this indicator focused on hard costs (such as purchase costs and fuel), it did not consider numerous other factors that would normally be included in a total cost of ownership comparison – such as insurance, tolls, etc. Many of those factors are expected to be approximately the same for PEV and ICE variation of a given vehicle in a given operating profile, and therefore wouldn't impact the CPM-I significantly. This approach allowed a statewide assessment of cost-per-mile parity on a vehicle class basis.

Electrification Schedule Model

The Electrification Schedule Model forecasts the adoption of PEVs in each vehicle class for each year. The adoption threshold was heavily influenced by the expectations of when PEV reach price parity with ICE vehicles gained from the CPM analysis. Outside of the segments impacted by requirements of New Jersey law (LDV and NJ Transit buses), other segments reflect adoption without any outside incentive. Six potential thresholds are crossed for each vehicle class (each was assigned a population %): limited feasibility (0%), expanded feasibility (2.5), compelling (16%), widespread (50%), unavoidable (84%), and saturation (100%).

The ESM is based on a Technology Diffusion Model that is considers the CPM-I Analysis (among other factors) to identify market evolution thresholds. This was used to create "anchor points," a year where one of the six thresholds is reached. That year is assigned the corresponding population percentage in the Technology Diffusion Model creating an adoption curve for each vehicle class. This modeling approach is described more fully in Section 4.1. The ESM determines the electrification schedule for each vehicle class, the energy required for charging vehicles according to that schedule, and a set of load curves for each year for each vehicle class.

- The model applies the corresponding adoption curve for each ST to overall vehicle sales projections (PEV and ICE) in order to translate it into annual PEV sales figures through 2050.

- The model adds new vehicles, based on the projected adoption curve, while subtracting the vehicles entering retirement, based on typical vehicle life, to maintain a realistic year-to-year population of vehicles effectively "on the road" in each class for each year of the study.

- The ESM determines what percentage of each class is electrified each year and applies the ratio to the total state VMT to determine the "electrified miles" in each class. It is assumed that PHEV rely on electricity approximately 70% of the time, then revert to gasoline the remaining 30%.

- Total electrified miles are converted to an energy requirement using typical vehicle efficiencies (miles per kwh).

- Annual energy requirements for LDV vehicles were broken out into six charging distributions: private residential (where 76% of charging occurs), shared residential, workplace, fleet, public community charging and public corridor charging.

- Most MHDVs were all assumed to charge primarily in one location, the depot, so the energy distribution remained in the typical STs. This distribution and the LDV distributions for each application were fed into a Natural TOU curve and a Managed TOU curve. As discussed in the charging infrastructure section, some MHDVs are also assumed to charge at "public charging" locations, especially in long-haul applications.

- For MHDV, various sources and assumptions were made in order to inform the TOD distributions. Light commercial trucks, motorhomes, and school buses were assumed to follow the same TOD charging patterns as LDV private residential since they charge overnight in order to be available for use during the next business-day. ICF and TOD curves from several California utilities (SCE, SDG&E, LADWP) provided insight for Refuse Trucks; Inter-City and Transit Buses; and the Combo segments (short and long haul).

- The output was a distribution of energy for each hour of the day across all six LDV applications and all MHDV classes in both a natural TOU pattern and a managed charging TOU pattern. These segment loads were aggregated, combining all classes and applications into a single natural aggregate load and managed aggregate load that showed, from year to year, how much energy is consumed during each hour of the day in both cases.

Charging Infrastructure Model (CIM)

The ESM provides PEV forecasts that serve as the basis for this model which determines infrastructure requirements for a growing PEV fleet over time.

- The model assumes that no LDV BEV will use L1 charging as a routine charging solution, half will use a low power (3.6kW) L2 charger, and the other half will use a high power (7.2 kW) L2 charger. Each half is further segmented into three routine charging locations, with 45% (of the original 100%) needing private residential charging, 0.5% needing multi-family charging and 4.5% needing fleet L2 (for a total of 50% at each power level).

- It is assumed that 20% of LDV PHEV will use L1 for residential routine charging. For the remaining 80%, these are again split in half with 40% of the total PHEV relying on low-power L2 (3.6 kW) charging and 40% relying on high-power L2 (7.2 kW) charging. These two segments are each divided into three routing charging locations, with 35% (of the original 100%) needing private residential charging, 0.5% needing multi-family charging and 4.5% needing fleet L2 (for a total of 40% at each power level).

