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Electrification Market and Technical Assessment

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Rochester Public Utilities

Electrification Market and Technical Assessment
Project No. 112056

Revision Final
4/29/2019

Electrification Market and Technical Assessment

prepared for

Rochester Public Utilities
Electrification Market and Technical Assessment
Rochester, MN

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4/29/2019

prepared by

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EXECUTIVE SUMMARY

The goal of this report is to outline, discuss, and demonstrate the potential impact vehicle electrification could have on the electric grid with a focus on how Rochester Public Utilities (RPU) might be impacted. The paper is divided into eight sections covering topics such as the state of the electric vehicle (EV) market, EV technology, fleet and mass transit electrification, impacts of EV charging in Rochester, federal and state policies encouraging EV adoption, EV rate structures, EV end of life, and other sources of electrification.

Over the past decade, EV sales have steadily increased. In 2018 over 1 million light duty EVs were registered on U.S. roads. In the next decade, there could be over 18.7 million light duty EVs on U.S. roads with some projections predicting new light duty EV sales reaching 38% of all new vehicles sold by 2030. Several factors are contributing to the increasing adoption of EVs. These factors include federal and state policies and initiatives that are encouraging the adoption of zero emission vehicles (ZEVs) such as fuel economy standards, emission reduction targets, and rebates for purchasing EVs. Furthermore, developments in technology are causing the cost of EVs to decrease in price, driving range from a single charge to increase, and the installation of fast charging stations that enable travel across the U.S. in an EV.

Medium and heavy duty vehicles, such as delivery vans, buses, and trucks, are also being electrified. Since EVs have fewer moving parts and require less maintenance than traditional gasoline or diesel vehicles, significant cost savings can be captured by electrifying gasoline and diesel powered vehicles. However, due to the size and weight of delivery vans, buses, and trucks and the distance these vehicles need to travel on a daily basis, challenges arise with the cost of installing high power charging infrastructure to support their operation. Hundreds of delivery vans, trucks, or transit buses can reside in one location creating the potential for a large load center that requires 5 MW to 15 MW of power. Determining the appropriate charging schedules, charge management equipment, and rate structures is critical to encouraging charge behaviors that can reduce peak load on the electric grid.

Since the number of light duty EVs on U.S. roads is expected to drastically increase in the next 10 to 20 years, it is important to understand how these vehicles will charge and what the potential peak load EV charging could add to the electric grid. Using the projected increase in new EV sales, the number of new vehicles sold in Minnesota, and the number of registered vehicles and EVs in Rochester, MN, a load profile was estimated. Using a 20% diversity factor, or in other words assuming only 20% of EVs will charge at once, the peak load could be as high as 21 MW in 2030 and 67 MW in 2040. This load profile assumes profile assumes that EV owners will mostly charge at home using Level 2 charging equipment with approximately 8 kW of peak power.

One of the best methods an electric utility can use to manage EV charging behavior is through the appropriate set up of EV charging tariffs. Around 84 to 87% of EV owners will charge at home and studies that are described in this report show that EV owners will charge when they arrive home from work which could coincide with peak demand on the electric grid. When a suitable Time of Use (TOU) rate is in place, consumers change their charging behaviors and take advantage of charging at times when prices are lower. Another technique a utility could a use is to install a load control switch that manages the EV charging equipment in a home. This system would be similar to demand response programs that control thermostats or that switch off hot water heaters.

Once an EV reaches the end of its useful life, there is the potential for the battery to be recycled or repurposed to have a “second life” as an energy storage device. Repurposing EV batteries could lead to a greater adoption of home energy storage systems as there could be potentially 200GWh of used EV batteries globally by 2030.

Lastly, this report discusses other sources of electrification that could impact RPU’s electric load. While there are many sources of electrification, the most applicable to RPU is the adoption of heat pumps and hot water heaters. However, due to high installation and energy costs the likelihood of customers installing or converting to electric heat pump and hot water heater systems is unlikely.

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LIST OF ABBREVIATIONS

Abbreviation	**Term/Phrase/Name**
Burns & McDonnell	Burns & McDonnell Engineering Company, Inc.
BEV	Battery Electric Vehicle
BNEF	Bloomberg New Energy Finance
CARB	California Air Resource Board
CP	Coincident Peak
CUV	Crossover Utility Vehicle
DCFC	Direct-Current Fast Charging
DoD	Depth of Discharge
EEI	Edison Electric Institute
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
FTA	Federal Transit Authority
GHG	Greenhouse Gas
ICE	Internal Combustion Engine
kW	Kilowatt
kWh	Kilowatt Hour
MWh	Megawatt Hour
LIB	Lithium Ion Battery
Li-ion	Lithium Ion
MUD	Multi-unit Dwellings
NGV	Natural Gas Vehicle

Abbreviation	**Term/Phrase/Name**
NHTSA	National Highway Traffic Safety Association
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
PUC	Public Utilities Commission
SoC	State of Charge
SUV	Sport Utility Vehicle
TCO	Total Cost of Ownership
TOU	Time of Use
VGI	Vehicle-grid Integration
V2G	Vehicle-to-Grid
ZEV	Zero Emission Vehicle

1.0 STATE OF THE ELECTRIC VEHCILE MARKET

The Electric Vehicle (EV) market has experienced growth over the past decade and is projected to grow substantially in the coming decade. Several factors have contributed to the growth in the EV market over the last decade including the decreasing cost of batteries technology, improvements in vehicle range, and supportive regulations and incentives that encourage EV adoption. As discussed in this section, the projected decrease in the cost of battery technology coupled with the existing regulations that encourage improvement in fuel efficiency and reduction of greenhouse gas emissions (GHGs) will continue to drive the growth of EV adoption. While over 50% of EVs in the U.S. have been purchased and registered in California, EV registrations and sales have been increasing across the United States as more cost-effective vehicles with greater range have become available. Furthermore, states outside of California have adopted Zero Emission Vehicle (ZEV) policies which mandate that a percentage of new vehicles sold by a manufacturer in the state must be a ZEV or plugin hybrid electric vehicle (PHEV).

1.1 Electric Vehicle Market

During the last 8 years, EV sales have steadily increased as consumer demands have changed, more capable and attractive EVs have been introduced to the market, and prices of EVs have decreased. In October of 2018, the Edison Electric Institute (EEI) reported that over 1 million EVs were on U.S. Roads. This number applies to plug-in electric vehicles (PEV) which include both plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs).

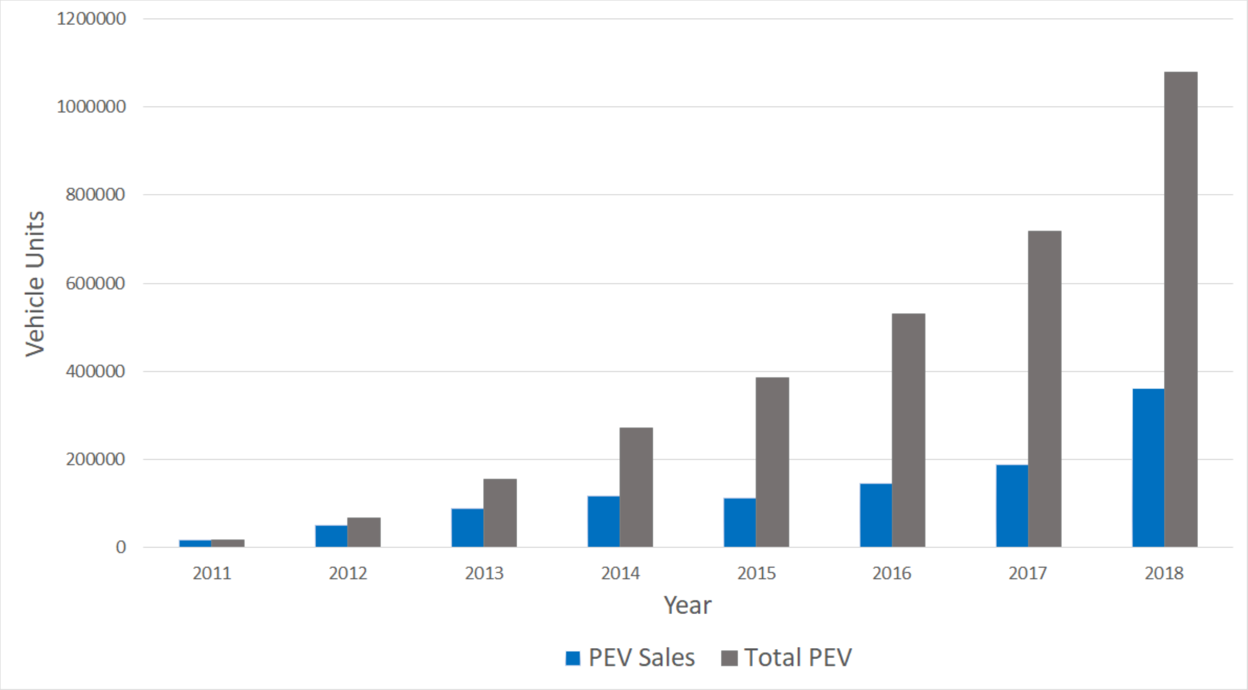
While it took 8 years for EV numbers on U.S. roads to reach 1 million units, the EEI report predicts that the next 1 million EVs will be on the road by 2021. The EEI report also states that EV sales are expected to increase to over 3.5 million units sold in the U.S. in the year 2030 (Edison Electric Instititute, 2018). To provide perspective to the projections for future EV adoption, sales of EVs increased by 80 to 90% between 2017 and 2018 (EV Volumes, 2018). A large contributing factor to this sales increase is the mass production of the Tesla Model 3 which occurred during Q3 and Q4 of 2018.

1.1.1 Historical and Current Electric Vehicle Sales

Figure 1-1 below shows the historical growth of plug-in electric vehicle sales in the U.S. from 2011 to 2018. The numbers shown include both PHEV and BEV sales. PEV sales from each previous year are summed to show the total number of PEV on U.S. roads per year. The total number of PEV on U.S. roads crossed 1 million units in October of 2018 according to the EEI (Edison Electric Instititute, 2018). Figure 1-1 shows that sales for PEV had been relatively steady until 2018.

In July of 2017, Tesla started selling the Model 3 in the U.S in limited numbers. After working through increasing weekly production numbers in Q1 and Q2 of 2018, Tesla began producing 5,000 Model 3s per week in July of 2018. For 2018, the website EV Volumes reported that around 140,000 Tesla Model 3s had been sold (EV Volumes, 2018). This increased production accounted for approximately 38% of the total PEVs sold in the U.S. in 2018.

Figure 1-1: Annual PEV Sales and Total Cumulative PEV Sales



Sources: (Auto Alliance, n.d.), (InsideEVs, n.d.), (Edison Electric Instititute, 2018)

To put total PEV sales into perspective, Table 1-1 below shows the breakdown of PEV sales in California, New York, Missouri, Kansas, and Minnesota. The sales column shows PEV sales between January 2011 and August 2018 according to Auto Alliance. The percentage column shows the total EVs out of total new light duty car sales in each state between January 2011 and August 2018. The state of California was chosen for this table as it accounts for a majority of EV sales in the United States. New York was chosen as it has enacted policies promoting the adoption of ZEV. Kansas and Missouri were selected as Kansas City Power & Light (KCP&L), which serves eastern Kansas and western Missouri, has built out a network of over 1,000 public EV charging stations.

Table 1-1: Sales Percentage by State from January 2011 to August 2018

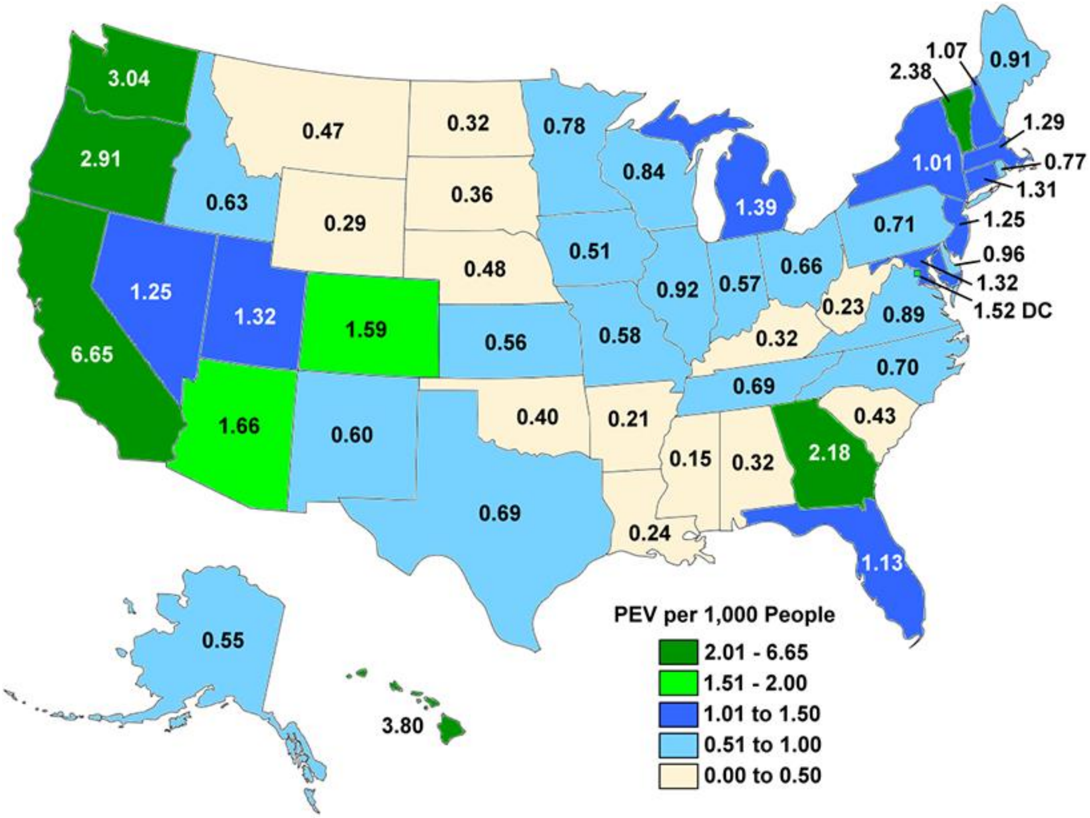
State	PEV Sales	% PEV
California	441,679	49.38%
New York	38,480	4.30%
Missouri	5,584	0.62%
Kansas	2,145	0.24%
Minnesota	7,342	0.82%

Source: (Auto Alliance, n.d.)

1.1.2 Current Electric Vehicle Registrations

Based on the sales data of PEV, the number of registered EVs in each state has been estimated by the Office of Energy Efficiency & Renewable Energy. Figure 1-2 shows the number of registered PEVs per 1,000 people in each state in the year 2016.

Figure 1-2: PEV Registrations per 1000 people



Source: (Office of Energy Efficiency & Renewable Energy, 2017)

For comparison, Table 1-2 below highlights the total number of EV registrations per 1,000 people in California, New York, Missouri, Kansas, and Minnesota as captured by the Office of Energy Efficiency & Renewable Energy.

Table 1-2: Comparison of PEV Registrations in CA, NY, MO, KS & MN

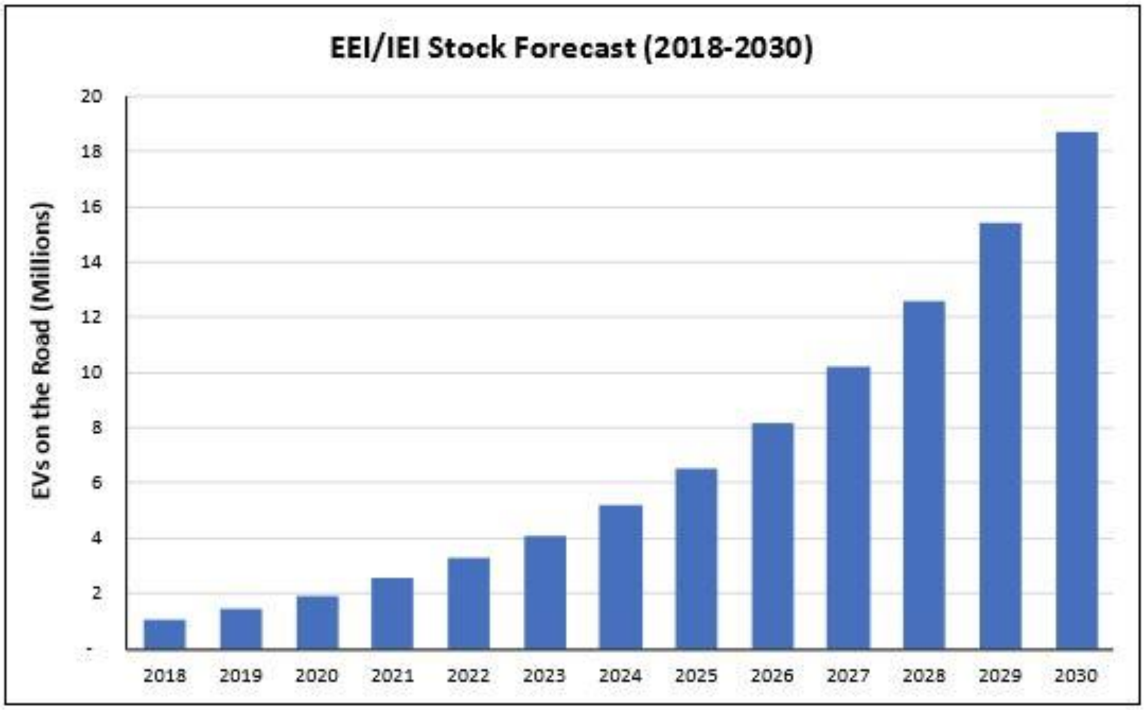
State	PEV Registrations per 1000 people
California	6.65
New York	1.01
Missouri	0.58
Kansas	0.56
Minnesota	0.78

To take these registrations per state a step further, the Alternative Fuels Data Center has developed a tool called “EV-Pro Lite” which shows the number of PEVs registered in a metropolitan area. This tool shows that in the year 2016, there were 110 PEVs registered out of a total of 122,700 registered light duty vehicles in the Rochester, MN metropolitan area (Alternative Fuels Data Center, n.d.).

