Why electric vehicles are a climate solution

MARCH 2016

Climate Solutions
PRACTICAL SOLUTIONS TO GLOBAL WARMING
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Climate Solutions is a Northwest-based clean energy economy nonprofit whose mission is to accelerate practical and profitable solutions to global warming by galvanizing leadership, growing investment, and bridging divides. We pioneered the vision and cultivated the political leadership in the Northwest for the proposition that clean energy and broadly shared economic prosperity can go hand-in-hand. For 17 years, we have led successful initiatives to deliver climate and clean energy policies, models, and partnerships that accelerate the transition from fossil fuels to a clean energy economy.

The **Strategic Innovation Team** at Climate Solutions focuses on developing solutions to reduce greenhouse gas emissions and remove carbon pollution from the atmosphere at the scale required to address the climate crisis. We identify the pathways to a low carbon future and create replicable models for emission reduction and carbon storage that provide economic as well as climate benefits, through the following programs:

- **Pathways Project** identifies, analyzes, and publicizes the pathways to transition from a fossil fuel-based economy to a low carbon, clean energy economy, focusing on the technically and economically viable solutions that will move the states of Washington and Oregon off of oil and coal.
- **New Energy Cities** partners with small- and medium-sized communities to achieve significant greenhouse gas reductions by 2030. We are catalyzing replicable models of city-led clean energy innovation by working with communities to set and attain quantifiable carbon reduction targets for buildings, transportation, and energy supply.
- **Sustainable Advanced Fuels** accelerates low carbon alternatives to petroleum fuels in the Northwest. By supporting state clean fuels policies, driving awareness of advanced fuel technologies, and helping to build a viable advanced fuels market, we aim to achieve significant reduction in carbon emissions from transportation fuels.

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Executive Summary

Transportation has thus far been a difficult sector of the economy to decarbonize. Increases in fuel economy have reduced the energy intensity of transportation, but it has proven difficult to supply the remaining fuel requirements renewably—unlike the utility grid, which has seen relatively rapid progress in places such as Germany and California where policy incentives support clean power. Mobile sources of emissions are more numerous, more diverse, and more challenging to transition to zero-emission technology than stationary sources of emissions.

In coming years, electric vehicles (EVs) offer one of the most promising ways to curb the climate pollution from transportation—particularly if the power to charge them is generated renewably, but even if it comes from natural gas, which supplies the marginal demand along the Pacific coast. In addition, the charging capacities of battery-powered vehicles can make it easier to integrate more wind and solar power onto the utility grid, since EVs' charging rate can be adjusted to match the availability of variable renewable energy. These two factors make EVs especially worthwhile to pursue as a synergistic climate solution.

This briefing paper explores the dimensions of the climate opportunity that EVs offer, with a focus on Oregon and Washington. It considers the additional demand for electricity that widespread adoption of EVs would require, as well as some of the challenges and barriers that must be addressed for EVs to play a significant role in decarbonizing the Northwest's economy.

In a nutshell, the electricity to power light-duty vehicles in Oregon and Washington would raise the energy demands on utilities noticeably but not overwhelmingly, amounting to a 6 percent increase over 2013 consumption if half of light-duty vehicle-miles were powered electrically.[1] This increase could be managed over time with offsetting increases in energy efficiency and complementary growth in renewable electricity supply.

Smart-grid technologies will be an essential complement to EVs, in order to avoid the need for costly upgrades to the utility distribution network and to maximize the climate benefits of the transition from internal combustion of fossil fuels to electric drive. With the help of smart charging, grid managers can match the timing of EV demand to the greatest availability of renewable power, and spread out the power demand for charging so that it does not overtax existing circuits. These technologies already exist in nascent form, but need further development as EVs grow in market share.

Delivering that power to a growing fleet of EVs will also depend on establishing streamlined systems that allow EV owners to charge their cars for a fair price, and on state and local action to remove institutional and financial barriers to constructing charging stations. Zoning regulations and utility commission rules may need to be changed to make charging an EV as smooth a transaction as withdrawing cash from an ATM.

Introduction

Imagine if you had just joined a team designing the transportation system of the future. "I know," says a participant across the table. "Let's fan out across the globe and look for deposits of a viscous, toxic substance buried deep underground, in some cases offshore, or even under the edges of the Arctic ice cap. We'll drill thousands of feet into the Earth and pump that black goo to the surface. We'll try not to spill it, because when we do, it'll contaminate the food chain and kill fish, seabirds, and marine mammals for decades.