- There are some exception charging events where vehicles will charge outside of a typical or routine schedule (workplace, public L2 and public DCFC charging). An “exception charge factor” was applied to each of these categories to account for these events. The factors for workplace and public L2 charging are based on a DOE/EERE Infrastructure Planning Report and the DCFC factor assumes 8 DCFC visits per year per BEV and a congestion threshold of 11 visits per day for each DCFC port.

- For the purposes of this report, all MHDV are assumed to charge at a depot using a 50 kW charger.

- Sales projections from the ESM are fed into the distribution described above to determine the number of vehicles each year that will charge in each routine behavior.

- Exception charge factors are applied to the population to account for workplace and public charging events. The result is a cumulative charger requirement for the number of plugs required in in each routine scenario and at all exception charging events.

Some charging configurations have more than one plug per charger and many charging locations have more than one charger. Ultimately, the goal of this model was to express requirements for plugs, chargers, and locations.

- The model assumes that single family home chargers are single plugs per charger which is consistent with typical configurations installed in the current market; MUD, fleet, workplace, and public L2 chargers are half dual-plug and half single-plug (average of three plugs for every two chargers); and DCFC are predominantly a single plug per charger. These factors were used to convert the plug requirement to a charger requirement.

- The model assumes there are two to six chargers for workplace locations (average of four is used); two L2 chargers per public L2 location; and two to four chargers per public DCFC location (average of three is used). These factors were used to convert required chargers to required locations.

2019 Snapshot (2019 Snap)

The 2019 Snapshot Model is a thought-experiment that characterizes the overall impact of New Jersey's transportation sector across three scenarios:

a. The 2019 New Jersey vehicle population, if it was powered completely by fossil fuels;

b. The same 2019 population, hypothetically 80% BEV / 20% ICE, with all electricity generated using the current generation mix, and;

c. The same 2019 vehicle population, again with a hypothetical 80% BEV / 20% ICE ratio, but with high renewable electricity generation.

The analysis for each scenario was similar.

- The total annual VMT for 2019 was determined across the twelve ST using data from the KIP module

- The VMT for each class was divided by the average fuel efficiency (gasoline or diesel) for that class. The study team achieved a close estimation of the total number of gallons of fuel consumed annually in each class.
- The average costs of gasoline and diesel were applied to these figures to express the consumption in economic terms.

- The emission impacts of each ST was determined using the VMT for that class and applying a mobile emissions conversion factor (from KIP) to convert miles traveled to pounds of pollutant.

- The volume of each pollutant was expressed in terms of economic terms using conversion factors from the KIP module.

- For each electrification scenario, the VMT for each class was divided by the average fuel efficiency (miles per kwhr) for that class. The study team achieved a close estimation of the total number of kwhr consumed annually in each class.

- Average residential costs of electricity were applied to LDV classes and average commercial costs were applied to MHDV segments.

- The emission impacts of each ST was determined by applying a generation emissions conversion factor (modeled in AURORA, to simulate the current electricity mix, or BAU conditions) to convert kwhr to pounds of pollutant.

- The volume of each pollutant was expressed in terms of economic terms using conversion factors from the KIP module.

- Finally, the process was repeated but the generation emissions conversion factor, modeled in AURORA was altered to simulate an electricity mix with high renewable content

- The three scenarios were compared to isolate environmental and economic impacts of vehicle electrification and to demonstrate the synergistic benefits of powering PEV with electricity generated with renewable resources.

Vehicle Cost Snapshot (VC Snap)

The Vehicle Cost Snapshot focuses on the most impactful economic aspects of ownership. First it determines purchase, fuel, and maintenance costs of all purchased vehicles assuming each is ICE. A second comparative scenario determines purchase, fuel, and maintenance costs of all projected purchased PEVs combined with the remaining ICE costs each year.

- Projected annual vehicle sales were fed in from the ESM for each ST which were multiplied by the typical ICE vehicle cost for each ST in order to determine the total sales volume for each class and year of the study.

- VMT values were applied to the number of new sales each year to represent total miles driven for each class. Using average fuel efficiency values and fuel cost projections from EIA, the total fuel cost for each class and each year was calculated.

- The total VMT for each class and year was also used to calculate maintenance costs from KIP, which are expressed on a dollars per mile basis. This portion of the model left the study team with annual purchase costs, fuel costs, and maintenance costs for all vehicles on the road for each class under a hypothetical 100% ICE fleet.

- Projected PEV sales were fed into the model from the ESM and, like the ICE vehicles, multiplied across the projected annual PEV purchase costs for each segment from the KIP. This calculated the total annual sales volume for each PEV class.

- Fueling cost was determined by multiplying the vehicles by VMT and dividing by vehicle efficiency to get the total kwh requirement.

