CENTER FOR CLIMATE
AND ENERGY SOLUTIONS

ASSESSING THE EV CHARGING NETWORK IN WASHINGTON STATE

Introduction

This paper offers an assessment of the existing electric vehicle (EV) public charging network in Washington State. The paper is part of a project on expanding the role of private sector investment in publicly available EV charging throughout Washington (see Box 1). It begins with an introduction to the challenges faced with investing in charging infrastructure. Next is an assessment of the existing infrastructure's ability to enable electric travel throughout the state. Specific travel corridors are than examined using trip simulations. 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 is working with C2ES and others 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

More information is available at www.c2es.org/TBD.

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 public EV charging to date, greater private investment will be needed to ensure adequate access to public charging to continue to advance EV adoption. However, it is currently challenging to construct a profitable business case for public EV charging investments for several reasons.

On the cost side, EV charging business models face capital cost, financing cost, and operating cost barriers. Deploying a charging station requires an upfront capital investment for equipment and installation, which ranges from $500 to $5,000 for a Level 2 charging station or $50,000 to $150,000 for a DC fast-charging station (see Box 2).[1] If nascent technologies and standards change, EV charging projects will require additional capital infusions to fund station retrofits. Access to 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 costs associated with powering DC fast chargers or sites with multiple Level 2 chargers.

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

TBD

On the revenue side, charging station investors face the headwinds of low and uncertain near-term demand for public charging as well as limited consumer willingness to pay for public charging due to competition with relatively inexpensive residential electricity. In Washington State, residential electricity prices averaged only $0.08 per kilowatt-hour in April 2014 and residential rates were as low as $0.03 per kilowatt-hour.[2] In addition, the potential for charging stations to capture other types of indirect revenue—such as increased retail sales near public chargers—from charging stations is uncertain and not well recognized.

Models of EV infrastructure deployment and value capture

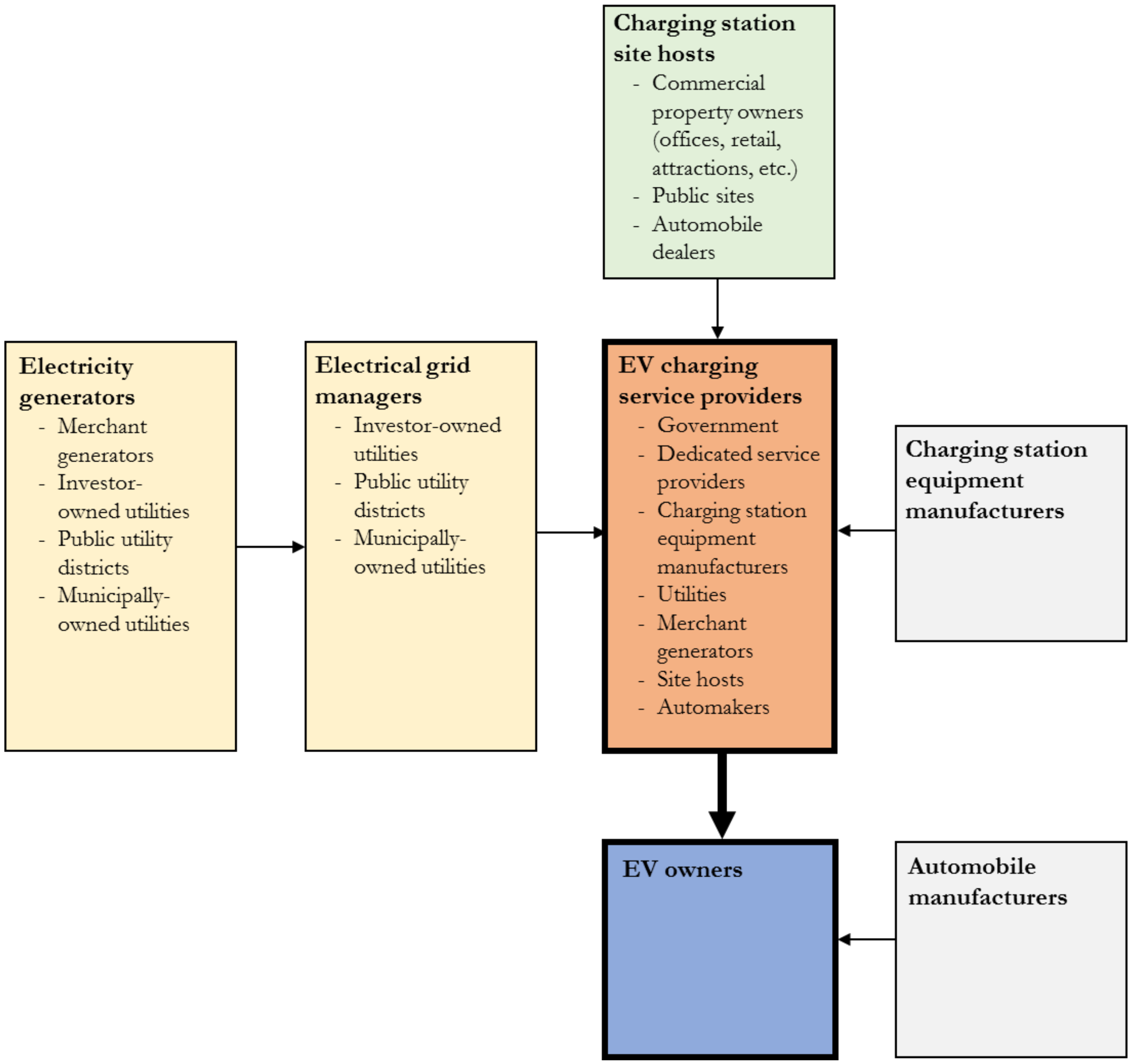
In order to understand and evaluate the range of potential deployment models for EV charging services, four primary questions must be considered:

1. *What must be provided in an EV charging network?*

While this effort 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, which are depicted in Figure 5. Installation sites are needed to deploy EV charging stations. Electricity generation, transmission, and distribution are needed to supply electricity to EV charging sites. Charging station equipment must be manufactured and purchased by an EV charging service provider. EVs must be manufactured and purchased by drivers. While each of these roles are essential, several of these roles—in particular the role of the EV charging service provider—could be played by multiple types of stakeholders.

Figure 1: Public EV charging network roles and flows of products and services

Roles needed to support a public 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.



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

A range of entities could potentially provide EV charging services, including: (a) dedicated charging service companies, (b) charging equipment manufacturers, (c) property owners acting as site hosts, (d) automakers, (e) electric utilities, and (f) electricity generators, and (g) state and local governments.

These stakeholders differ in their potential interests in and concerns about EV charging deployment. The opportunities of EV charging deployment from the perspective of each stakeholder are presented in Table 1 and the challenges are presented in Table 2.

Table 1: Opportunities presented by EV charging deployment from the perspective of stakeholders

For each stakeholder (columns), opportunities (rows) 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.

