BUSINESS

ASSESSING THE ELECTRIC VEHICLE CHARGING NETWORK IN WASHINGTON STATE

CENTER FOR CLIMATE AND ENERGY SOLUTIONS

by

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The Washington State Legislature is interested in exploring government's role in fostering new business models that will expand the private sector commercialization of electric vehicle (EV) charging services. This paper provides an assessment of the existing EV publicly available charging network in Washington. The paper begins with the challenges of ensuring adequate access to EV charging infrastructure and identifies the barriers to increasing the private sector role in expanding charging access. Next, the paper assesses the current state of publicly available charging infrastructure in the state and identifies where additional infrastructure may be needed. Finally, the paper investigates specific travel corridors where private investment could increase EV adoption.

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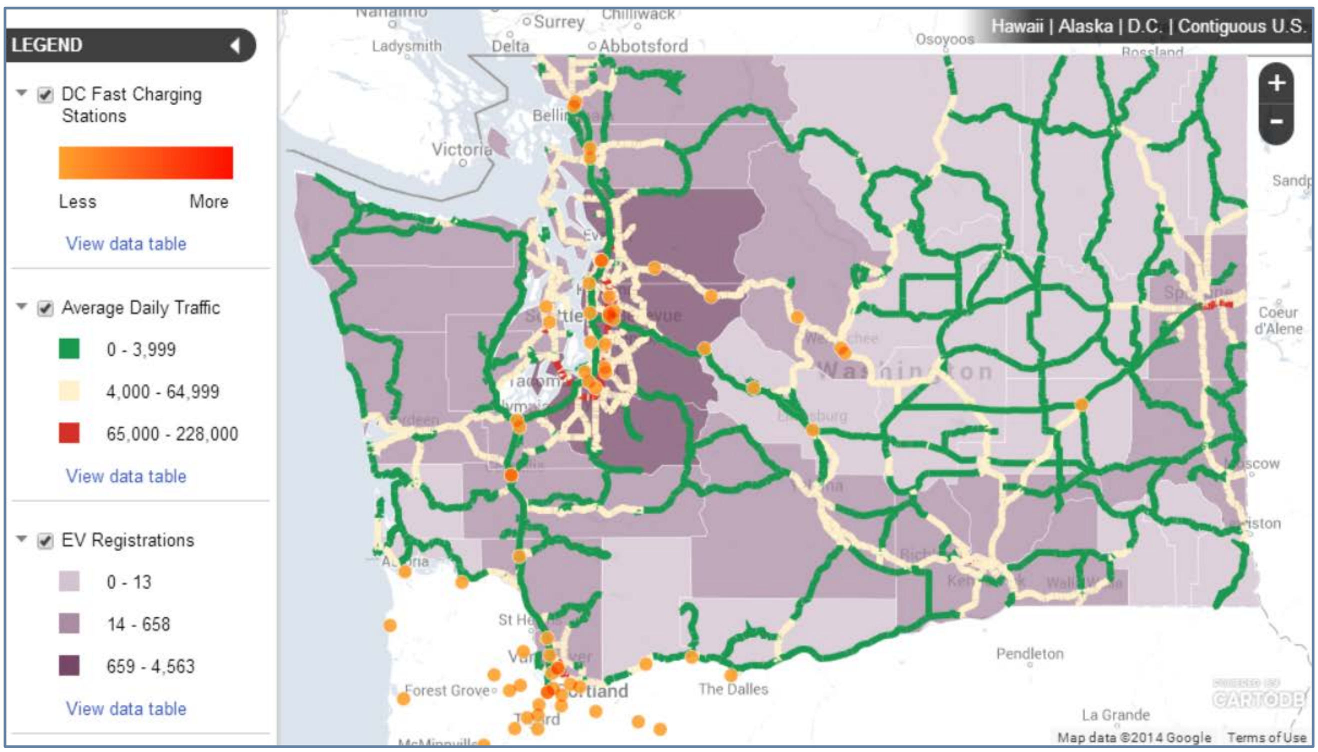
EXECUTIVE SUMMARY

Electric vehicles (EVs) are a small, but fast growing part of the passenger vehicle market in the United States. In the state of Washington, EVs have been more popular than in other markets, in part because of action by the state government to build out publicly available charging infrastructure. The Washington State Legislature is interested in exploring government's role in fostering new business models that will expand the private sector commercialization of EV charging services.

This paper provides an assessment of the existing EV publicly available charging network in Washington. The paper begins with the challenges of ensuring adequate access to EV charging infrastructure and identifies the barriers to increasing the private sector role in expanding charging access. Next, the paper assesses the current state of publicly available charging infrastructure in the state and identifies where additional infrastructure may be needed. Finally, the paper investigates specific travel corridors where private investment could increase EV adoption.

FIGURE 1: DC Fast Charging Network Intensity Map as of June 2014



Large segments of many major roadways do not have any publicly available DC fast charging. Major roadways are denoted by green, yellow, and red colors depending on the average daily traffic in 2012.

Source: C2ES. 2014. DC Fast Charging Network in Washington State. August. Accessed September 21, 2014. http://www.c2es.org/initiatives/alternative-fuel-vehicle-finance/maps/wa-dc-fast-charging-network.

While the national trend has been for plug-in hybrid vehicle (PHEV) adoption to outpace battery electric vehicle (BEV) adoption, Washington has not followed this trend. Washington has more than twice the number of BEVs on the road as PHEVs. As of December 2013, there were 5,655 BEVs registered in the state compared to only 2,493 PHEVs, according to the Washington Department of Licensing.

In most Washington counties, the distribution of EVs is roughly proportional to that of regular passenger vehicles.

EVs are concentrated in five counties, which make up 85 percent of the EV registrations, but only 64 percent of total passenger vehicle registrations. EVs are particularly concentrated in King County, which is home to 56 percent of EVs registered in the state, compared with 30 percent of total passenger vehicles.

Washington has 423 publicly available charging locations as of June 2014, giving it the fourth highest per capita publicly available charging network in the country.[1] A relationship may exist between the number of EVs and the number of publicly available charging locations in a county. These charging stations are primarily concentrated in the state's most populous region around Puget Sound. King County also contains 57 percent of the state's Level 2 charging locations and 39 percent of DC fast charging locations. Publicly available charging stations around the rest of the state are mostly sparse, with the exception of the Vancouver area near Portland, Oregon.

The direct current (DC) fast charging network in Washington provides access to charging along much of the Interstate 5 corridor and in King County, but DC fast charging is unavailable in much of the state (see Figure 1). The alternating current (AC) Level 2 charging network in Washington provides access in King County, but does not provide access in much of the rest of the state outside of Vancouver. Seventy-four percent of populated ZIP codes in the state, covering 44 percent of the population, have no Level 2 charging stations. As a result, many possible destinations may be inaccessible to BEV drivers.

Based on travel simulations completed, EVs with longer electric-only ranges are more likely to complete trips with the current charging infrastructure. Any BEV on the market today can travel from Seattle to Portland, Oregon along Interstate 5 because of the relatively high density of publicly available charging stations. However, additional charging infrastructure is needed to facilitate travel to the Pacific Coast and between the eastern and western part of the state along Interstate 90.

ACKNOWLEDGEMENTS

The Center for Climate and Energy Solutions (C2ES) would like to thank the Washington State Legislature Joint Transportation Committee for providing financial support for this report. C2ES would also like to thank the following for their substantial input: Representative Judy Clibborn, Representative Ed Orcutt, Representative Jake Fey, Representative Drew MacEwen, Representative Chad Magendanz, Senator Mark Mullet, Representative Dick Muri, Wayne Amondson, Scott DeWees, Ben Farrow, Stephen Johnsen, Ron Johnston-Rodriguez, Charles Knutson, Dan O'Shea, David Peterson, Sandra Pinto de Bader, Colleen Quinn, Glen Stancil, Nick Bowman, Tonia Buell, Alyson Cummings, Jeff Doyle, Debbie Driver, Mary Fleckenstein, Kim Johnson, Jerry Long, Jackson Maynard, Peter Moulton, Sonia Plasencia, Dana Quam, Beth Redfield, and Andrew Russell.

INTRODUCTION

Electric vehicles (EVs) are a small, but fast growing part of the passenger vehicle market in the United States. In the state of Washington, EVs have been more popular than in other markets, in part because of action by the state government to build out publicly available charging infrastructure. The Washington State Legislature is interested in exploring government's role in fostering new business models that will expand the private sector commercialization of EV charging services. This paper is part of a project on expanding the role of private sector investment in publicly available EV charging throughout Washington (see Box 1).

The paper provides an assessment of the existing EV publicly available charging network in Washington. The first section identifies the challenges of ensuring adequate access to EV charging infrastructure and the barriers to increasing the private sector role in expanding charging access. The next section assesses the current state of charging infrastructure in the state and identifies where additional infrastructure may be needed. The third section investigates specific travel corridors where private investment could increase EV adoption. Finally, the paper offers conclusions and identifies next steps for the project.

Box 1. Business Models for Financially Sustainable EV Charging Networks

The Washington State Legislature's Joint Transportation Committee selected C2ES to develop new business models that will foster private sector commercialization of public EV charging services. First, C2ES will assess the state of EV charging in Washington and create useful products for the state to perform similar assessments as the market evolves. Second, leveraging its experience with the Alternative Fuel Vehicle (AFV) Finance Initiative and similar activities, C2ES will identify and evaluate business models for EV charging in Washington. Finally, C2ES will develop recommendations on the role of the public sector in supporting those business models in order to maximize private sector investment in EV charging.

Evaluate Current Status of EV Charging in Washington

- Construct Public Charging Network Database
- Create interactive maps for charging suitability assessment
- Provide insights into role of public charging networks in encouraging EVs
- Summarize findings

May – August 2014

Develop Business Models

- Leverage C2ES's AFV Finance Initiative
- Conduct Business Model Workshop
- Create 2-3 Business Model Summaries

July – November 2014

Identify Public & Private Roles

- Execute financial analysis on business model viability
- Identify public sector role in addressing barriers to private investment

October – December 2014

This project is a part of C2ES's AFV Finance Initiative. More information is available at www.c2es.org/initiatives/alternative-fuel-vehicle-finance.

THE CHALLENGE OF EXPANDING THE PRIVATE SECTOR ROLE IN OFFERING EV CHARGING SERVICES

While state and federal governments have played a central role in providing EV charging infrastructure to date, greater private investment will be needed to ensure adequate access to publicly available charging stations to continue to advance EV adoption. However, it is currently challenging to construct a profitable business case for EV charging investments for several reasons.

EV charging business models face barriers including high capital costs for new infrastructure and the associated financing costs, as well as operating costs. Deploying a charging station requires an upfront capital investment for equipment and installation, which ranges from $500 to $5,000 for an alternating current (AC) Level 2 charging station or $50,000 to $150,000 for a direct current (DC) fast charging station (see Box 2).[2] If nascent technologies and standards change, EV charging locations will require additional capital infusions to fund station retrofits. Access to public or private financial capital needed for these investments may present an additional barrier. Charging station hosts or service providers may also bear substantial operating costs, including electricity distribution costs associated with powering DC fast charging stations or sites with multiple Level 2 charging stations. Electricity regulators could reduce these operating costs through new electricity rate structures.[3]

On the revenue side, charging station investors face the headwinds of low and uncertain near-term demand for publicly available charging, as well as limited consumer willingness to pay for publicly available charging due to competition with relatively inexpensive home charging. In Washington, residential electricity prices averaged only $0.08 per kilowatt-hour in April 2014, with prices as low as $0.03 per kilowatt-hour.[4] In addition, the potential for charging stations to capture indirect revenue—such as increased retail sales near publicly available charging locations—from charging stations is uncertain and not well recognized.

MODELS OF EV INFRASTRUCTURE DEPLOYMENT AND VALUE CAPTURE

Public and private entities could employ a variety of models to deploy and manage EV charging infrastructure. This section considers four questions in order to understand the range of possible models and, in subsequent phases of this project, enable comparison and evaluation of these models.

Box 2. EV Charging Installation Cost for West Coast Electric Highway

One of the main barriers to deploying DC fast charging stations is the high cost of installation. Until 2013, DC fast charging equipment was not readily available and costs were high as a result. Over time, equipment costs have declined and providing a high-powered connection to the electrical grid now constitutes much of the installation cost.[5] Below is the cost summary for DC fast charging stations installed in Washington for the West Coast Electric Highway project. Installation of these stations was completed in 2012. More information is available online at http://www.westcoastgreenhighway.com/electrichighway.htm.

COMPONENT	COST (2012)
DC fast charging equipment	$58,000 per unit
Level 2 charging station co-located with DC fast charging station	$2,500 per unit
Equipment installation (labor and electric-panel upgrade)	$26,000 per location
Host-site identification, analysis, and screening	$5,000 per location
Negotiation, legal review, and execution of lease	$6,000 per location
Utility interconnection	$12,500 to $25,000 per location
Total	$109,500 to $122,000

Source: Washington State Department of Transportation

1. What are the critical functions and stakeholders in an EV charging network?

While this paper is focused on EV charging services specifically, it is helpful to consider the broader set of products and services needed to support an EV charging network, depicted in Figure 2, which include that:

- Installation sites must be selected to host EV charging stations;
- Electricity must be generated, transmitted and distributed to supply electricity to EV charging sites;
- Charging station equipment must be manufactured and purchased by an EV charging service provider; and
- EVs must be manufactured and purchased.