- Electricity cost projections from KIP were used to determine the equivalent cost value for each year and class.

- Operating costs were also calculated on a per mile basis using the multiplier value from the KIP as was done in the ICE portion of the model.

- The final portion of the model determined the total costs of PEV migration. The first process for ICE vehicles was repeated, but this time, only for the vehicles that were not replaced by PEV sales.

- The result was two sets of costs – an entirely ICE fleet and an ICE fleet that is gradually displaced by growing PEV sales.

AURORA Dispatch Simulation

A detailed market simulation of PJM -wide dispatch of generation assets for both baseline loading, and incremental loading imposed by PEV charging was performed as part of this study. This simulation is based on the AURORAxmp® modeling platform (a fundamental market-based dispatch and simulation model that calculates forward market energy prices), and benefits from a variety of proprietary datasets developed by Gabel Associates for accurate modeling of energy market response to changes in loading. The Energy Model outputs the overall wholesale cost of power for each scenario and vehicle charging schedule, physical emission rates for CO2, NOx, and SO2, and projected wholesale capacity-build requirements over time. As a result, the Energy Model simulates hour by hour dispatch conditions for the known and projected wholesale fleet in PJM, for both the BAU and RE scenarios, from 2018 through 2050.

Net Benefit Model (NBM)

The Net Benefit Model (NBM) was the most comprehensive element of the model, and combines data from the other elements to project the impacts of electrification by vehicle class per year through 2050. Most of the other models that were a part of the study intersect with the NBM.

- Typical ICE vehicle efficiencies were used to convert total annual PEV VMT for each ST to gallons of gasoline and diesel, in order to determine the total amount of fuel displaced.

- Typical PEV efficiencies were used to convert total annual PEV VMT for each ST to the total required electricity at the point of consumption

- The requirement at the point of consumptions was used to determine the requirement at the point of generation using a transmission and distribution loss factor as a multiplier

- LDV distributions were applied to determine the total energy consumed in each charging environment (private residential, shared residential (multi-family), workplace, fleet, public community, and public corridor charging). Medium- and Heavy-Duty vehicles were assumed to charge at the depot.

- Each of these distributions was further broken down to an hourly basis resulting in hourly energy requirements using a natural charging model and a managed charging model (shifting load to off-peak hours).
- Both the offset gasoline and diesel in the baseline case and the electricity in the electrification case were totaled for each class and converted using mobile and generation emission factors, respectively. These were expressed in terms of total tons for each pollutant and the equivalent environmental cost in dollars for each year through 2050 (in both the natural and managed charging cases).
- A sensitivity was also added so that these results could be evaluated both under the BAU case and the RE case for electricity generation. Both the offset gasoline and diesel in the baseline case and the electricity in the electrification case were expressed in economic terms using projected fuel and electricity costs.
- Using the VMT for each class per year and average operating cost per mile factors from KIP, the total projected operating costs were determined for each class and each year.
- Through the dilution of energy costs due to the increased use of electricity, changes in electricity costs were also tracked in both the natural and managed charging cases. This include changes in distribution, wholesale, energy, ratepayer, capacity, and transmission costs.
- Finally, the study team evaluated how electrification reduces the collection of gas and diesel taxes at both the state and federal level over time due to the decreasing use of fossil fuels.

Key Assumptions

1. The study considers a single-year snapshot for 2019, and multi-year scenarios from 2021 through 2050.
2. The demographic, vehicle, and travel statistics are based on New Jersey conditions to the greatest extent possible. When NJ-specific information was not available, regional or national analogs were used.
3. The study considers only on-road light duty vehicles, I,e, any vehicle registered for use on a public road. Off-road construction or agricultural equipment, or equipment that operates solely within a private facility (such as a marine port or airport) are not included. The study considers all on-road vehicles except motorcycles, including light, medium, and heavy-duty vehicles typically consuming either gasoline or diesel fuel. See Section 3.1 for more details.

4. The size of the vehicle population is always changing, and annual vehicle sales can vary widely from year to year depending on numerous conditions. The typical travel profile of these vehicles is also changing, and subject to long term – but potentially evolving – trends (i.e. higher VMT over time). Attempting to model these multiple factors over such an extended period (through 2050) is beyond the scope of this study, and accounting for those variations can obscure market changes that result from electrification. The study therefore considers a "fixed world" in which the vehicle population, annual sales, and vehicle efficiencies are fixed over time. The only exceptions are a) efficiency of ICE vehicles change over time due to the CAFÉ standards (which slowly drive mpg-efficiency up), and b) the clear shift in consumer buying preferences for light duty trucks (typically SUVs) over traditional "cars". This approach allows almost all change in market characteristics to be attributed exclusively to electrification impacts.