	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							
Economic development from EV and charger use	X	X						X
Increased revenue from electricity use		X	X					
More efficient use of off-peak generation capacity	X	X	X					
Long-term prospect of V2B and V2G grid benefits	X	X	X		X			X
Greater EV sales							X	
Sales of EV charging equipment						X		
Increased retail sales from offering charging on site								X
Charging network support services		X	X		X			X

Table 2: Challenges presented by EV charging deployment from the perspective of stakeholders

For each stakeholder (columns), challenges (rows) 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.

	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-grid or vehicle-to-building technology could reduce demand for grid electricity		X	X	X				
Financial sustainability of charging station investment	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	

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 governments, the social benefits of EV charging deployment may also be considered.

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

EV charging stations may also generate additional types of ancillary 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 the bear the costs of offering charging services based on the value of these ancillary revenue streams.

In addition to the monetary value of charging services, state and local governments and public utilities may consider the indirect value of the social benefits associated with increased EV deployment, including public health, environmental, economic development, and energy security benefits. 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 capital costs (equipment and installation) and operating costs (electricity, maintenance, and supporting services).

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 also 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.

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 or electric utility ratepayer funds. Charging station subsidies could take the form of grants, rebates, tax credits, or low-cost lending programs. Notably, such programs in Washington State 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 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.

The Washington EV Market

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 State 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.[3] Figure 2 shows the national EV market has followed this assumption, with 27 percent more PHEVs sold than BEVs. Washington State, on the other hand has more than twice the number of BEVs on the road as PHEVs, as shown in Figure 3. 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.

Table 3: EVs registered in Washington (2011-2013)

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

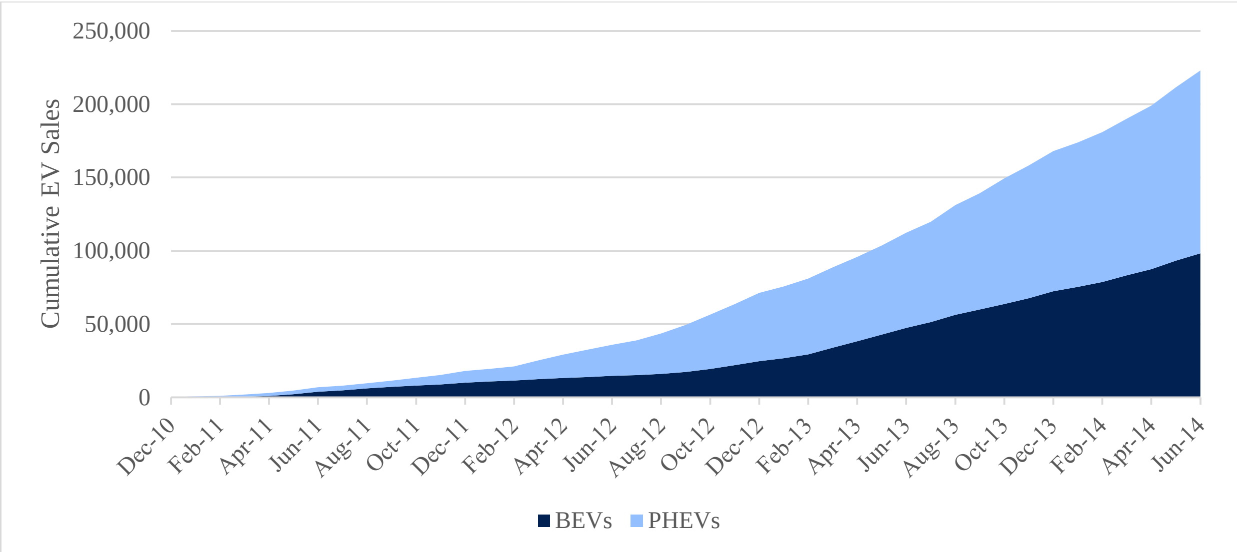
	2011	2012	2013
PHEVs Registered	125	1,056	2,493
BEVs Registered	1,121	1,871	5,655
Total EVs	1,246	2,927	8,148
Total Passenger Vehicles	4,315,782	4,284,923	4,401,768

Source: Washington State Department of Licensing

Two possible explanations for the popularity of BEVs over PHEVs in Washington State are policy incentives and consumer preference. The sales tax exemption available at the time of vehicle purchase is only available for BEVs and 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.[4] Notably, BEVs are also much more popular than PHEVs in Georgia where a $5,000 vehicle tax credit and high-occupancy vehicle lane access, both available only to BEVs, have made Atlanta the top market for the all-electric Nissan LEAF for many months.[5]

Figure 2: Cumulative U.S. Sales of BEVs and PHEVs

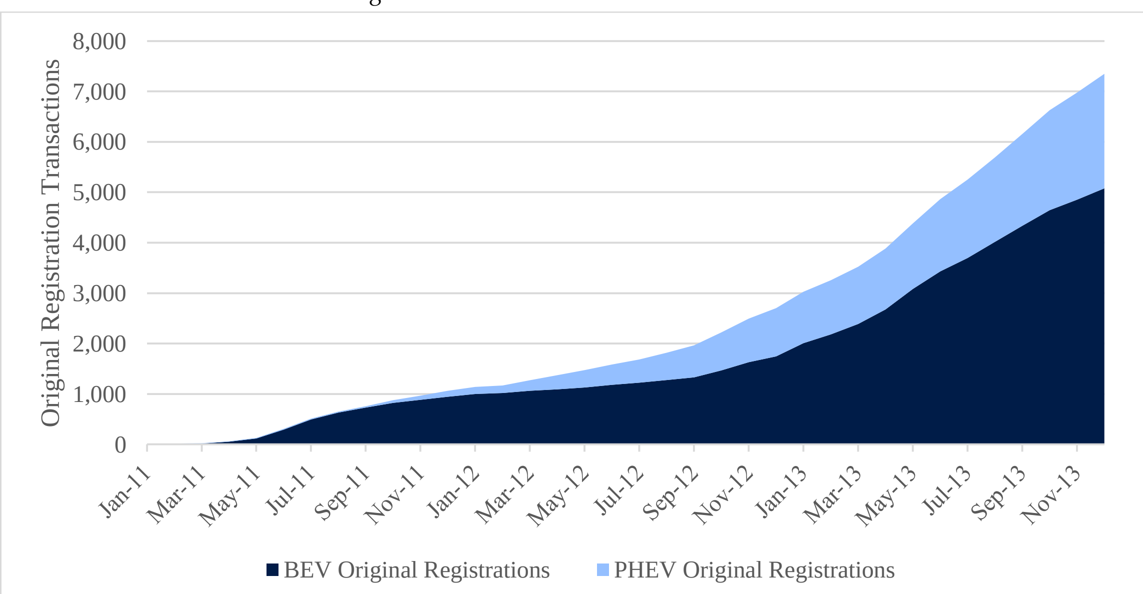
124,718 PHEVs and 98,267 BEVs have been sold in the US through June 2014. PHEVs have consistently outsold BEVs on a monthly basis since early 2011.