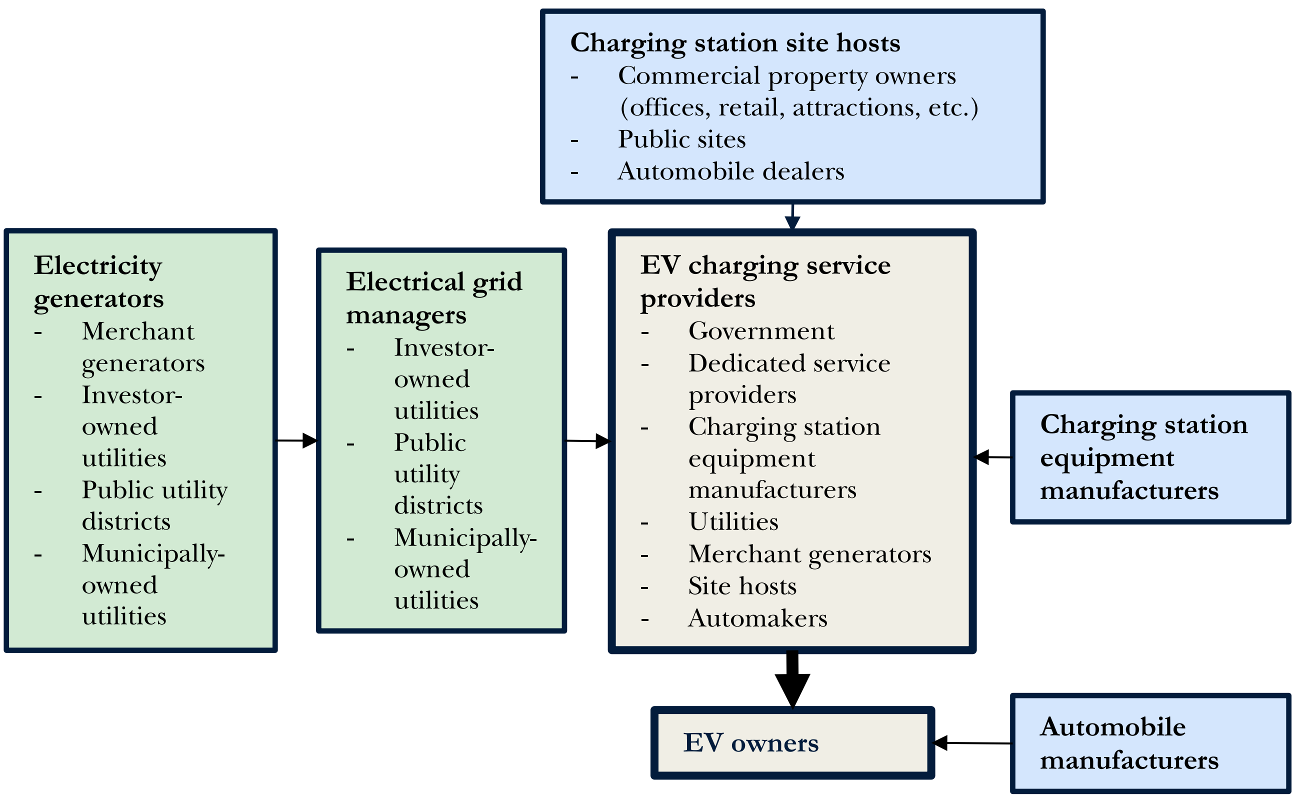
Each of these functions is essential to providing charging services, and several of these functions can be carried out by multiple types of stakeholders, listed in Figure 2.

2. Which entities are positioned to provide EV charging services?

As shown in Figure 2, the function of the EV charging service provider could be played by many alternative stakeholders, including:

- dedicated charging service companies,
- charging equipment manufacturers,
- property owners acting as site hosts,
- automakers,
- electric utilities,
- electricity generators, and
- state and local governments.

FIGURE 2: Public EV Charging Network Roles and Flows of Products and Services



Roles needed to support an EV charging network are depicted as boxes and titled within each box in bold. Stakeholders that could play each role are bulleted within each box in cases where more than one stakeholder could play a role. Flows of products and services are depicted as arrows.

Source: C2ES

These stakeholders differ in their potential interests in and concerns about EV charging deployment. Each stakeholder's perspective on EV charging deployment opportunities is presented in Table 1 and challenges are presented in Table 2. Notably, stakeholders face many of these benefits and concerns whether or not they directly assume the function of EV charging service provider.

3. How would these entities derive value from providing such a network?

In order for any of these entities to consider investing in EV charging, they will need to expect that the project will generate value that is greater than its total cost. For commercial entities, the monetary value of EV charging projects is of primary concern. For government entities, the social benefits of EV charging deployment may also be considered.

The monetary value of providing EV charging services is dependent on the total revenue these services generate. The most straightforward sources of revenue are station user fees. User fees may be collected at the time of charging, through a flat fee per charging session, a fee based on the time spent parked or connected to the charging station, or a fee based on the amount of energy used. Alternatively, user fees may be collected through subscriptions, membership fees, or permits.

EV charging stations may also generate additional types of indirect revenue streams for businesses. For example, offering EV charging at retail locations may increase sales revenue by drawing EV drivers to the destination and by increasing customer time spent parked at these locations. EV charging infrastructure deployment may increase sales of EVs, potentially increasing expected automaker revenues as they work to drive down costs for these advanced technology vehicles. Over a longer time frame, technology and infrastructure development may enable EVs to provide vehicle-to-building (V2B) and vehicle-to-grid (V2G) power services that generate additional revenues or cost savings. Some businesses may choose to bear the costs of offering charging services based on the value of these indirect revenue streams.

In addition to the monetary value of charging services, state and local governments and public utilities may consider the social benefits associated with increased EV deployment, including public health, environmental, economic development, and energy security benefits.[6] The value of these benefits is uncertain and difficult to quantify.

4. What sources of financial capital are available to fund station deployment and operations?

Any entity seeking to deploy EV charging infrastructure will need financial capital to fund upfront costs (equipment and installation) and operating costs (electricity, maintenance, and supporting services). Upfront capital costs could be funded in several ways:

- Commercial entities may choose to devote their own available cash-on-hand to deploy and operate charging stations.
- Private financing through commercial loans or leases may be used to secure adequate funds for deployment.
- Deployments of larger-scale networks of EV charging stations may be financed with capital from third-party investment partners.
- Investor-owned electric utilities may finance EV charging station projects using shareholder revenues.[7]
- Electric utility ratepayer fees.

The public sector may contribute funds to EV charging deployment projects, either by owning and operating stations themselves, or by subsidizing commercially managed deployments. Funding for public investment in charging stations could come from tax revenues. Charging station subsidies could take the form of grants, rebates, tax credits, or low-cost lending programs. Notably, such programs in Washington must be designed to ensure compliance with constitutional limitations on any gifting of public funds and/or loaning of state credit.

Taken together, these four questions—what is a charging network, who can provide it, how is value captured, and how is it funded—frame the challenges of and opportunities for ensuring adequate access to publicly available charging infrastructure and expanding the private sector role in this effort. The next section investigates the current state of EV market station usage in Washington to better understand both the needs of EV drivers and the potential for revenue generation from charging station investments.

TABLE 1: Opportunities from the deployment of EV charging from stakeholders' perspective

	PUBLIC / GOVERNMENT	PUBLIC UTILITY DISTRICTS AND MUNICIPALLY-OWNED UTILITIES	INVESTOR-OWNED ELECTRIC UTILITIES	MERCHANT ELECTRICITY GENERATORS	DEDICATED CHARGING SERVICE PROVIDERS	CHARGING EQUIPMENT MANUFACTURERS	AUTOMAKERS	CHARGING SITE PROPERTY OWNER
Vehicle fuel cost savings	X							
Reduced environmental and public health costs	X	X						
Economic development from EV and charging station use	X	X						X
Increased electricity use		X	X	X				
More efficient use of off-peak generation capacity	X	X	X	X				
Long-term prospect of vehicle-to-building and vehicle-to-grid benefits	X	X	X	X	X	X	X	X
Greater EV sales							X	
Sales of EV charging equipment						X		
Increased retail sales from offering charging on site								X
Sales of charging network support services		X	X		X			X

For each stakeholder, opportunities that are within their scope of interest are indicated with an 'X.' Opportunities are presented as general categories that are illustrative of stakeholders' primary motivations.

Source: C2ES

TABLE 2: Challenges from EV charging deployment from stakeholders' perspective

	PUBLIC / GOVERNMENT	PUBLIC UTILITY DISTRICTS AND MUNICIPALLY-OWNED UTILITIES	INVESTOR-OWNED ELECTRIC UTILITIES	MERCHANT ELECTRICITY GENERATORS	DEDICATED CHARGING SERVICE PROVIDERS	CHARGING EQUIPMENT MANUFACTURERS	AUTOMAKERS	CHARGING SITE PROPERTY OWNER
Cost to public of charging investment and subsidies / equity concerns	X	X	X					
High-power charging impacts on grid reliability / need for distribution upgrades	X	X	X					
Vehicle-to-building technology could reduce demand for grid electricity		X	X	X				
Financial sustainability of charging station investment	X	X	X	X	X			X
Rate of return of charging station investment				X	X			
Uncertain impacts of charging station deployment on EV adoption	X						X	
Lack of interest in owning and operating charging infrastructure	X	X	X				X	

For each stakeholder, challenges that are within their scope of interest are indicated with an 'X.' Challenges are presented as general categories that are illustrative of stakeholders' primary concerns.

Source: C2ES

THE WASHINGTON EV MARKET

This section provides an overview of the EV market in Washington with a focus on why battery electric vehicles (BEVs) have been more popular than plug-in hybrid electric vehicles (PHEVs), see Box 3. This section also describes a potential relationship between the concentration of EVs and charging locations at the county level.

Box 3. Defining the Types of EVs

Battery electric vehicles (BEVs) are powered by rechargeable batteries. Many BEVs currently available can only travel 100 miles or less on a single charge. As a result, BEVs require a robust fast charging network to enable long distance travel. A plug-in hybrid electric vehicle (PHEV) can be powered by batteries and/or a gasoline-powered internal combustion engine. The flexibility offered by the gasoline engine enables a PHEV to travel more easily without the need to stop and recharge the vehicle's battery. On the other hand, PHEVs typically have less than 40 miles of all-electric range, so their share of electric miles traveled decreases on longer trips unless the batteries are recharged.

EV ADOPTION OVER TIME AND THE RATIO OF BEVS TO PHEVS

While the national trend has been for PHEV adoption to outpace BEV adoption, Washington has not followed this trend. Many studies have concluded that PHEVs are likely to be more popular than BEVs in the near term because of the high cost of batteries and the lack of charging infrastructure.[8] Figure 3 shows the national EV market has followed this projection, with 27 percent more PHEVs sold than BEVs. Washington, however, has more than twice the number of BEVs on the road as PHEVs, as shown in Figure 4. As of December 2013, there were 5,655 BEVs registered in the state compared to only 2,493 PHEVs according to the state's Department of Licensing.

TABLE 3: EVs registered in Washington

	2011	2012	2013
PHEVs Registered	125	1,056	2,493
BEVs Registered	1,121	1,871	5,655
Total EVs	1,246	2,927	8,148
Total Passenger Vehicles	4,315,782	4,284,923	4,401,768
U.S. Cumulative EV Sales	17,655	70,301	165,663

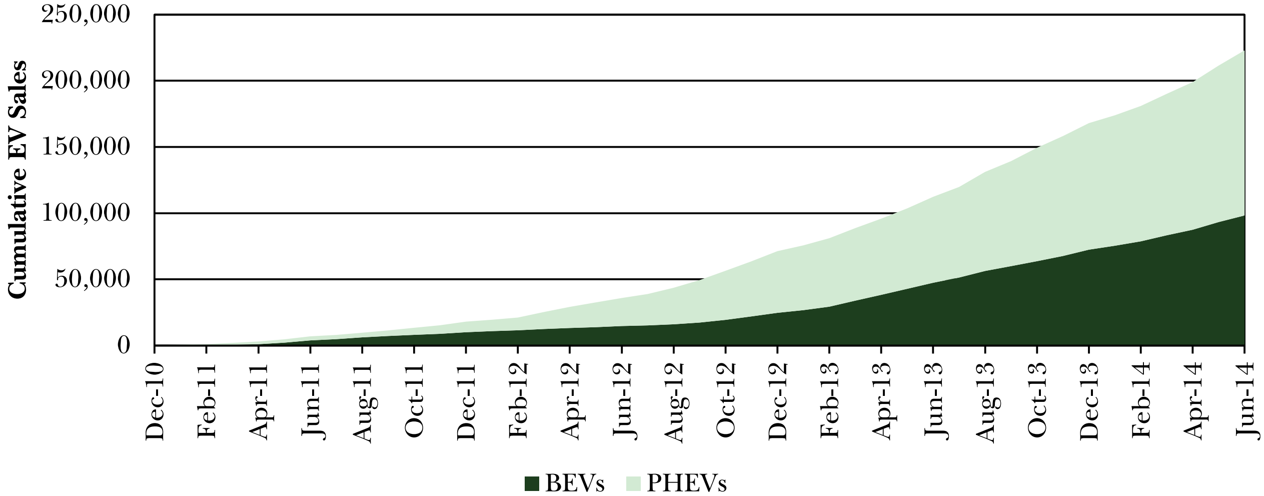
The total for registrations was calculated by adding all registration-related transactions provided by Department of Licensing: 'original,' 'registration renewal,' 'title transfer,' and 'other.'

Source: Washington State Department of Licensing, Hybridcars.com

One possible explanation for the popularity of BEVs over PHEVs in Washington is the presence of state policy incentives. A time-of-purchase sales tax exemption only available for BEVs amounts to a multi-thousand dollar "discount" for a BEV compared to a PHEV. Automakers have indicated that sales can be increased through incentives available for use at the time of vehicle purchase, especially incentives in excess of $1,000.[9] Notably, BEVs are also much more popular than PHEVs in Georgia, where a $5,000 vehicle tax credit and high-occupancy vehicle lane access are both available only to BEVs. These incentives have helped make Atlanta the top market for the all-electric Nissan LEAF for many months.[10]

Because BEVs outnumber PHEVs by a large margin in Washington, charging infrastructure needs in Washington may differ from those in other markets. Washington EV drivers may need greater access to high-powered charging to meet their travel needs than drivers in other states.