1.1.3 Projected Electric Vehicle Market Growth

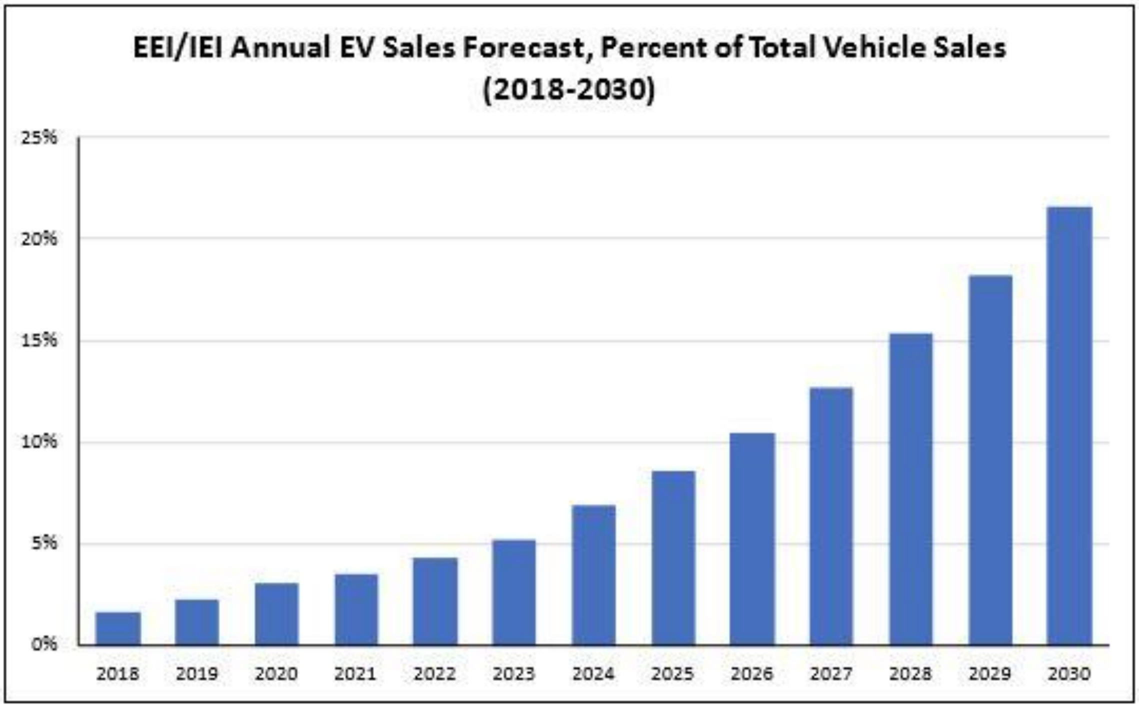
EV market growth in 2018 was strong and the projected growth over the next decade is not showing signs of slowing down. According to a report titled “Electric Vehicle Sales Forecast and the Charging Infrastructure Required Through 2030” the EEI is projecting that EV sales will grow exponentially during the next decade. By early 2021 EEI expects that 1 million additional EVs will be sold, for a total of 2 million EVs on U.S. roads. Furthermore, by the year 2030 EEI projects that 18.7 million EVs will be on U.S. roads with over 20% of total new car sales in 2030 being EVs. Figure 1-4 and Figure 1-5, produced by EEI, show the expected projections for PEV sales and the percent of total new car sales being EVs. However, the Electric Power Research Institute (EPRI) also collected data from several sources and has predicted that PEV sales could potentially be as high as 38% by the year 2030 (Electric Power Research Institute , 2017).

Figure 1-3: PEV Growth on U.S. Roads



Source: (Edison Electric Instititute, 2018)

Figure 1-4: Percentage of PEV New Sales



Source: (Edison Electric Instititute, 2018)

1.2 Market Drivers

Several factors have contributed to the growth of the EV market over the past decade such as increased model variety, advanced vehicle technology, lower battery costs, increased range, faster and more widely spread charging infrastructure, consumer desires for cleaner and sustainable transport, and federal and state policies that favor ZEV adoption. One of the biggest drivers of EV sales in 2018 was the increased production and availability of the Tesla Model 3. In the coming decades the improvement in technology and lowering prices combined with policies that favor ZEV adoption will continue to bolster EV sales in the next 10 years.

1.2.1 Development of Electric Vehicle Technology

Since 2010 the mileage that EVs can travel on a single charge has increased while the cost of the vehicles has reduced. One of the most important aspects of improving EVs in terms of range and cost are improvements in battery technology and increased battery production. Lithium-ion batteries (LIBs) have been the chosen battery type for EVs to date, and since 2010, the price per kWh of LIBs has decreased significantly. Figure 1-5 below shows the price history of LIB packs from 2010 to 2016. In March of 2018 Bloomberg New Energy Finance published an article estimating battery pack costs to be at $209 per kWh (Finance, 2018).

Figure 1-5: Lithium-ion Battery Pack Cost per kWh

Source: (McKinsey & Company, 2017)

According to the Boston Consulting Group, LIB packs are projected to cost $100 per kWh between 2025 and 2030 (Edison Electric Instititute, 2018). Once LIB packs reach $100 per kWh, the costs of EVs are expected to be comparable to the price of internal combustion engine (ICE) vehicles. During the time that the cost of LIB packs has decreased, battery production has increased from 1 GWh in 2011 to 37 GWh in 2017 (EV Volumes, 2018). As an example of increasing battery production, the Tesla Gigafactory in Nevada started producing around 20 GWh of annual battery production in August of 2018 (Stumpf, 2018). As of August 2017, the facility was only around 30% complete (Lambert, 2018; Stumpf, 2018). Production from the Gigafactory is expected to increase to 35 GWh/yr in the coming years.

Due to the decreasing price of battery technology, larger battery packs can be incorporated into EVs which in turn enables EVs to travel further on a single charge thus reducing consumer concerns about range anxiety. BEVs on the market today have ranges from 58 to 335 miles (InsideEVs, 2018; InsideEVs, n.d.).When DC fast charging (DCFC) technology is used, EVs can regain 10 to 20 miles of range per minute depending on the peak power output of the charging infrastructure.

1.2.2 Electric Vehicle Policies and Initiatives

Another key component to the growing EV market is the presence and availability of state and federal policies and initiatives that have encouraged and incentivized the purchase of ZEVs; however, in the future, some of these policies will expire and change which could impact the market response to purchasing EVs in the future. Some of the policies and incentives are listed below:

- **Emissions and Fuel Economy Standards:** Corporate Average Fuel Economy (CAFÉ) standards that are put in place by the Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) mandate the average fuel economy and GHG emissions for all vehicles a manufacturer produces.

- **Qualified Plug-In Electric Vehicle (PEV) Tax Credit**: This federal tax credit was introduced in 2010 and currently applies to newly purchased BEVs and PHEVs. The tax credit ranges from $2,500 to $7,500 and is set to expire once a vehicle manufacturer sells 200,000 units.

- **State Tax Incentives**: Several states offer tax credits on the purchase of EVs. For example, Colorado currently offers a $5,000 tax credit for BEVs and PHEVs, California offers $2,500 for BEVs and $1500 for PHEVs, and New York offers $2,000 for PEVs.

- **Utility Incentives**: The most common incentive that electric utilities in the U.S. offer are rebates on the purchase of electric vehicle supply equipment (EVSE). In Minnesota, Connexus Energy offers a $500 rebate to residential customers. However, some utilities are also offering rebates for the purchase of EVs.

- **Regulations:** Ten states have agreed to adopt and put into place a ZEV standard that is managed by the California Air Resource Board (CARB) (California Air Resources Board, n.d.). The ZEV standard mandates that a percentage ranging from 2.5% in 2018 to 8% in 2025, of new vehicles sold in CA by a manufacturer must be ZEV (California Air Resources Board, n.d.). Other state regulations in place include programs approved by the California Public Utility Commission (CPUC) for spending on make ready EVSE infrastructure programs.

2.0 ELECTRIC VEHICLE DEVELOPMENT

To support the future projections expected from EV growth outlined in section 1 of this report, there needs to be development in EV technology, investments in EV model creation by automotive manufacturers, and a reduction of the initial purchase price of EVs. This section discusses these topics by outlining the different vehicle types that have been developed, presenting developments in technology such as batteries and charging equipment, discussing investments that will be made by EV manufacturers in the future, and comparing the costs of purchasing and owning an EV to a conventional ICE vehicle.

2.1 Electric Vehicle Technology

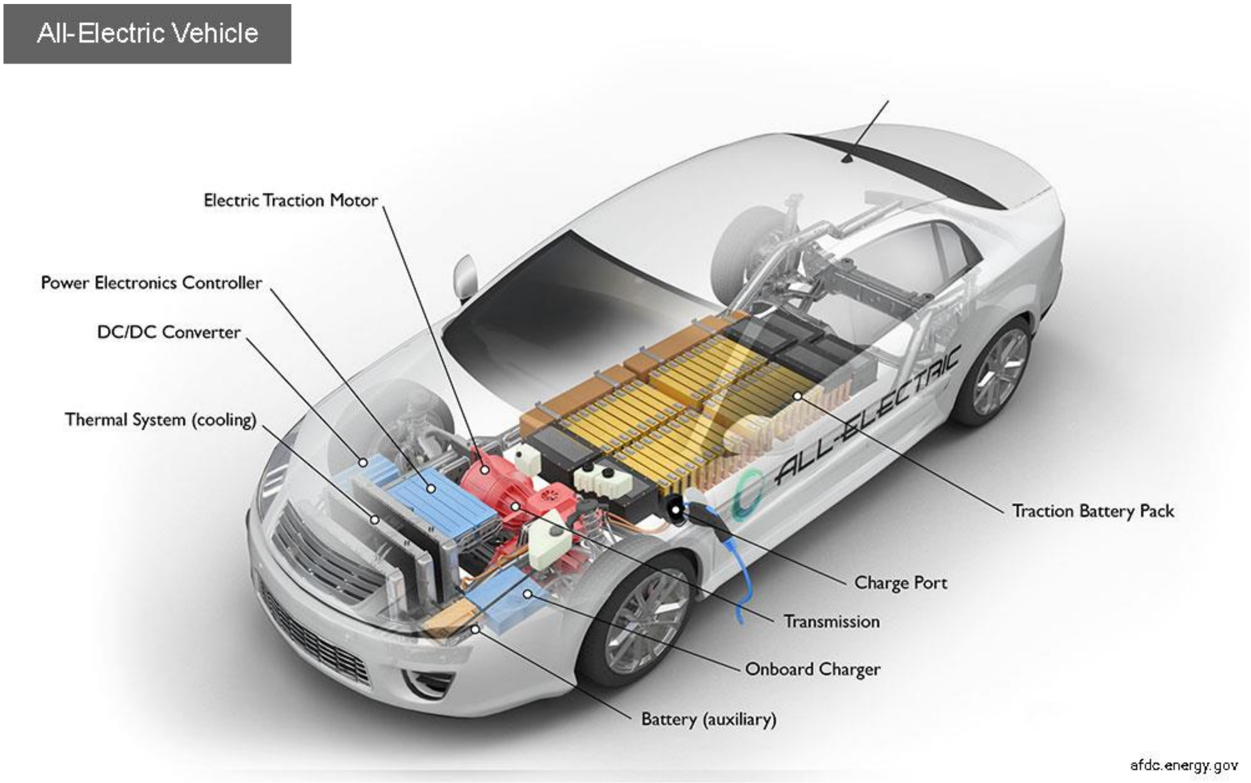
There are four main types of electric vehicles; battery electric vehicles (BEVs) which are completely powered by an electric drivetrain and battery, plug-in hybrid electric vehicles (PHEVs) which have both a battery and internal combustion engine (ICE) and can recharge from the grid, hybrid electric vehicles which have both an ICE and a battery which is recharged from the ICE, and extended range electric vehicles which use an all-electric drive train and battery with an ICE used as a generator to power the electric system when needed. One of the major developments in EV technology has been the decreasing cost of lithium-ion battery (LIB) packs and the production of more EV models that feature longer driving ranges. Developments in EVSE technology have also progressed to the point where a 1 minute charge could potentially provide 20 miles of driving range. With vehicle-grid integration there is also the potential for EV owners to receive incentives from utilities for peak shaving, frequency response, or the use their own vehicle for back-up power and storage.

2.1.1 Electric Vehicle Types

There are various types of electric vehicles on sale today that offer different capabilities and technology. The list below details the different EV types available today. The focus of this report will be on vehicles that can plug into the grid such as PHEVs and BEVs.

- **Battery Electric Vehicles (BEVs):** BEVs do not have an internal combustion engine (ICE) on board and rely on a large battery pack and electric motor(s) for propulsion. Typical battery pack sizes range from 24 kWh to 100 kWh. Figure 2-1 below shows the typical components included in a BEV.

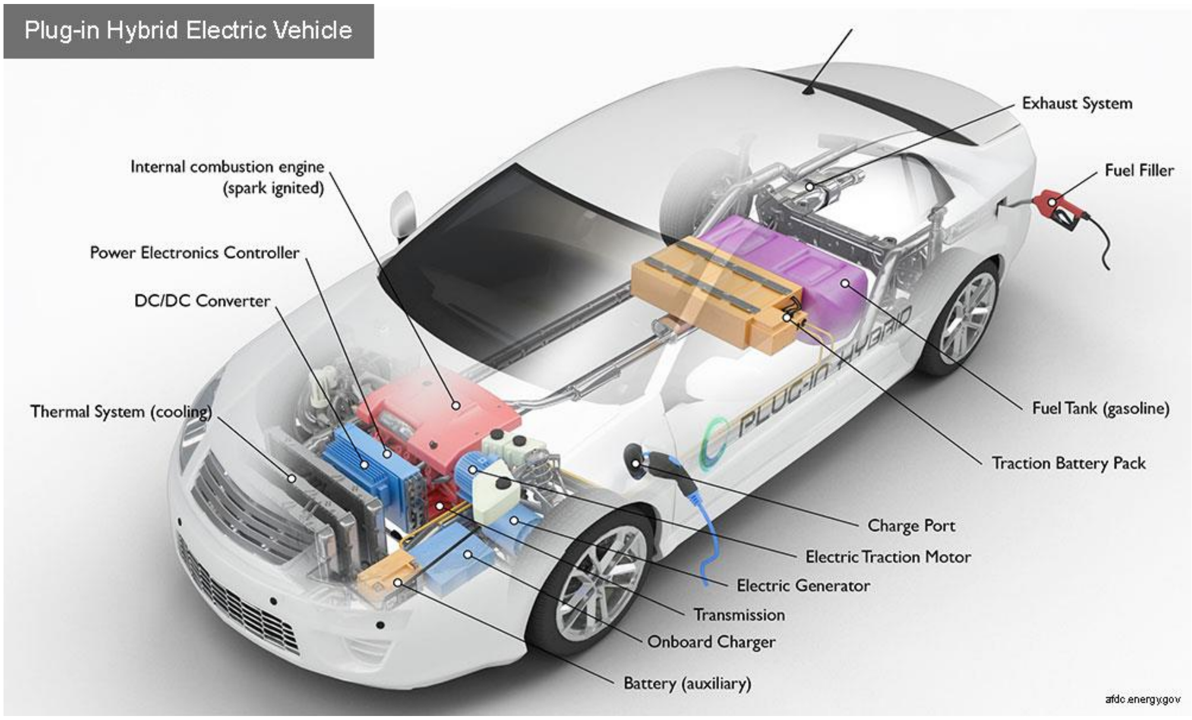
Figure 2-1: Typical Components in a Battery Electric Vehicle



afdc.energy.gov

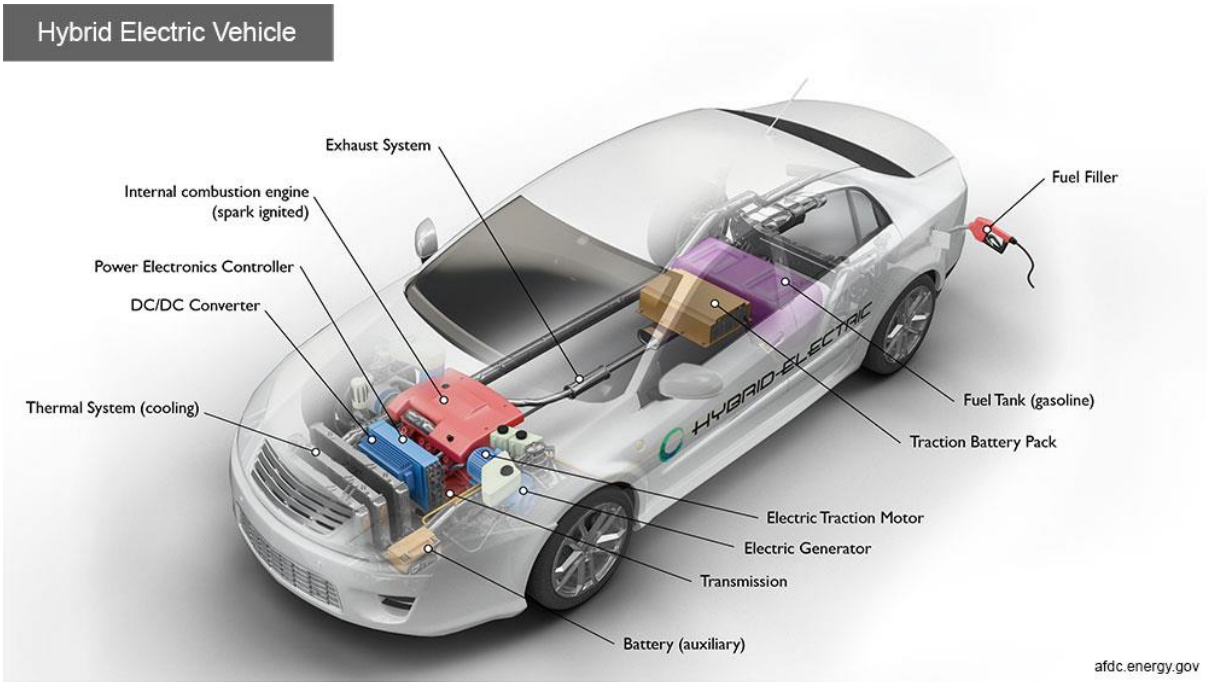
- **Plug-in Hybrid Electric Vehicles (PHEVs):** PHEVs use an ICE, electric motor, and smaller battery pack to propel the vehicle. This vehicle continues to drive when the battery is depleted and needs to be connected to the grid to recharge. Typical battery pack sizes range from 4 kWh to 10 kWh. Figure 2-2 below shows the typical components included on a PHEV.