Source: http://www.hybridcars.com/market-dashboard.html.

Figure 3: BEVs and PHEVs original registrations in Washington State

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 State. The data below shows new and used vehicles as they were first registered. Washington State 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.

Because BEVs outnumber PHEVs by a large margin in Washington State, charging infrastructure needs in Washington may differ compared to other markets. For example, Washington State EV drivers may need greater access to high-powered charging to meet their travel needs than in other states because of Washington's greater proportion of BEVs on the road.

Geographic distribution of EVs

The distribution of EVs is generally similar to that of regular passenger vehicles throughout Washington, although EVs are concentrated in five counties. These top five counties make up 85 percent of the EV registrations (see Table 4), but account for 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, with over 55 percent of EVs registered in the county, compared with 32 percent of total passenger vehicles. King County also contains 60 percent of the public AC Level 2 charging locations and 43 percent of DC fast charging locations. Considering that AC Level 2 charging stations are often intended to accommodate daily travel, a similar share of AC Level 2 charging locations and EV registrations in a county is intuitive. For example, 60 percent of AC Level 2 charging locations and 55 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 to enable travel to and from distant locations.

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

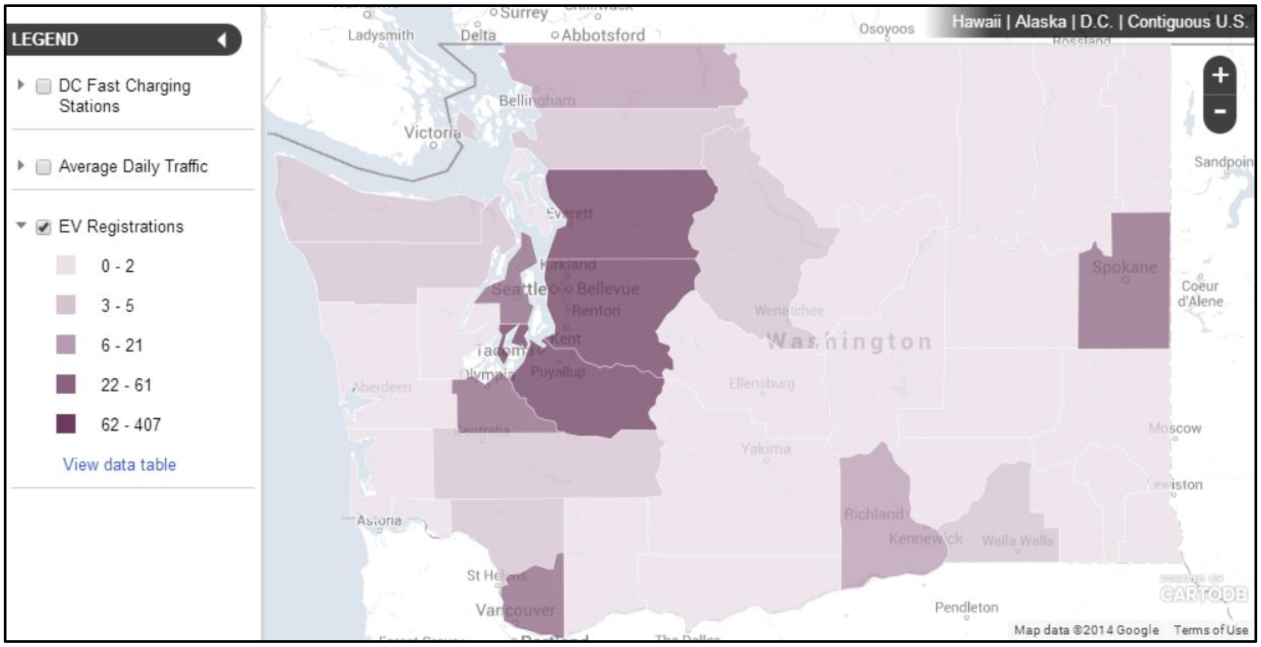
The table below provides summary statistics for the five counties with most EVs registered in Washington as of December 2013. These counties make up 85 percent of total EV registrations.

COUNTY	BEVS REGISTERED	PHEVS REGISTERED	EVS REGISTERED	POPULATION (%)	BEV (%)	PHEV (%)	EV (%)	DC FAST CHARGING LOCATIONS (%)	AC LEVEL 2 CHARGING LOCATIONS (%)
Clark	22	14	36	6.3%	5%	6%	5%	15%	3%
King	285	122	407	28.8%	55%	32%	55%	43%	60%
Kitsap	24	17	41	3.7%	5%	4%	5%	5%	3%
Pierce	37	25	62	11.8%	8%	11%	8%	5%	11%
Snohomish	45	40	85	10.6%	11%	11%	11%	8%	8%

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

Figure 4: Registered EVs in Washington State by county through December 2013

Nearly all EVs in Washington State are registered in the Puget Sound region. Many counties have two or fewer EVs registered, denoted by the lightest purple color.



Source: C2ES Map - http://bit.ly/1q6WwXG

Charging Network Assessment

An assessment of the public EV charging network in Washington depends on the charging technology supported by existing charging stations and the charging needs demanded by different EV technologies.

Washington State has 423 public charging locations as of June 2014, giving it the fourth highest per capita public charging network in the country.[6] These charging stations are primarily concentrated in the state's most populous region around Puget Sound. Public charging stations around the rest of the state are mostly sparse with the exception of the Vancouver area near Portland, Oregon.

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 about 3.5 miles with each kilowatt-hour (kWh) of energy delivered to its batteries, or by charging the vehicle at 1 kW for an hour, see Figure 5. Charging a vehicle at 30 kW for 15 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

All EVs currently support the SAE J1772 connector standard for (alternating current) AC Level 2 charging. Siting for AC 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 AC Level 2 goes up to 19.2 kW, but is typically offered at 3.3 kW or 6.6 kW.

A direct current (DC) fast charging station is intended to enable the quick recharging of an EV. These public stations are often sited in locations where drivers are expected to spend less than 30 minutes, such as along the roadway similar to a gasoline station. DC fast charging stations can provide power to a vehicle's batteries at up to 90 kilowatts (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 than if there were only one standard. The three DC fast charging standards:

- 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 (SAE) in conjunction with the J1772 connector standard used for AC Level 2 charging; followed by most American and European automakers. There are no SAE J1772 Combo charging stations in Washington State as of June 2014.
- Tesla: a proprietary standard developed by Tesla Motors that is currently only compatible with Tesla vehicles.

Figure 5: Charging Levels Explained

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

Low – AC 120V *"AC" LEVEL 1*	Medium – AC 240V *"AC" LEVEL 2*	High – DC Fast Charge *"DC" LEVEL 2*
• Uses standard outlet • Power requirements are like 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 are like 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 (~$100k) • Equipment costs vary widely • *80% charge a Nissan LEAF in 20 minutes*

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.

Charging Equipment Capabilities

All-electric or 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 in order 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 throughout the network without the need to stop and recharge the vehicle's batteries. 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.