5. The study assumes that driver travel patterns do not change as the result of using a PEV rather than a traditional fueled vehicle. In particular, annual miles traveled per vehicle remain the same between traditional vehicles and PEVs.

6. To make the scenario space manageable, all days are assumed to be equal regarding vehicle charging loads. The study does not account for PEV travel seasonality or day-of-week differences.

7. The electric market quantification is based on a detailed hour-by-hour simulation of dispatch for the entire PJM wholesale generation fleet, using known run-prioritization rules, heat factors, marginal costs, emission rates, etc. Emission factors are based on RFC-East, consistent with emerging DEP guidance on emission accounting methodology. Outputs from the simulation include wholesale energy costs, physical emission rates, and wholesale generation capacity build requirements.

8. Electricity cost calculations that impact residential PEV drivers reflect average residential electricity costs, while charging for commercial vehicles is based on the average commercial cost of electricity statewide. In most cases, calculations of charging costs assumed payment into New Jersey Transportation Trust (NJTTF) as a replacement for lost gasoline tax revenues[o].

9. Fuel costs over time are based on U.S. Energy Information Administration (EIA) projections for gasoline costs through 2050.

10. The model accounts for mobile emission rates by vehicle class based on data from EPA – primarily an analysis by Argonne National Labs of MOVES 2013a input data[22]. Generation emissions are based on Aurora simulation results for CO_2, NO_x, and SO_2. PM2.5 results are based on data from eGrid specifically for 2018 PM2.5 emissions induced by NJ load[23], and was adjusted over time in proportion with trends in NO_x emissions for RFC-East.

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[o] Although this study added a cents/kwhr premium to the cost of electricity to ensure that PEV owners pay their fair share into the Transportation Trust Fund, that was a modeling expediency and is not intended to endorse that particular approach. There are a variety of ways that contribution could be structured besides per-kwhr surcharges. The premium used in the study is equivalent to the current gasoline tax (on an average per mile basis), and any other funding mechanism is expected to be similar economically.

11. Energy characteristics of BEVs, PHEVs, and traditionally fueled vehicles are modeled separately and aggregated to assess the impact. In most cases, vehicle efficiencies are based on a sample of real-world vehicles available in New Jersey or announced for commercial availability

12. As detailed in Section 5, all vehicle charging is modeled through six different charging segments for light duty vehicles, and two charging segments for Medium- Heavy-duty vehicles. Each charging segment has its own time-of-day charging profile per vehicle type. These time-of-day profiles were developed based on a review of a variety of sources, including data from real chargers where available.

13. The study assessed the economic impact of vehicle emissions using parameters from the federal inter-departmental working group on the social cost of carbon (for CO2), and a separate study from EPA for impact factors on NOx, SO2, and PM2.5. The EPA factors allow for consideration of the impact of emissions being displaced geographically, since they provide one set of factors for stationary generation sources (like power plants), and mobile sources (like vehicles, which mostly use roadways in high population density zones).