Figure 2-2: Typical Components in a Plug-in Hybrid Vehicle



- **Hybrid Vehicles:** Hybrid vehicles use an ICE, electric motor, and small battery pack to propel the vehicle. The ICE drives an electric generator that recharges the vehicles battery. This vehicle cannot be connected to the grid to recharge the battery. Figure 2-3 below shows the typical components of a hybrid vehicle.

Figure 2-3: Typical Components in a Hybrid Vehicle



- **Extended Range Electric Vehicles:** Extended range electric vehicles are very similar to a PHEV. However, an ICE is used to power an all-electric drive train for propulsion. They can be plugged into the grid and have battery packs approximately 20 kWh to 30 kWh in size.

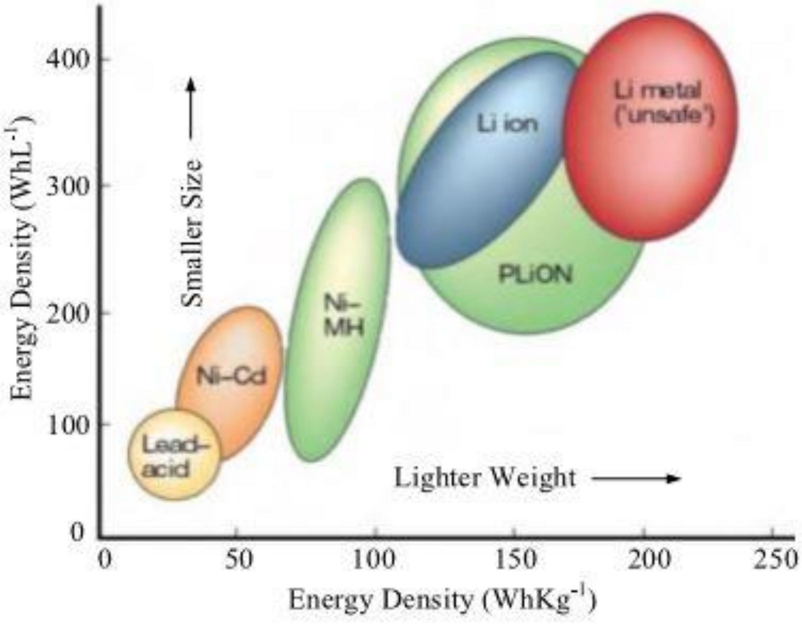
The component each vehicle type has in common is that they all have a battery pack on the vehicle. A critical development in the adoption of EVs is the range that they can travel on a single charge. The range an EV can travel has been tied to the production and cost of lithium-ion batteries (LIB), and if larger battery packs can be installed at a lower, cost the range of the EV will increase while the price decreases.

2.1.2 Battery Technology

The battery is the most critical component of a PEV. The range a PEV can travel and the cost of the PEV is directly tied to the price of the battery pack. Using the Tesla Model 3 as an example, it can be estimated that a battery pack accounts for approximately 33% of the total cost of an EV. This percentage assumes that the battery pack is 75kWh in size, costs Tesla $190 per kWh to produce, and is placed into a rear drive Tesla Model 3 with a $42,900 MSRP before rebates (Lambert, Electric vehicle battery cost dropped 80% in 6 years down to $227/kWh – Tesla claims to be below $190/kWh, 2017).

There are various battery types manufactured and installed in EVs today. Over the last decade the most widely used battery type for EVs has been lithium-ion (Li-ion). Li-ion batteries have been a preferred choice for EVs due to their excellent energy density and lighter weight when compared to other battery types. Figure 2-4 below shows a comparison of some of the most widely used battery types.

Figure 2-4: Energy Density of Different Battery Types



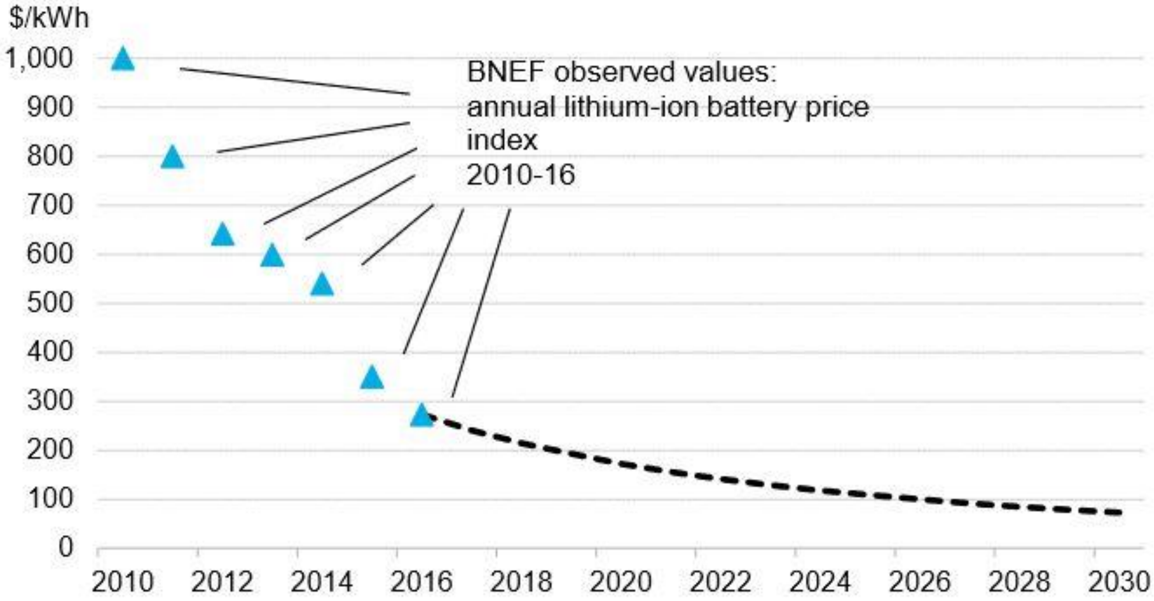
Source: (Hannan, Hoque, Yusof, & Ker, 2018)

Within the LIB family there are different battery chemistries that have been developed over the last decade. Today the most widely used and adopted LIB battery chemistry for light duty EVs is lithium nickel manganese cobalt oxide (NMC) (EV Volumes, n.d.). Lithium NMC batteries have been chosen due to good overall performance in terms of specific energy output, cost, life span and safety. Recently, Tesla has started production in partnership with Panasonic to produce lithium nickel cobalt aluminum (NCA) batteries (Irle, n.d.). The advantages of shifting to lithium NCA batteries include; higher specific energy output, lower costs, and longer life spans when compared to lithium NCM batteries.

Since manufacturers of electric vehicles continue to produce and sell more units, LIB production has increased and is expected to increase over the next 10 years. Tesla's Gigafactory, which was built in Nevada, is currently at 30% capacity and has a production rate of 20 GWh/yr of battery packs (Lambert, Tesla confirms Gigafactory 1 battery production at '~20 GWh' – more than all other carmakers combined, 2018). A report produced by Bloomberg New Energy Finance (BNEF) has estimated Li-ion battery production to be at 131 GWh/yr today. It is expected that production will increase to 400 GWh/yr in 2021 with a demand of over 1,500 GWh in 2030 to support vehicle electrification (Goldie-Scot, 2018).

As production increases the total cost of battery packs is expected to decrease. Figure 2-5 below shows the projected cost of LIB over the next decade with the price reaching $73 per kWh by 2030.

Figure 2-5: Lithium-ion Battery Price Projection



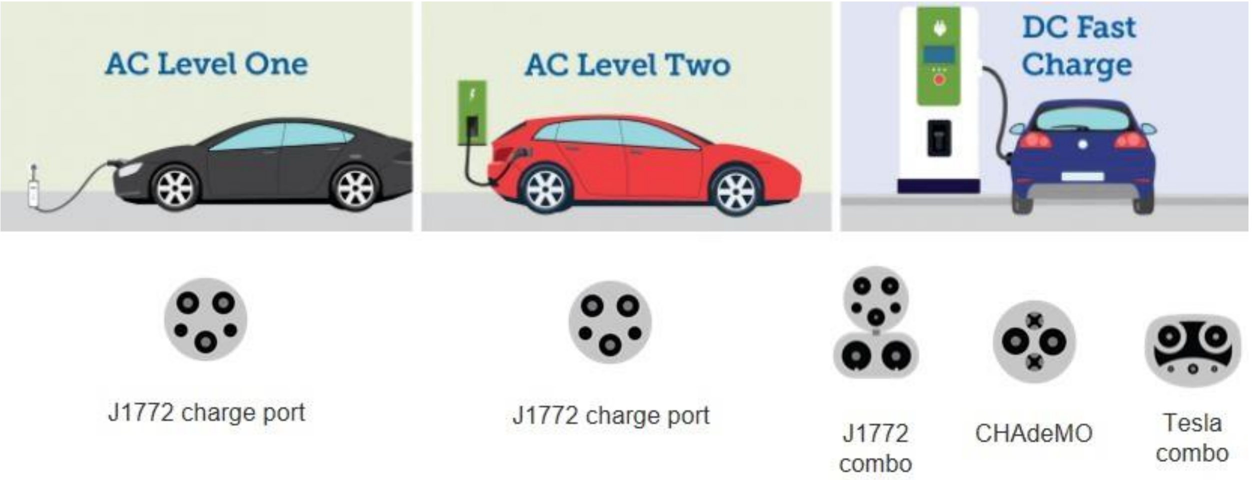
Source: (Bloomberg New Energy Finance, 2017)

Battery pack sizes for both BEV and PHEV range from 4kWh to 100kWh in today’s market and in the future battery capacity could increase. Since electric pickup trucks could have battery packs that could be up to 180kWh in capacity the decreasing cost of LIB is critical in expanding the range of EVs available to consumers.

2.1.3 Charging Technology

Batteries are an essential component that directly determine the range an EV can travel and its price. Electric vehicle supply equipment (EVSE) is the critical infrastructure that is needed to enable cross country travel and reduce consumer concerns about range anxiety. There are various charger types available today with different voltage levels and power outputs. Figure 2-6 shows the main types of EVSE technology and charge ports that are currently used. Table 2-1 summarizes the capabilities of each EVSE type.

Figure 2-6: Different EVSE Types



Source: (Alternative Fuels Data Center) (Brodd, 2017)

Table 2-1: Summary of EVSE Types

	Level 1	Level 2	DC Fast Charging
Input Voltage	Single Phase 120VAC	Single Phase 240VAC	Three Phase 480VAC
Charge Power	1.4-1.9 kW	3.5-19.2 kW (typ. 7 kW)	50-350 kW
Charge Port	J1772	J1772	J1772 CCS, CHAdeMO, Tesla Combo
Charge Time	12-24 hours	4-8 hours	80% charge in 20-30 min
Typical Location	Home	Home/Workplace	Highways/Rest Stops Near Highway

Table 2-2 below highlights how using the different EVSE types relates to the time it takes to replenish charge into the battery of an EV and how much mileage can be gained by charging over time. The table assumes that EVs provide an average efficiency of approximately 3 miles per kWh of energy consumed.

Table 2-2: EVSE Charge Rates

EVSE Power Output (kW)	EVSE	Assumed EV Efficiency (kWh/mi)	Energy Added (kWh/min)	Mileage Added Per Charge Time (miles/min)	Mileage Added Per Charge Time (miles/20 min)
1.4	Level 1	0.3	0.02	0.08	2
1.9	Level 1	0.3	0.03	0.11	2
3.8	Level 2	0.3	0.06	0.21	4
7.6	Level 2	0.3	0.13	0.42	8
19.2	Level 2	0.3	0.32	1.07	21
50	DCFC	0.3	0.83	2.78	56
100	DCFC	0.3	1.67	5.56	111
150	DCFC	0.3	2.50	8.33	167
350	DCFC	0.3	5.83	19.44	389

As Table 2-2 shows, using DC fast charging (DCFC) with a power output of 150kW or above provides a reasonable range from a 15 to 20 minute charge. If DCFC equipment is positioned along interstates roughly every 70 miles, consumers are enabled to travel cross country with their EV and reduces the concerns of range anxiety. An example of these charge networks includes the Tesla Supercharging network and the Electrify America network which is currently building out a national DCFC system along major US travel corridors (Evarts, 2018). While the Tesla Supercharger network uses the proprietary Tesla combo plug and only supports Tesla supercharger enabled vehicles, the Electrify America DCFC equipment will support any vehicle that supports DCFC and has a J1772 combo or CHAdeMO plug. In North America most manufacturers have adopted the use of the Society of Automotive Engineers (SAE) J1772 combo plug for DC fast charging. However, the CHAdeMO plug is still used mainly by Japanese manufacturers such as Nissan. To install a DCFC station a suitable site with access to a 480V three phase source is required. When multiple chargers and plugs are installed transmission and distribution systems need to be considered and verified for enough capacity. DCFC sites generally consist of a utility transformer, electrical switchgear, power electronics, and in some cases a pedestal that holds the charge cable. Figure 2-7 shows an example site constructed by Electrify America.

Figure 2-7: Example DCFC Site

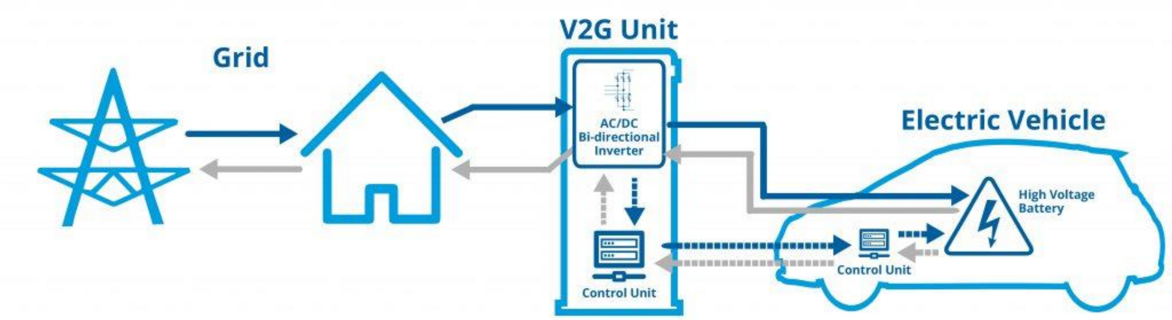
Currently, a majority of the installed DCFC stations have an output between 50 kW and 150 kW. In recent times vehicle and EVSE manufacturers have been deploying DCFC technologies in cars and along highways that can use and provide a charge greater than 150kW. To enable charge rates higher then 150kW the EV must support high charge rates and the DCFC equipment must use liquid cooled cables. In May of 2018 Electrify America commissioned a 350kW charger in Chicopee, MA and plans to install a minimum of two 350kW units at each of the 300 DCFC stations it is planning to install (Evarts, 2018).

For a typical day to day commute, a Level 2 charger at home will provide the needed energy to support travel between work and home. An advantage to using Level 2 AC charging is that a charge cycle can occur overnight during off peak hours which lowers demand on the distribution grid and reduces the infrastructure costs associated with installing DCFC stations. Many workplaces are also installing and providing Level 2 charging for employees to use during the day.

2.1.4 Vehicle-grid Integration

Vehicle-grid integration (VGI) is most commonly discussed in terms of Vehicle-to-Grid (V2G) technology that allows an EV to participate in bi-directional power flow with the electric grid. This means that the energy from the EV’s battery system can both take and return power to the grid when a suitable opportunity exists. In order to enable V2G connectivity, both the EV and EVSE must support bi-directional power flows as shown in Figure 2-8 below.

Figure 2-8: Example V2G System



Source: (Schmidt, 2017)

Since the presence of BEVs and PHEVs is expected to increase, opportunities could exist for electric utilities to benefit from V2G technologies by introducing programs that pay customers for using their EV batteries for peak load shaving or frequency response programs (Schmidt, 2017). However, while customers may receive incentives from participating in V2G programs there are the hidden costs of using EVs for V2G functions such as decreasing the EVs usable life. The life of the LIBs used in EVs is directly dependent on both the charge and discharge rates and the number of charge and discharge cycles the battery has experienced. Furthermore, most people are travelling before and after when peak demand is the highest and they will require energy in their EV to complete their commute or errands. The likelihood of consumers participating in these programs at times of peak demand could be very low.

Another challenge to implementing V2G systems is the availability of commercial charging systems and vehicles that support bi-directional power flows. At this time, few vehicles and EVSE manufacturers provide this option and few programs have been piloted or implemented in the U.S. However, Nissan and BMW have enabled the EVs to work with bi-directional chargers and a company called Nuvve that is based out of San Diego that has been piloting EV chargers that support V2G in the United Kingdom, Denmark, and the United States. In the United Kingdom, Nuvve is expecting to deploy 1,500 chargers alongside EDF Energy to business customers and EDF Energy sites. EDF Energy expects to collect 15MWh of energy that will be sold on the energy market or used for peak shaving (Kane, 2019). In the United States the University of California San Diego is using 50 Nuvve EV V2G chargers that allow the EVs to support the campus micro-grid. (Bigelow, 2017).