An assessment of EV travel along major corridors in Washington State must consider charging and roadway locations, power availability, 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 2. 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 6). The maps created for this analysis show the range of an EV that charges for a fixed time period at different types of chargers, and the risk that vehicles will not be able to access that charging location due to congestion from other vehicles.

Box 3. Charging Station Utilization

One measure of the effectiveness of station siting and the need for additional stations is to examine 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 should meet expectations before the station was installed.

The following formula was used to separately calculate AC Level 2 and DC fast charging station utilization percent:

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

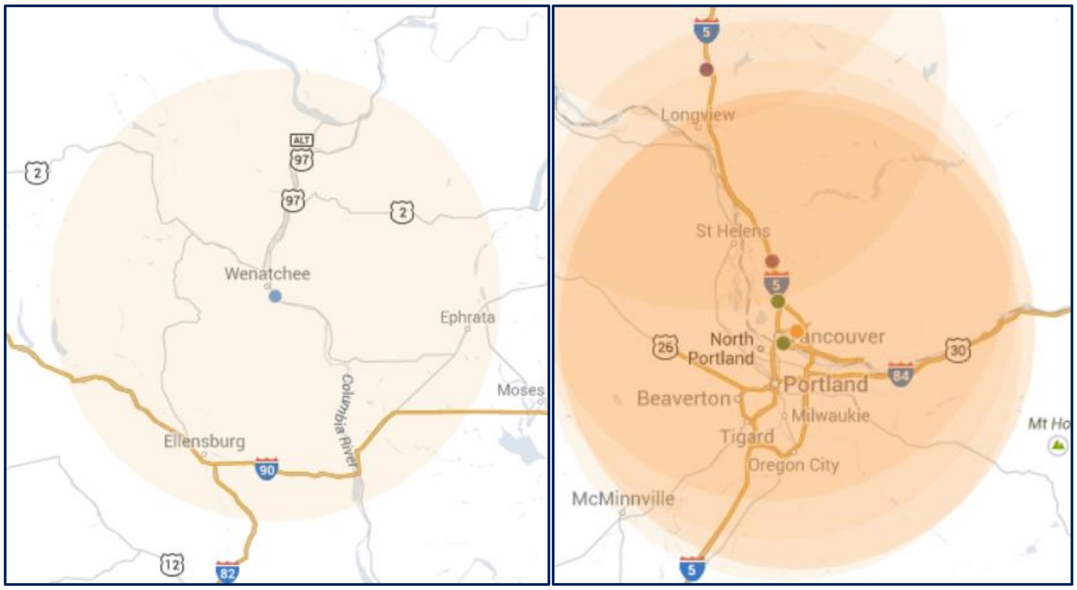
Where

- *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.

Figure 6: Using Maps to Demonstrate Expected Travel Range of a Charging Location

The images below 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.



The fixed-size circle provides an estimate of electric miles traveled following a reasonable amount of time to recharge the vehicle's batteries. 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.

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 consumer's fear of exhausting the vehicle's battery energy either during the course of a trip or in additional driving required to find a station.

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

DC fast charging provides rapid battery recharging, which is 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. 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. For the purposes of this assessment, it is assumed that the DC fast charging network will be used to power all miles traveled by both BEVs and PHEVs.

The table below summarizes DC fast charging locations by charging network. 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 to enable travel to more destinations in the state. Public 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.[7]

The Blink Network was funded in part by a federal grant through the American Recovery and Reinvestment Act. 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 State (see Table 5).[8] Although many locations have access to more than one DC fast charging port, most locations only enable one vehicle to charge at a time (Tesla is an exception).[9] This means that drivers looking to "charge and go" run the risk of having to wait for an extended period if any of the charging ports are occupied. 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.

Table 5: DC Fast Charging Network Summary

This table summarizes the 10 counties that comprise the public DC fast charging network. Values in parentheses are the number of the ports.

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)**

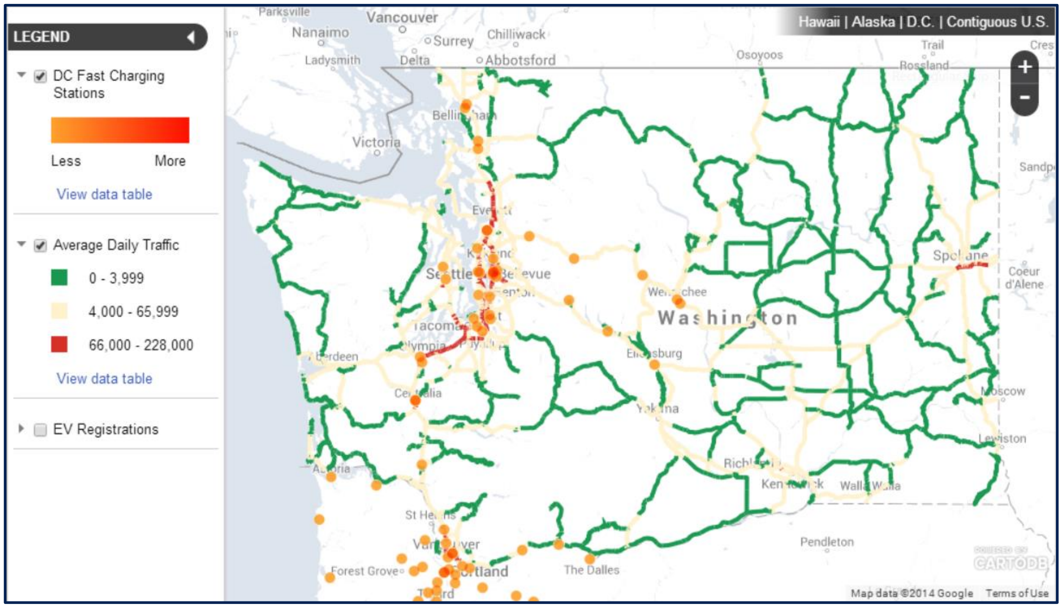
Source: AFDC Website, June 2014

As seen in

Figure 7Figure 7 and Figure 8Figure 8, 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.