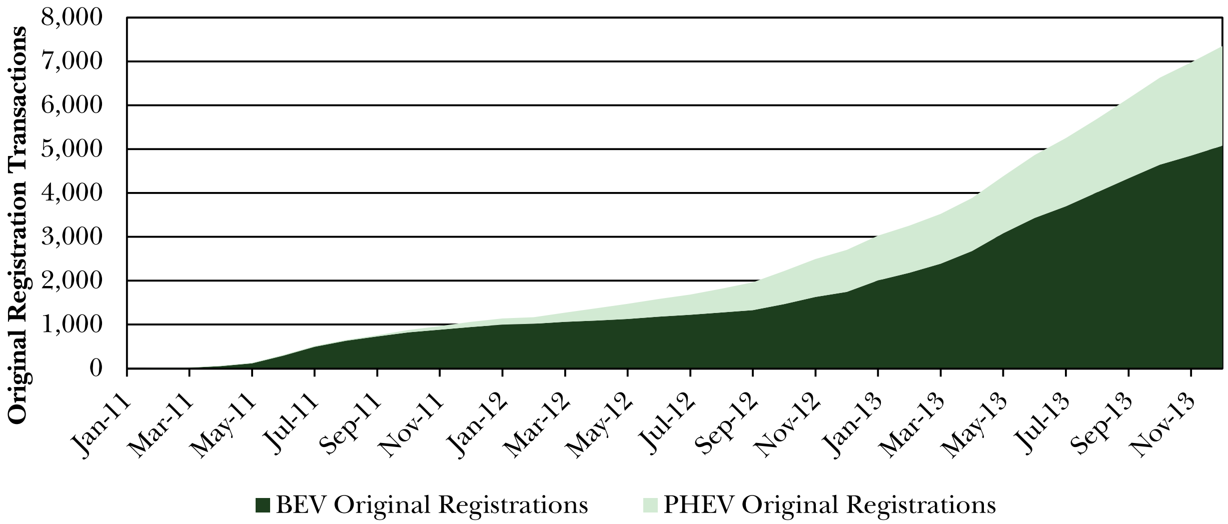
FIGURE 3: PHEVs have outsold BEVs in United States by over 25 percent.



124,718 PHEVs and 98,267 BEVs have been sold in the United States through June 2014. PHEVs have consistently outsold BEVs on a monthly basis since early 2011.

Source: Hybridcars.com. 2014. Hybrid Market Dashboard. July. Accessed September 21, 2014. http://www.hybridcars.com/market-dashboard.html.

FIGURE 4: BEVs Have Outsold PHEVs in Washington by a Large Margin



This figure shows the history of original registrations for BEVs and PHEVs from January 2011 to December 2013. An original registration occurs when a vehicle owner first registers the vehicle in Washington. The figure shows new and used vehicles as they were first registered. Washington differs from the national EV market because BEVs have outsold PHEVs by a large margin. The actual number of vehicles on the road will differ from the total vehicles shown below at any given time because it does not include the existing vehicle stock.

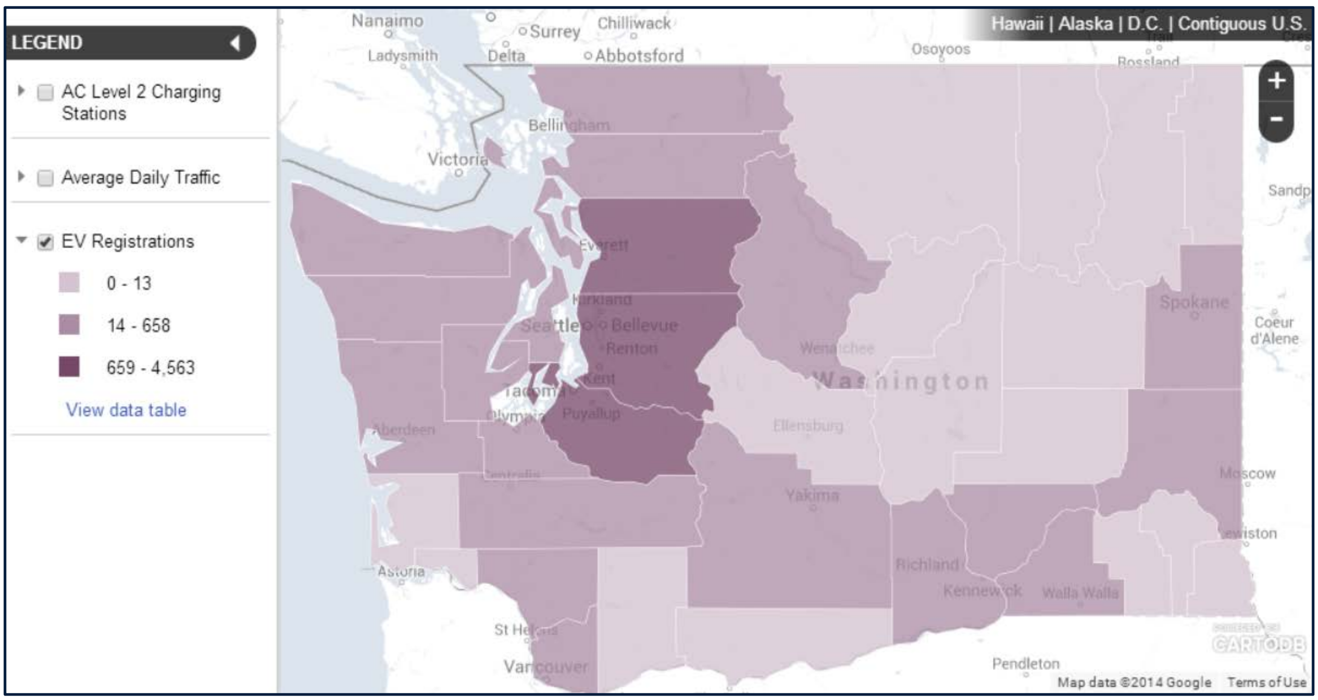
Source: Washington Department of Licensing.

GEOGRAPHIC DISTRIBUTION OF EVS

In most Washington counties, the distribution of EVs is roughly proportional to that of regular passenger vehicles. EVs are concentrated in five counties, which make up 85 percent of the EV registrations (see Table 4), but only 64 percent of total passenger vehicle registrations.

A relationship may exist between the number of EVs and the number of publicly available charging locations in a county. EVs are particularly concentrated in King County, home to 56 percent of EVs registered in the state, compared with 30 percent of total passenger vehicles. King County also contains 57 percent of the Level 2 charging locations and 39 percent of DC fast charging locations. Considering that Level 2 charging stations are often intended to accommodate average daily travel needs, a similar share of Level 2 charging locations and EV registrations in a county is intuitive. For example, 57 percent of Level 2 charging locations and 56 percent of EVs are in King County. On the other hand, a strong relationship between DC fast charging and BEV sales is less likely at the county level since DC fast charging is often cited as enabling travel to and from distant locations.

FIGURE 5: Registered EVs in Washington by county through December 2013



Nearly all EVs in Washington are registered in the Puget Sound region. Many counties have very few EVs registered, denoted by the lightest purple color.

Source: C2ES. 2014. AC Level 2 Charging Network in Washington State. August. Accessed September 21, 2014. http://www.c2es.org/initiatives/alternative-fuel-vehicle-finance/maps/wa-ac-level-2-charging-network.

TABLE 4: Top 5 Counties for EV registrations (December 2013)

COUNTY	BEVS REGISTERED	PHEVS REGISTERED	EVS REGISTERED	POPULATION (%)	BEV (%)	PHEV (%)	EV (%)	DC FAST CHARGING LOCATIONS (%)	AC LEVEL 2 CHARGING LOCATIONS (%)
Clark	278	157	435	6.3%	5%	6%	5%	15%	3%
King	3433	1130	4563	28.8%	61%	45%	56%	43%	60%
Kitsap	264	107	371	3.7%	5%	4%	5%	5%	3%
Pierce	399	260	659	11.8%	7%	10%	8%	5%	11%
Snohomish	569	272	841	10.6%	10%	11%	10%	8%	8%

These five counties make up 85 percent of total EV registrations. Percentages in this table are a share of state totals.

Source: Washington State Department of Licensing; U.S. Census Bureau, U.S. Department of Energy

CHARGING NETWORK ASSESSMENT

This section assesses the ability of the existing publicly available charging network to enable travel throughout Washington, considering the location of EVs and average daily traffic. It begins with a description of assumptions about vehicle and charging technologies that formed the basis for the analysis. The section then describes an independent assessment of the DC fast charging and AC Level 2 charging networks. An assessment of the EV charging network in Washington depends on the charging technology supported by existing charging stations and the charging needs demanded by different EV technologies. Although these assessments were performed separately, the two charging technologies can complement each other to accommodate average daily driving needs and the occasional long distance trip.

Washington has 423 publicly available charging locations as of June 2014, giving it the fourth highest per capita publicly available charging network in the country.[11] These charging stations are primarily concentrated in the state's most populous region around Puget Sound. Publicly available charging stations around the rest of the state are mostly sparse, with the exception of the Vancouver area near Portland, Oregon. There are three publicly available charging networks in the state: AeroVironment, Blink, and ChargePoint. Tesla's fast charging network is only available to Tesla vehicles and is not considered in this analysis.

VEHICLE AND CHARGING TECHNOLOGIES CONSIDERED AND ASSUMPTIONS

The following section describes the vehicle and charging technologies considered in the network assessment and any assumptions used in the analysis. For example, an EV can be expected to travel 3.5 miles with each kilowatt-hour (kWh) of energy delivered to its batteries, or by charging the vehicle at 1 kilowatt (kW) for an hour (see Figure 6). Charging a vehicle at 30 kW for 30 minutes provides about 50 miles of range. Thus, the higher the power the charging station provides to the vehicle, the faster the vehicle's batteries can recharge.

Competing Charging Equipment Standards in the Marketplace

An EV can recharge at three power levels: AC Level 1, AC Level 2, and DC fast charging (see Figure 6). Most BEVs support all three levels of charging while current PHEVs only support AC Level 1 and 2. All EVs support a common standard for charging at AC Level 1 and 2, but there are three competing standards for DC fast charging presently.

All EVs are currently equipped with the Society of Automotive Engineers (SAE) J1772 connector for AC

Level 2 charging. Siting for Level 2 charging stations is typically done at locations where drivers are expected to spend several hours, such as retail outlets, public parks, recreational areas, public parking lots, and sports stadiums. The power level for Level 2 goes up to 19.2 kW, but is typically offered at 3.3 kW or 6.6 kW.

DC fast charging provides rapid battery recharging at a somewhat similar timeframe as refueling a conventional gasoline powered vehicle. It is intended to enable long distance EV travel and accommodate EV owners without access to convenient, daily charging at the home or workplace. These charging stations are often sited at locations where drivers are expected to spend less than 30 minutes, such as along the roadway, similar to a gasoline station. An adequate DC fast charging network must link major roadway segments with enough charging density to minimize the risk of being stranded or the need to wait for an excessive amount of time to access the station.

FIGURE 6: Charging Levels Explained

Low – AC 120V *"AC" LEVEL 1*	Medium – AC 240V *"AC" LEVEL 2*	High – DC Fast Charge *"DC" LEVEL 2*
•Uses standard outlet •Power requirements similar to a toaster •Adapter comes with the car •Accommodates average daily driving needs •Very low cost installation, often free •*Fully charge a Nissan LEAF: 17 hours*	•Requires high-voltage circuit •Power requirements similar to an electric clothes dryer •Charging stations can cost about $500 •Installation costs vary widely (~$1,500) •*Fully charge a Nissan LEAF in 3.5-7 hours*	•Requires very high voltage circuit & 3-phase power •Power requirements are up to max power for 15 homes •No common standard for electric vehicles (CHAdeMO, SAE, Tesla) •Very high installation cost (~$100,000) •Equipment costs vary widely •*80% charge a Nissan LEAF in 20 minutes*

This figure explains the three kinds of EV charging. AC Level 1 is not included in the scope of this work.

Source: SAE. 2011. SAE Charging Configurations and Ratings Terminology. Accessed September 21, 2014. http://www.sae.org/smartgrid/chargingspeeds.pdf.

DC fast charging stations can provide power to a vehicle's batteries at up to 90 kW, though stations typically only provide power at a rate up to 50 kW. There are currently three competing standards for DC fast charging, and they are not inter-operative, making it more challenging for drivers to charge their vehicles. As a result, the business case for private investment in DC fast charging is made more complicated than if there were only one standard. The three DC fast charging standards are:

- CHAdeMO: a standard developed by an association of Japanese companies and followed by Nissan and Mitsubishi.
- SAE J1772 Combo: a standard developed and adopted by the Society of Automotive Engineers in conjunction with the J1772 connector standard used for AC Level 2 charging and followed by most American and European automakers. There were no SAE J1772 Combo charging stations in Washington as of June 2014.
- Tesla: a proprietary standard developed by Tesla Motors that is currently only compatible with Tesla vehicles.

AC Level 1 charging can be accommodated through a standard 120 Volt power outlet using an automaker-supplied charging adapter. Power levels at AC Level 1 only go up to 1.4 kW and are out of scope for this project.

Box 5. Charging Station Utilization

One measure of the effectiveness of station siting and the need for additional stations is the utilization percent of a charging station—the share of time a station is charging a vehicle. If a station has a low utilization, it is possible that an additional station in that location will be unnecessary.

Utilization is not the only metric to evaluate effective charging siting and, depending on the stakeholder's point of view, it may not be the most important metric. For example, some stations will not be used frequently because they are intended to facilitate travel to rural parts of the state.