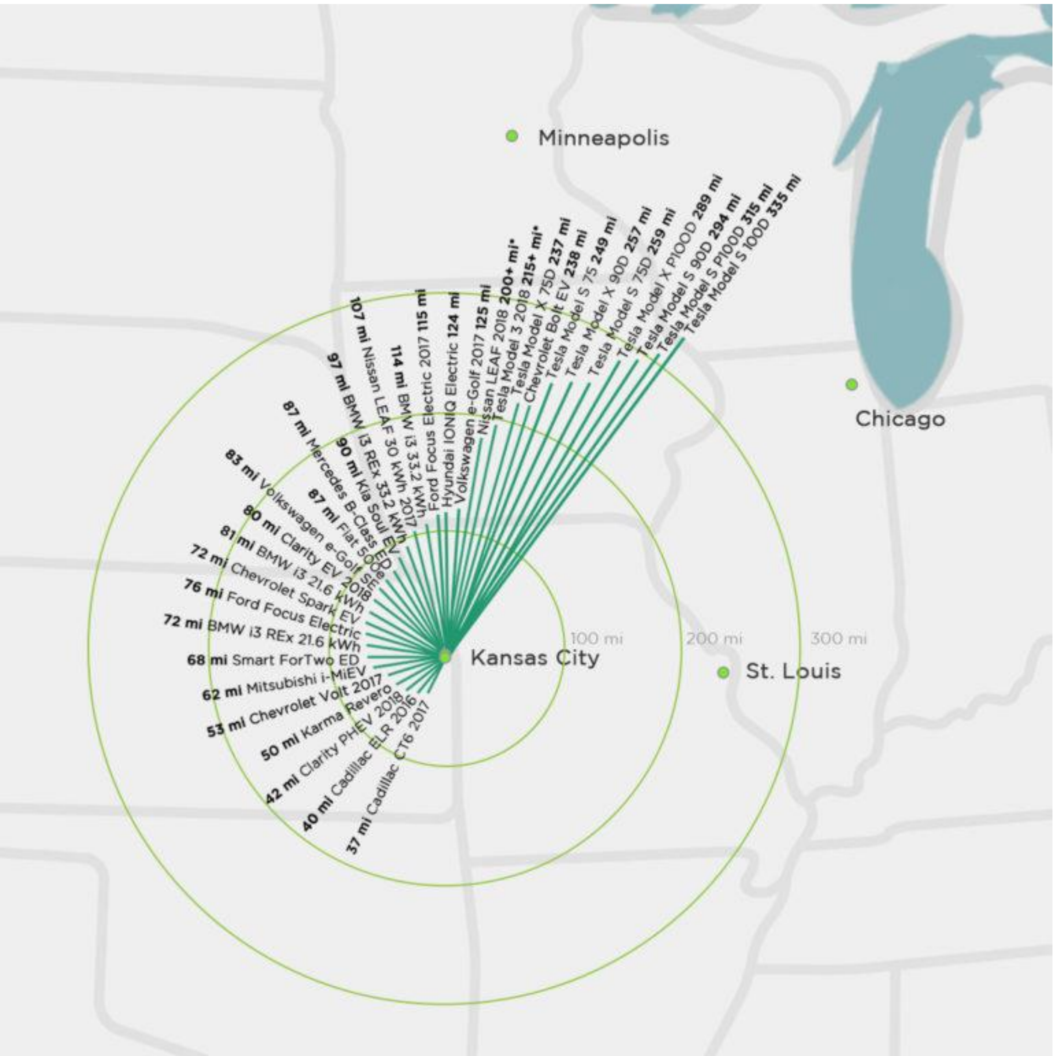
Lastly, while V2G is possible the cost of stationary battery storage systems is expected to be lower and more competitive than using the traction batteries in EV’s. Since battery storage can perform the same functions as an EV at lower costs without affecting the range or life of a consumers expensive EV, using stationary systems could present a better option for energy storage. For example, the cost of a Tesla Powerwall with 27kWh of storage capacity is $14,500 (not including installation). Whereas the cost of a Tesla model 3 is around $42,900.

2.2 Electric Vehicle Manufacturers

There are over 50 different PEV models currently available for purchase in the United States. These different models include both PHEVs and BEVs with travel ranges varying between 8 miles to 58 miles for PHEVs and 58 miles to 335 miles for BEVs (InsideEVs, 2018). Some of the major manufacturers that produce these vehicles include Volkswagen, Volvo, Mercedes, BMW, Hyundai, Nissan, Chrysler, Ford, Chevrolet and Tesla.

PHEVs and EVs are currently available in most vehicle types ranging from small compact vehicles to large Sport Utility Vehicles (SUVs). A recent development in vehicle availability has been the introduction of cheaper BEVs costing between $35,000 and $44,000 with ranges over 200 miles. At this time Chevrolet has produced the Bolt with a 60 kWh battery and Tesla has built the Model 3 with a 75kWh battery. In California, Hyundai has started selling a battery electric hatchback which can seat 5 people, is equipped with a 28 kWH battery, and can travel 141 miles on a single charge. Figure 2-9 below shows the travel range and availability of some common PHEV and BEV.

Figure 2-9: PHEV and BEV Models and Range



Source: (Plugless, 2017)

Two of the fastest growing and most popular vehicle classes in the U.S are Sport Utility Vehicles (SUVs) and Compact Utility Vehicles (CUVs). While there are limited models with high price tags available in the CUV and SUV class today, most manufactures have plans to begin producing more of these types of EVs in the future. For example, Tesla sells the model X and plans to create a CUV based on the Model 3, Jaguar recently released the EV400, and Volkswagen will be releasing its ID concept model in the near future.

The bestselling vehicle class in the United States is the pickup truck, and while no commercially available EV pickup trucks are on sale at this time, announcements have been made to produce these vehicles in the future. For example, a startup company called Rivian has announced the R1T, a full-size pickup truck that boasts a 180kWH battery pack, over 400 miles of range, and a starting MSRP of $69,000. Ford, who produces the bestselling F-150 pickup truck has announced it will release a hybrid version in 2020 and plans to build an all-electric version shortly after.

In the coming years several major vehicle manufactures have announced plans supporting the production of more EV models. In 2017 Volkswagen announced that it will spend $40 billion until 2025 to add 50 BEVs and 30 Hybrids to its vehicle lineup and in 2020 Volkswagen expects to start selling its line of I.D. electric concept vehicles. In 2018 Ford announced that it will invest $11 billion to add 40 hybrid and BEVs to its model line up by 2022. Daimler has announced similar plans with a $11.7 billion investment to produce 10 BEVs and 40 hybrid models. GM has also announced that it expects to add 20 new BEV and fuel cell vehicles to its vehicle lineup by 2023 (Global carmakers to invest at least $90 billion in electric vehicles, n.d.).

2.3 Electric Vehicle Costs

PEV prices have steadily been decreasing as battery prices have dropped and more affordable PEV models have come to the market. Chevrolet and Tesla offer BEVs with ranges greater than 200 miles and starting prices from $36,000. Hyundai which has a history of producing reliable low-cost vehicles sells the Ioniq which provides 124 miles of range and has a MSRP of $29,815. The prices listed are before any rebates or tax incentives. For comparison, the average price of a new light duty vehicle sold in January 2019 in the United States was $37,149, an increase of 4.2% over new vehicle prices from January 2018.

While the purchase price of BEV and PHEV are higher than the equivalent ICE vehicle, the total cost of owner ship (TCO) needs to be considered for a comparison between the two. BEVs have fewer moving parts and require less maintenance than an ICE vehicle and electric energy costs are lower and more stable than the price of gasoline. When compared to conventional ICE vehicles, PHEVs return better fuel efficiency and offer substantial fuel savings. Table 2-3 compares three similar vehicles and compares the savings from fuel consumption between BEVs, PHEVs, and conventional ICE vehicles.

Table 2-3: Comparison of BEV, PHEV, and ICE Prices

Vehicle Type	BEV	PHEV	ICE
Vehicle Make and Model	Nissan Leaf	Toyota Prius Plug-in Hybrid	Toyota Corolla
Cost (MSRP)	$29,990	$23,475	$18,700
Combined MPG	+	52	32
Fuel Cost Per Year*	$532	$741	$1,205
Fuel Savings Over 5 Years	$3,361	$2,317	$0

*Assumes 15,000 miles travelled in a year with an average fuel cost assumed to be $2.57/gallon and electricity cost of 13.31 cents/kWh. + Assumed EV efficiency is 0.267kWh/mi

In addition to savings in operation and maintenance of a BEV versus an ICE vehicle there are also federal and state incentives available which help make the price more competitive. However, one issue that has yet to be addressed is taxes that are tied to fuel prices which pay for maintenance and construction of interstates and highways. Inclusion of these taxes could equate to EVs having higher or additional registration fees in the future. Some states have already placed additional registration fees on EVs. These fees have been ranged between $50 to $100. For the price of a BEV to reach parity with a comparable ICE vehicle it is projected that the cost of LIB will need to reach $100 per kWh.

3.0 FLEET & MASS TRANSIT ELECTRIFICATION

Sections 1 and 2 have focused mainly on light duty vehicles and technology. While the concepts for light duty electrification in terms of vehicle batteries and charging apply to heavy and medium duty vehicles, the scale becomes larger. Furthermore, when fleet and mass transit is involved several large battery vehicles could reside and charge in a central location. This could lead to the creation of large load centers coming onto the distribution system. For example, if more long-haul semi-trucks are converted to electric, truck stops that would traditionally provide millions of gallons of diesel would now need to provide MWh of energy at locations across the United States. In addition to large trucks, USPS, Fed-Ex, and UPS provide delivery services, with smaller vans and trucks, to homes and businesses across the United States. With more people shopping online, delivery services are only expected to grow.

The electrification of bus fleets must also be considered. These large vehicles will need to charge at strategic locations along a route and have charging capacity available at a central depot that could house hundreds of buses. People are also utilizing services like Lyft and Uber. With autonomous vehicles looming on the horizon there could be a future potential for more electric vehicles in urban areas that are provide ride sharing services.

Lastly, one of the strongest reasons that could encourage more trucking operators and delivery companies to convert to electric vehicles are the cost savings that can be realized in terms of both operation and maintenance. Since electric vehicles have better efficiencies and require less maintenance, fuel and repair savings become greater than light duty vehicles.

3.1 Light Duty Electric Vehicle Adoption

Potential areas for electrification of light duty mass transit include ride hailing services like Uber, Lyft, and traditional taxi companies. However, at this time, the large-scale adoption of EVs for ride hailing services has not occurred in the United States. In New York City a trial was conducted in 2013 to understand the feasibility of converting one third of the city’s 13,500 taxi cab fleet to EVs. Six Nissan Leafs were used for the trial and it was determined that recharging the taxis would need to occur for 40 minutes twice in a shift. The study also determined that if one third of the fleet was converted to EVs, a network of 350 50 kW DCFC stations would be needed to support the operation of the electric taxis (NYC Taxi & Limousine Commission, 2013). Nissan has reported that over 500 of its EV models have been deployed as Taxis in Europe (More Than 500 Nissan Electric Cars In Taxi Service Now, 2015).

In India, Uber has partnered with local manufacturer Mahindra to deploy hundreds of EVs. Furthermore, Uber has incentivized its 40,000 drivers in London to convert to EVs by offering a $6,600 (USD) rebate towards the purchase of an EV. Uber stated that it is ready to spend up to $200 million (USD) to support this effort (Lambert, Uber wants its 40,000 drivers in London to switch to electric cars, 2017). While Uber has not made this rebate available in the United States, if such incentives were created in the future, EVs used for ride hailing services could more electric demand in an urban area. The increased presence of EVs used for ride hailing services could help support a business case for installing the required DCFC infrastructure to support their activities.

Rental car companies and businesses with fleet vehicles could also cause a large-scale adoption of light duty EVs. Adoption of EVs by a rental car company or business could lead to 20 to 50 vehicles needing to charge at one location. Level 2 charging would most likely be able to support these vehicles; however, DCFC might be required as well. Companies like Reach Now in Seattle, WA and Portland, OR offer EVs for rental, however, EVs have not been widely adopted by the rental car companies.

Lastly, if society begins to shift towards using autonomous vehicles, these vehicles will most likely be electric. If more people chose to adopt ride sharing services versus ownership of a vehicle, the presence of autonomous vehicles in urban areas could lead to the creation of charging depots with both DCFC and Level 2 charging equipment. However, this will depend on the construction and proliferation of DCFC infrastructure over the next 10 years and whether it will have enough capacity to support the increased energy use from ride sharing services.

3.2 Medium & Heavy-Duty Electric Vehicle Adoption

In recent years manufacturers of mass transit busses and heavy duty trucks have started creating all electric models. These vehicles have a range of applications and sizes that could introduce the possibility of large load centers being created at truck stops, bus depots, and delivery centers across the United States.

3.2.1 Buses

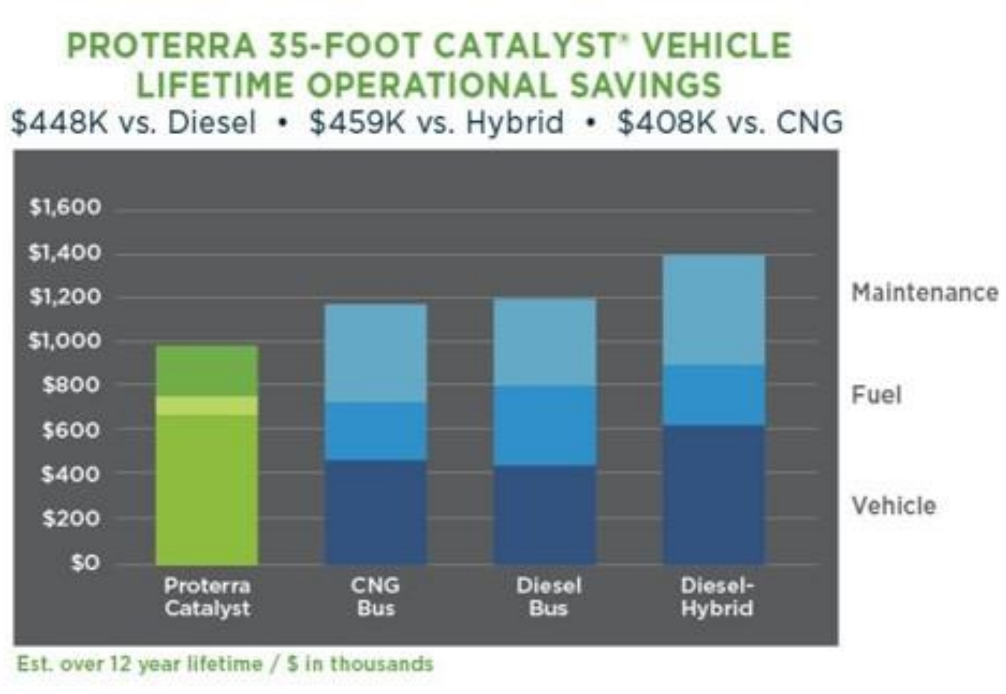
Transit agencies across the United Sates have started investigating converting their bus fleets from diesel to electric. The Federal Transit Administration (FTA) has been providing transit agencies across the U.S. with funding to support the purchases of electric buses and charging infrastructure since 2016. For example, in 2018 the city of Rochester, MN, was awarded $2.3 million in funds. Many transit agencies have been studying electric buses by running pilot programs to understand how they will perform in their service territories. Some transit agencies in California, like Foothill Transit, King County Metro Transit and LA Metro, have proceeded with performing analysis to evaluate the requirements needed to electrify their entire bus fleets. Requirements for bus electrification include integrating infrastructure with bus routes and determining if the electric grid has enough capacity at a bus depot.

Transit operators can maintain a single depot with anywhere from a handful of buses to over 500 buses. Considering that the size of a battery in an electric bus can range from 79 kWh to 660 kWh, the charging output required to energize an electric bus can be substantial. For example, a 50 kW DCFC located at a bus depot would require a window of 12 hours to recharge the battery. Depot chargers can provide between 50 kW to 300 kW; however, future equipment could provide a peak power output of 500kW as demonstrated by ChargePoint's power block system (ChargePoint, n.d.). If 100 buses at a depot needed to be recharged, there could be the potential for a peak load of 5 MW to 15 MW depending on the energy requirements of the bus routes. Electric buses can also benefit from opportunity charging that would occur at advantageous locations along a bus route. The on-route chargers are typically a pantograph style, but in the future wireless solutions may be adopted. Today's pantograph chargers can provide a peak power output of up to 600 kW. Due to this high-power output and the short duration of charging, planning and engagement of the local electric utility is crucial in the positioning and installation of these chargers.

Electric bus manufacturers with models in operation today include Proterra, New Flyer, BYD, and Nova Bus. Each manufacturer has buses of different lengths, passenger capacity, and battery pack size. Benefits for the adoption of electric buses include lowering GHG form a sector that traditionally has high emissions, quieter and cleaner rides for passengers, and operation and maintenance cost savings. Over a 12-year life cycle, bus manufacturer Proterra claims that an electric bus can save over $400,000 in fuel and maintenance costs when compared to a diesel bus. Figure 3-1 and Figure 3-2, produced by bus manufacturer Proterra, show the benefits and savings from operating an electric bus.

Figure 3-1: Proterra Electric Bus Advantages

Figure 3-2: Proterra Electric Bus Savings Comparison



3.2.2 Trucks and Delivery Vehicles

In 2016 there were approximately 11 million large trucks on U.S. roads with around 2.7 million of those being semi-trucks (Federal Motor Carrier Safety Administration, 2018). A single long-haul class 8 semi-truck can have a gross vehicle weight rating (GVWR) of 33,000lbs or more, can travel 1,200 miles in a day, and consume 200 gallons of diesel (Houseman, 2018). Current manufacturers of electric semi-trucks are claiming an efficiency of less than 2 kWh of energy per mile driven. Based on a 1,200 mile a day trip, each semi-truck would need to consume around 2400 kWh of energy a day. Considering that the average truck stop can have between 70 to 200 parking spaces (Houseman, 2018), energy consumption could range from 42 MWH to 120 MWH at a single truck stop each day. This would assume that a 600 kWH battery was in the truck. The peak power required to supply this energy could vary depending on how much time the vehicles charge and the peak power of the charger. As discussed earlier in this report, the peak power for a heavy duty DCFC could range from 150 kW to 350 kW and beyond.

Several class 8 semi-truck manufacturers have announced models that are being tested or will be released in the future. Manufacturers with electric models include BYD, Tesla, Peterbilt, Cummins, Daimler and Thor. Available battery sizes range between 140 kWh to 435 kWh. It is anticipated that the Tesla semi-truck could potentially have a battery pack that is 1 MWh in size.

Semi-trucks are not the only large vehicles that are expected to be electrified. Companies such as Workhorse and Chanje have been producing small all electric delivery trucks and vans that can carry a 6,000 lb. payload and provide 100 miles to 150 miles of range from a battery pack that is 120kWh in size. These vehicles are suitable for delivery services such as UPS, Fed-Ex, and Ryder. For example, in 2018 UPS announced that it would be deploying 50 plug-in electric trucks. UPS also announced that they expected the cost to be the equivalent to purchasing conventional ICE vehicles (UPS, 2018). According to Workhorse, over a 20-year lifecycle their E-100 electric delivery truck can provide a total cost of ownership saving of $150,000 per vehicle (Workhorse, n.d.).

An average delivery vehicle operates for around 8 to10 hours per day and travels an average of 65 miles on a route (Chanje, 2018). A typical depot can have 20 to 150 delivery vans and 40 dock spaces for semi-trucks (Houseman, 2018). If an average of 65 miles was traveled a day by each vehicle, and an efficiency of 1.5 kWh per mi was assumed, each vehicle would need around 100 kWh of electrical energy per day. If the depot had 20 vehicles, this would equate to an energy consumption of 2 MWh in a day. Furthermore, if 10 hours of charging was available overnight, a depot with 20 vehicles using 19 kW Level 2 chargers may only need a peak power of 200 kW. This assumes that 10 vehicles charge for 5-hours at the same time, with a second charging session of 5-hours being needed to charge a total of 20 vehicles. The challenge to electrifying depots, comes in busy times through the year such as the holiday season when deliveries increase and semi-trucks dropping off cargo may need to charge as well. If the delivery trucks had a 30 minute stop between reloading at a depot, and they needed to charge during the return stop, a 200 kW DC fast charger would be necessary to replenish the vehicles battery. If 10 vehicles needed to fast charge during at the same time with 200 kW chargers, a peak load of 2 MW would be required at the depot. This could lead to expensive distribution upgrades or the need to install battery storage at the depot to shave peak demand (Houseman, 2018).