Figure 7: DC Fast Charging Network Intensity Map as of June 2014

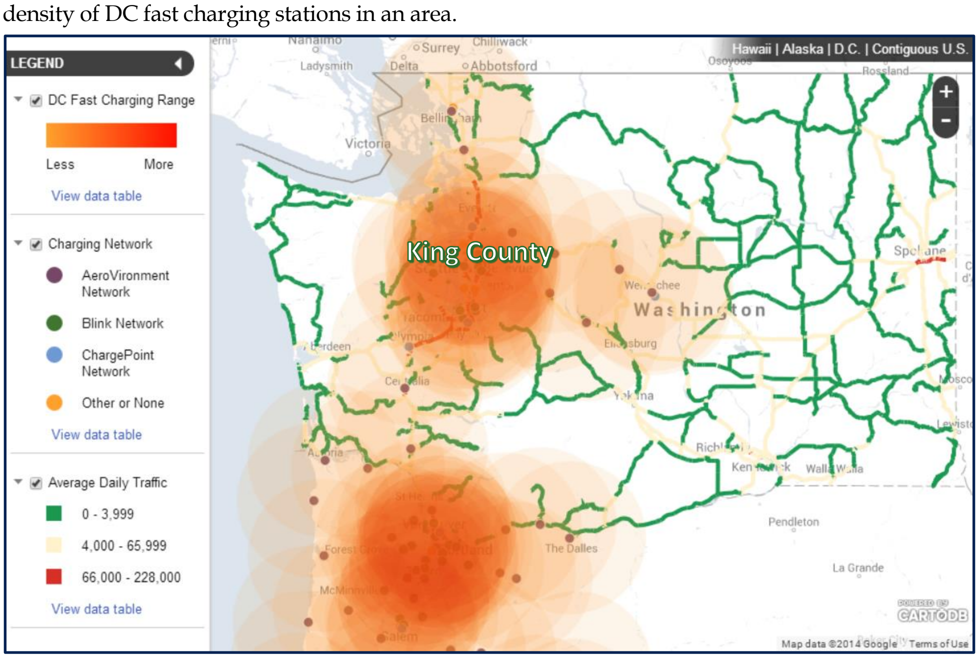
This figure shows DC fast charging locations in Washington State as of June 2014. Charging locations are concentrated in the Puget Sound region with some stations located along U.S. 2, Interstate 90, and Interstate 5. Large segments of many major roadways do not have any publicly available DC fast charging. Major roadways are denoted by green, yellow, and red colors depending on the average daily traffic in 2013.



Source: C2ES Map - http://bit.ly/1uxnFJS

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

The map below 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 Map - http://bit.ly/1pvEWuM

King County (Seattle) has the largest concentration of stations with 33 percent of total locations, or 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 low risk that an EV driver will be unable to access a DC fast charging location. Figure 8 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. Although the large amount 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). As one travels 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 connects some portions of the roadway. The lack of redundant charging in these areas could discourage some drivers from making trips or prolong trips due to station outages or excessive wait times. As one travels towards the Oregon border along Interstate 5, however, the density of DC fast charging locations increases again, indicating DC fast charging stations are very accessible in and around Vancouver.

Box 4. 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)

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

ZIP CODE	COUNTY	TOTAL ENERGY DELIVERED (KWH)	AVERAGE UTILIZATION (%)	CHARGING LOCATIONS
98122	King	19,198	22.4%	2
98233	Skagit	15,811	34.7%	1
98225	Whatcom	13,880	45.9%	1
98294	Snohomish	13,729	35.2%	1
98034	King	13,272	10.5%	4
98424	Pierce	12,113	8.4%	4
98109	King	11,855	14.0%	2
98125	King	9,326	10.3%	2
98007	King	8,828	8.2%	2
98531	Lewis	8,404	20.0%	1

Source: Idaho National Laboratory, Washington State Department of Transportation

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 west to east travel across the state using DC fast charging 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 little or no DC fast charging locations.[10]

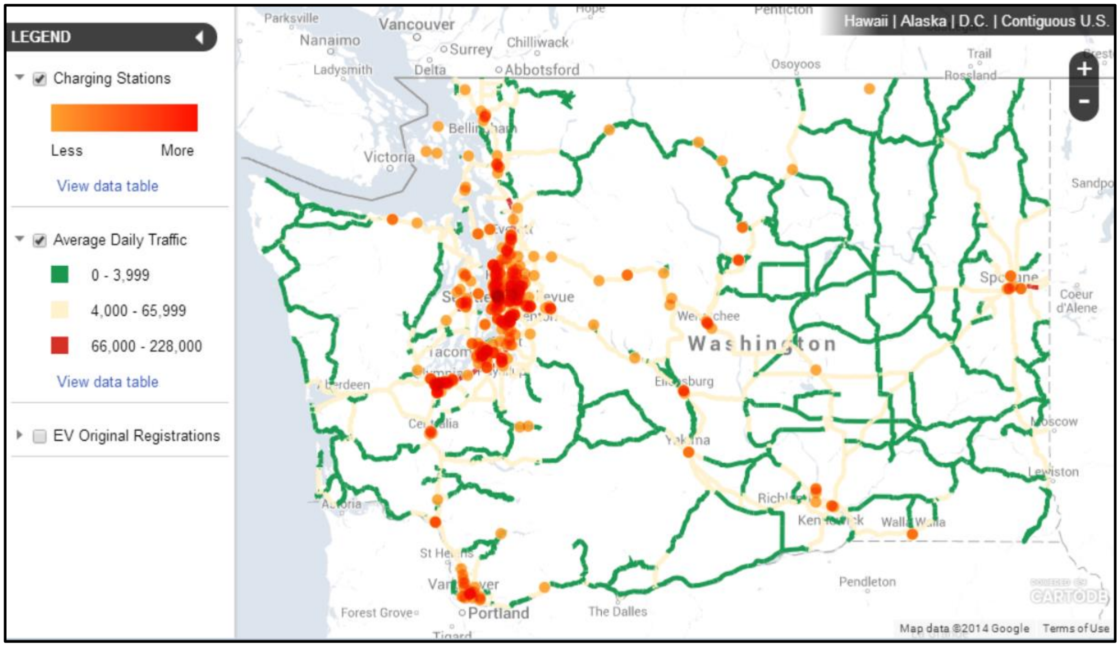
AC Level 2 Charging Network Assessment

TBD

1. Level 2 charging is mostly accessible in King County.
2. Reliable Level 2 connectivity north of Seattle on I-5.
3. Less reliable connectivity south of Seattle on I-5 until you approach Oregon border.
4. Little connectivity outside I-5 corridor, especially along I-90.

Figure 9: AC Level 2 Charging Network Intensity Map as of June 2014

This figure shows AC Level 2 charging locations in Washington State 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 Map: http://bit.ly/1uxnGqW , http://bit.ly/1wF4Mk5

EV Travel along Key Washington State Corridors

Overview of Travel Simulation

Using a combination of traffic data from the 2013 Washington Department of Transportation Annual Traffic Report, U.S. Department of Energy's Alternative Fuel Data Center listing of publicly available charging stations, time-series data from Idaho National Laboratory, and socioeconomic census data, C2ES has evaluated the effective coverage of public charging networks along four key traffic corridors in Washington.

Generally, EV owners charge their vehicles at home and are able to drive to work without having to stop along the way to charge their vehicle. However, publicly available charging infrastructure is needed to expand the potential travel range of EVs and reduce "range anxiety" for BEV drivers.

C2ES simulated travel along four routes to gauge coverage of existing public charging stations for EVs. The simulations identified:

- Whether travel was possible along these routes, through reliance only on public charging stations;
- 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 between: Seattle and Portland, Seattle and Bellingham, Seattle and Spokane, and Olympia and Port Angeles.