However, utilization can help assess the business case for charging stations when the business model's success depends on delivering energy at an expected frequency (e.g., a pay-per-use station). For those business models to be effective, the station utilization must meet the expectations the business defined to its investors before the station was installed.

For this study, the following formula was used to separately calculate Level 2 and DC fast charging station utilization using ZIP code-level data:

$$Utilization\_Percent = \frac{Time\_Charging\_Vehicle}{Days\_in\_Month \times Expected\_Hours\_in\_Operation \times Charging\_Count}$$

Where

- *Time_Charging_Vehicle* is the number of hours the charging station is delivering power to the vehicle in a month in a ZIP code.
- *Expected_Hours_in_Operation* is eight, the number of hours a charging station could be expected to be in use in a 24-hour period assuming it is sited at a typical public location.
- *Charging_Count* is the total number of charging locations (DC fast charging) or ports (AC Level 2) that provided energy in a month in a ZIP code.

For example, 5 charging stations in Longview charged vehicles for 128 hours in May and 186 hours in June. Using the formula above, Longview had a utilization rate of 10.3 percent in May and 15 percent in June.

Charging Equipment Capabilities

An assessment of EV travel along major corridors in Washington must consider charging by location and power level, charging station density, and traffic conditions. Using maps to assess EV travel is an intuitive way to assess overall travel potential for EVs throughout the state.

Box 4. BEV Charging Time for a 50-mile Trip

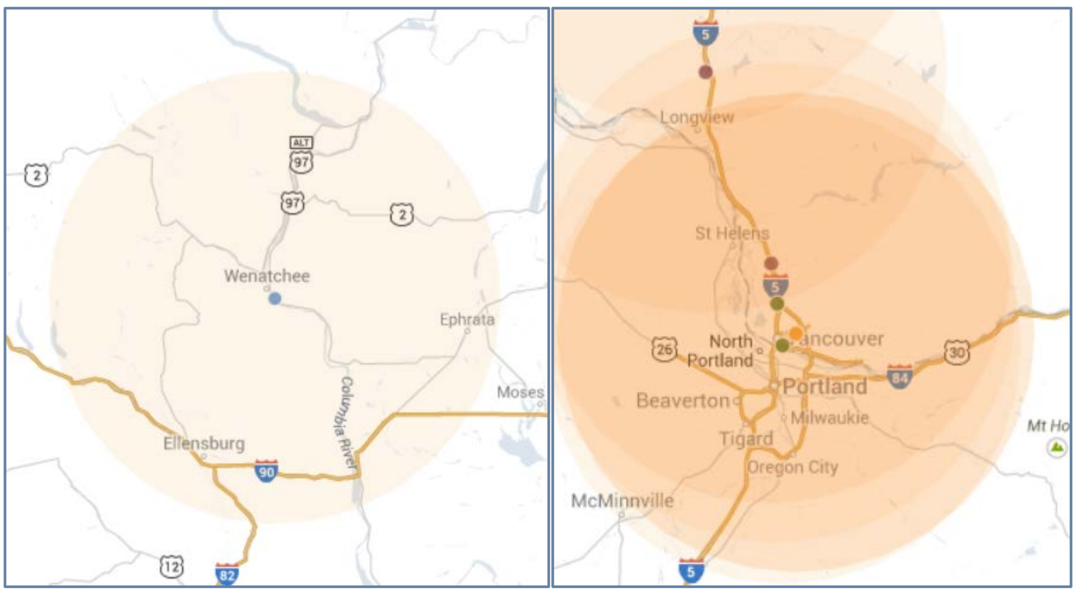
DC Fast Charging: 20 minutes at 50 kW

AC Level 2: 2.5 hours at 6.6 kW

AC Level 2: 4.5 hours at 3.3 kW

Maps can demonstrate at a glance the expected travel range of a charging location (see Figure 7). The maps created for this analysis served as a tool to assess the range of an EV that charges for a fixed period at different types of charging stations, and the risk that vehicles will not be able to access that charging location. These maps include fixed-size circles that provide an estimate of electric miles traveled following a reasonable amount of time to recharge the vehicle's battery. For DC fast charging, fixed-size circles are calculated assuming 30 minutes of charging at a conservative 30 kW. For AC Level 2 charging, fixed-size circles are calculated assuming 90 minutes of charging at 6.6 kW. Both charging levels assume 3.5 miles traveled for each kWh of battery energy stored. The resulting driving range calculations are then decreased by 20 percent to account for the lack of direct roads from an origin to a destination, yielding circles with a radius of 40 miles for DC fast charging and 28 miles for AC Level 2 charging.

FIGURE 7: Using Maps to Demonstrate Expected Travel Range of a Charging Location



These images demonstrate how fixed-size circles can convey expected travel from a charging location at a glance. The image on the left is of a single charging location (blue dot) in Wenatchee, Washington with a semi-transparent, fixed-size circle of 40 miles around the charging location. The image on the right is of five charging locations around Vancouver, Washington; each point also contains semi-transparent, fixed-sized circles of 40 miles around the charging locations. The fixed-size circles demonstrate the expected range after charging a vehicle at that location. The overlap of several locations denoted by a darker orange color indicates a greater likelihood that a charging location will be available in that area.

Source: C2ES

The circles drawn along a travel corridor provide a means of assessing charging location density and travel risk. That is, the darker the circles, the more charging locations in an area, resulting in reduced risk of individual station outages or unexpected wait times. In assessing the viability of the charging network, redundancy and reduced risk are keys to overcoming consumers' fear of exhausting the vehicle's battery energy either during the course of a trip or in additional driving required to find a station. Station outages are an important consideration in Washington, as it has experienced issues with the reliability of the Blink Network stations.[12]

As utilization of charging infrastructure increases in certain locations and charging congestion becomes an issue, drivers will face greater risk of extended trip times as they wait to charge their vehicle. Future versions of this map could account for congestion using expected utilization by altering the color or density of the circles around the charging location.

DC FAST CHARGING NETWORK ASSESSMENT

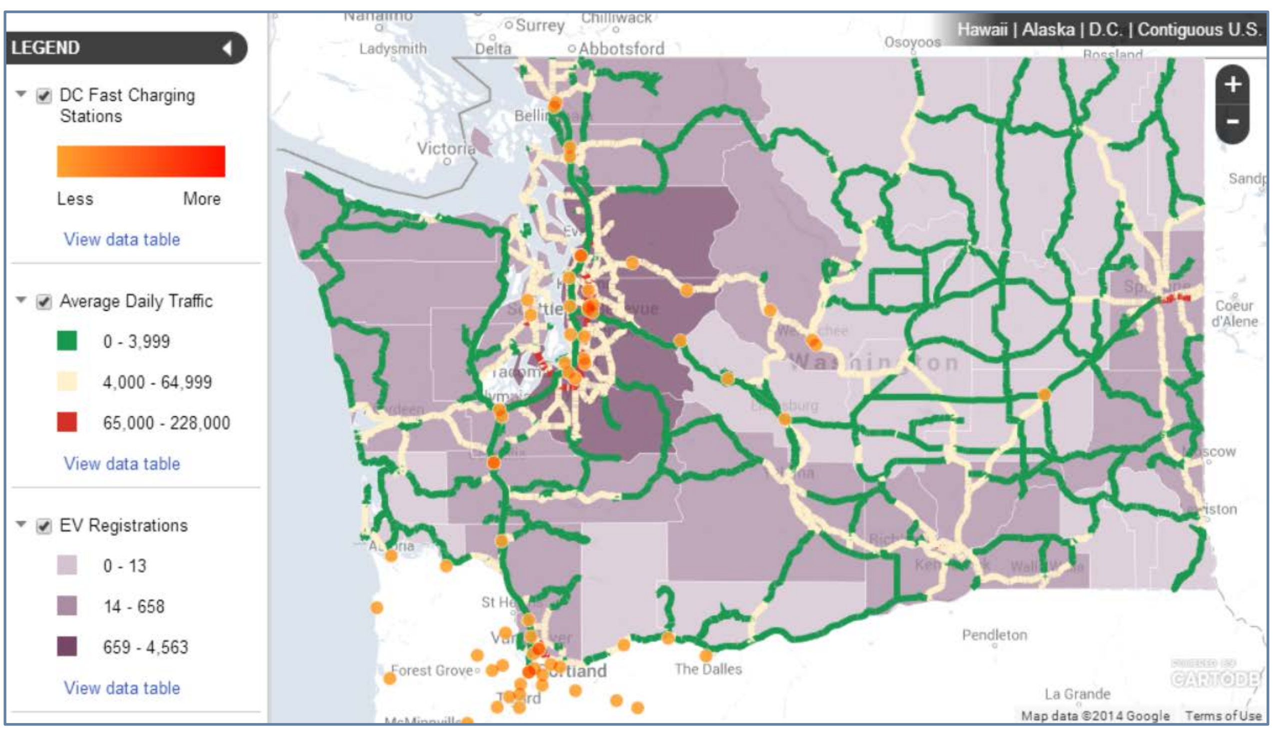
The DC fast charging network in Washington provides access to charging along much of the Interstate 5 corridor and in King County, but DC fast charging is unavailable in much of the state. Table 5 summarizes DC fast charging locations by charging network. The network consists of stations that either support the CHAdeMO standard or Tesla vehicles. As of June 2014, no DC fast charging stations existed in the state that supported the SAE Combo standard.

The Washington State Department of Transportation and Department of Commerce funded the installation of charging locations operated by the AeroVironment Network. The locations for the AeroVironment stations were picked to complement other planned DC fast charging locations around Puget Sound (operating on the Blink Network) to enable travel to more destinations in the state. Publicly available charging locations include private retail locations such as shopping malls, restaurants, and fueling stations in addition to two “gateway” safety rest areas along Interstate 5.[13]

The Blink Network was funded in part by a federal grant through the American Recovery and Reinvestment Act. As with AeroVironment charging stations, stations on the Blink Network currently support only the CHAdeMO fast charging standard. Charging locations operating on the Tesla Network can only be accessed with Tesla EVs presently.

There are currently 42 DC fast charging locations in Washington (see Figure 8).[14] Although many locations include more than one DC fast charging port, only Tesla enables more than one vehicle to charge at a time.[15] For other providers, charging is limited to the number of locations rather than the number of charging ports. This means that drivers looking to “charge and go” run the risk of having to wait for an extended period if a charging ports is occupied, since reserving access to a station can be difficult. Additionally, in cases where only one port or station is found within a county, drivers run the additional risk of the station being out of service.

Figure 8: DC Fast Charging Network Intensity Map as of June 2014



Large segments of many major roadways do not have any publicly available DC fast charging. Major roadways are denoted by green, yellow, and red colors depending on the average daily traffic in 2012.

Source: C2ES. 2014.

TABLE 5: DC Fast Charging Network Summary

COUNTY	AEROVIRONMENT NETWORK	BLINK NETWORK	CHARGEPOINT NETWORK	OTHER OR NONE	TESLA NETWORK	TOTAL LOCATIONS (PORTS)
Chelan	2 (2)					**2 (2)**
Clark	1 (1)	2 (4)	1 (1)	1 (1)		**5 (7)**
Cowlitz	1 (1)					**1 (1)**
Douglas			1 (1)			**1 (1)**
King	1 (1)	9 (18)	1 (1)	3 (3)		**14 (23)**
Kitsap		2 (4)				**2 (4)**
Kittitas	2 (2)				1 (5)	**3 (7)**
Lewis	1 (1)				1 (10)	**2 (11)**
Pierce		1 (2)	1 (1)			**2 (3)**
Skagit	1 (1)				1 (8)	**2 (9)**
Snohomish	1 (1)		1 (1)	2 (2)		**4 (4)**
Thurston	1 (1)		1 (1)			**2 (2)**
Whatcom	1 (1)			1 (1)		**2 (2)**
Total Locations (Ports)	**12 (12)**	**14 (28)**	**6 (6)**	**7 (7)**	**3 (23)**	**42 (76)**

Values in parentheses are the total number of charging ports.

Source: U.S. Department of Energy (DOE). 2014. Alternative Fuels Data Center. Accessed September 21, 2014. http://www.afdc.energy.gov.

As seen in Figure 8 and Figure 9, DC fast charging locations are concentrated in the Puget Sound region with some stations located along U.S. 2, Interstate 90, and Interstate 5. AeroVironment and Blink make up over 60 percent of the DC fast charging locations. Blink Network stations are concentrated in King County while AeroVironment Network stations are spread throughout 10 counties (see Table 5).

King County (Seattle) has the largest concentration of stations with 33 percent of total locations and 30 percent of total charging ports. The Blink Network operates nine locations, or 64 percent of the total, while three are operated by Nissan dealerships. In and around this area, the minimal distance between stations indicates that there is a high probability that an EV driver will be able to access a DC fast charging location.