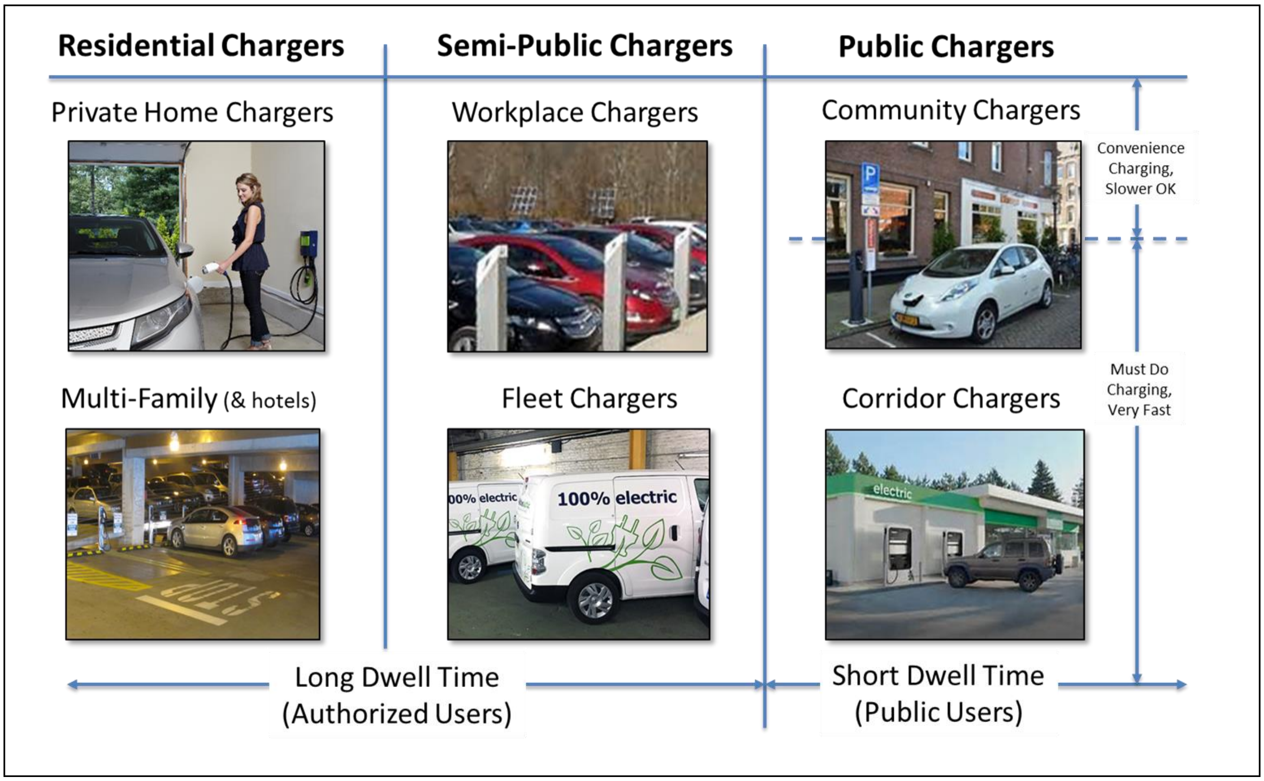
14. As part of assessing potential vehicle adoption schedules, the study team identified key adoption barriers in each vehicle segment. A potential market development program that would address these barriers, with a focus on the most impactful and strategic initiatives. The team defined these programs (nine in all), covering the LDV market as well as the MH-duty segments. Strategic initiatives with equity dimensions such as electric school buses and NJ Transit were also included. The estimated costs for those programs are included as a cost in the net benefit analysis. These program definitions should be considered working assumptions for potential costs, included in the spirit of taking a comprehensive approach to cost accounting.

15. The study included consideration of potential grid reinforcement costs, based on engineering parameters developed from detailed studies in other utility territories. A primary “front line of impact” is single phase transformers impacted by residential charging. Adding a L2 charger will approximately double the load of a typical home. These potential grid reinforcement costs are considered in both the natural and managed charging cases.

Appendix E: Vehicle Charging Ecosystem For Light Duty Vehicles

This section summarizes the segmentation model that defines the ecosystem of charging services for light duty vehicles. LDVs can charge using a variety of technology, with a range of use cases, across multiple settings. Note that a given PEV could charge in multiple places to meet its charging needs. The following diagram summarizes that ecosystem.

Figure D – 1: The LDV Charging Ecosystem



As annotated along the horizontal axis at the bottom, vehicle charging can be conceptualized as long dwell time events, or short dwell time events. Most charging happens where vehicles spend most of their time not moving: parked at home or (to a lesser extent) at work. This convenient fact makes frequent long duration (and lower power) charging of EVs possible. Public chargers support relatively short transactions (by comparison), when the vehicle is away from home or work. These public chargers vary (along the horizontal axis) by whether the public charge is a "must do" charging transaction (i.e. the battery is nearly exhausted, and a quick charge is needed), to more optional charging when it is convenient but not necessarily needed. The six segments capture different vehicle charger settings, each of which has a unique role in the vehicle charging ecosystem, including distinctive user, ownership, business model, and usage profiles, as summarized below:

1) **Privately Owned Home Chargers (with integrated parking):** Located in single family homes, or any residential unit with adjacent and accessible parking where a charger can be easily installed and conveniently used on a daily basis. These chargers are typically Level One or Level Two equipment, and typically owned by the person that owns the car and/or home. In general, the users of the charging equipment are limited to the vehicle/home owners. These chargers are simply a load within the building and the energy delivered to the EV is part of the monthly electricity bill. The charge transaction can take place at any time of the day, but typically EVs will be charged overnight.