Travel Simulation Assumptions

For the simulations, C2ES used two illustrative examples of EVs: a PHEV (based on the Chevy Volt) making use of its electric-only mode with a range up to 40 miles and a BEV (based on the Nissan Leaf) with an electric-only range up to 80 miles. These EVs are meant to be illustrative and may not reflect current options.

For travel along these routes, C2ES assumed that the illustrative EVs would follow the speed limit, would make the trip with a minimum number of stops to recharge the vehicle's batteries, and would start the trip with a full charge. Under these simulations, PHEVs only make use of their all-electric mode and do not use their gasoline engine. In addition, these vehicles make exclusive use of the DC fast charging network or the AC Level 2 network to recharge, and use these networks to recharge their battery to up to 80 percent of capacity. C2ES made the following charging assumptions based on charger type and vehicle:

- BEV charge time for DC Fast Chargers is 0.5 hours at 30 kW, which would allow the vehicle to travel an additional 53 miles.
- PHEV charge time for DC Fast Charger is 0.3 hours at 30 kW, which would allow the vehicle to travel an additional 32 miles.
- BEV charge time for AC Level 2 is 2.25 hours at 6.6 kW, which would allow the vehicle to travel an additional 52 miles.
- PHEV charge time for AC Level 2 is 1.5 hours at 6.6 kW, which would allow the vehicle to travel an additional 35 miles.

For each route and vehicle type, C2ES determined the actual distance of the trip, the minimum number of charging station stops, the charge time based on the number of charging stops, and total drive time under normal traffic conditions. The total trip time is the sum of driving time and charge time.

For example, consider a BEV making the 175-mile trip from Seattle to Portland along Interstate 5. With a fully charged battery, a BEV can travel a maximum 80 miles before needing to recharge the battery. To avoid range anxiety and to account for variable conditions, the driver would prefer not to allow the battery to drop below a 20 percent charge level, so the driver would plan for a comfortable range of 64 miles before stopping to recharge the vehicle. Along the way, the driver can charge at available charging stations. Each 30 minute DC fast charging stop allows the vehicle to travel an additional 53 miles.[11] The public charging infrastructure along this route can be considered adequate as long as the driver can travel from charger to charger without falling below a 20 percent charge level. Based on the total trip distance and these assumptions, it is clear that the driver will need to make at least two DC fast charging stops to complete the trip.

Simulation 1: Travel between Seattle and Portland along Interstate 5

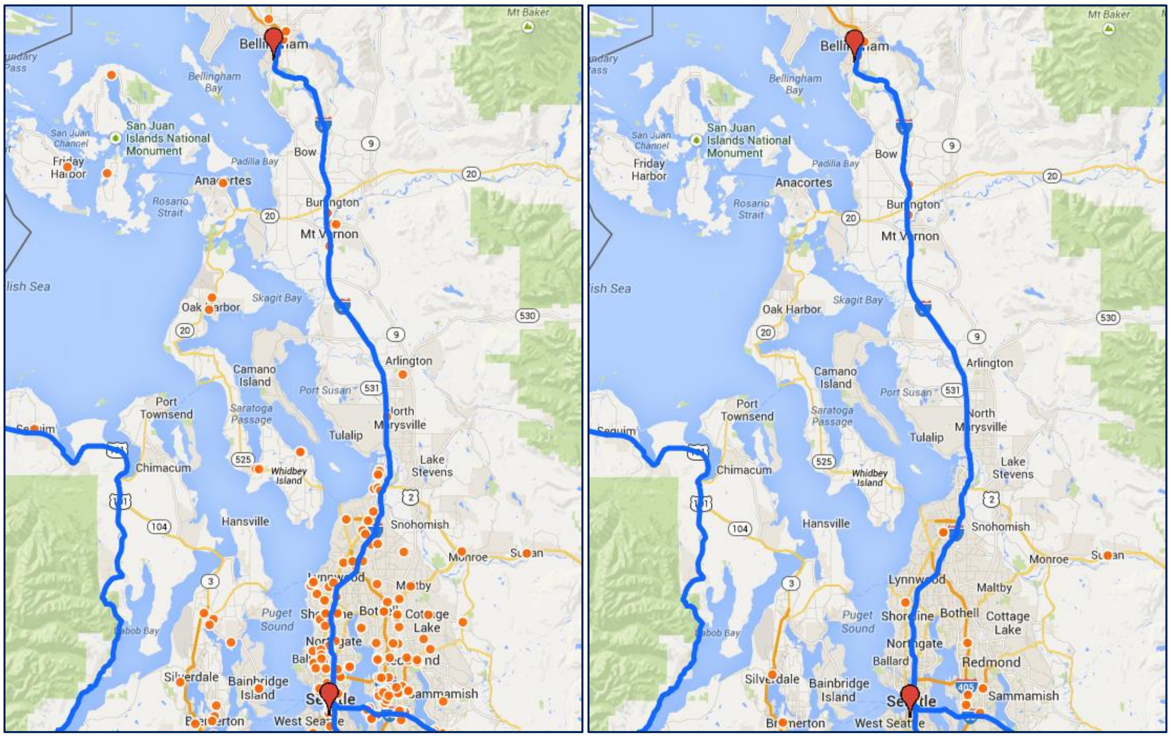
CHARGING TYPE	VEHICLE	MILES TRAVELED	NUMBER OF CHARGING STOPS	DRIVE TIME (MIN)	CHARGE TIME (MIN)	TOTAL TIME (MIN)
N/A	Gasoline Powered	173	N/A	170	N/A	170

CHARGING TYPE	VEHICLE	MILES TRAVELED	NUMBER OF CHARGING STOPS	DRIVE TIME (MIN)	CHARGE TIME (MIN)	TOTAL TIME (MIN)
DC Fast Charging	BEV-80	175	2	184	60	244
DC Fast Charging	PHEV-40	178	5	184	90	274
AC Level 2	BEV-80	178	2	178	270	448
AC Level 2	PHEV-40	178	5	188	675	863

Public charging infrastructure is in place to complete travel between Seattle, Washington and Portland, Oregon in all simulations. There is a higher concentration of public charging stations in the Puget Sound region than in the southern portion of the route. (See Figure 10.)

Figure 10: Public Charging Stations between Seattle and Bellingham

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



Total trip travel is longer for EVs along the preferred route because of the time required to charge the vehicle. A gasoline-powered vehicle—with a full tank of gas—would take 2 hours and 50 minutes to travel 173 miles on I-5 between Seattle and Portland. Total trip time using the DC Fast charging network is about 4 to 4.5 hours—the charge time is about one-third of the total drive time—which is about an hour longer than a trip made with a gasoline-powered vehicle. Total trip time using the AC Level 2 network ranges from 10 to 14 hours—the charge time is about 70 to 80 percent of the total drive time—which is about 7 to 11 hours longer than a trip made with a gasoline-powered vehicle.