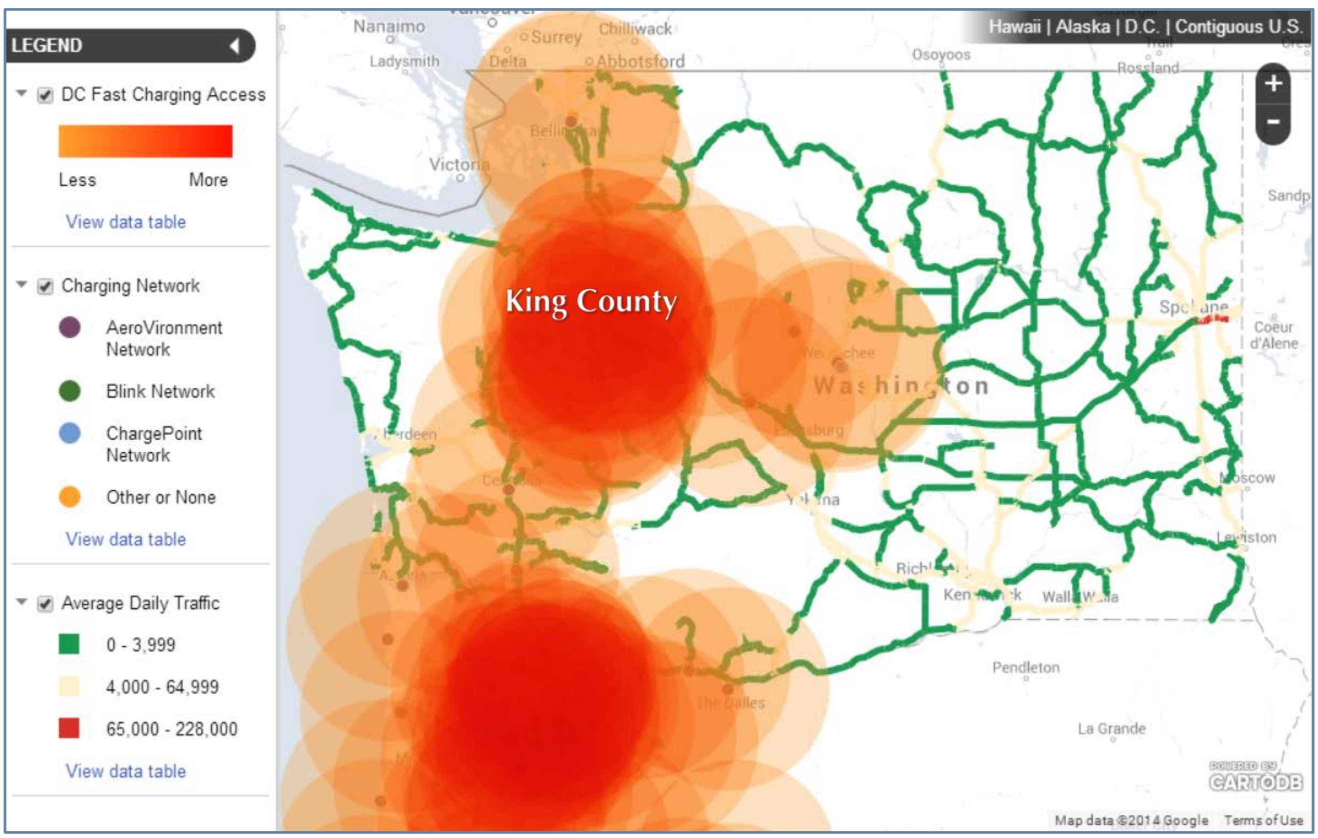
Figure 9 also shows that DC fast charging is very accessible in King County. The dark orange circles indicate significant redundancy in charging locations within the expected range of a DC fast charging station. As a result, drivers will likely have more confidence that DC fast charging station in and around King County will be available when needed, though the large number of EVs in King County could lead to wait times.

As mentioned above, the spacing of charging locations along the Interstate 5, U.S. 2, and Interstate 90 corridors was intended to enable travel from Bellingham to Vancouver (north to south along Interstate 5), Everett to

Wenatchee (west to east along U.S. 2), and Seattle to Ellensberg (west to east along Interstate 90). When traveling away from King County along Interstate 5, Interstate 90, and U.S. 2, however, the network becomes less dense, with only a single charging location connecting some portions of the roadway. The lack of redundant charging in these areas could discourage some drivers from making trips, or could prolong trips due to station outages or excessive wait times. As one travels towards the Oregon border along Interstate 5 the density of DC fast charging locations increases again, indicating DC fast charging stations are accessible in and around Vancouver.

Notably, there is very little connectivity for the DC fast charging network outside of Interstate 5 and parts of U.S. 2 and Interstate 90. Although these areas are less traveled than the roadways around Seattle on average, access to these parts of the state is an essential component to an adequate DC fast charging network. No DC fast charging exists east of Ellensberg and Wenatchee on U.S. 2 and Interstate 90, meaning east-west travel across the entire state for most BEVs is not possible. There are also no DC fast charging stations in or around Spokane. Access to the Pacific coast is also severely limited due to a lack of DC fast charging stations west of Centralia and Olympia. In addition, segments of Interstate 90, U.S. 395, Interstate 82, and Route 12 have moderate daily traffic, ranging from 6,000 to over 20,000 vehicles, but have few or no DC fast charging locations.[16]

Figure 9: DC Fast Charging Access as of June 2014



This map shows the expected electric-only range provided by DC fast charging locations. Each semi-transparent circle is 40 miles wide, the expected range provided after 30 minutes of charging. The circles' transparency provides a way to view the density of DC fast charging stations in an area.

Source: C2ES. 2014.

Box 6. DC Fast Charging Usage

Utilization helps explain how frequently a station is used and the possible need for additional stations at a location. The table below shows the top 10 locations by ZIP code in 2013, as measured in energy provided to EVs. In 4 ZIP codes, only one DC fast charging station was measured.

Further examination of frequently used stations might reveal station congestion, indicating additional charging stations may be needed at or near that location.

TABLE 6: Top 10 ZIP Codes for DC Fast Charging (January-December 2013)

ZIP CODE	COUNTY	TOTAL ENERGY DELIVERED (KWH)	AVERAGE UTILIZATION (%)	CHARGING LOCATIONS
98424	Pierce	22,622	30.6%	1
98122	King	21,087	32.2%	1
98007	King	17,297	23.9%	1
98233	Skagit	15,811	27.4%	1
98109	King	15,701	24.1%	1
98034	King	14,566	20.3%	1
98225	Whatcom	13,880	25.9%	1
98294	Snohomish	13,729	21.4%	1
98125	King	11,234	16.6%	1
98531	Lewis	8,404	18.3%	1

This table shows the most popular locations for DC fast charging for the AeroVironment and Blink Networks.

Source: Idaho National Laboratory, Washington State Department of Transportation

AC LEVEL 2 CHARGING NETWORK ASSESSMENT

The AC Level 2 charging network in Washington provides EV charging access in King County, but does not provide access in much of the rest of the state outside of Vancouver. Seventy-four percent of populated ZIP codes in the state, covering 44 percent of the population, have no Level 2 charging stations. As a result, many possible destinations for drivers may be inaccessible to BEVs.

Although Level 2 and DC fast charging complement each other, the assessment here assumes that Level 2 charging stations power all miles traveled by both BEVs and PHEVs.

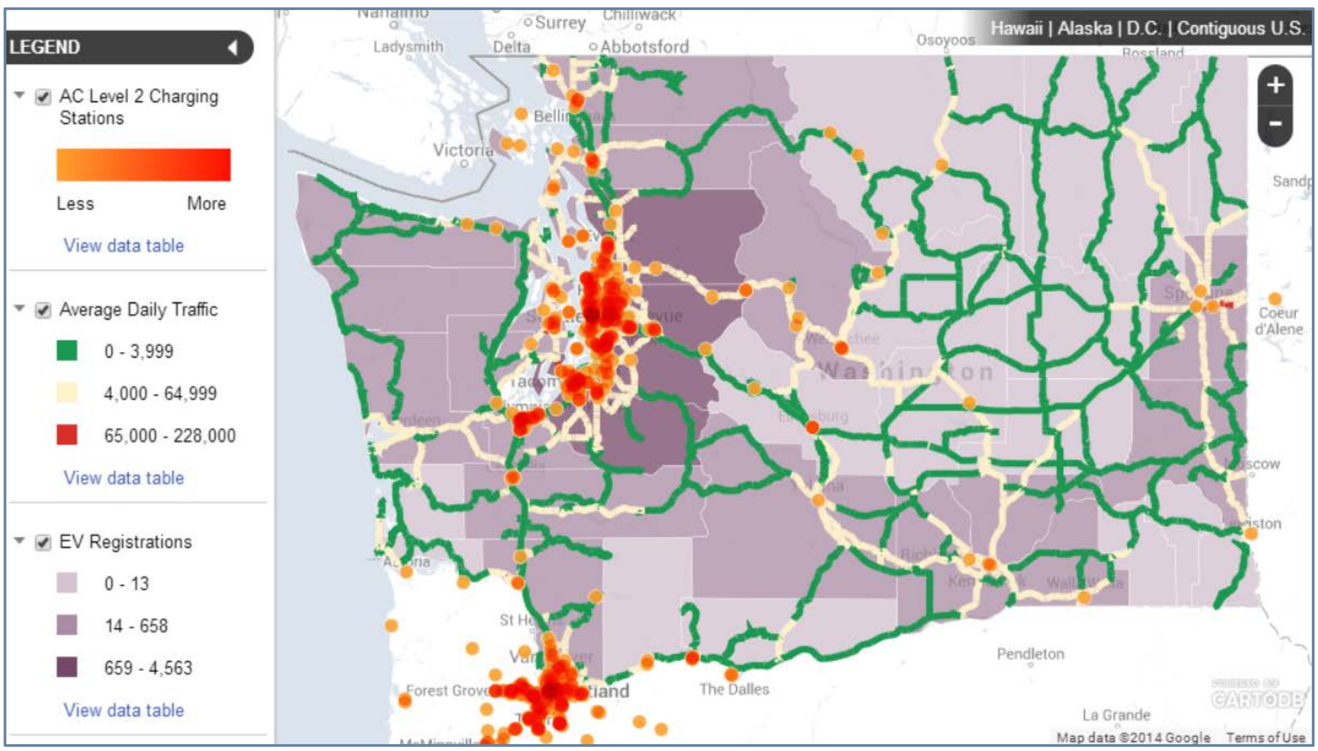
Even though Washington has one of the most extensive Level 2 charging networks in the United States, it may not be enough to accommodate the current EV fleet in the state. Studies have suggested that a Level 2 charging port can accommodate less than 3 EVs. There are 19 EVs for every Level 2 publicly available charging location or 9 EVs for every Level 2 charging ports.

Level 2 charging can play an integral role at trip destinations because Level 2 charging provides energy to an EV at a rate that requires several hours to fully recharge. Drivers are unlikely to use AC Level 2 charging stations to travel along highway corridors because of these long charging times. Instead, these charging stations are typically located in places where drivers are expected to charge for longer than an hour (e.g., shopping malls and other retail outlets, workplaces, and public parking garages). For example, Plug-in North Central Washington has a program to promote EV tourism by facilitating the installation of Level 2 charging stations at businesses throughout the region.[17]

Even though Washington has one of the most extensive Level 2 charging networks in the United States, it may not be enough to accommodate the current EV fleet in the state. There are 418 Level 2 charging locations with 893 charging ports. Unlike DC fast charging stations, most locations can charge more than one vehicle at a time. There are 19 EVs for every Level 2 publicly available charging location or 9 EVs for every Level 2 charging ports. These ratios indicate far less publicly available charging is available than studies have assumed would be necessary to provide adequate publicly available charging. For example, the National Research Council's 2013 report Transitions to Alternative Vehicles and Fuels assumed one Level 2 charging port would be needed for 2.5 EVs.[18]

The Blink and ChargePoint networks have nearly the same number of charging locations and ports, making up 36 and 35 percent of the network, respectively. AeroVironment only has 15 charging locations, which complement the DC fast charging stations installed in partnership with the Washington State Department of Transportation.

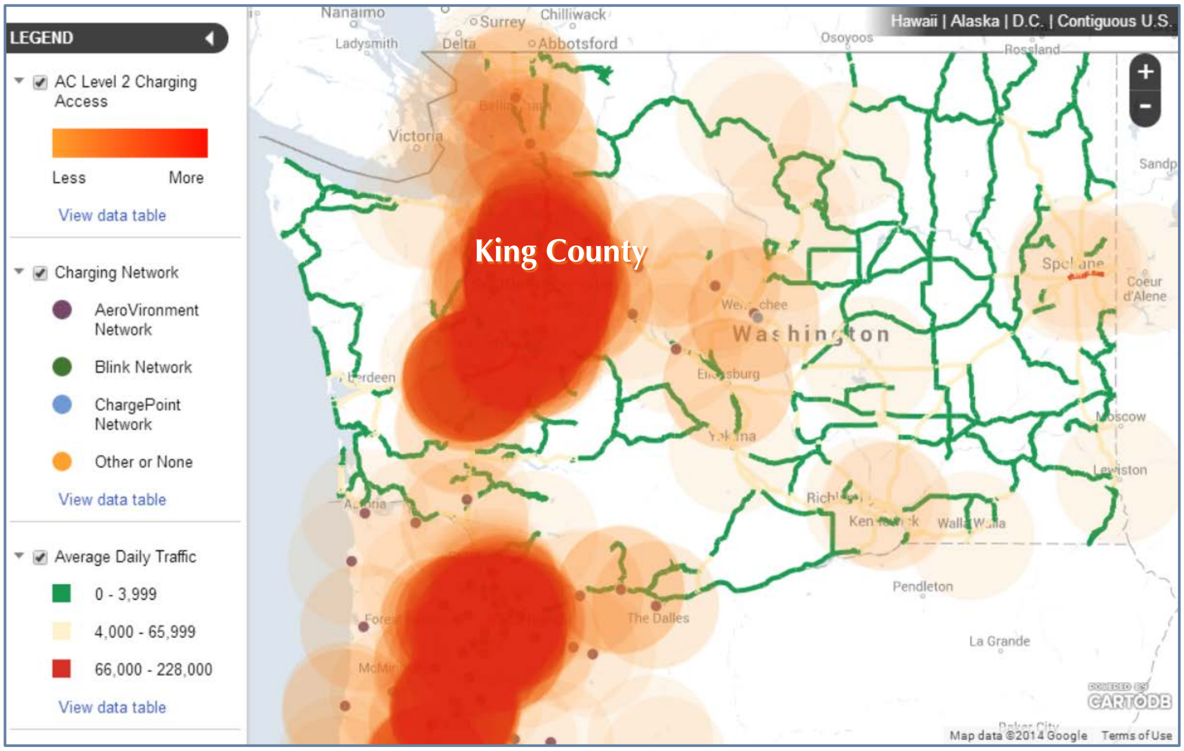
FIGURE 10: AC Level 2 Charging Network Intensity Map as of June 2014



There is a heavy concentration of charging stations in Puget Sound region with very little charging outside that area except for Vancouver, Washington. Large segments of many major roadways do not have any publicly available AC Level 2 charging. Major roadways are denoted by green, yellow, and red colors depending on the average daily traffic.