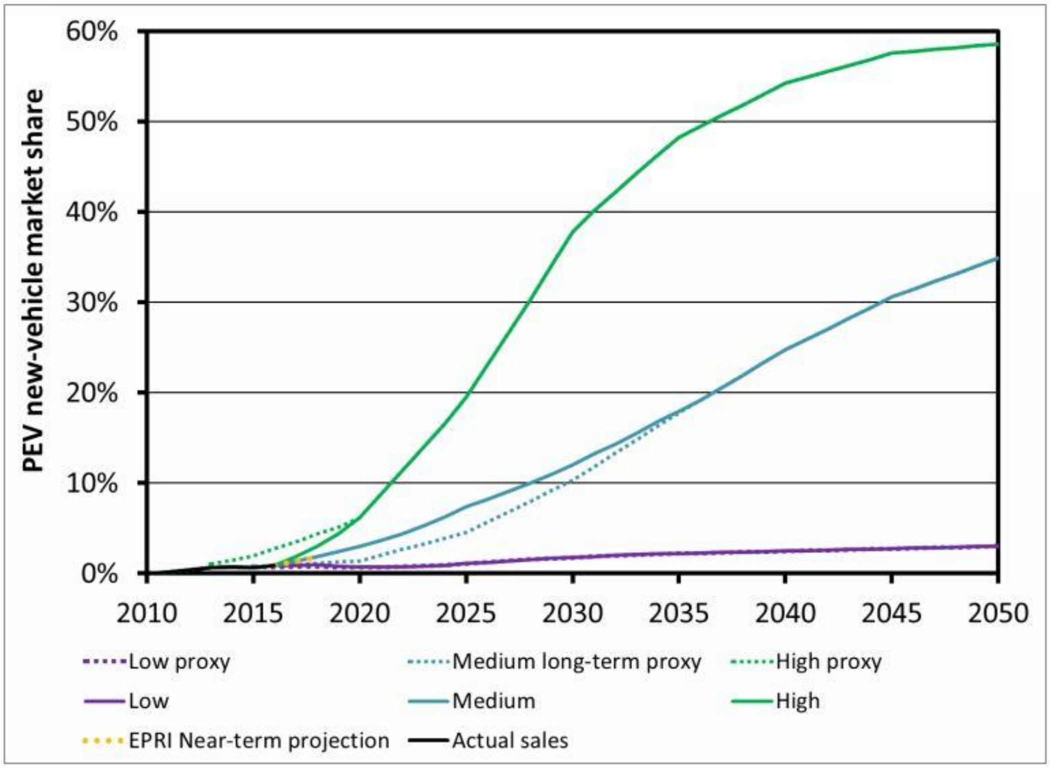
4.0 ELECTRIC VEHICLE LOAD FORECASTS

As manufacturers continue to create more PEV models and PEV sales increase, there is uncertainty to what will happen to load forecasts. To help mitigate this concern, future PEV registrations in a state or city can be estimated, and the expected charging behavior of PEV drivers can be analyzed. In this section, the expected growth of PEVs in Rochester, MN, will be analyzed. An assumed charging behavior will then be applied to the growth of PEVs that will include a charging diversity factor to estimate a charge profile for light duty residential PEVs charging in Rochester, MN.

4.1 Light Duty Forecasts

As discussed in section 1.1.3, the EEI predicted that in 2030 20% of new vehicle sales would be PEVs. However, after assessing multiple sources EPRI created their own projections and predicted that by 2030 new PEV sales could be as high as 38%. Figure 4-1 provides EPRI's projections.

Figure 4-1: EPRI Projections for PEV Market Share



Source: (Electric Power Research Institute , 2017)

To create a light duty PEV forecast for the city of Rochester, over the next 20 years, several points of data were analyzed, and reasonable assumptions were made. To begin, it is assumed that PEV sales will reach the EPRI high forecasts as shown in Figure 4-1. The total vehicles registered in Minnesota were then compared to the total vehicles registered in Rochester to determine a Rochester to Minnesota vehicle sales ratio. The number of PEVs sold and the total new vehicle sales in Minnesota, was developed to determine the percentage of new vehicles that are PEV. Lastly, the forecasted number of new PEVs sold in Minnesota was used to forecast the growth of PEV numbers in Rochester. Table 4-1 and Table 4-2 show the data that was used and the assumptions that were made to forecast registered PEV growth in Rochester. By 2030, it is predicted that nearly 10 percent of all vehicles in Rochester, MN, will be PEVs.

Table 4-1: Registered PEV Projection for Rochester

Year	New Vehicles Sold in MN	New Vehicle Sales Growth in MN	% PEV New Vehicle Sales	New PEV sold in MN	% New Vehicle Sales in Rochester	New PHEV and BEV Sold in Rochester	Projected Total Registered PEV in Rochester
2016							**110**
2017	229180		0.61%	1398	2.50%	35	**145**
2018	230326	0.5%	0.92%	2107	2.50%	53	**198**
2019	231478	0.5%	4%	9259	2.50%	231	**429**
2020	232635	0.5%	6%	13958	2.50%	349	**778**
2021	233798	0.5%	8%	18704	2.50%	468	**1246**
2022	234967	0.5%	9%	21147	2.50%	529	**1774**
2023	236142	0.5%	11%	25976	2.50%	649	**2424**
2024	237323	0.5%	14%	33225	2.50%	831	**3254**
2025	238509	0.5%	20%	47702	2.50%	1193	**4447**
2026	239702	0.5%	22%	52734	2.50%	1318	**5765**
2027	240900	0.5%	24%	57816	2.50%	1445	**7211**
2028	242105	0.5%	31%	75052	2.50%	1876	**9087**
2029	243315	0.5%	34%	82727	2.50%	2068	**11155**
2030	**244532**	**0.5%**	**38%**	**92922**	**2.50%**	**2323**	**13478**
2031	245755	0.5%	40%	98302	2.50%	2458	**15936**
2032	246983	0.5%	42%	103733	2.50%	2593	**18529**
2033	248218	0.5%	45%	111698	2.50%	2792	**21322**
2034	249459	0.5%	47%	117246	2.50%	2931	**24253**
2035	250707	0.5%	48%	120339	2.50%	3008	**27261**
2036	251960	0.5%	49%	123460	2.50%	3087	**30348**
2037	253220	0.5%	51%	129142	2.50%	3229	**33576**
2038	254486	0.5%	52%	132333	2.50%	3308	**36885**
2039	255758	0.5%	53%	135552	2.50%	3389	**40273**
2040	257037	0.5%	54%	138800	2.50%	3470	**43743**

Table 4-2: Assumptions for Registered PEV Projection in Rochester

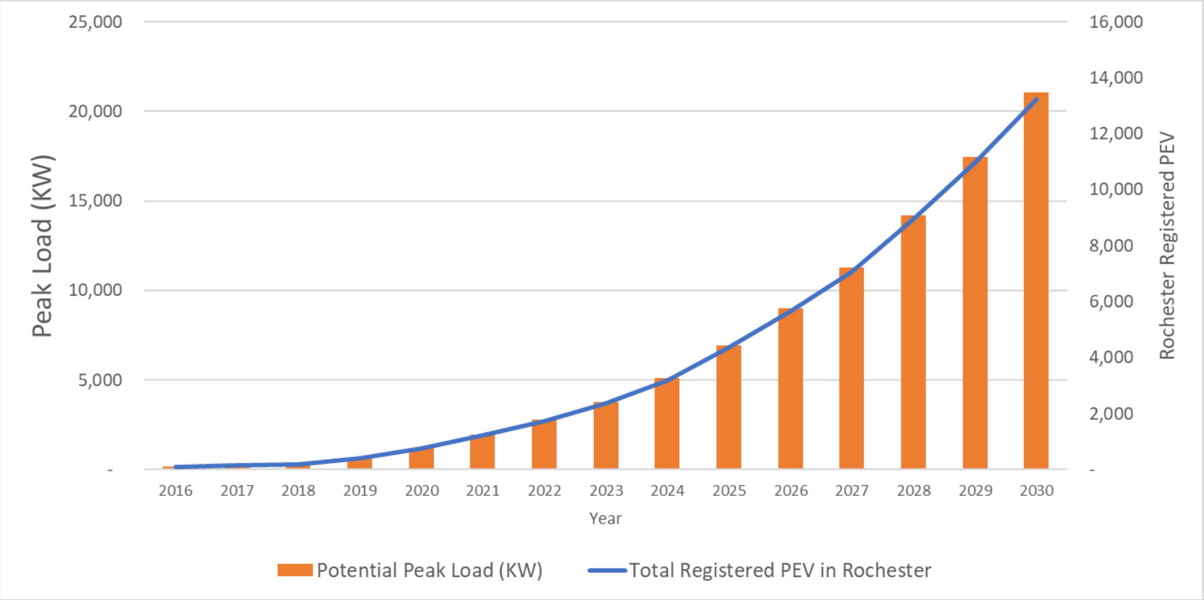
Assumptions	Units	Source
Total Registered EV in 2016	110	(Alternative Fuels Data Center, n.d.)
Total New PEV Sold in MN 2017	1,398	(EVAdoption, 2017)
Total New Vehicles Sold in MN	229,180	(EVAdoption, 2017)
Total Registered Vehicles in MN 2016	4,940,300	(Alternative Fuels Data Center, n.d.)
Total Registered Vehicles in Rochester 2016	122,700	(Alternative Fuels Data Center, n.d.)
% of Registered MN Vehicles in Rochester	2.5%	
% of EV Sales YoY in Rochester	2.5%	

Based on the estimations shown in Table 4-1, a load profile for residential light EV charging can be created as discussed in Section 4.1.1.

4.1.1 Residential Charging Profile and Load Forecast

To estimate a load profile for PEV charging, several assumptions on the charging behavior of PEV drivers were made. Research has shown that approximately 84% to 87% of light duty EV charging will occur at home, when people arrive home from work, and that every PEV will not be charged each day or at the same time (Idaho National Labs, 2013). This analysis assumes that Level 2 charging will be used with a peak power of 7.68 kW per charger. Since PEV charging will not occur every day and at the same time, a diversity factor of 20% was applied to PEVs charging on any given day to estimate coincident peak (CP) demand impacts. This equates to a CP demand of 1.536 kW per EV. In addition to peak demand growth, Rochester will realize energy sales growth from new PEVs. Based on an average EV efficiency of 300 Wh per mile and 12,000 mile per year average driving distance, each new PEV added in Rochester will add approximately 3,600 kWh per year in Residential energy sales. Figure 4-3 presents the growth of CP demand over the next 10 years and the growth of registered PEVs in Rochester.

Figure 4-2: Estimated Peak Load Growth vs. PEV Growth in Rochester, MN



*Assumes no peak load management from load control or time of use rates

By 2030, this analysis forecasts that light duty residential PEV charging could contribute up to 21 MW of additional peak load to RPU's system. Since PEV charging typically occurs on peak, a suitable Time of Use (TOU) rate or other load control device should be deployed to modify the charging behavior of PEV drivers and prevent increases to the RPU system CP demand. The impact that TOU rates and load control switches can have on EV charging is discussed further in section 6 of this report.

5.0 ELECTRIC VEHICLE POLICIES AND INTIATIVES

One of the key driving forces for EV adoption are policies and initiatives that promote the purchase of ZEV's. To support the adoption of ZEVs, a Federal Tax Credit was introduced that offered the buyer $7,500 for the first 200,000 vehicles sold of a particular make and model. The Federal government also revised CAFÉ standards that required manufacturers to build more vehicles with better fuel economy. However, the federal government is not the only entity enacting policies that promote the adoption of ZEVs. Several states have also created legislation and policies that are supportive of ZEV adoption. In addition to states, electric utilities have also introduced their own programs to encourage ZEV adoption within their service territory. This section will discuss state regulations and initiatives as well as utility regulations and initiatives that are in place in Minnesota and across the U.S.

5.1 State Regulations & Initiatives

Many U.S. states have adopted their own policies and incentives for encouraging citizens to purchase ZEVs. This section we will discusses the different policies and initiatives that have been introduced in Minnesota as well as other key states. California is the biggest proponent of pro-ZEV policies in the U.S. and some other states such as New York have adopted similar goals and legislation.

5.1.1 Minnesota

ZEV related laws and regulations in Minnesota include an All-Electric Vehicle fee of $75 dollars for EV registrations and a plug-in electric vehicle (PEV) Charging Tariff. According to Minnesota Statute 216B.1614, utilities that sell electricity for retail, with the exception of municipal utilities such as RPU, must file a tariff with the Minnesota Public Utilities Commission (PUC) that is for the express purpose of a consumer charging a PEV (Office of Energy Efficiency & Renewable Energy, n.d.). The tariff must include:

- A Time of Use (TOU) or off-peak electricity rate.
- Ability for the consumer to purchase electricity from current electricity mix or renewable sources.
- Availability to residential customers.

Other laws and regulations include policies such as the "State Agency Sustainability Plan and Requirements" and the "State Agency Vehicle Procurement and Management Requirements" that say the state of Minnesota must implement plans to reduce the consumption of petroleum, and when purchasing new vehicles, must consider EVs or Natural Gas Vehicles (NGVs) if the TCO is less than or comparable to a conventional ICE vehicle.

Minnesota has also offered EVSE grants in the past. In 2018 the Minnesota Pollution Control Agency made money available for the installation of public DCFC stations. If the location of the station was along a highway or interstate the grant offered to cover 80% of the project cost up to $170,000 per 150 kW of charging output (eligible in Albert Lea only) and up to $70,000 per 50 kW of charging output everywhere else (Minnesota Pollution Control Agency, 2018). The origin of the funds came from money allocated to Minnesota out of the Volkswagen Environmental Mitigation Trust.

5.1.2 California, NY, and Other States

California is the most aggressive state in the union for promoting ZEV adoption through laws, regulations, and incentives. From a Clean Vehicle Rebate that offers $2,500 for the purchase of a BEV and $1,500 for a PHEV, to the 2016 ZEV initiative which requires vehicle manufacturers to achieve ZEV sales of 2.5% in 2018 and shifting this to 8% by 2025. In January 2018, Governor Jerry Brown signed Executive Order B-48-18 into law. This order set the goal of achieving 1.5 million ZEVs on California roads by 2025, 5 million ZEV by 2030, and installing 250,000 EV chargers to support these vehicles. The California Air Resource Board (CARB) is supporting the goals of the executive order through the ZEV initiative, which it manages. In addition to California, nine other states (Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont) have adopted the ZEV initiative.

Several states also offer tax credits on the purchase of EVs. For example, Colorado currently offers a $5,000 tax credit for BEVs and PHEVs and New York offers $2,000 dollars. Texas through the “AirCheckTexas Drive a Clean Machine” program offers vouchers up to $3,500 for the purchase of a hybrid, BEV, PHEV, or NGV.

In addition to vehicle rebates, many states also provide rebates for the installation of EVSE. In New York, the “Charge Ready” program offers rebates of $4,000 per charge port for Level 2 chargers at public locations, workplaces, and multi-unit dwellings (MUD). Through the “Charge Ahead” program, Colorado offers funding to support 80% of the cost of installing EVSE up to $9,000 for Level 2 chargers and $30,000 for DCFC stations.

Another development in legislation that supports EV adoption has been the introduction of Right-to-Charge (RtC) policies. RtC policies state that the if a tenant of a condominium owns an EV, the owner of the property must allow, at the tenant’s expense, the installation of EVSE with reasonable restrictions (Brady, 2019).

5.2 Utility Programs & Initiatives

Federal and state governments are not the only entities promoting the adoption of ZEVs through incentives and grants. Many utilities across the U.S. are offering rebates on the purchase and installation of EVSE and some even offer rebates on the purchase of BEVs.

5.2.1 Minnesota

Several electric utility companies in Minnesota are supporting EVSE installations by offering rebates and discounts. For example, Xcel Energy was running an EV charging pilot program that offered customers a discount on Level 2 chargers. It ended in September of 2018. The Dakota Energy Association has a program that offers a $500 rebate to offset the cost of installing EVSE that can be controlled by the utility. Connexus Energy also offers a $500 rebate on Level 2 chargers when you enroll in its Time-of-Day or Off-peak rate programs.

5.2.2 California, NY, and Other States

Many utilities offer programs that provide rebates to customers wanting to install EVSE. In California, utilities have been successful in winning approval from the Public Utilities Commission to spend capital, that can be included in the rate base, to build out large networks of EV charging infrastructure. Pacific Gas & Electric (PG&E) was approved to spend $236 million to install 6,500 medium and heavy-duty EV chargers to support trucks, buses, and other industrial equipment at 700 commercial and industrial locations in its territory (PG&E, 2018). They will also spend an additional $22 million to construct 234 DCFC stations at 52 locations (O'Kane, 2018). San Diego Gas & Electric (SDG&E) will invest $137 million on customer rebates and installation services for EVSE for 60,000 customers in both homes and MUDs (O'Kane, 2018). Lastly, Southern California Edison (SCE) will spend $343 million to build 8,500 medium and heavy-duty EV chargers at 870 locations in its service territory (Good Day Sacramento, 2018). The main driver behind the approval of these large investments in make ready EVSE infrastructure is California's SB 350 which mandates that half of the state's electricity must come from renewable sources by 2030.

While the California PUC has approved utilities to invest in make ready EVSE infrastructure, other utilities have had a challenging time receiving approval for the construction of EVSE infrastructure to be included in their rate base. For example, Kansas City Power & Light (KCP&L) built out the Clean Charge Network which is comprised of over 1,000 Level 2 chargers and is one of the largest public EV charging systems in the United States. In 2017, the Missouri PUC ruled that KCP&L could not include the chargers in its rate base as they did not constitute "electric plant". However, in 2018, the appellate court overturned this decision and has returned the matter to the PUC to reevaluate their initial determination based on the court's rulings (Walton, 2018).