2) **Multi-Family Residential (with separated parking):** A residential property with less convenient parking arrangements, especially in lease/rent scenarios where charger availability is determined by a building owner or manager that is different from the EV owner. Typical examples include condominium and apartment buildings with common lots or parking garages, buildings with "street-side" parking, or rental/lease free-standing homes or duplexes where the landlord makes charger installation decisions. The usage profile for chargers located at multi-family dwellings is similar to that of the private residential segment (mostly overnight), but there are significant differences in the equipment ownership, vehicle access rights and scheduling, and payment arrangements. In general, the charging equipment must be approved by, and will typically be owned by[p], the commercial property owner or homeowner association, and the resident will pay for charging services in some form. A key aspect of this segment is that the Level One or Level Two chargers are typically neither assigned to a single vehicle/user, nor available for general public use – they are available for use by *authorized users.* The multi-family segment is significant in New Jersey since a substantial portion of building stock is multi-family, and many families rent or lease their homes. Overnight lodging (hotels, etc.) are also modeled as multi-family residential properties since their characteristics are nearly identical. In hotel setting, most charging will still be done overnight, but the owner of the equipment is different than the owner of the vehicle, and therefore only *authorized users* (registered guests) may use the charging facilities. Vehicle charging privileges will be offered similar to the way WIFI access is offered to guests today.

3) **Workplace Charging:** EV chargers at a non-residential property for use by employees[q]. These chargers are typically Level One or Level Two equipment and are provided as an employee benefit and/or in support of corporate sustainability or CO_2 reduction goals. These workplace chargers are especially useful for two usage profiles: those employees that don't have a charging option at home (if they live in an apartment, for example) and for whom charging at work is their primary

[p] Even in cases where the tenant pays for and owns the charging equipment, the landlord, management company, or homeowner's association retains significant decision-making authority about its installation and its use.

[q] To be more precise, workplace chargers should really be thought of as "chargers used by EV drivers while they are at work". For some employees, this may not be at the workplace itself. In urban settings, in particular, some employees park in a public lot and work in a nearby office. Similarly, an employee may drive to a commuter lot, and park their car there all day while taking the train or bus to and from work. Both of these situations benefit from typical Level Two charging similar to what would be found at the workplace, but in what would normally be considered a more typical "public charging" setting.

routine charging option, or as a "back-up" for employees that are able to charge at home but need redundant charging options (to cover extended travel during the day, forgot to charge at home the night before, etc.). In some cases, employees may be using a workplace charger to extend their daily driving range, and if they own a PHEV, to minimize fuel use. Workplace chargers are therefore part of the charging ecosystem that supports EV owners living in a multi-family environment, while also providing greater confidence in charging away from home for all drivers. It should be noted that workplace chargers are often effective awareness building mechanisms, and there are examples of workplace chargers stimulating EV purchases, even if many of those employees end up charging at home. Similar to multi-family settings, the chargers are not owned by the vehicle owners, and equipment usage is by authorized users only. These chargers are usually "behind the meter" of the commercial building and the EV charging load is part of the overall building load. Precautions must be taken to avoid EV charging having a negative impact on commercial demand charges. Employers may provide EV charging at no cost, but increasingly, the electricity will be paid for by the employee.

4) **Fleet Chargers:** Chargers at non-residential properties focused on supporting light duty EVs owned by the hosting entity. Functionally, these chargers operate the same as a residential unit, with charging typically happening overnight to support vehicle use during the day – but that can vary depending on the vehicle usage profile. As with workplace chargers, there is only a loose coupling between vehicles and chargers, and only authorized users/vehicles may use the charging facilities. Unlike workplace chargers for employees, the owner of the vehicle and the owner of the charger are typically the same entity, which may simplify (or eliminate) the need for the vehicle driver to pay for charging services.

5) **Public Charger – Corridor Locations:** Chargers, typically with higher power levels that allow open public access to faster charging, located on or near heavily used travel arteries. In New Jersey, these corridor locations can serve BOTH long distance travelers and local travelers. In either case, these chargers are most frequently used under "must charge" conditions where the battery is nearly exhausted. The recent rapid advancement of DC Fast Chargers (DCFC), which within a few years will be able to charge vehicles to within 80% of full capacity in 15 minutes or less, are ideal applications for corridor public chargers. These charging facilities will typically be owned by an operator that is providing charging as a service available to the public, and charging will be a purchased service. The property owner may own the charger (at a coffee shop or gas station, for example) or the site host may enter into an agreement for a third party to own and operate the asset.

6) **Public Charger – Community Locations:** Chargers for public use, but located away from travel corridors. They will typically be located at public parking areas (sponsored by the municipality), destination locations (entertainment or park facilities), or retail locations – community locations are near where drivers live or work, or near where drives visit frequently as part of daily routine. Like corridor chargers, they will be owned and operated for use by the public for a wide variety of reasons. Community chargers will benefit from fast charging equipment similar to corridor

chargers, but there may be applications for lower power Level Two chargers as well in some properly matched locations.