"Then we'll ship it in oil trains that blow up from time to time, or send it halfway around the world in supertankers that occasionally wreck, and process it in refineries that pollute the air in the communities where they are located and occasionally explode, too. We'll take the highly flammable stuff that comes out of the refineries, and truck it to 'gas stations' where people will pump it into their cars. When the car engines burn it, the exhaust will be full of poisons, most of which we will be able to remove by putting special equipment on the tailpipe of every single car. The one pollutant we won't be able to remove is the stuff that screws up the climate, so the more we drive, the more we'll overheat the planet." You'd wonder whether they were insane or pulling your leg.

Nonetheless, that crazy vision describes the system that powers most of our transportation today. Its staying power stems from the inertia of a powerful industrial model that arose before we understood the consequences that oil drilling, refining, and combustion would have, and when petroleum deposits were far more accessible. It is sustained thanks to countless incremental decisions made since the early 20th century when this system's shortcomings were less evident and when personal motorized mobility was used at a much smaller scale, creating fewer obvious impacts.

Fortunately, auto designers all over the world are developing a number of sounder alternatives to a transportation ecosystem anchored by petroleum and the internal combustion engine. These alternatives include plant-based biofuels that can be burned in internal combustion engines; fuel-cell vehicles powered by hydrogen; and plug-in electric vehicles (EVs)—both the purely electric (battery electric vehicles, or BEVs) as well as those with an on-board engine for supplemental power (plug-in hybrid electric vehicles, or PHEVs). Each of these has its merits, but this paper focuses only on the last two and most widely available of those alternatives—cars which store energy on board in batteries and use it to propel electric drive motors—and only on the EVs' effectiveness as a tool in reducing climate pollution.

Using the average U.S. generating mix, an EV accounts for about half as much carbon pollution as the average new conventional vehicle; in locations with a cleaner electric grid, such as the Pacific Northwest, it emits only a quarter as much. An EV's carbon footprint will decrease over time as the electric grid transitions to renewable energy, and could theoretically approach zero if it were powered entirely with renewably generated electricity (and the car and related infrastructure were built with renewable energy).

However, until the electric grid is fully decarbonized, an EV's actual carbon footprint is a question worthy of investigation. What's more, to understand how quickly and thoroughly EVs can decarbonize the transportation system, it is important to imagine the transition from today's situation to a system that includes a substantial share of electric vehicles, which can in turn have a beneficial effect on the grid's ability to absorb a larger share of renewable energy. That's the task of this paper.

Why decarbonizing personal mobility is an essential challenge

Ever since the 1973 OPEC oil embargo and 1979 oil price shock raised the profile of energy on the public agenda, U.S. energy consumption trends have mostly pointed away from fossil fuels and petroleum in particular. For instance, the residential and commercial sectors were nearly 20 percent dependent on oil in 1970, but by 2014, that figure had dropped into the low single digits.[2]

For electric utilities, the shift away from oil was even more dramatic: 13 percent of the electricity generated in the U.S. came from oil in 1970, a figure that dropped below 1 percent by 2014.[3] That shift, along with the growth in carbon-free electricity and less carbon-intensive fossil-fueled generation, have brought about a 20 percent decrease since 1975 in the amount of carbon pollution released for every kilowatt-hour generated in this country.[4]

Nevertheless, transportation has remained stubbornly reliant on petroleum, even in the face of substantial gains in fuel economy, which drove the U.S. fleet average from 13.5 mpg in 1970 to 23.4 mpg in 2013,[5] with an additional doubling of fuel economy required under the Corporate Average Fuel Economy standards by 2025.[6] Oil supplied 95 percent of the energy to the U.S. transportation sector in 1970. More than 40 years later, in 2014, that fraction remains at 91 percent. Liquid fuels offer a potent, concentrated, easily transportable energy source—an energy packet so convenient that the auto industry has been slow to develop alternatives to it despite the mounting evidence that we must curb the use of fossil fuels to hand off our planet in good condition to our progeny.