Other programs utilities across the U.S. have been involved in, range from providing education to local businesses and car dealerships on EVs to providing rebates on some BEVs. In Florida, the Jacksonville Electric Authority (JEA) will give customers a $1,000 rebate on the purchase of any eligible PEV. In Kansas and Missouri, KCP&L is offering a $3,500 to employees and customers on a 2019 Nissan Leaf. Oncor in Texas is also offering a similar rebate of $3000 on a 2019 Nissan Leaf.

6.0 ELECTRIC VEHICLE RATE STRUCTURE PRACTICES

Research has shown that most light duty EV charging occurs at home. When no incentive exists people will recharge their vehicle after they arrive home from work. Since EV charging has the potential of adding the equivalent of an average load of a home to the distribution network per vehicle, it can become critical to move this load from coinciding with the electric utilities daily peak. To encourage consumers to shift the load of EV charging, Time of Use (TOU) rates can be created to encourage the consumer to change their charging habits.

For fleet, mass transit, and public DCFC station operators it is critical to mitigate the peak load of their facilities to avoid costly demand charges from the electric utility. Managing EV load in this situation can be accomplished by optimizing charge schedules, implementing load management systems, and working with the electric utility to determine the best rate schedules for EV charging.

Many utilities within Minnesota and the rest of the United States have implemented modifications to their rate structures, line extension policies, and demand side management programs to enable cost effective EV charging for both customers and the utility. This section summarizes practices being employed for residential and commercial customers purchasing and installing EVs and highlights some of the common practices being employed for EV public charging stations and EV demand side management programs.

6.1 Residential Rates

According to studies completed by Idaho National Labs (INL), 84% to 87% of EV owners charge their vehicle at home instead of at a public charging station (Idaho National Laboratory, 2015). Since EV owners charge at home, most EV charging sessions occur when people arrive home from work. This causes an increase in load from 1.4 kW to 19.2 kW, depending on the vehicle and the EVSE, between 6pm and 9pm. EV charging load, if placed on a utilities electric system during on-peak hours, could significantly increase local distribution system peak loads and contribute to the system peak.

Implementing a TOU rate that includes super-off-peak pricing has been proven to effectively shift EV charging loads from on-peak to super off-peak time periods. For example, the San Diego Gas & Electric Plug-in EV TOU Pricing and Technology Study found that EV owners conducted approximately 80 percent of their charging during the super off-peak periods when offered a 2:1 or 4:1 on-peak to super off-peak price ratio. Ratios greater than 6:1 had little incremental impact (Nexant, 2014). INL conducted a TOU pilot which demonstrated that utilities who offer a cost based TOU rate were far more successful in having customers shift EV charging loads to off-peak time periods, as compared to utilities who did not offer a TOU rate. Figure 6-1 and Figure 6-2 demonstrate Pacific Gas & Electric’s (PG&E) three-time period TOU rate is effective in shifting EV charging load to super off-peak time periods (Idaho National Labs, 2013). PG&E's results are compared to the EV load profiles of Nashville Electric Service (NES), as shown in Figure 6-3 and Figure 6-4, where a TOU rate is not in place (Idaho National Labs, 2013). If a TOU rate is not available, as in NES's case, the majority of EV charging load occurs during on-peak hours, since there is not a price benefit for customers to charge during off-peak hours.

Figure 6-1: Weekday Residential EV Charging Availability in PG&E Territory, Q1 2013

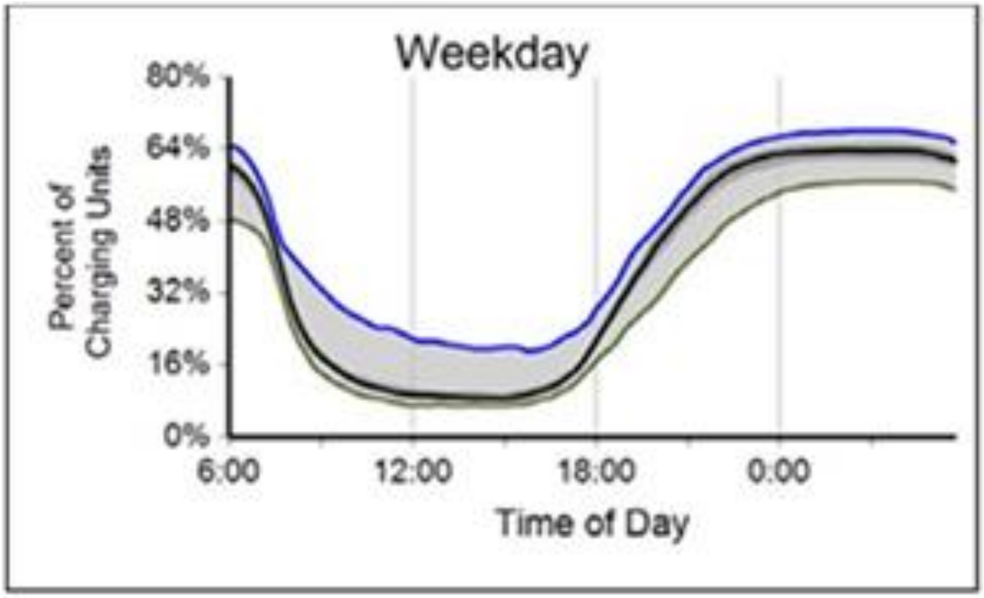


Figure 6-2: Weekday Residential EV Charging Demand in PG&E Territory, Q1 2013

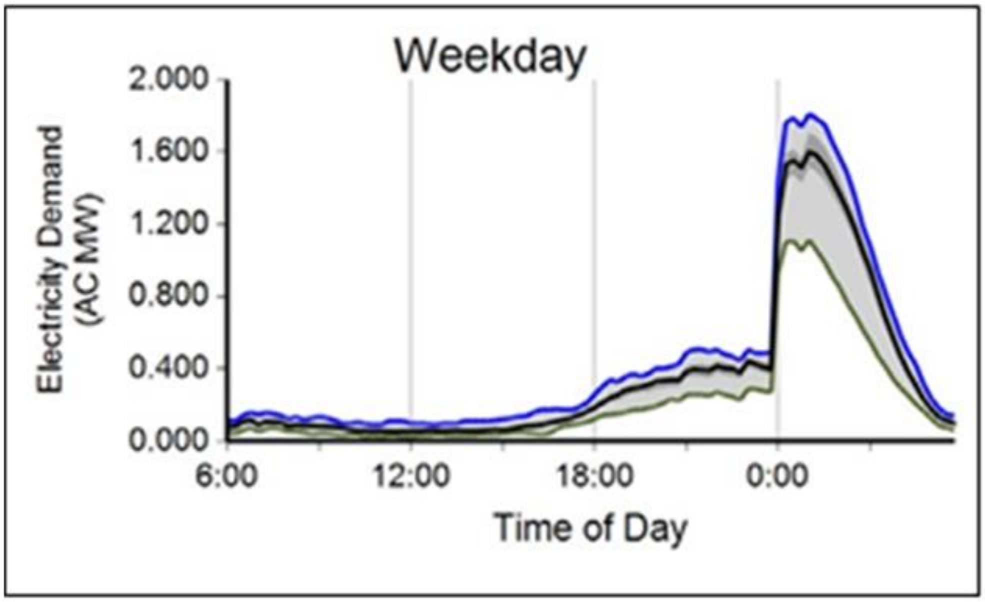


Figure 6-3: Weekday Residential EV Charging Availability in NES Territory, Q1 2013

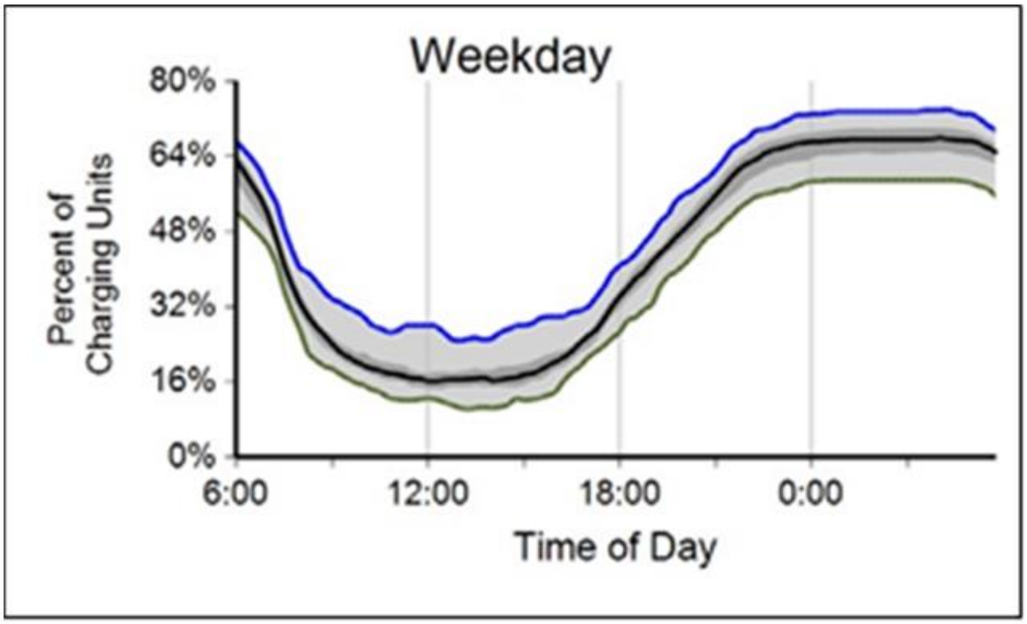
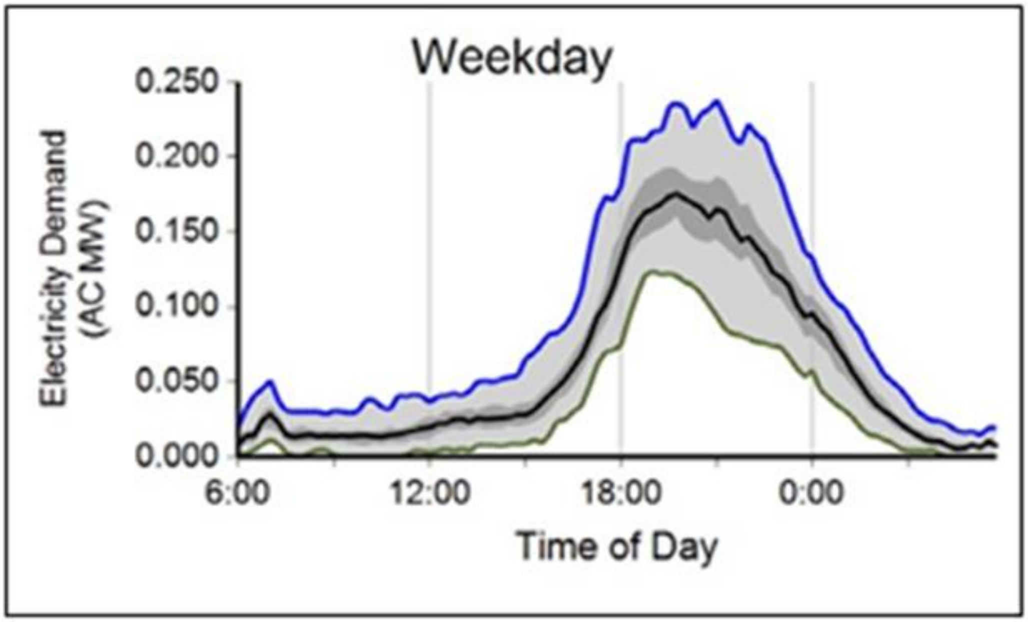


Figure 6-4: Weekday Residential EV Charging Demand in NES Territory, Q1 2013



As of June 2015, at least 28 utilities across the country offered special EV rates to their customers (Salisbury, 2016). In addition, over 200 utilities offered TOU rates to their residential customers to encourage off peak charging of EVs. There are several ways to implement TOU rates. The list below outlines the different options that have been used.

- **Single Meter Rates:** These rates are offered to customers as a general TOU rate that applies to all electricity consumed. This rate still offers EV drivers the opportunity to save by charging at off-peak times and does not require additional equipment or meters to be installed at the home. This is the least complicated system to implement and does not raise the issue of consumers asking to have special rates for different equipment used at home such as an electric water heater. RPU does not have a metering and billing system that can accommodate the mass deployment of TOU for all residential customers. However, the rate could be offered as part of an EV TOU pilot.

- **EV Single Meter Rates:** These rates apply specifically to an EV and require the utility to have an enrollment program in place that verifies the customer has an EV and charging infrastructure installed at home. The utility then monitors that the EV charging behavior is as expected. RPU already has the metering and billing system for a General Service (GS) TOU rate. The GS TOU rate could be redesigned and repurposed for residential EV customers with the express intent of peak load management.

- **EV TOU Separate Meter Rates:** This rate requires the installation of a separate meter specifically for charging an EV. The cost of installing a second meter can range from a few hundred dollars to over $1,000. This cost has been found to outweigh the advantages for a customer to adopt a second meter.

The state of Minnesota already has a law in place, known as the Plug-In electric Vehicle (PEV) Charging Tariff, that mandates that investor owned electric utilities must allow a customer to purchase electricity for the sole purpose of charging an EV. Furthermore, the tariff must contain either a time of day or off-peak electricity rate (Plug-In Electric Vehicle (PEV) Charging Tariff, n.d.). Multiple electric utilities in Minnesota have already adopted time-of-day and TOU rates specifically for EV charging. For example, Connexus Energy offers both a Time-Of-Day and storage program for off-peak charging. The Time-Of-Day program requires the installation of a separate sub-metered circuit and the rate can be applied to just the EV or the whole house. Table 6-1 below, shows the existing rates for the Connexus Time-Of-Day program.

Table 6-1: Connexus Energy Time-Of-Day Program

Energy Charge	Rate	Time	Day	Month
Off-Peak Period* (50%)	7.3¢/kWh	8 p.m. - 8 a.m.	All Days	All Year
Intermediate Period* (38%)	10.8¢/kWh	8 a.m. - 4 p.m. 8 a.m. - 8 p.m.	M-F Sat/Sun	All Year All Year
Peak Period Winter* (8%)	34.5¢/kWh	4 p.m. - 8 p.m.	M-F	Oct. - May
Peak Period Summer* (4%)	45.5¢/kWh	4 p.m. - 8 p.m.	M-F	June-Sept.

Source: (Connexus Energy, n.d.)

The off-peak charging program applies a rate of $0.045 per kWh between the hours of 11pm to 7am and requires metering equipment provided by Connexus. The Dakota Electric Association also offers a Time-Of-Day and storage program for EV charging that is similar to Connexus. Xcel energy does not currently offer a specific EV rate in Minnesota, but it does offer a Time of Day rate which applies to the whole home.

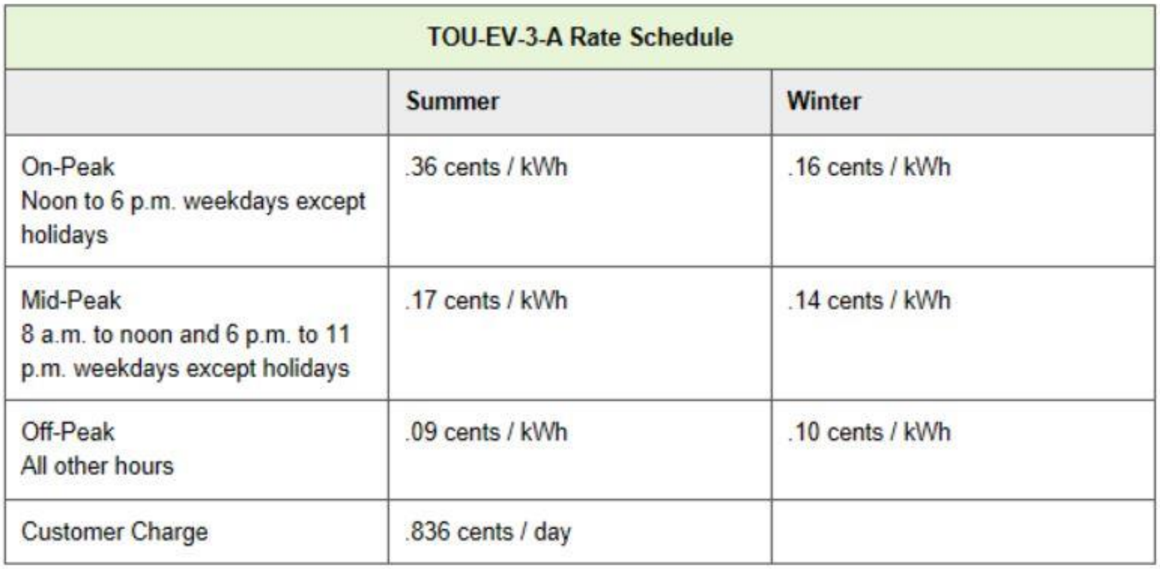
6.2 Fleet and Mass Transit Rates

One of the largest costs for fleet and mass transit operators is fuel. Electricity prices have generally been cheaper and more stable when compared to oil-based fuels, such as gasoline and diesel, and by using electricity, a fleet or mass transit operator could save substantial operating costs. However, one of the biggest barriers to cost savings from operating fleet and mass transit EVs are electric demand charges.

For example, if a bus depot charged 20 buses at the same time, during off-peak hours, with 150 kW DC fast chargers this would cause a peak load of 3,000 kW. If RPU’s current LGS demand charge of $20/kW was applied to this peak load, it would add $60,000 to a bus depots monthly electricity bill. If we further assume that the bus depot had 100 buses and that each bus consumed 500 kWh of energy per day, that would equate to 1,500 MWh of energy a month. Assuming an electricity rate of $0.06 per kWh, the cost of energy consumed would be $90,000 for a total electric bill of $150,000. In this example, the demand charge is around 40% of the total cost of the bill.

Table 6-2 and Table 6-3 show two different EV rates that Southern California Edison has in place today. One is for EV charging that will not exceed 20 kW and includes no demand charges. The other is for facilities with an EV charging load greater than 20 kW and includes a demand charge.