Additional public charging stations are needed along the southern portion of the route—between Centralia and Longview—to reduce reliance on charging stations in Castle Rock and Ridgefield to complete the trip. Travel along the southern portion of this route using the public charging network is contingent on using charging stations located in Castle Rock and Ridgefield. There is one public DC fast charging station located between Centralia and Ridgefield—in Castle Rock—which is an essential stop for a BEV to complete the trip. Due to lower battery capacity, PHEVs would need to make two essential charging stops in Castle Rock and Ridgefield to complete the trip.

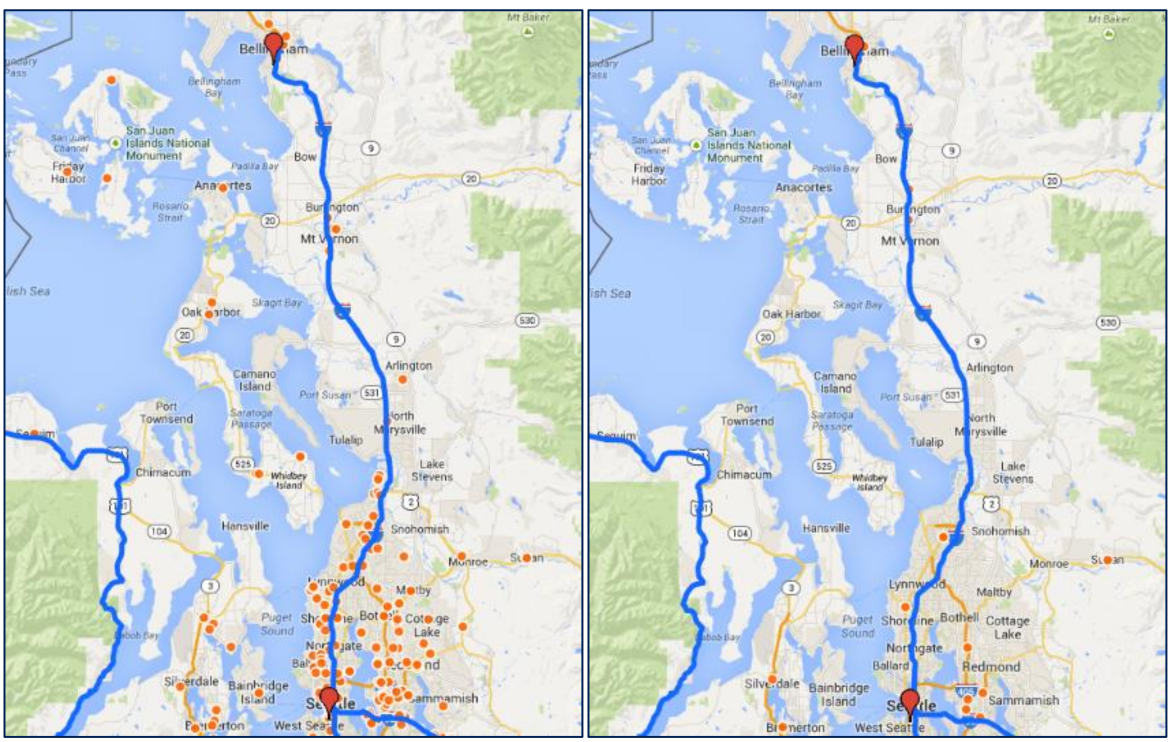
Simulation 2: Travel between Seattle and Bellingham along Interstate 5

Note that for simulations where travel could not be completed due to lack of public charging stations are denoted with an "X".

CHARGING TYPE	VEHICLE	MILES TRAVELED	NUMBER OF CHARGING STOPS	DRIVE TIME (MIN)	CHARGE TIME (MIN)	TOTAL TIME (MIN)
N/A	Gasoline Powered	88.7	N/A	90	N/A	90
DC Fast Charging	BEV-80	89.2	1	89	30	119
DC Fast Charging	PHEV-40	X	X	X	X	X
AC Level 2	BEV-80	90.3	1	93	135	228
AC Level 2	PHEV-40	90.3	2	94	270	364

Figure 11: Public Charging Stations between Seattle and Bellingham

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



- Public charging infrastructure is in place to complete travel between Seattle and Bellingham in all but one of the simulations.

- There is a higher concentration of public charging stations in the Puget Sound region than in the northern portion of the route.

- Total trip travel is longer for EVs along the preferred route because of the time required to charge the vehicle.

    - DC Fast charging: For BEV, 2 hours, charge time is about one-quarter of total drive time. PHEV not able to complete travel along the preferred route.

    - AC Level 2: 4 to 6 hours, charge time is about 60 to 74 percent of total drive time.

- Additional public DC Fast charging stations are needed between Everett and Burlington to allow a PHEV to travel the preferred route making exclusive use of DC Fast charging network.

    - There is a lower concentration of DC Fast chargers than AC Level 2 chargers along the preferred route.

    - There are no DC Fast chargers between Everett and Burlington, whereas there are about 15 Level 2 chargers.

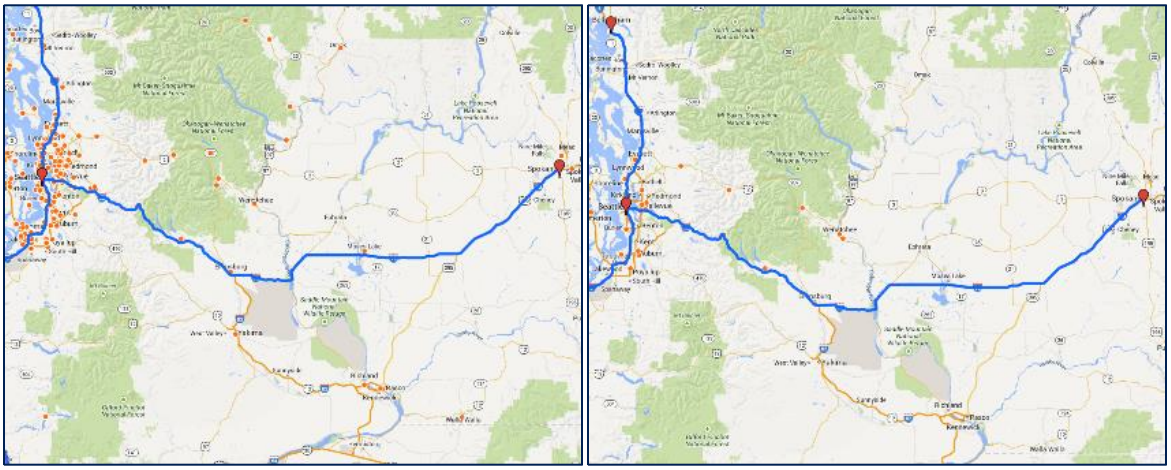
Simulation 3: Travel between Seattle and Spokane along Interstate 90

Note that for simulations where travel could not be completed due to lack of public charging stations are denoted with an "X".