Source: C2ES. 2014.

FIGURE 11: AC Level 2 Charging Access as of June 2014



This map shows the expected electric-only range provided by AC Level 2 charging locations. Each semi-transparent circle is 28 miles wide, the expected range provided after 90 minutes of charging. The circles' transparency provides a way to view the density of AC Level 2 charging stations in an area.

Source: C2ES. 2014.

King County contains 57 percent of the Level 2 locations, but only 29 percent of total population in the state. Part of this additional charging may be explained by a 9 percent jump in population during the workday from commuters.[19] More likely, however, is the fact that 55 percent of registered EVs reside in the county. Similar to the DC fast charging network, Figure 11 shows drivers in King County have numerous access points to Level 2 charging stations. The deep orange color indicates there are redundant charging locations in the same area, improving the likelihood a driver can access a publicly available charging station. The map only conveys access, however, meaning drivers may be required to wait to charge if utilization at these stations is high.

As mentioned previously, Level 2 charging stations are typically located in places where drivers are expected to spend longer than an hour. On a daily basis, drivers typically stay close to where they live, so locating publicly available charging near where EVs are registered is sensible to extend daily travel beyond what home charging can provide. Of the populated ZIP codes in Washington with an EV registered, 59 percent do not have a Level 2 charging station. In fact, there are nine ZIP codes with more than 50 EVs registered and no Level 2 charging stations (see Table 7). All but one of those ZIP codes are in the Seattle area (see Figure 12). The ZIP code with the highest ratio of EVs to publicly available charging stations is 98053 in Redmond, with 132 EVs and only one publicly available charging station.

On occasion, EV drivers can be expected to take trips beyond the electric range near their home and charging at their destination may be required. Many locations throughout the state have no Level 2 charging stations. In counties constituting 25 percent of Washington's population, there are less than five Level 2 charging ports. EV drivers may be unable to travel to these locations.

TABLE 7: ZIP Codes with More than 50 EVs and No Public AC Level 2 Charging Stations

ZIP CODE	PRIMARY CITY	COUNTY	BEVS REGISTERED	PHEVS REGISTERED	EVS REGISTERED
98012	Bothell	Snohomish	63	36	99
98074	Sammamish	King	120	17	137
98115	Seattle	King	121	34	155
98116	Seattle	King	42	20	62
98118	Seattle	King	38	13	51
98144	Seattle	King	44	18	62
98177	Seattle	King	50	16	66
98199	Seattle	King	44	14	58
98607	Camas	Clark	39	13	52

All ZIP codes with 50 or more EVs as of December 2013 and no Level 2 charging stations.

Source: Washington State Department of Licensing, U.S. DOE. 2014.

FIGURE 12: ZIP Codes with More than 50 EVs and No Public AC Level 2 Charging Stations

All ZIP codes with 50 a more EVs as of December 2013 and no Level 2 charging stations. 98607 in Clark County is not shown.

Source: Washington State Department of Licensing, U.S. DOE. 2014.

Box 7. AC Level 2 Charging Usage

For Level 2 charging stations, utilization can be an important metric depending on the purpose of the station. For example, if the station is intended to increase retail sales by providing EV drivers a place to charge while they shop, utilization provides evidence of whether or not that goal is being met. On the other hand, charging intended to provide access to popular public attractions, such as a public park, might require less use to validate the station's installation.

Table 8 shows charging use on the ChargePoint network in 2013 for the 5 ZIP codes that provided the most energy to EVs. The utilization in all but one ZIP code was greater than 25 percent with a relatively large sample of 50 or more ports per ZIP code. Utilization rates higher than 25 percent indicate that a driver may have to wait to use a charging station.

TABLE 8: AC Level 2 Charging Use in 2013

ZIP CODE	TOTAL ENERGY DELIVERED (KWH)	AVERAGE UTILIZATION (%)	CHARGING PORTS
98075	17,223	43.7%	48
98055	19,457	28.8%	72
98033	22,207	27.8%	81
98004	51,778	22.6%	241
98101	13,329	11.5%	130

This table shows 5 ZIP codes with that have delivered the most energy from January to December 2013 in the ChargePoint network. All ZIP codes are in King County.

Source: ChargePoint

BEV TRAVEL ALONG KEY WASHINGTON STATE CORRIDORS

This section simulates travel for BEVs in four key traffic corridors in Washington, including three simulations along the heavily-traveled Interstates 5 and 90, and one simulation from the state's capital, Olympia, to the Pacific Coast. The purpose of these simulations is to evaluate an EV driver's ability to travel using the existing publicly available charging network based on practical assumptions.

Drivers in the United States generally drive less than 30 miles per day.[20] As such, daily driving needs for EV drivers can often be met with a single charge while at home or at work. However, longer trips from home requires publicly available charging infrastructure to extend the potential travel range of EVs and to reduce EV drivers' "range anxiety," which is the fear of running out of power along the road and being stranded. Adequate charging infrastructure serves to mitigate range anxiety concerns.

EV travel throughout Washington is contingent on EV battery capacity and the availability of publicly available charging stations along key travel corridors. Based on travel simulations completed, EVs with longer electric-only ranges are more likely to complete trips with the current charging infrastructure. Any BEV on the market today can make the trip along Interstate 5 from Seattle to Portland, Oregon because of the relatively high density of publicly available charging stations. However, additional charging infrastructure is needed to facilitate travel to the Pacific Coast and between the eastern and western part of the state along Interstate 90.

OVERVIEW OF TRAVEL SIMULATION

Evaluations on EV travel were completed using a combination of traffic data from the 2013 Washington Department of Transportation Annual Traffic Report and the U.S. Department of Energy's Alternative Fuel Data Center listing of publicly available charging stations as of June 2014. Travel was simulated along four routes in Washington to gauge coverage of existing publicly available charging stations for BEVs. The simulations identified:

- Whether travel was possible along these routes, using the AC Level 2 charging network or the DC fast charging network;
- Areas with high charging station density and areas with low charging station density; and
- Noticeable coverage gaps that would be critical to completing travel along the preferred routes.

The simulations examined travel along preferred routes: using I-5 to travel between Seattle and Portland, using I-5 to travel between Seattle and Bellingham, using I-90 to travel between Seattle and Spokane, and using US-101 North and South to travel between Olympia and Port Angeles.

Travel analysis of these routes are divided into thirds to better assess publicly available charging station density along portions of the route, and to identify noticeable coverage gaps along the route.

TRAVEL SIMULATION ASSUMPTIONS

The simulations used three illustrative examples of battery electric vehicles: a BEV-40 with a range up to 40 miles, a BEV-80 with a range up to 80 miles, and a BEV-200 with a range up to 200 miles. These BEVs are meant to be illustrative and are not intended to reflect current options in the marketplace. Importantly, only Tesla Motors offers a BEV with a range of 200 miles or more, so conclusions drawn in the simulations do not reflect experiences of most BEV drivers in Washington.

PHEV are not included in these simulations because they do not have the same range issues as a BEV. PHEVs have both a battery and a gasoline-powered internal combustion engine, so they do not have the same degree of dependency as BEVs on publicly available charging infrastructure. In addition, BEV adoption in Washington has outpaced PHEV adoption. There are nearly two BEVs for every one PHEV in Washington.

For travel along these routes, the BEVs followed the speed limit and started the trip with a full charge. In most instances, the BEVs charged once the battery reached about a 20 percent state of charge to account for range anxiety, and BEVs would reach the final destination with a 20 percent state of charge.[21] At each charging station, the BEVs charged only enough to make it to the next charging stop or final destination to minimize charge time.

Under these simulations, BEVs made exclusive use of either the DC fast charging network or the AC Level 2 network to recharge. In some instances, the BEV charged above 80 percent battery capacity or the BEV battery dropped below a 20 percent state of charge to travel to the next charging station. The simulations assumed DC fast charging stations had a power output of 30 kW and AC Level 2 charging stations had a power output of 6.6 kW.

For each route and vehicle type, the simulations determined the actual distance of the trip, the number of charging station stops, the minimum charge time based on the number of charging stops, and total drive time under normal traffic conditions. The total trip time was calculated as the sum of driving time and charge time.

The publicly available charging infrastructure along any route was considered adequate as long as a BEV driver could complete travel along the route relying only on the publicly available charging network.

SIMULATION 1: TRAVEL BETWEEN SEATTLE AND PORTLAND ALONG INTERSTATE 5

The route along I-5 between Seattle, Washington and Portland, Oregon was divided into three parts. The northern portion connected Seattle and Olympia, the middle portion connected Olympia and Ridgefield, and the southern portion connected Ridgefield and Portland.

Publicly available charging infrastructure is in place to complete travel between Seattle, Washington and Portland, Oregon in all simulations. The total trip time along the preferred route was longer for BEVs than a gasoline-powered vehicle because of the time required to charge the vehicle (see Table 9). A fully fueled gasoline-powered vehicle would take 3 hours to travel 175 miles on I-5 between Seattle and Portland. The total trip time for BEVs using the DC fast charging network ranged from 3 to 4.5 hours, and the charge time ranges from 4 to 33 percent of total time. This trip was 20 minutes to 1.5 hours longer than a trip made with a gasoline-powered vehicle. The total trip time for EVs using the Level 2 network ranged from 8 to 9.5 hours, and the charge time ranged from 4 percent to two-thirds of total drive time. The total trip was 50 minutes to 6.5 hours longer than a trip made with a gasoline-powered vehicle.

The high concentration of publicly available charging locations along the upper and lower portion of the route enable BEVs to easily travel along these portions of the route. There are 12 DC fast charging locations and 207 Level 2 charging locations in and around Seattle, and there are 5 DC fast charging locations and 20 Level 2 charging locations in and around Vancouver. All BEVs in the simulations were able to travel the upper and lower portions of the route without the vehicles' battery dropping below a 20 percent state of charge.

The low number of publicly available charging locations in the middle portion of the route makes existing charging locations critical to completing the trip. There are 2 DC fast charging locations and 6 Level 2 charging locations along the middle portion of the route. As such, travel along this route for the BEV-40 and the BEV-80 was dependent on charging locations located in Castle Rock and Ridgefield, see Figure 13.

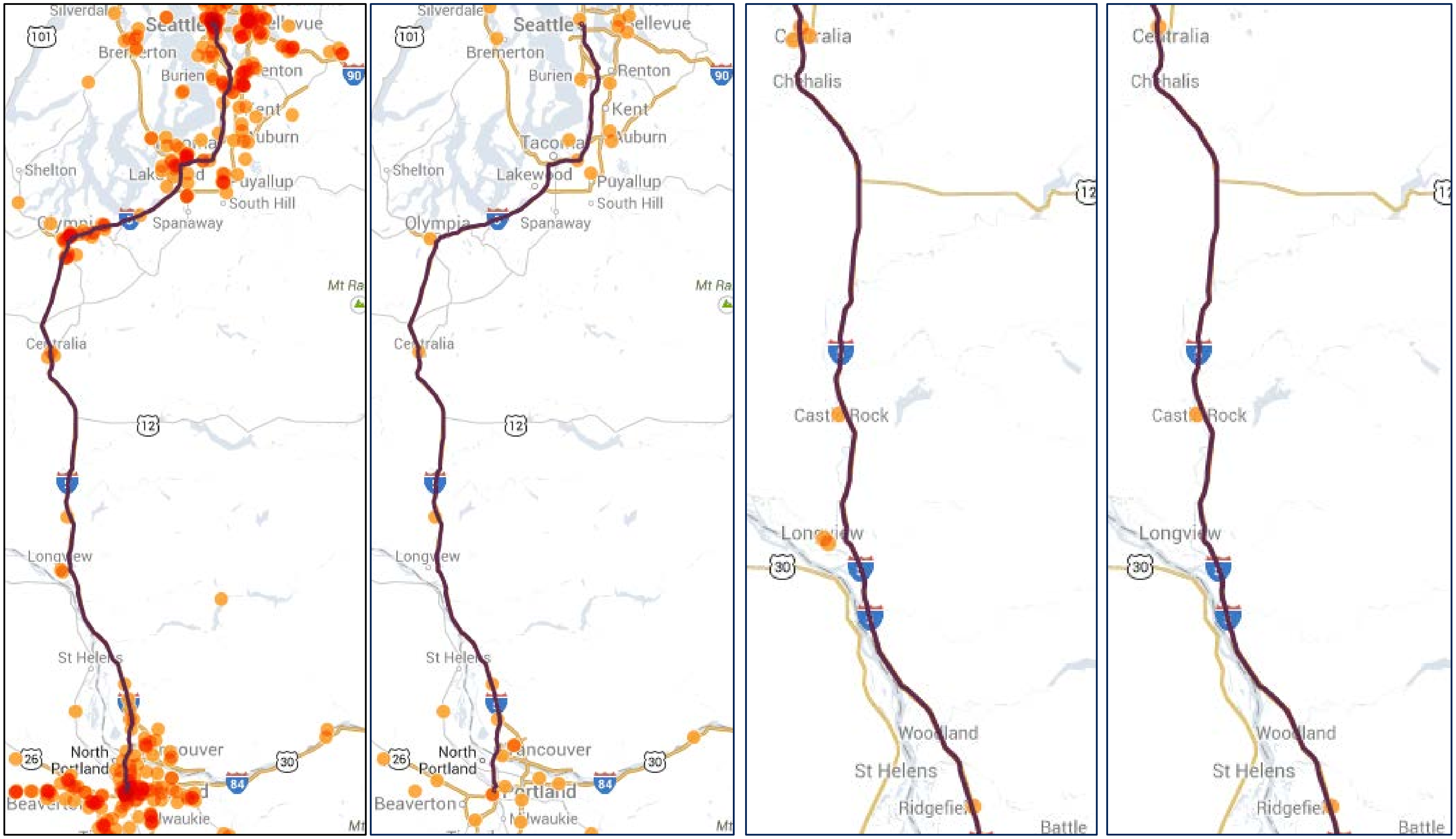
Travel between these two cities resulted in the BEV-40 dropping to a 10 percent state of charge. Installing additional Level 2 charging locations between these two cities would allow the BEV-40 to travel this portion of the route and not drop below a 20 percent charge level. There is one DC fast charging station between Centralia and Ridgefield—located in Castle Rock—which was a critical stop for the BEV-80 to complete the trip. Installing additional DC fast charging locations between Centralia and Ridgefield would alleviate dependency on the one Castle Rock publicly available charging station for BEV-80 travel. The BEV-200 only needed to make one charging stop and is not reliant on publicly available charging locations in the southern portion of the route.