In the Pacific Northwest, where our supply of electricity is particularly clean because of the region's natural endowment of hydropower, reducing petroleum used for transportation is especially significant to any climate impact strategy. In Washington, 53 percent of the state's fossil carbon pollution in 2012 came from the combustion of petroleum for transportation.[7] For Oregon, the comparable figure was 45 percent.[8]

Transportation's climate impact requires particular attention because it has continued to grow in the Northwest even as the emissions curve for electricity bends lower. Thanks to more efficient use of power, the closure of coal plants, and their replacement with renewable and gas-fired generation in Washington State, climate pollution from electricity use was already 10 percent below 1990 levels in 2012. In contrast, Washington's carbon pollution from on-road use of gasoline and diesel was 17 percent above its 1990 benchmark.[9]

In Oregon, annual greenhouse gas pollution from all sources grew by 4 million metric tons of carbon-dioxide equivalent between 1990 and 2012; transportation accounted for three-quarters of that increase.[10] In neighboring California, where cuts in climate pollution have been mandated since 2006, per capita emissions from road transportation have edged down while climate pollution from electricity consumption has fallen by nearly half. (See Figure 1, below.)

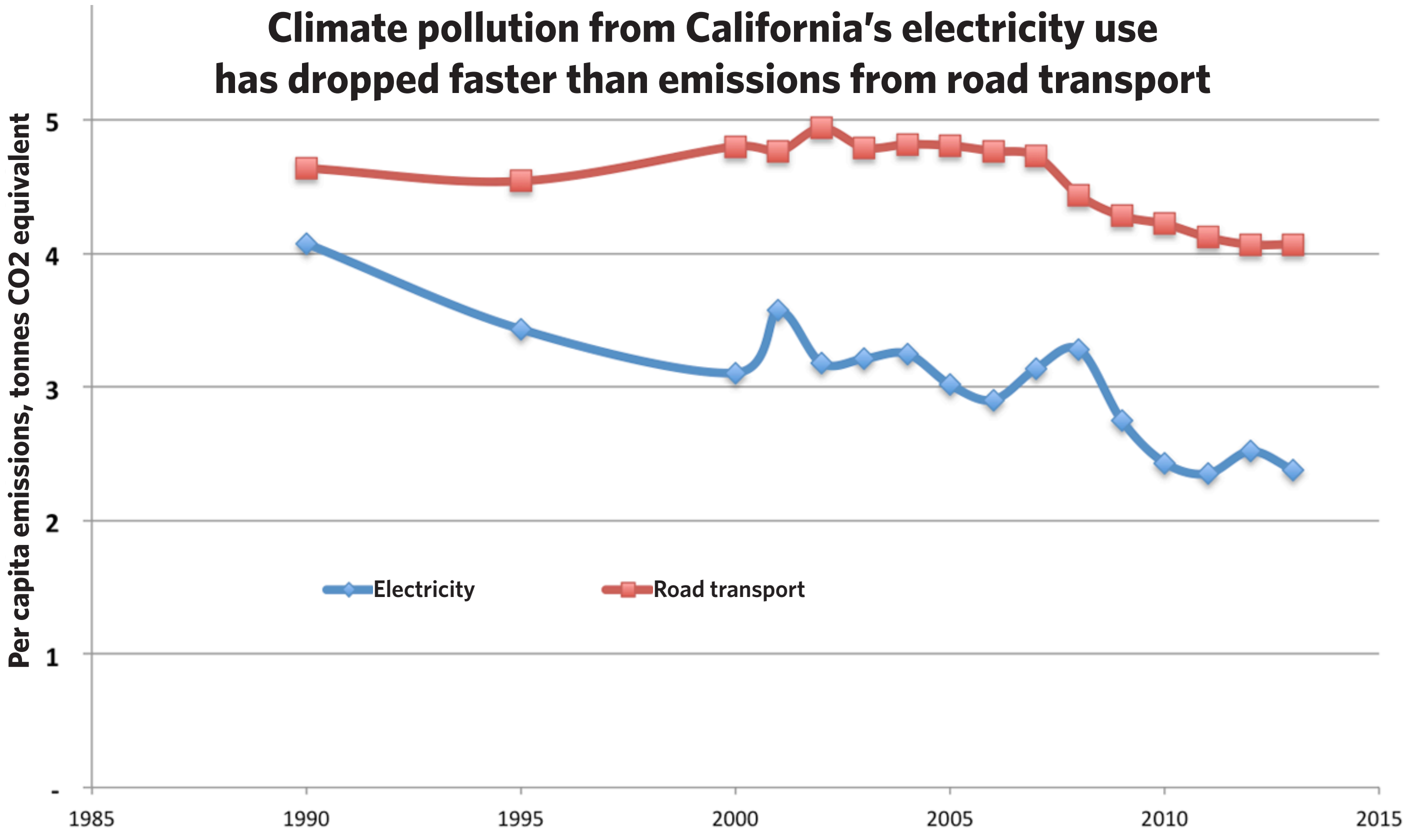

Figure 1. California's climate pollution from road transport and electricity. *Sources: Emissions inventory from California Air Resources Board; yearly population figures from California Dept. of Finance*