These six segments create an ecosystem of charging solutions that cover the majority of charging settings and use cases. Recent research has identified several important modes of interplay and distinction between the segments:

- Most charging energy is delivered through the residential, and to a much lesser extent, the workplace settings. Therefore, ensuring availability of these routine charging solutions is critical to market adoption – **most consumers will not transition to a PEV unless they have access to convenient charging at home and/or work**. Current market statistics indicate that as much as 70% of all EV charging energy is delivered at home and work, and this is expected to increase (due to increasing battery capacity) to at least 90% over time. This is an important fundamental fact about EV charging – most of the energy is delivered at home at night, and there is some flexibility about the scheduling of that charging transaction as long as the vehicle is fully charged by the morning.

- The amount of energy needed for each overnight charge is, on average, NOT a function of the capacity of the battery. It is related to the number of miles driven each day. For most drivers in New Jersey, the overnight charge will average about 10 KWhrs a day.

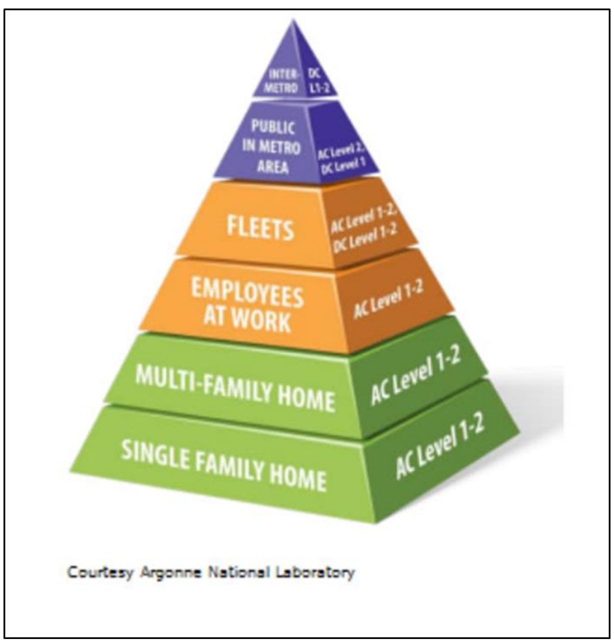
- This residential charging dynamic represents a fundamental departure from the way traditional vehicles are fueled today. **EV drivers will charge their cars similar to the way they charge their cell phones.** Unlike traditional gasoline fueled vehicles – which for most drivers MUST be fueled at a commercial gas station – charging an EV at home is a viable, usually more cost effective, and frequently a preferred option[r]. The role of public chargers is therefore very different than the role of gas stations. While gas stations provide routine fueling of a traditional vehicle, public EV charging transactions happen relatively rarely – only on a long distance trip, or when the driver is outside their normal travel pattern. Comparisons between gas station density and public EV charging requirements are irrelevant, since they support fundamentally different roles.

- Although they do not deliver much charging energy on a MWhr basis, Public Chargers, are absolutely critical for market adoption since they address consumer concerns about range anxiety.[24] The amount of energy delivered is not an appropriate metric for the success of a public charging station, since the intended effect is reduced consumer concerns about range anxiety and an associated increase in EV adoption.

[r] For this reason, especially in the early years of market development when EV ownership is still small, utilization of public charging stations can be relatively low. This naturally stresses the economics of public charging stations, especially the higher power stations preferred by consumers due to the demand rates inherent in typical tariffs.