TABLE 9: Travel between Seattle, Washington and Portland, Oregon

CHARGING TYPE	VEHICLE	MILES TRAVELED	CHARGING STOPS	DRIVE TIME (MIN)	CHARGE TIME (MIN)	TOTAL TIME (MIN)
N/A	Gasoline Powered	173	N/A	170	N/A	170
DC Fast Charging	BEV-40	178	5	184	83	267
DC Fast Charging	BEV-80	175	2	184	64	248
DC Fast Charging	BEV-200	174	1	184	8	192
AC Level 2	BEV-40	179	4	188	381	569
AC Level 2	BEV-80	178	2	178	288	466
AC Level 2	BEV-200	174	1	184	37	221

Total trip time was longer for BEVs versus a gasoline-powered vehicle because of charging time. BEVs with a larger battery capacity had to make fewer charging stops and generally spent less time charging. All BEVs simulated were able to complete travel between Seattle, Washington and Portland, Oregon.

FIGURE 13: Publicly Available Charging Locations between Seattle and Portland and between Centralia and Ridgefield



The figures on the left show existing AC Level 2 and DC fast charging locations, respectively, between Seattle and Portland. The figures on the right shows existing AC Level 2 and DC fast charging locations, respectively, between Centralia and Ridgefield.

SIMULATION 2: TRAVEL BETWEEN SEATTLE AND BELLINGHAM ALONG INTERSTATE 5

The route along I-5 between Seattle and Bellingham was divided into three parts. The northern portion connected Bellingham and Burlington, the middle portion connected Burlington and Everett, and the southern portion connected Seattle and Everett.

Publicly available charging infrastructure is in place to complete travel between Seattle and Bellingham in all but one simulation. The total trip time along the preferred route was longer for BEVs than a gasoline-powered vehicle because of the time required to charge the vehicle (see Table 10). A fully fueled gasoline-powered vehicle would take 1.5 hours to travel 90 miles on I-5 between Seattle and Bellingham. The BEV-40 would not be able to complete travel along the preferred route using the existing DC fast charging network. The total trip time for the BEV-80 and BEV-200 using the DC fast charging network ranged from 1.5 to 2.8 hours, and the charge time was up to 15 percent of the total drive time. For a BEV, this trip could be up to 15 minutes longer than a trip made with a gasoline-powered vehicle. The total trip time for BEVs using the Level 2 network ranged from 1.5 to 4 hours, and the charge time ranged from 40 to 60 percent of total drive time. The trip was 2.3 to 2.5 hours longer than a trip made with a gasoline-powered vehicle.

The high concentration of publicly available charging locations in the southern portion of the route enables BEVs to easily travel along this portion of the route. There are 12 DC fast charging locations and 210 Level 2 charging locations in and around Seattle, and there are 2 DC fast charging locations and 2 Level 2 charging locations in and around Burlington. All BEVs in the simulations were able to travel the lower portion of the route without the vehicles' battery dropping below a 20 percent state of charge.

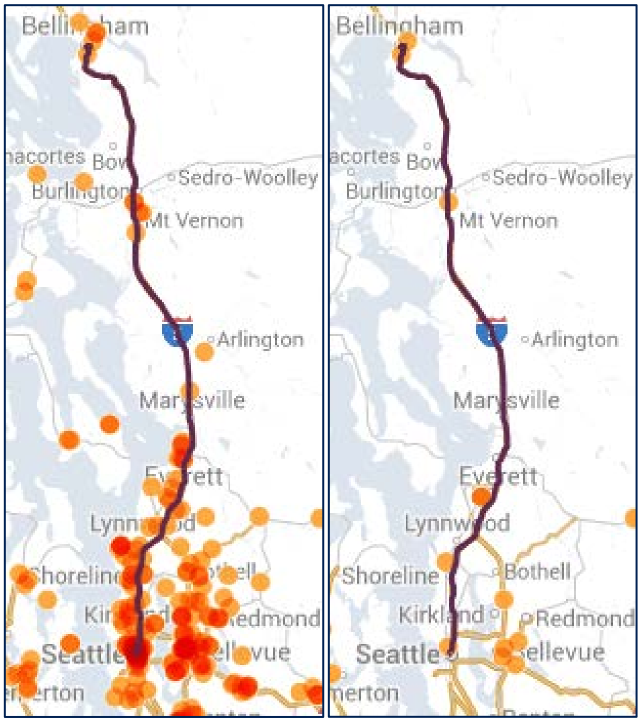
The low number of publicly available charging locations located in the middle and northern portion of the route makes the charging stations located in the southern portion of the route critical to completing the trip. There are 2 DC fast charging stations and 5 Level 2 charging stations along the middle and northern portion of the route. The BEV-80 was able to complete this trip using the DC fast charging network as long as it charges between Burlington and Seattle. Conversely, the BEV-40 was unable to complete the trip because the distance between the Burlington and Everett DC fast charging station was greater than the vehicle's range. Installing additional DC fast charging locations between these two cities would allow the BEV-40 to complete travel along this route. There are an adequate number of Level 2 charging locations for the BEV-40 and BEV-80 to complete travel. However, installing additional Level 2 charging locations between Burlington and Everett would allow the BEV-40 to make one less charging stop along this route. The BEV-200 would not need to make a charging stop when traveling the preferred route.

TABLE 10: Travel between Seattle and Bellingham

CHARGING TYPE	VEHICLE	MILES TRAVELED	NUMBER OF CHARGING STOPS	DRIVE TIME (MIN)	CHARGE TIME (MIN)	TOTAL TIME (MIN)
N/A	Gasoline Powered	89	N/A	90	N/A	90
DC Fast Charging	BEV-40	X	X	X	X	X
DC Fast Charging	BEV-80	89	1	89	14	103
DC Fast Charging	BEV-200	89	0	90	0	90
AC Level 2	BEV-40	90	3	94	152	246
AC Level 2	BEV-80	90	1	93	68	161
AC Level 2	BEV-200	89	0	90	0	90

Total trip time was longer for BEVs versus a gasoline-powered vehicle because of charging time. BEVs with a larger battery capacity had to make fewer charging stops and spent less time charging. Most of the BEVs were able to complete travel between Seattle and Portland. The BEV-40 was unable to complete the trip due to a lack of publicly available charging locations, and is denoted with an "X."

FIGURE 14: Publicly Available Charging Locations between Seattle and Bellingham



The figure on the left shows existing AC Level 2 charging locations while the figure on the right shows existing DC fast charging locations.

SIMULATION 3: TRAVEL BETWEEN SEATTLE AND SPOKANE ALONG INTERSTATE 90

The route along I-90 between Seattle and Spokane was divided into three parts. The eastern portion connected Spokane and Moses Lake, the middle portion connected Moses Lake and Cle Elum, and the western portion connected Cle Elum and Seattle.

Existing publicly available charging infrastructure only allows a BEV-200 to complete travel between Seattle and Spokane. The BEV-40 and the BEV-80 were unable to complete travel between these two cities using the Level 2 network or DC fast charge network. The BEV-200 was able to complete travel between Seattle and Spokane. The total trip time along the preferred route is longer for the BEV-200 than a gasoline-powered vehicle because of the time required to charge the vehicle (see Table 11). A fully fueled gasoline-powered vehicle would take 4.3 hours to travel 280 miles on I-90 between Seattle and Spokane. The total trip time for the BEV-200 using the DC fast charging network was 5.5 hours, and the charge time was 20 percent of the total drive time. The trip time was 1.3 hours longer than a trip made with a gasoline powered vehicle. The total trip time for the BEV-200 using the Level 2 network was 9.5 hours, and the charge time was 55 percent of the total drive time. The trip time was 5.3 hours longer than a trip made with a gasoline-powered vehicle.

The high concentration of publicly available charging locations along the western portion of the route enables BEVs to easily travel along this portion of the route. There are 12 DC fast charging locations and 210 Level 2 charging locations in and around Seattle. All BEVs in the simulations were able to travel the western portion of the route without the vehicles' battery reaching a 20 percent state of charge.

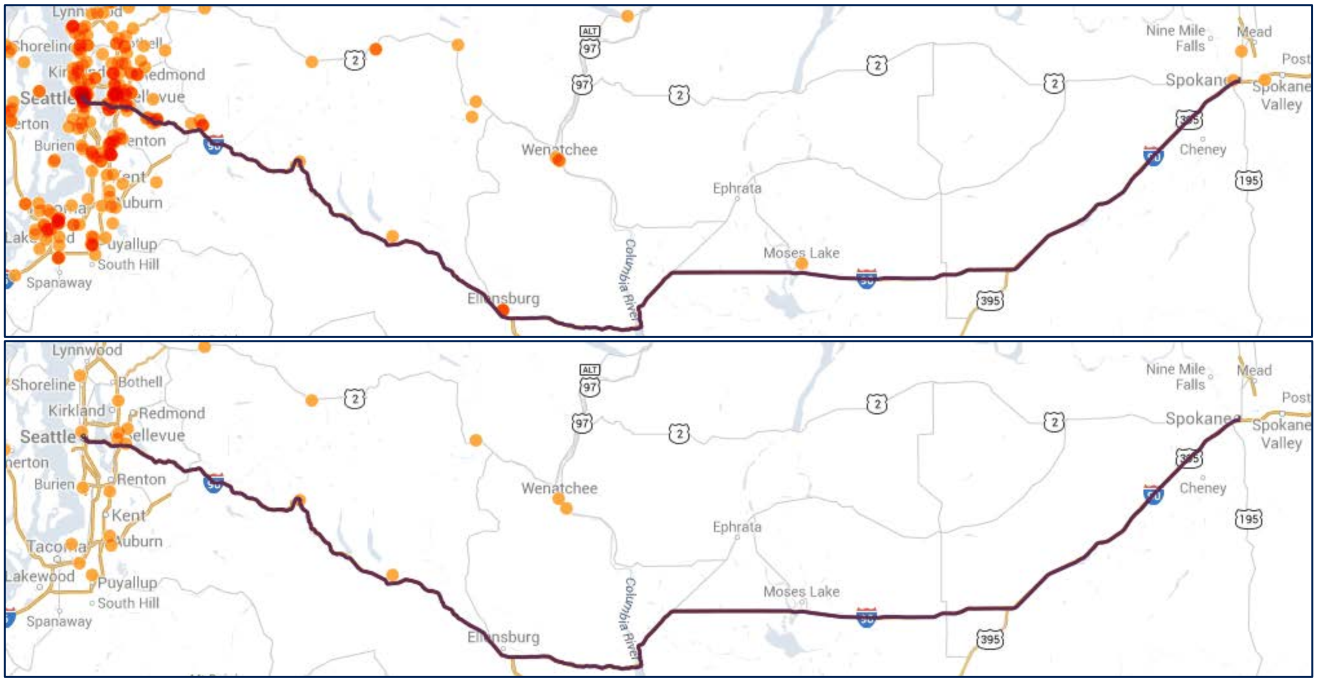
The low number of publicly available charging locations in the middle and eastern portion of the route prevents the BEV-40 and BEV-80 from completing the trip. There are 2 DC fast charging locations and 6 Level 2 charging locations along the middle and eastern portion of the route. There are no DC fast charging locations between Ellensburg and Spokane, and there are no Level 2 charging locations between Moses Lake and Spokane. Installing at least 6 DC fast charging locations and 6 Level 2 charging locations between Ellensburg and Spokane would allow the BEV-40 and BEV-80 to travel between Seattle and Spokane and not drop below a 20 percent charge level. The BEV-200 needed to make one charging stop and was only reliant on publicly available charging locations in Ellensburg to travel between Seattle and Spokane.

TABLE 11: Travel between Seattle and Spokane

CHARGING TYPE	VEHICLE	MILES TRAVELED	NUMBER OF CHARGING STOPS	DRIVE TIME (MIN)	CHARGE TIME (MIN)	TOTAL TIME (MIN)
N/A	Gasoline Powered	279	N/A	254	N/A	254
DC Fast Charging	BEV-40	X	X	X	X	X
DC Fast Charging	BEV-80	X	X	X	X	X
DC Fast Charging	BEV-200	282	2	254	68	322
AC Level 2	BEV-40	X	X	X	X	X
AC Level 2	BEV-80	X	X	X	X	X
AC Level 2	BEV-200	282	2	254	318	572

The BEV-200 was able to complete travel along this route. Total trip time was longer for the BEV-200 versus a gasoline-powered vehicle because of charging time. The BEV-40 and BEV-80 were unable to complete travel between Seattle and Spokane due to a lack of publicly available charging locations, and is denoted with an "X."

FIGURE 15: Publicly Available Charging Locations between Seattle and Spokane



The figure on the top shows existing AC Level 2 charging locations while the figure on the bottom shows existing DC fast charging locations.

SIMULATION 4: TRAVEL BETWEEN OLYMPIA AND PORT ANGELES ALONG U.S. 101 NORTH

The route along US-101 North and South between Olympia and Port Angeles was divided into three parts. The northern portion connected Port Angeles and Sequim, the middle portion connected Sequim and Shelton, and the southern portion connected Shelton and Olympia.