Substituting renewable sources of energy for fossil fuels has been slow to reduce the transportation sector's climate impact. In contrast to the electricity sector—where substantial increases in energy supplied from such carbon-free sources as wind and solar photovoltaics have occurred in the last few years—transportation remains heavily dependent on liquid fossil fuels. Even where substitutes have begun to penetrate the market, thanks to the federal Renewable Fuels Standard, they have made a disproportionately small dent in the carbon footprint of U.S. transportation.

In 2014, ethanol provided 1.11 quads (quadrillion BTU, also abbreviated Q) of energy of U.S. transportation fuel,[11] and biodiesel another 0.18 quads,[12] for a total of 1.29 quads out of the 27.1 quads of U.S. transportation energy,[13] or just under 5 percent. That 1.11 quad contribution from ethanol overstates its climate benefit, however, because significant greenhouse gas emissions occur throughout the corn ethanol fuel cycle, from farming practices through distillation.

Corn ethanol uses just 37 percent less fossil energy than the production of gasoline with the same energy content,[14] which means that the ethanol blended into motor gasoline reduced fossil fuel demand by 0.5 quads, under 2 percent of U.S. transportation energy demand.[15] Biodiesel has a much more favorable energy ratio, returning 5.5 times as much usable energy as the fossil fuel expended in its production, suggesting that the 0.18 Q of biodiesel reduced the nation's fossil fuel demand by about 0.15 Q, about half of 1 percent.[16]

By comparison, renewable power (apart from large hydro) accounted for 7 percent of U.S electrical generation in 2014,[17] and in California, all three major investor-owned utilities exceeded a 20 percent Renewable Portfolio Standard in 2013.[18] In the Pacific Northwest, where both states are net exporters of electricity, generation from solar, wind, geothermal, and biomass totaled 8 percent in Washington and 14 percent in Oregon. Thanks to the high fraction of inexpensive, long-standing hydropower on the Pacific Northwest grid, there is less room for improvement than in California. Perhaps a better metric is the fraction of non-hydro generation that came from renewable sources: 24 percent in Washington and 32 percent in Oregon.[19] In sum, transportation's carbon footprint has been harder to shrink than the electric grid's climate impact, and new approaches will be needed to reduce it significantly.

Although electrified transportation is the focus of this paper, it is worth noting other carbon reduction avenues being pursued as well. For starters, strengthened federal fuel economy standards will cut gas and diesel consumption by internal-combustion vehicles. Another path is alternative fuels: Oregon has instituted a Clean Fuels Standard that will require its motor fuel stream's average carbon intensity to decline 10 percent by 2025[20] by using fuels with a lower carbon intensity, such as biofuels, natural gas, or renewable natural gas.

An EV's carbon pollution includes the impact of producing the electricity to charge its batteries and the energy used in the car's manufacture and eventual disposal.

Lower-carbon fuels can reduce the climate impact of current vehicles on the road, although questions remain about the ultimate share of U.S. transportation needs that could be met through the sustainable production of biofuels. Ultimately, they will likely be used primarily to power transportation modes that are harder to electrify, such as aviation, long-distance marine, and long-haul trucking.

Hydrogen-powered fuel-cell vehicles offer another possible approach to clean transportation, with two models currently offered to US consumers. At the moment, almost all hydrogen is produced from natural gas, leaving fuel cells tied to fossil fuels. However, the hydrogen can be manufactured from biomass or by using renewably generated electricity to split water into oxygen and hydrogen, leading to a fossil-free supply chain; California requires that one-third of the hydrogen supplied as motor fuel be produced renewably.

This report focuses on the potential for battery electric vehicles (BEVs, or EVs for short) to reduce the climate impact of driving. Electric vehicles produce no tailpipe emissions, so their carbon footprint results only from their manufacture and from the generation of electricity to recharge them. As the mix of energy sources used to power the grid gets cleaner, the footprint of EVs will get lighter as well. This analysis also applies to plug-in hybrid electric vehicles (PHEVs), to the extent that they are operated using their on-board batteries rather than their companion liquid-fueled engines.