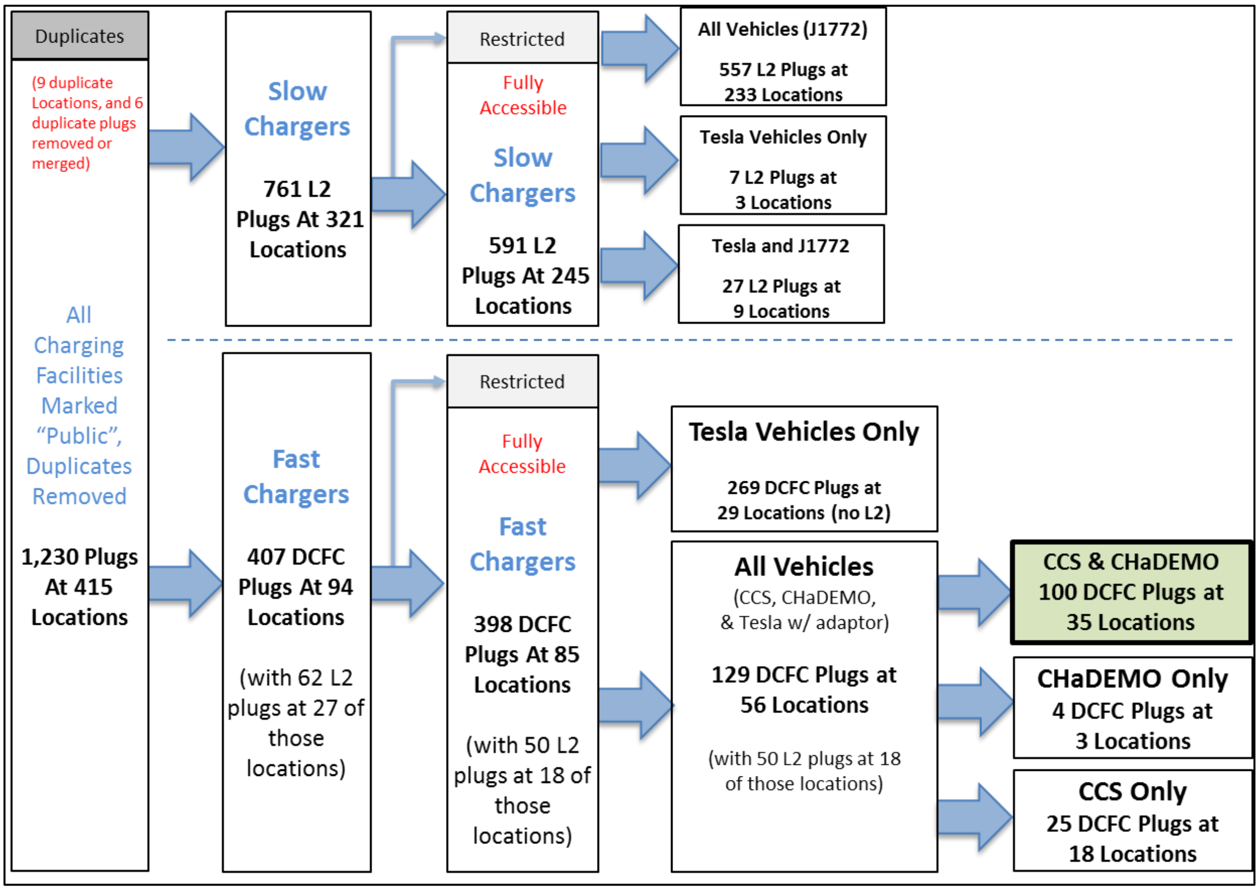
- In the early stages of market development, affordable but longer range EVs (which are now becoming available), geographic density of public charging (especially fast chargers), and public awareness of public charging availability, are key factors in reducing consumer range anxiety. The need for sufficient geographic coverage of public chargers (especially DCFC), BEFORE the EV population is large enough to ensure economically viable asset utilization, is a particularly challenging aspect of EV market development. In short, sufficient geographic density is needed BEFORE they can be economically viable on a stand-alone basis, but this effect declines as the size of the EV population grows and utilization of charging infrastructure naturally increases. The essential challenge for addressing range anxiety is therefore supporting public charging economics (especially for DCFC) during the early years when economics are challenging.

- Both the private and multi-family residential, and the workplace employee and fleet chargers, are long dwell time solutions – typically measured in hours. Public chargers tend to be much shorter transactions, and with corridor chargers (and long-distance travelers) especially, the consumer need is for the shortest possible charge time. Matching dwell time characteristics with the location usage profile is critical to application success. In general, the first four segments (residential and commercial for employees and fleets) are Level One or Level Two equipment, while public chargers are best served by DC fast chargers that are capable of faster, high power charge transactions. The following diagram summarizes the "EV Charging Ecosystem" and, as characterized by their respective sizes at each level, illustrates the fraction of energy delivered in each charging segment.



- Pricing of delivered electricity for both workplace and public chargers has a large impact on how they are used. Recent research at UC-Davis suggests that if workplace or public charging is FREE, it is used by EV drivers that actually do not need the charge. Their research suggests that free workplace charging creates a need for approximately 80 chargers for every 100 EVs on the lot. In instances where the electricity is priced similar to residential costs, that coverage factor reduces to about 60 chargers per 100 EVs. If the workplace charger is double the cost of home charging, only 20 chargers per 100 EVs are needed. Free charging can therefore induce unnecessary demand, force the need for more infrastructure investment, create parking spot usage conflicts, and increase less preferable daytime (on-peak) charging.

Appendix F: AFDC Scrub – September 1 2020



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