Existing publicly available charging infrastructure only allows a BEV-200 to complete travel between Olympia and Port Angeles. The BEV-40 and the BEV-80 were unable to complete travel between these two cities using the Level 2 network or DC fast charge network (see Table 12). The BEV-200 was able to complete travel between Olympia and Port Angeles. The total trip time along the preferred route was equivalent for the BEV-200 and a gasoline-powered vehicle because the BEV-200 did not have to charge along the preferred route. Both the BEV-200 and a fully fueled gasoline-powered vehicle would take 2.3 hours to travel 140 miles along US-101 North between Olympia and Port Angeles.

There is a higher concentration of publicly available charging locations in the southern portion of the route versus the middle and northern portions of the route, though additional charging locations are needed for a BEV-40 and BEV-80 to complete the trip. There are 2 DC fast charging locations and 30 Level 2 charging locations in and around Olympia, and there are no DC fast charging locations and 2 Level 2 charging locations in and around Port Angeles.

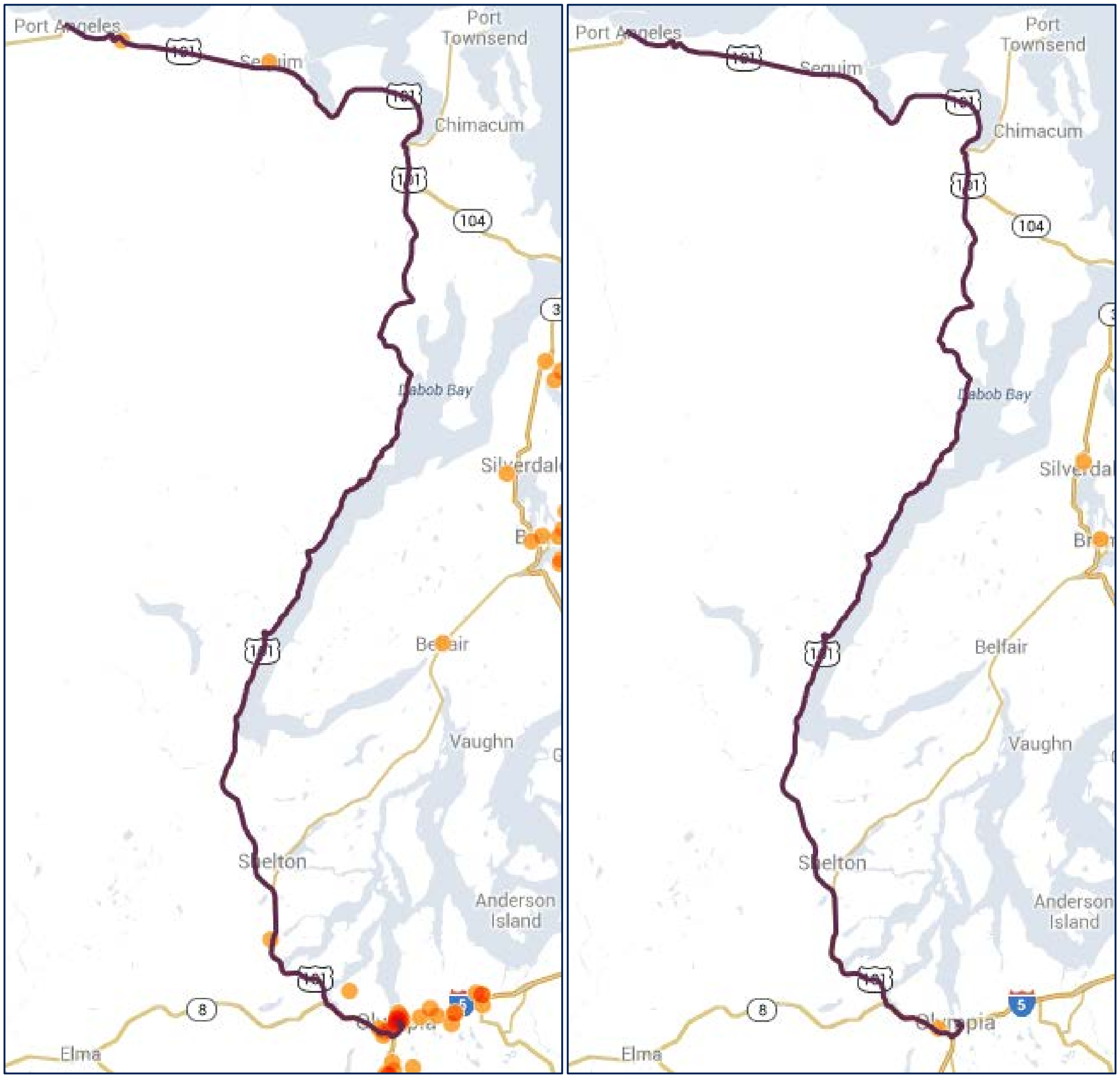
Additional publicly available charging locations in the upper and middle portion of the route are needed to facilitate travel for the BEV-40 and the BEV-80 using US-101 North and South. The BEV-200 did not need to make a charging stop along the preferred route.

TABLE 12: Travel between Olympia and Port Angeles

CHARGING TYPE	VEHICLE	MILES TRAVELED	NUMBER OF CHARGING STOPS	DRIVE TIME (MIN)	CHARGE TIME (MIN)	TOTAL TIME (MIN)
N/A	Gasoline Powered	120	N/A	137	N/A	137
DC Fast Charging	BEV-40	X	X	X	X	X
DC Fast Charging	BEV-80	X	X	X	X	X
DC Fast Charging	BEV-200	120	0	137	0	137
AC Level 2	BEV-40	X	X	X	X	X
AC Level 2	BEV-80	X	X	X	X	X
AC Level 2	BEV-200	120	0	137	0	137

The BEV-200 was able to complete travel along this route. Total trip time was the same for the BEV-200 versus a gasoline-powered vehicle because it did not have to charge. The BEV-40 and BEV-80 were unable to complete travel between Seattle and Spokane due to lack of publicly available charging locations, and is denoted with an "X."

FIGURE 16: Publicly Available Charging Locations between Olympia and Port Angeles



The figure on the top shows existing AC Level 2 charging locations while the figure on the bottom shows existing DC fast charging locations.

CONCLUSIONS AND NEXT STEPS

Although Washington's EV network is ahead of most other states in the United States, many parts of the state remain inaccessible to EV drivers who rely on publicly available charging locations. As shown in the third travel simulation, for example, a lack of publicly available charging makes it impossible for most BEVs to travel between Seattle and Spokane. Widespread adoption of EVs depends in part on a robust publicly available charging network. Access to charging that enables EV drivers to travel desired destinations in a reasonable amount of time is essential for EVs to compete with gasoline-powered vehicles on a mass scale.

Washington has a disproportionate number of BEVs compared to PHEVs relative to the rest of the United States, indicating the state's charging network may be more dependent on high-powered charging to meet drivers' travel needs. The largest concentration of EVs is in King County, which corresponds well with the density of charging locations.

This assessment of the charging network's ability to facilitate EV travel in Washington is a first step in identifying business models that will foster private sector commercialization of EV charging services. Washington's network of EV charging consists of DC fast charging and AC Level 2 charging locations. These charging technologies can complement each other to enable EV drivers to complete daily travel needs along with occasional trips that require charging while in route.

DC fast charging is concentrated along the Interstate 5 corridor with little connectivity to other major roadways. AC Level 2 charging is mostly located in King County and near Vancouver, Washington. More publicly available charging is needed outside these regions to enable access to popular destinations, like the Pacific Coast, and to link major traffic corridors of the state, like Interstate 90.

Quantifying the success of charging station siting can be difficult because the motivation for a charging station may be to enable access to distant locations rather than delivering a significant amount of energy to EVs. At the same time, some business models for publicly available charging rely on frequent use in order to be profitable. Whether revenue comes directly from station use or indirectly from increased retail sales or other sources, more capital investment from the private sector is needed to provide adequate access to publicly available charging stations and continue to advance EV adoption.

The next step in this project is to identify and assess potential business models that could be deployed to provide access to publicly available charging in regions around Washington that currently have insufficient access to charging. A final report will then be delivered to the Washington State Legislature identifying recommendations on the role of the public sector in supporting those business models in order to maximize private sector investment in EV charging.

APPENDIX A: DATA SOURCES

The following summarizes the data sources used throughout this document. Publicly available data are noted.

Publicly Available Charging Station Network Locations: The U.S. Department of Energy's Alternative Fuel Data Center provided a database of all charging locations throughout the United States. The dataset is updated monthly. Source: http://www.afdc.energy.gov.

Washington State Average Daily Traffic: Washington State Department of Transportation provided detailed data on the average daily traffic for all major roads in the state. Source: http://www.wsdot.wa.gov/mapsdata/tools/traffictrends.

ChargePoint Network: ChargePoint provided monthly usage data for all its publicly available charging locations in Washington from January 2011 to June 2014.

AeroVironment Network: Washington State Department of Transportation provided monthly usage data for DC fast charging stations operated on the AeroVironment Network from January 2011 to December 2013.

Vehicle Registrations: Washington State Department of Licensing provided monthly data for vehicle registrations, including battery electric and plug-in hybrid electric vehicles from January 2011 to December 2013.

EV Project and ChargePoint America: The U.S. Department of Energy Clean Cities Program and Idaho National Laboratory provided ZIP code level data for AC Level 2 and DC fast charging stations for the federally funded initiative called the EV Project operated on the Blink Network. The period covered by these data is January 2011 through December 2013.

ENDNOTES

[1] Only Vermont, Hawaii, and Oregon have a higher ratio of charging locations to people. U.S. DOE, AFDC website. U.S. Census Bureau.

[2] Sarah Dougherty and Nick Nigro. 2014. *Alternative Fuel Vehicle and Fueling Infrastructure Deployment Barriers and The Potential Role of Private Sector Financial Solutions,* Center for Climate and Energy Solutions, Arlington, VA (April), available at http://www.c2es.org/docUploads/barriers-to-private-finance-in-afvs-final-12-20-13.pdf.

[3] In June 2014, Connecticut regulators approved a pilot project for Connecticut Light and Power to address electricity demand charges for DC fast charging stations. See http://www.transmissionhub.com/articles/2014/06/connecticut-regulators-approve-electric-vehicle-rate-rider-pilot-for-cl-p.html.

[4] U.S. EIA. 2014. Washington Electricity Profile. Accessed September 22, 2014. http://www.eia.gov/state/rankings/?sid=WA#series/31. Chelan County Public Utility District. 2012. Rates and Policies. Accessed September 21, 2014. http://www.chelanpud.org/rates.html.

[5] C2ES. 2014. "Electric Vehicle (EV) and Market Technology Overview." EV Study Advisory Panel Meeting #1. Olympia, Washington: Center for Climate and Energy Solutions.

[6] C2ES. 2012. "An Action Plan to Integrate Plug-in Electric Vehicles with the U.S. Electrical Grid." Center for Climate and Energy Solutions. March. Accessed December 4, 2013. http://www.c2es.org/initiatives/pev/action-plan-report.

[7] Williams, Juliana, and Ann Rendahl, interview by Nick Nigro. 2014. Conversation about Washington Electric Utility Regulation (July 15).

[8] National Research Council. 2013. Transitions to Alternative Vehicles and Fuels. Washington, DC: National Academies

Press. http://www.nap.edu/catalog.php?record_id=18264.

[9] General Motors Alex Keros, EV Roadmap 7, July 24, 2014. https://www.evroadmapconference.com/program/

[10] Wall Street Journal. 2014. Atlanta's Incentives Lift Electric Car Sales. June 4. Accessed September 21, 2014. http://online.wsj.com/articles/why-electric-cars-click-for-atlanta-1401922534.

[11] Only Vermont, Hawaii, and Oregon have a higher ratio of charging locations to people. U.S. DOE, AFDC website. U.S. Census Bureau.

[12] InsideEVs. 2014. Blinkless in Seattle. July 31. Accessed September 21, 2014. http://insideevs.com/blinkless-seattle/#comment-499326.

[13] Doyle, Jeff, interview by Nick Nigro. 2014. Conversation about the West Coast Electric Highway (July).

[14] U.S. DOE. 2014. Alternative Fuels Data Center. Accessed September 21, 2014. http://www.afdc.energy.gov.

[15] Buell, Tonia, interview by Nick Nigro. 2014. Conversation about the West Coast Electric Highway (July).

[16] C2ES. 2014. DC Fast Charging in Washington State. August. Accessed September 21, 2014. http://www.c2es.org/initiatives/alternative-fuel-vehicle-finance/maps/wa-dc-fast-charging-network.

[17] Plug-in North Central Washington. 2014. High Amperage Level 2 Charging Network. Accessed September 21, 2014. http://www.pluginncw.com/high-amperage-level-2-charging-network.

[18] National Research Council. 2013. Transitions to Alternative Vehicles and Fuels. Washington, DC: National Academies Press. http://www.nap.edu/catalog.php?record_id=18264.

[19] U.S. Census Bureau. 2011. Commuting (Journey to Work). Accessed September 21, 2014. http://www.census.gov/hhes/commuting/data/acs2006_2010.html.

[20] Federal Highway Administration. 2011. Summary of Travel Trends: 2009 National Household Travel Survey. Washington, DC: Federal Highway Administration. Accessed September 21, 2014. http://nhts.ornl.gov/2009/pub/stt.pdf.

[21] The 20 percent charge level varies by battery capacity. At 20 percent capacity, C2ES assumes the driver will look for a publicly available charging station within about 6 percent of battery capacity.

C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

The Center for Climate and Energy Solutions (C2ES) is an independent nonprofit organization working to promote practical, effective policies and actions to address the twin challenges of energy and climate change.

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