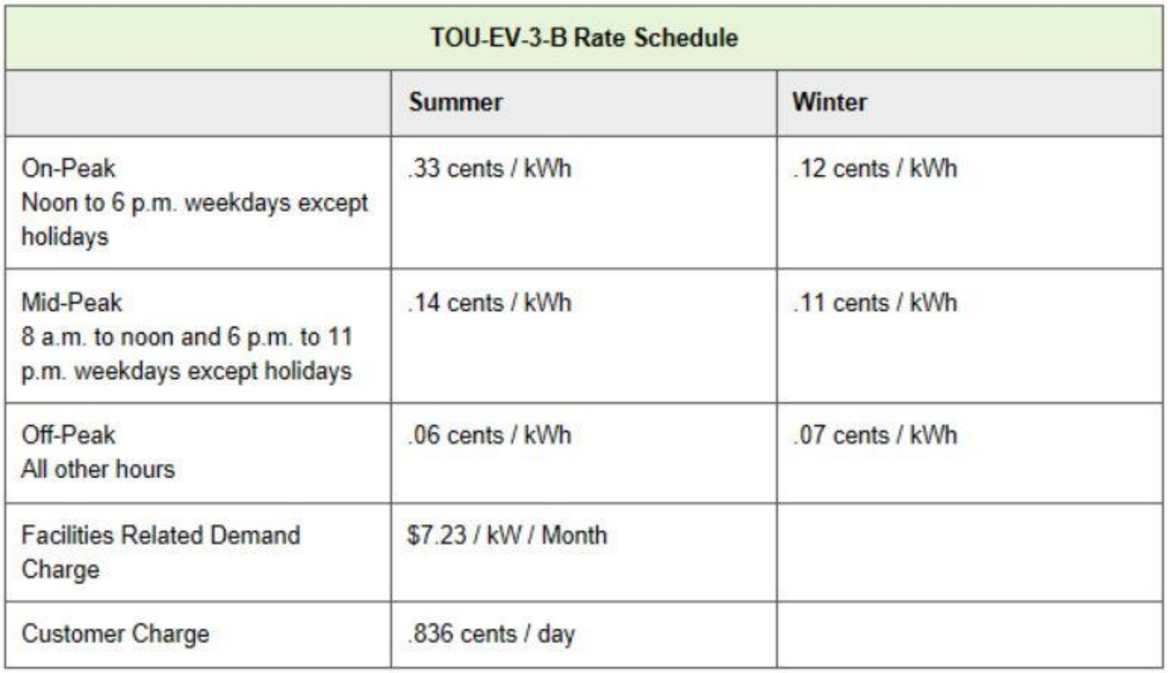
Table 6-2: SCE Electric Vehicle TOU Rate 1



TOU-EV-3-A Rate Schedule		
	Summer	**Winter**
On-Peak Noon to 6 p.m. weekdays except holidays	.36 cents / kWh	.16 cents / kWh
Mid-Peak 8 a.m. to noon and 6 p.m. to 11 p.m. weekdays except holidays	.17 cents / kWh	.14 cents / kWh
Off-Peak All other hours	.09 cents / kWh	.10 cents / kWh
Customer Charge	.836 cents / day	

Source: (Southern California Edison, n.d.)

Table 6-3: SCE Electric Vehicle TOU Rate 2



TOU-EV-3-B Rate Schedule		
	Summer	**Winter**
On-Peak Noon to 6 p.m. weekdays except holidays	.33 cents / kWh	.12 cents / kWh
Mid-Peak 8 a.m. to noon and 6 p.m. to 11 p.m. weekdays except holidays	.14 cents / kWh	.11 cents / kWh
Off-Peak All other hours	.06 cents / kWh	.07 cents / kWh
Facilities Related Demand Charge	$7.23 / kW / Month	
Customer Charge	.836 cents / day	

Source: (Southern California Edison, n.d.)

One approach that some electric utilities have used to encourage the adoption of electric buses is to waive the demand charge at the facility while working with the transit agency to utilize charging at off peak hours. Depending on the rates that are in place, it is critical for operators of fleet and mass transit vehicles to work with the local electric utility in reducing peak load by spreading charging activity for its fleet during off peak times.

6.3 Public Charging Rates

ChargePoint is one of the largest providers of publicly accessible charging stations in the United States. Since ChargePoint cannot resell electricity, they generally charge a service fee for the time a user spends connected to its chargers. In Rochester, MN, the Level 2 chargers that are owned by RPU at the Rochester Community and Technical College, RPU Service Center, and the First Street Parking Ramp cost $2.00 per hour between 4pm and 7pm and cost $0.75 per hour at other times. In contrast, the Level 2 chargers at a Hy-Vee grocery store in Rochester, MN, are currently free to use. Some businesses believe that providing free charging to customers increases the businesses revenue. In a case study performed by ChargePoint, they estimate that at a leading retailer increased customer dwell time in their store by 50 minutes and increased their revenue by $56,000. All for the cost of around $430 for the electricity that was used to charge customers EVs and the initial installation cost of the chargers (ChargePoint, 2015).

In a similar way to fleet and mass transit charging, demand charges can present a barrier to the financial success of businesses that install and operate publicly accessible DC fast chargers. The Rocky Mountain Institute conducted a study in 2016 of EVgo’s 230 50 kW DC fast charging stations in California and found that demand charges have the potential of accounting for over 90% of the energy bill (Nelder, 2017). However, it can be argued that the reason these demand charges accounted for such a high percentage of the bill is due to relatively low utilization rates at certain DC fast charging sites. In the report, the Rocky Mountain Institute recommended limiting or eliminating the demand charge and adopting a volumetric TOU rate. The report advised that the TOU rate should increase to coincide with times of increased load, and if needed a potential adder could be used to cover excessive costs on the distribution system. They also suggested that rates could be varied by location to encourage developers to place DCFC stations in areas where the grid is overbuilt or underutilized.

Many businesses that install Level 2 or DCFC stations have the flexibility in how they recover their costs. If TOU rates are available, the owner of the charging station can adjust their rate throughout the day to reflect the TOU rate structure in place. For example, if a TOU rate is in place that charges $0.20 per kWh during the on-peak time period (i.e. 4-8 pm) the owner can charge $1.40 per hour or $0.023 per minute for the energy which will provide nearly 28 miles of EV driving range. The TOU rate can correspondingly be reduced during off-peak times to incent customers to charge during less expensive time periods.

6.4 Peak Demand Management

In addition to electric rate structures, utilities can deploy peak demand management devices to control when customers with EVs can charge. This approach has been used for many years by RPU and other utilities to control peak demand caused by air conditioners and electric water heaters. The load control switches can be remotely operated over WiFi and can delay charging to off-peak times. The cost of the switch and the program costs are like those for home HVAC and water heaters systems. These mechanisms can provide a non-coincident peak load reduction of 5 kW to 7 kW or diversified peak reductions of approximately 1.2 kW for an installation cost of less than $300 per device. Assuming a typical avoided capacity cost of $48 per kW per year this can provide a strong 10-year benefit to cost ratio of 1.92 without factoring in program administration costs, marketing costs, and escalation.

One-way fleet and mass transit operators can reduce demand charges, is by utilizing solar generation and battery storage to shave peak demand. Since the RPU MGS demand rates can range between $17.83 to $24 per kW per month, and as discussed in section 6.2, can account for a large cost of operating a fleet of EVs, the economics may benefit the installation of solar and battery storage. As an example, Electrify America has announced that it will install Tesla power packs with 350kWh of capacity at over 100 of its DCFC sites (Graham, 2019). Each non-residential application needs to be studied on a case by case basis to determine the best solution for the customer and utility.

7.0 ELECTRIC VEHICLE END OF LIFE

The lifetime of EVs is still being determined due to the relatively recent adoption of modern EVs. The biggest question for EV longevity relates to the battery packs used in the vehicles. Factors such as charge rates and cycles and operating conditions can drastically impact the life of an EV battery. Currently, most EV manufacturers offer 8 year or 100,000 mile warranties on their battery and powertrain systems.

After a LIB has reached its useful life, there are different options for reusing the battery. These can include recycling the battery or repurposing the battery for a second life as a stationary storage battery. Currently, EV recycling methods are lagging the development of battery technology. However, several manufacturers have investigated or created storage systems using spent EV batteries. This section will discuss the life cycle of EVs in terms of battery life and the end of life of EVs in terms of recycling batteries or repurposing them for a second life as a stationary storage battery.

7.1 Electric Vehicle Life Cycle

Since the increasing presence of EVs on U.S. roads started in 2010, there is limited data regarding how different EV models will perform during their useful lifetime. BEVs have fewer moving parts than ICE vehicles and the main components include an electric motor, power electronics and a traction battery. Motors are well known for reliability and longevity and power electronics have been tested and used in industrial applications for decades. This leaves the degradation of the traction battery as the biggest area of concern for BEV owners.

The life of a battery can be affected by several factors such as extremely high and low operating temperatures, how frequently the battery is cycled, and how fast the battery is charged. As an approximate estimate, a LIB can perform between 300 and 500 full discharge cycles (Battery University, n.d.). A full discharge cycle is defined as taking a battery with a state of charge (SoC) of 100% and discharging it to a depth of discharge (DoD) of 100%. If we assume that on a typical day most people will drive around 40 miles, an EV may not experience a full discharge every day. If a LIB is not discharged to a DoD of 100%, the battery can perform more cycles thus increasing the life of a BEV. Table 7-1 below shows an estimate of how many cycles a LIB can perform when discharged to varying DoD.

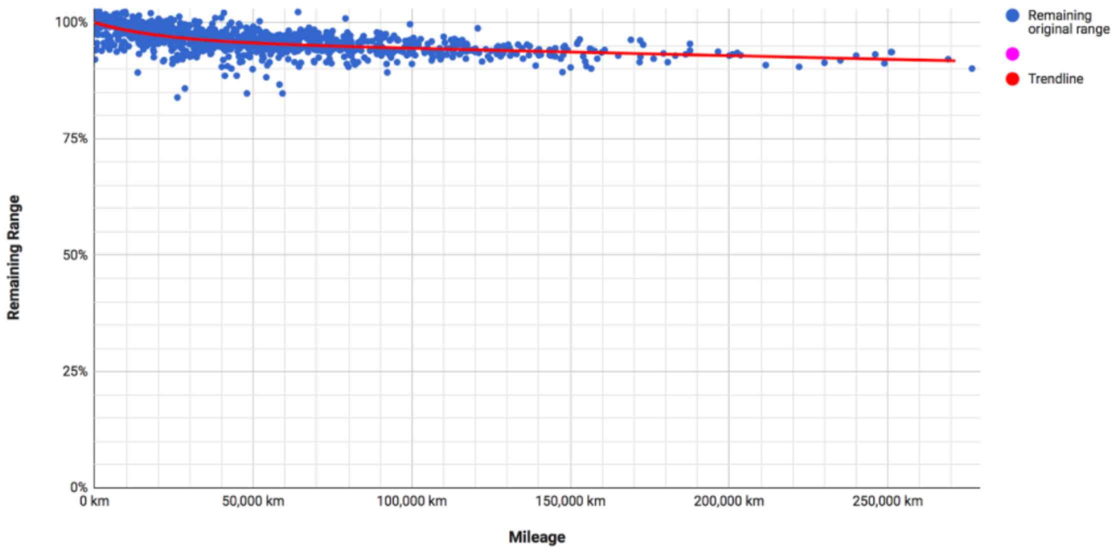
Table 7-1: Depth of Discharge (DoD) vs. Life Cycle of Lithium-ion Batteries

Depth of Discharge (DoD)	Discharge cycles (NMC / LiPO4)
100% DoD	~300 / 600
80% DoD	~400 / 900
60% DoD	~600 / 1,500
40% DoD	~1,000 / 3,000
20% DoD	~2,000 / 9,000
10% DoD	~6,000 / 15,000

Source: (Battery University, n.d.)

A LIB is considered useful in an EV if it can maintain approximately 70% to 80% of its original charge. Once the battery reaches this point it will need to be replaced. In 2015, Maarten Steinbuch and Merijn Coumans created a publicly accessible spreadsheet to record how much charge a LIB in a BEV would retain over time. The data was collected from Tesla drivers all over the world and as of November 2017, 396 drivers had participated in the survey. Figure 7-1 below, shows that most Tesla Model S and Model X vehicles experienced a 10% loss in battery life on average, with a few outliers losing more than this. While the number of data points is relatively low, the data collected aligns with the warranties that EV manufactures provide on their batteries. Chevy, Nissan, and Tesla offer very similar warranties on the battery's installed in their vehicles. The batteries are generally warrantied for 8 years or 100,000 to 125,000 miles (depending on vehicle).

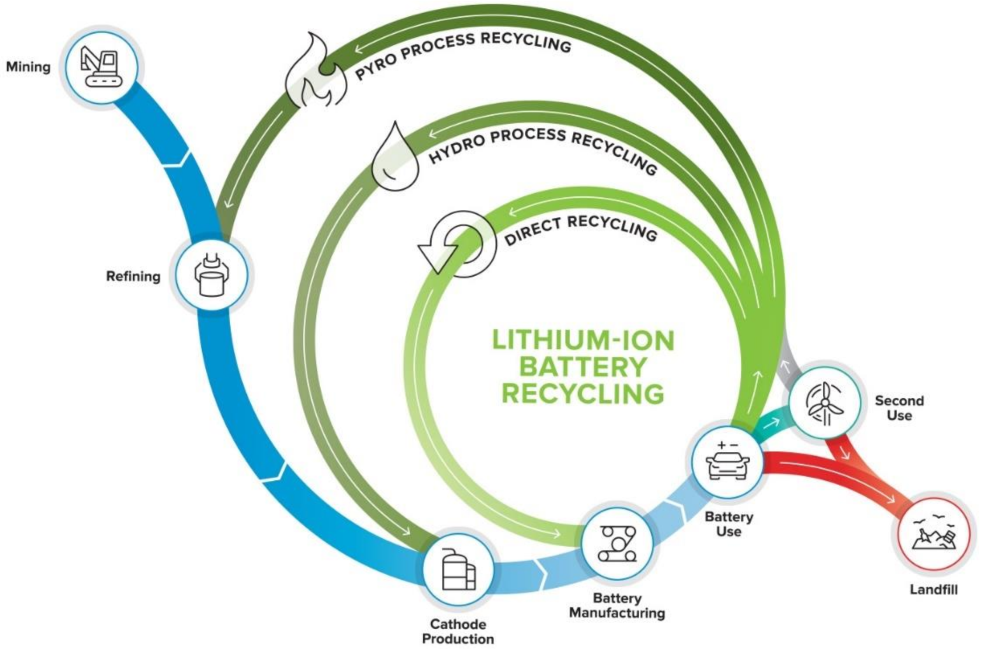
Figure 7-1: Tesla Model S & Model X Battery Degradation



Source: (Maarten Steinbuch)

Another topic of discussion regarding EV end of life is the recycling and remanufacturing of EV components and batteries. There are more rare earth materials used in EVs when compared to ICE vehicles, making reuse of components critical for reducing the over consumption of materials. However, due to low EV numbers, Europe has seen low rates of battery recycling, with as little as 5% of Li-ion batteries being recycled (The Guardian, 2017). These low recycling numbers combined with the increasing presence of EVs on roads worldwide, could lead to several issues with reusing EV batteries in the future. To address the increased presence of used EV traction batteries, the U.S. Department of Energy (DOE) has set forth to improve the recycling process of LIB packs by creating the ReCell recycling center. The goal of the ReCell center will be to reduce energy use and waste caused by mining and processing LIB by creating a closed-loop recycling process (Argonne National Laboratory, 2019). This process is outlined in Figure 7-2 below.

Figure 7-2: LIB Recycling Process



Source: (Argonne National Laboratory, 2019)

As shown in Figure 7-2. one recycling process repurposes the battery to be used in stationary applications. This is known as the batteries second life and will be discussed further in section 7.2.

7.2 Electric Vehicle Battery Second Life

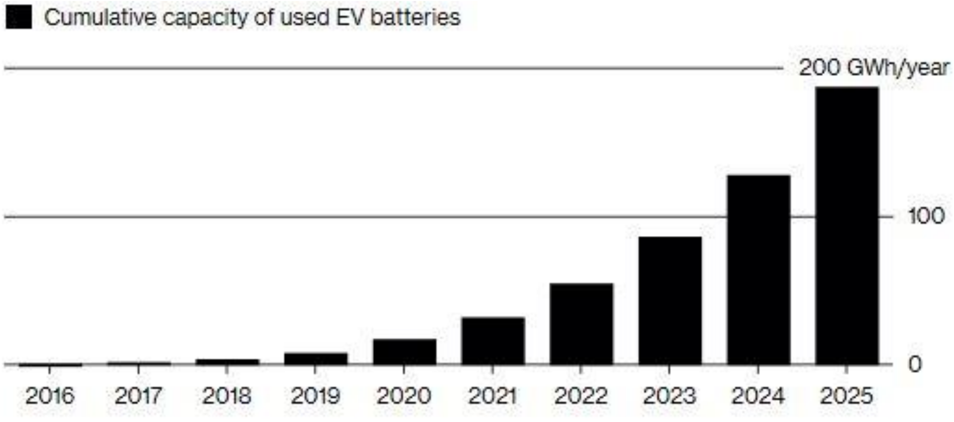
When a BEV or PHEV battery reaches the end of its useful life as a traction battery it can still have 70% or more of useable capacity remaining. While this remaining capacity may not be suitable for intense use in an EV, the battery is still suitable for stationary use. Repurposing an EV battery for stationary use is known as its second life. Due to the high production cost of producing a battery pack for an EV, there is a good business case for EV manufacturers to recover the batteries to create battery energy storage systems (BESS). Producing a BESS from a used traction battery provides the opportunity to create a second line of revenue from the initial production of a battery. This also poses an advantage to the environment as the energy and materials used to create the original battery are not wasted.

Mercedes Benz Energy was created to produce BESS from used EV batteries. These systems are designed to provide back-up power, act as a UPS, and support black start events. The system can also be left "off-grid" and integrated with renewable resources such as wind and solar. The size of the Mercedes Benz BESS ranges from 100 kWh up to 100 MWh of energy storage capacity. Mercedes Benz is not the only manufacturer using spent EV batteries to create BESS. GM, BMW, Toyota, BYD and Nissan either have plans or have already reused EV batteries to create storage systems. As an example, BMW partnered with Bosch Energy Storage Solutions to reuse batteries from 100 vehicles to create a 2.8MWh storage system in Germany (Brown, 2016) and Toyota is going to repurpose battery's from the Prius and install them across 7-eleven stores in Japan (Bloomberg, 2018).

7.2.1 Utility Applications for Used EV Batteries

The amount of battery storage capacity from used EV batteries is expected to grow over the next decade. Figure 7-3 below, shows the anticipated worldwide trends for how much battery storage could be available.