CHARGING TYPE	**VEHICLE**	**MILES TRAVELED**	**NUMBER OF 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-80	X	X	X	X	X
DC Fast Charging	PHEV-40	X	X	X	X	X
AC Level 2	BEV-80	X	X	X	X	X
AC Level 2	PHEV-40	X	X	X	X	X

Figure 12: Public Charging Stations between Seattle and Bellingham

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



- Public charging infrastructure is not in place to fully complete travel between Seattle and Spokane in any of the simulations.
    - There is a higher concentration of public charging stations along the western half of the preferred route versus the eastern half.
- The lack public charging stations in the eastern half of the preferred route prevents an EVs from completing travel.
- Additional public charging stations—at least 3 DC Fast charging spaced at least 60-miles apart and 5 Level 2 charging stations spaced at least 35 miles apart—are needed between Ellensburg and Spokane to facilitate EV travel between Seattle and Spokane.

Simulation 4: Travel between Olympia and Port Angeles along U.S. 101 North

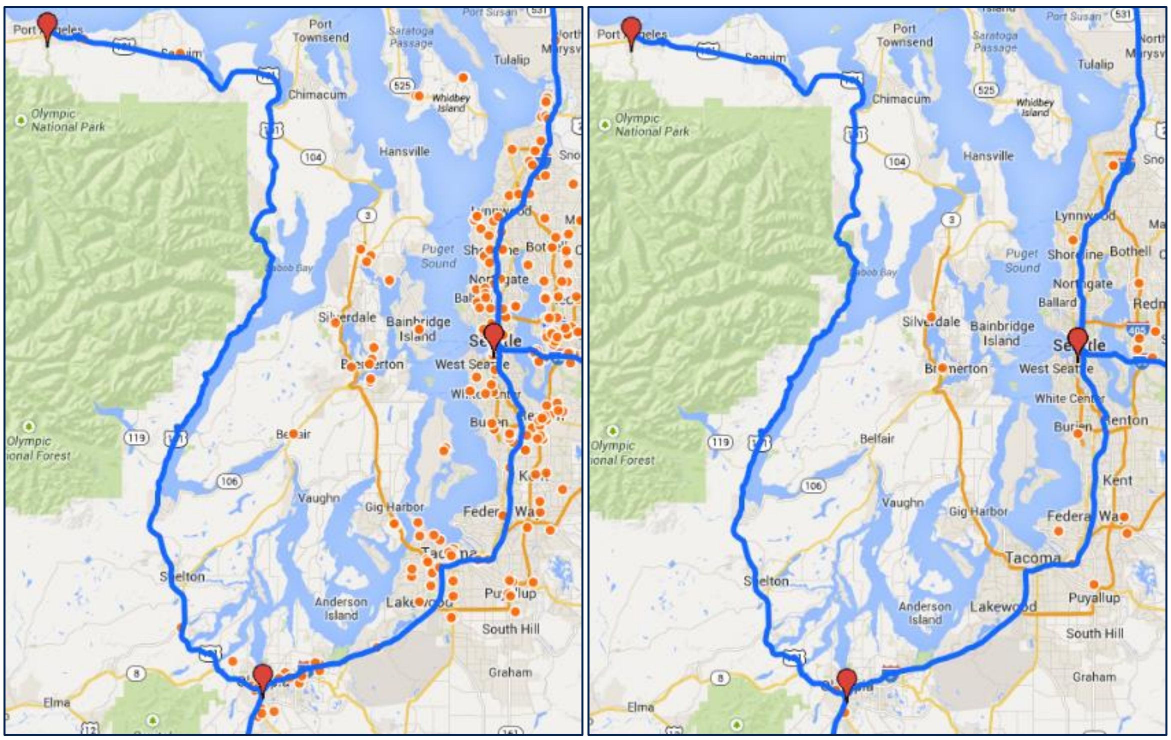
Note that for simulations where travel could not be completed due to lack of public charging stations are denoted with an "X".

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-80	X	X	X	X	X
DC Fast Charging	PHEV-40	X	X	X	X	X
AC Level 2	BEV-80	X	X	X	X	X

CHARGING TYPE	VEHICLE	MILES TRAVELED	NUMBER OF CHARGING STOPS	DRIVE TIME (MIN)	CHARGE TIME (MIN)	TOTAL TIME (MIN)
AC Level 2	PHEV-40	X	X	X	X	X

Figure 13: Public Charging Stations between Seattle and Bellingham

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



- Public charging infrastructure is not in place to complete travel between Olympia and Port Angeles using US-101 North and South in any of the simulations.
  - Though, public charging infrastructure is in place along US-101 East for a BEV to complete travel along this route.
- Public charging stations are concentrated around Olympia along this preferred route.
- Additional public charging stations are needed along the southern portion of the route—between Centralia and Longview—to reduce reliance on charging stations in Castle Rock and Ridgefield to complete the trip.

- Additional public charging stations are needed—at least 2 DC Fast charging stations and 2 Level 2 charging stations—between the 100-mile stretch of road between Port Angeles and Shelton are necessary to facilitate travel for an EV along US-101 North and South.
    - Additional Level 2 charging stations are needed between Sequim and Poulsbo to facilitate travel for a PHEV along US-101 East.

Conclusions and Next Steps

a. High-level conclusions.
b. Areas of additional research.
c. Preview work for Task 2 and 3.

Data Sources

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

Public Charging Station Network Locations: The U.S. Department of Energy's Alternative Fuel Data Center provides 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 provides 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 public charging locations in Washington State 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 XX 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: Idaho National Laboratory provided ZIP code level data for AC Level 2 and DC fast charging stations for two federally funded initiatives: the EV Project (Blink Network) and ChargePoint America (ChargePoint Network). The period covered by these data is January 2011 through December 2013. Some charging stations in the Blink and ChargePoint Networks in Washington are publicly available, but are not being measured by Idaho National Laboratory. In addition, there have been issues with the reliability of charging locations on the Blink Network.[12]

The following are current issues with the integrity of the data provided for this analysis.

- Idaho National Laboratory data is not disaggregated by network, so there is overlap from the data for charging locations for ChargePoint America and the data provided by ChargePoint.

- All vehicle data from the Department of Licensing does not separate out new from used original registrations.

- Many of the vehicle registration entries from the Department of Licensing have invalid ZIP codes.

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[1] 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.

[2] http://www.eia.gov/state/rankings/?sid=WA#series/31 and conversation with Peter Moulton, Washington State Department of Commerce, July 2015.

[3] NRC report: http://www.nap.edu/catalog.php?record_id=18264

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

[5] http://online.wsj.com/articles/why-electric-cars-click-for-atlanta-1401922534

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

[77] Conversation with Jeff Doyle, WSDOT. July, 2014.

[8] U.S. DOE, AFDC website.

[9] Conversation with Tonia Buell, WSDOT. July 15, 2014.

[10] C2ES Map http://bit.ly/1tQqQs8

[11] BEV can travel up to 80 miles so after driving 60 miles it will have a remaining battery range of 20 miles. A 30-minute charge will provide enough energy to extend the range by 40 miles, allowing the EV to travel an additional 60 miles.

[12] Conversation with Jeff Doyle, July 21, 2014.