Figure 7-3: Projected Used EV Battery Capacity



Source: Bloomberg New Energy Finance

Since battery storage systems from recycled batteries could be as large as 100 MWh, the potential for using recycled battery storage on the grid exists. One application that could be relevant to grid operators would be installing the recycled battery capacity at DCFC sites. However, since new batteries are being produced for large BESS, using new purpose built batteries for storage systems may present a better option in terms of similar if not cheaper costs and better availability versus systems with recycled batteries. Recycled batteries from EVs, could be used for home and business storage applications.

8.0 OTHER SOURCES OF ELECTRIFICATION

Sections 1 through 7 of this report focused on the electrification of light, medium, and heavy duty vehicles and how this may impact RPUs electric system. At the request of RPU, this section will discuss impacts that other sources of electrification could have on RPUs future load forecasts. The most applicable types of electric load that will impact RPU from other electrification sources include heating sources such as electric heat pumps and hot water heaters. A focus will be placed on the economics of using electric heating including converting from gas heating and installing an electric system in a new building.

8.1 Electrification of Heating Sources

Utilities have long pursued the promotion and development of other forms of beneficial electrification for their customers, such as cost based energy for electric space heating and electric hot water heating. Most municipal utilities, such as RPU, do not have the overarching goal of simply selling more energy to improve the utility’s return on rate base for its common share-holders but rather strive to provide low cost and reliable service while meeting other state and local mandates such as renewable portfolio standards, energy efficiency targets, and greenhouse gas reduction targets. This section provides a discussion of several potential sources of electrification including electric heating and electric hot water heating and weather those are beneficial opportunities for RPU and its customers.

8.1.1 Existing Heating and Hot Water Equipment

The majority of RPU’s residential and commercial customers receive space heating by natural gas furnaces. Based on information provided by RPU staff, over 90 percent of customers in RPU’s service territory already have access to natural gas for space heating and hot water heating. In Olmsted County, MN, for example, over 74% of homes are heated with natural gas heating sources (Eleff, 2017). The average efficiency of Residential customer’s natural gas heating and hot water systems installed over the last 20 years are anywhere from 80% to 95%. With an assumed efficiency of 80% and average cost of natural gas between $7.00 and $8.00 per MMBtu, customers can receive space heat and hot water heat for between $8.75/MMBtu and $10.00/MMBtu.

8.1.1.1 Electric Heat Pumps

Existing RPU customers can elect to replace their home or apartment air conditioning systems with an air source electric heat pump. These retrofits can cost anywhere from a $5,000 to $7,500 depending on the size and complexity of the system. New residential heat pump systems are required to be 15 SEER and 8.5 HSPF or better. Based on RPU’s existing winter residential high efficiency HVAC rate of

$0.08836/kWh (after the first 600kWh), the cost of heating energy is $10.40/MMBtu which is comparable to the cost of heating with natural gas.

Under these circumstances, existing customers with an existing gas service will not likely switch to an air source heat pump even when their existing HVAC system has reached the end of life unless there is some utility incentive. In this situation, RPU is not able to provide rebate incentives for these customers because it involves fuel switching which is not allowed under Minnesota CIP rules. Without a significant change in global gas supply or heating technologies, air source heat pumps are not expected to drastically increase for existing residential customers.

Customers constructing new homes with tighter construction methods, lower infiltration and higher insulation levels may choose to install an air source heat pump rather than a traditional gas furnace. In this situation, the upfront installation and operating costs between the two systems are comparable. The heat pump system offers the potential of having lower lifetime emissions as the electric grid moves to higher levels of renewables.

8.1.1.2 Electric Hot Water Heaters

Like electric heat pumps, electric hot water heaters are traditionally installed in those homes and apartments that do not already have access to natural gas service. A 100 percent efficient electric resistance hot water heat under RPU’s existing winter residential rate is nearly $31/MMBtu. As a result, electric resistance heating for hot water is generally only installed in buildings or areas that do not have access to natural gas or cannot use propane or fuel oil. Based on a report produced by the Minnesota House of Representatives titled “Residential Space Heating Fuels in Minnesota”, over 74 percent of homes in Olmsted County have access to natural gas and even the most efficient hot water heat pump system is more expensive to operate than a gas fired hot water heater. As a result, the use of electric hot water heaters in Rochester are not expected to change without cross subsidization.

8.2 Electric Heating and Hot Water Growth Strategies

Many utilities will often employ a declining block energy rate into the residential winter energy rate to provide a price signal to customers indicating that more use in the winter does not require more generation, transmission, and distribution capacity. This can improve the economics of electric space heating with heat pumps. However, it does not alleviate the condition in which the heat pump can’t perform in extreme cold conditions. Additionally, the declining block structure would need to be evaluated in the context of a full class cost of service and rate design study to evaluate the other consequences of such a rate change.

Many utilities will often offer incentives, rebates, or lower line extension contribution in aid of construction (CIAC) fees to developers and builders who commit to installing all electric homes or buildings. These incentives, or line extension fee reductions, are supported by the guarantee of higher winter energy sales and revenues to RPU which can help pay for the infrastructure and allow RPU to provide that as a credit to those customers. A careful review and analysis of RPU's line extension program would need to be performed to assess if this opportunity is viable for RPU.

9.0 BIBLIOGRAPHY

Alternative Fuels Data Center. (n.d.). *Developing Infrastructure to Charge Plug-In Electric Vehicles.* Retrieved from https://afdc.energy.gov/fuels/electricity_infrastructure.html

Alternative Fuels Data Center. (n.d.). *Electric Vehicle Infrastructure Projection Tool (EVI-Pro) Lite*. Retrieved from https://afdc.energy.gov/evi-pro-lite

Argonne National Laboratory. (2019, February 15). *DOE launches its first lithium-ion battery recycling R&D center: ReCell* . Retrieved from Argonne National Laboratory: https://www.anl.gov/article/doe-launches-its-first-lithiumion-battery-recycling-rd-center-recell

Auto Alliance. (n.d.). *Advanced Technology Vehicle Sales Dashboard*. Retrieved from https://autoalliance.org/energy-environment/advanced-technology-vehicle-sales-dashboard/

Battery University. (n.d.). *How to Prolong Lithium-based Batterie*. Retrieved from Battery University: https://batteryuniversity.com/index.php/learn/article/how_to_prolong_lithium_based_batteries

Bigelow, B. V. (2017, Jun 16). *Startup Pioneers EV-to-Grid Technology in Pilot at UC San Diego*. Retrieved from Xconomy: https://xconomy.com/san-diego/2017/06/16/startup-pioneers-ev-to-grid-technology-in-pilot-at-uc-san-diego/

Bloomberg. (2018, June 27). *Where 3 Million Electric Vehicle Batteries Will Go When They Retire*. Retrieved from https://www.bloomberg.com/news/features/2018-06-27/where-3-million-electric-vehicle-batteries-will-go-when-they-retire

Bloomberg New Energy Finance. (2017, 7 5). *Lithium-ion Battery Costs and Market*. Retrieved from Bloomberg New Energy Finance: https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf

Brady, K. (2019, January 28). *Boston Right to Charge*. Retrieved from Moriarty Troyer & Malloy: https://www.lawmtm.com/boston-right-charge-electric-vehicles.html

Brodd, K. (2017, July). *Find Charging Options for Your Electric Vehicle*. Retrieved from Carolina Country: https://www.carolinacountry.com/your-energy/energytech/know-charging-options-to-keep-your-ev-rolling

Brown, B. (2016, September 27). *BMW recycles used electric vehicle batteries as backup power storage*. Retrieved from Digital Trends: https://www.digitaltrends.com/cars/bmw-used-ev-batteries-powergrid/

California Air Resources Board. (n.d.). *The Zero Emission Vehicle (ZEV) Regulation Fact Sheet*. Retrieved from https://arb.ca.gov/msprog/zevprog/factsheets/zev_regulation_factsheet_082418.pdf

Center, A. F. (2018, 1 17). *Electric Vehicle Infrastructure Projection Tool*. Retrieved from Alternative Fuels Data Center: https://afdc.energy.gov/evi-pro-lite

Chanje. (2018). *Vehicles*. Retrieved from Chanje: https://chanje.com/vehicles/

ChargePoint. (2015). *Leading Retailer Partners with ChargePoint to Attract and Retain Loyal Customers*. Retrieved from https://www.chargepoint.com/files/casestudies/cs-retail.pdf

ChargePoint. (n.d.). *Express Plus Specifications for Power Block*. Retrieved from ChargePoint: https://www.chargepoint.com/files/datasheets/ds-expressplus.pdf

CleanFleet Report. (n.d.). *Ford To Add To Its "Juggernaut" F-Series Truck Lineup*. Retrieved from www.cleanfleetreport.com/detroit-auto-show-ford-f-150-electric-pickup-coming/

Connexus Energy. (n.d.). *Electric vehicles provide many benefits to our members*. Retrieved from https://www.connexusenergy.com/save-money-and-energy/programs-rebates/electric-vehicle

Edison Electric Instititute. (2018, November). *Electric Vehicle Sales Forecast and the Charging Infrastructure Required Through 2030.* Retrieved from www.edisonfoundation.net/iei/publications/Documents/IEI_EEI%20EV%20Forecast%20Report_Nov2018.pdf

Electric Power Research Institute . (2017). *Plug-In Electric Vehicle Market Projections.*

Eleff, B. (2017). *Residential Space Heating Fuels in Minnesota.* St Paul: Research Department Minnesota House of Representative.

EV Volumes. (2018). *USA Plug-in Sales for 2018 Full Year*. Retrieved from www.ev-volumes.com/country/total-world-plug-in-vehicle-volumes/

EV Volumes. (n.d.). *Battery Chemistry Evolution*. Retrieved from EV Volumes: www.ev-volumes.com/country/total-world-plug-in-vehicle-volumes/

EVAdoption. (2017). *EV Market Share by State* . Retrieved from EVAdoption: https://evadoption.com/ev-market-share/ev-market-share-state/

Evarts, E. C. (2018, April 23). *Electrify America maps out charging network to rival Tesla Superchargers*. Retrieved from Green Car Reports: https://www.greencarreports.com/news/1116375_electrify-america-maps-out-charging-network-to-rival-tesla-superchargers

Federal Motor Carrier Safety Administration. (2018). *2018 Pocket Guide to Large Truck and Bus Statistics.*

Finance, B. N. (2018, March 28). *BNEF*. Retrieved from https://about.bnef.com/blog/tumbling-costs-wind-solar-batteries-squeezing-fossil-fuels/

Ford plans $11 billion investment, 40 electrified vehicles by 2022. (n.d.). Retrieved from https://www.reuters.com/article/us-autoshow-detroit-ford-motor/ford-plans-11-billion-investment-40-electrified-vehicles-by-2022-idUSKBN1F30YZ

Global carmakers to invest at least $90 billion in electric vehicles. (n.d.). Retrieved from https://www.reuters.com/article/us-autoshow-detroit-electric-idUSKBN1F42NW

Goldie-Scot, L. (2018). *Batteries and material demand.* Retrieved from Bloomberg New Energy Finance: https://bnef.turtl.co/story/evo2018?teaser=true

Good Day Sacramento. (2018, May 31). *California To Spend $768 Million On Electric Car Infrastructure*. Retrieved from Good Day : https://gooddaysacramento.cbslocal.com/2018/05/31/california-electric-cars-infrastructure/

Graham, K. (2019, Feb 4). *Volkswagen to install Tesla battery packs at EV charge stations*. Retrieved from Digital Journal: http://www.digitaljournal.com/business/volkswagen-to-install-tesla-battery-packs-at-ev-charge-stations/article/542434

Greentech Media. (2018, May 31). *California Regulators Approve Landmark Utility EV-Charging Proposals* . Retrieved from https://www.greentechmedia.com/articles/read/california-cpuc-approves-landmark-ev-charging-proposals#gs.v5CgrXio

Hannan, M. A., Hoque, M. M., Yusof, Y., & Ker, P. J. (2018). State-of-the-Art and Energy Management System of Lithium-Ion Batteries in Electric Vehicle Applications: Issues and Recommendations. *IEEE Access*.

Houseman, D. (2018). *The Future of Batteries in an Electrified Fleet.* IEEE.

Idaho National Laboratory. (2015). *Plug-in Electric Vehicle and Infrastructure Analysis.*

Idaho National Labs. (2013). *Plugged In: How Americans Charge Their Electric Vehicles.*

InsideEVs. (2018, May). *Over 50 Plug-In EVs Compared: Price, Range + More – May 2018*. Retrieved from https://insideevs.com/over-50-plug-in-evs-compared-price-range-more-march-2018-us/

InsideEVs. (n.d.). *Monthly Plug-In EV Sales Scorecard: Historical Charts*. Retrieved from https://insideevs.com/monthly-plug-in-ev-sales-scorecard-historical-charts/

Irle, R. (n.d.). *Battery Chemistry Evolution*. Retrieved from EV Volumes: http://www.ev-volumes.com/country/total-world-plug-in-vehicle-volumes/

Kane, M. (2019, Jan 3). *Nuvve Announces Vehicle-to-Grid (V2G) Pilot Programs*. Retrieved from Inside EVs: https://insideevs.com/nuvve-vehicle-to-grid-v2g-pilot-programs/

Lambert, F. (2017, 1 30). *Electric vehicle battery cost dropped 80% in 6 years down to $227/kWh – Tesla claims to be below $190/kWh*. Retrieved from electrek: https://electrek.co/2017/01/30/electric-vehicle-battery-cost-dropped-80-6-years-227kwh-tesla-190kwh/

Lambert, F. (2017, September 8). *Uber wants its 40,000 drivers in London to switch to electric cars*. Retrieved from electrek: https://electrek.co/2017/09/08/uber-electric-cars-london/

Lambert, F. (2018, 8 2). *Tesla confirms Gigafactory 1 battery production at '~20 GWh' – more than all other carmakers combined*. Retrieved from electrek: https://electrek.co/2018/08/02/tesla-gigafactory-1-battery-production-20-gwh/

Maarten Steinbuch, M. C. (n.d.). *Tesla Battery Range Data.* Retrieved from https://docs.google.com/spreadsheets/d/t024bMoRiDPIDialGnuKPsg/edit#gid=1669966328

McKinsey & Company. (2017, January). *Electrifying insights: How automakers can drive electrified vehicle sales and profitability*. Retrieved from https://www.mckinsey.com/~/media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/Electrifying%20insights%20How%20automakers%20can%20drive%20electrified%20vehicle%20sales%20and%20profitability/Electrifying%20insights%20-%20How%20automakers%2

Minnesota Pollution Control Agency. (2018). *EV fast-charging station grants*. Retrieved from Minnesota Pollution Control Agency: https://www.pca.state.mn.us/air/ev-fast-charging-station-grants

More Than 500 Nissan Electric Cars In Taxi Service Now. (2015). Retrieved from https://www.greencarreports.com/news/1101296_more-than-500-nissan-electric-cars-in-taxi-service-now

Nelder, G. F. (2017). *EVGO Fleet and Tariff Analysis.* Rocky Mountain Institute.

Nexant. (2014). *Final Evaluation for San Diego Gas & Electric's Plug-in Electric Vehicle TOU Pricing and Technology Study*.

NYC Taxi & Limousine Commission. (2013). *Take Charge A Rodmap to Electric New York City Taxis.*

Office of Energy Efficiency & Renewable Energy. (n.d.). *Electric Vehicles: Tax Credits and Other Incentives*. Retrieved from https://www.energy.gov/eere/electricvehicles/electric-vehicles-tax-credits-and-other-incentives

Office of Energy Efficiency & Renewable Energy. (2017, November 20). *California Had the Highest Concentration of Plug-in Vehicles Relative to Population in 2016*. Retrieved from https://www.energy.gov/eere/vehicles/articles/fotw-1004-november-20-2017-california-had-highest-concentration-plug-vehicles

O'Kane, S. (2018, Jun 1). *Three US states will spend $1.3 billion to build more electric vehicle charging*. Retrieved from The Verge: https://www.theverge.com/2018/6/1/17416778/california-new-york-electric-charging-investment-stations

PG&E. (2018). *Learn about our electric fleet vehicle charging program*. Retrieved from PG&E: https://www.pge.com/en_US/large-business/solar-and-vehicles/clean-vehicles/ev-charge-network/fleetready.page

Plug-In Electric Vehicle (PEV) Charging Tariff. (n.d.). Retrieved from https://afdc.energy.gov/laws/11483

Plugless. (2017). *32 Different EVs Can Cover 100% of Daily Driving on Pure Electric Power in 2017*. Retrieved from Plugless: https://www.pluglesspower.com/learn/28-different-evs-can-cover-100-daily-driving-pure-electric-power/

Salisbury, T. (2016). *How Leading Utilities are Embracing Electric Vehicles.*

Schmidt, E. (2017, Oct 25). *The Latest in Vehicle to Grid (V2G) Charging*. Retrieved from Fleet Carma: https://www.fleetcarma.com/latest-vehicle-grid-v2g-charging/

Southern California Edison. (n.d.). *Electric Vehicle Rates* . Retrieved from https://www.sce.com/business/rates/electric-car-business-rates/business/rates/electric-car-business-rates

Stumpf, R. (2018, 8 8). *Tesla's Gigafactory Is Already Dominating EV Battery Production*. Retrieved from The Drive: http://www.thedrive.com/sheetmetal/13297/teslas-gigafactory-is-already-dominating-ev-battery-production

The Guardian. (2017, Aug 10). *The rise of electric cars could leave us with a big battery waste problem*. Retrieved from The Guardian: https://www.theguardian.com/sustainable-business/2017/aug/10/electric-cars-big-battery-waste-problem-lithium-recycling

UPS. (2018, 2 22). *UPS To Deploy First Electric Truck To Rival Cost Of Conventional Fuel Vehicles* . Retrieved from https://pressroom.ups.com/pressroom/ContentDetailsViewer.page?ConceptType=PressReleases&id=1519225541368-230

Voeckler, J. (2017, Jun 9). *How much is a replacement Chevy Bolt EV electric-car battery?* Retrieved from Green Car Reports: https://www.greencarreports.com/news/1110881_how-much-is-a-replacement-chevy-bolt-ev-electric-car-battery

Walton, R. (2018, Aug 14). *Missouri court overrules regulators, finds PSC has jurisdiction over EV charging stations*. Retrieved from Utility Drive: https://www.utilitydive.com/news/missouri-court-overrules-regulators-finds-psc-has-jurisdiction-over-ev-cha/530066/

Workhorse. (n.d.). *E-100*. Retrieved from Workhorse: https://workhorse.com/stepvans

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