How EVs reduce the carbon footprint of each mile traveled

The climate impact of driving an EV depends primarily on how the electricity to charge it is produced. Although nothing would come out of an EV's tailpipe even if it had one, that doesn't mean it is carbon pollution-free. As Rocky Mountain Institute's Amory Lovins observed, " 'Zero-emission vehicles' are actually 'elsewhere-emissions vehicles.' "[21] Any reckoning of an EV's carbon pollution must therefore look upstream, to the impact of producing the electricity to charge its batteries, and to a lesser extent, to the energy used in its manufacture and eventual disposal.[22]

The main climate benefit of using battery power instead of internal combustion arises from the vehicles' well-to-wheels emissions: a reduction in the amount of greenhouse gases produced throughout the fuel cycle, from the extraction of primary energy all the way to its use to power the vehicle. While "well-to-wheels" is a term based on the fuel cycle of petroleum-powered vehicles, this term could stand in for "mine-to-wheels" if coal-fired electricity were used to charge the EV, or "air-to-wheels" if the electricity were generated with wind.

Even on today's partly fossil-fueled grid, the climate impact of driving a mile in an EV is lower than for an average petroleum-fueled car, with the precise amount of savings dependent upon the mix of generating technologies that power the grid. In the Midwest, which relies heavily on coal power, the climate advantage of EVs is relatively small because the electricity charging them is carbon-intensive. Even there, however, driving the average U.S. electric car on the road today would have the same climate impact as driving a 35- to 44-mpg gasoline car.[23]

Electric cars offer a much greater advantage in the West and Northeast, where the average mix of electricity on the grid is lower in carbon content, making them less harmful to the climate than the most efficient gasoline- or diesel-powered autos. In the seven-state regional power pool to which Oregon and Washington belong, an average EV caused as little climate pollution as a 94-miles-per-gallon gasoline car, according to Union of Concerned Scientists calculations based on 2012 emissions factors.[24] That figure was nearly as high in California, where the comparable figure was 87 mpg.

Even on today's partly fossil-fueled grid, the climate impact of driving a mile in an EV is lower than that of an average petroleum-fueled car.

These comparisons are based on the climate impact of the average kilowatt-hour sold recently in each of those regions, which is one of three paradigms to use in considering the climate impact of electrified driving. This approach allocates an equal share of the high- and low-carbon generation resources to all loads on each regional grid. Two other perspectives can be used to analyze more specific questions about the carbon footprint of an EV.

One of these alternative approaches considers only the ultra-short-run impact of driving one more mile in an EV, based on the generating resources used to produce the last kilowatt of power on the grid at the moment the EV will be recharged. At the margin, almost anywhere on the U.S. grid, the marginal kilowatt is typically generated with fossil fuel, except for rare instances in which renewable generation is curtailed because of transmission or load constraints. In the western U.S., that fossil fuel is natural gas, since western coal plants are typically run for base load, with natural gas power stations called into service as the load rises and falls.

Generating a kWh of electricity with natural gas accounts for just under one pound[25] of CO_2. Since a Nissan Leaf[26] and other EVs in its class can travel a little over three miles on that kWh,[27] and a gallon of gasoline liberates about 19 pounds of CO_2 when it is burned,[28] the marginal climate impact of that EV is comparable to a 64-mpg car.

This calculation—based on the resources dispatched to satisfy EVs' loads in the short run—reflects the current climate impact of a mile driven in an EV today, but it ignores the changing mix of resources used to supply the grid over time. During the lifetime of an EV placed in service today, the average kilowatt-hour everywhere in the United States will become less carbon-intensive as coal plants retire as a result of citizen campaigns to remove coal from the grid and the Obama Administration's Clean Power Plan.[29] For drivers weighing the climate footprint of their next car, the carbon-intensity to consider is a function of the expected mix of resources on the grid over the course of the vehicle's lifetime—a blend that will be shaped by government policies and utility planning.

It turns out that large-scale adoption of EVs would result in only a modest bump in electricity consumption, all other factors being equal.

For policy-makers deciding how vigorously to promote the adoption of EVs as a measure to reduce carbon pollution, it is crucial to anticipate how the generating mix can be shaped during the coming decades, and to consider how to dovetail the simultaneous processes of electrifying transportation and decarbonizing the grid. Readers interested in delving deeper into these questions will find it useful to digest a recent analysis by the Electric Power Research Institute in association with the Natural Resources Defense Council, which offers a detailed discussion of emissions rates under scenarios of more or less rapid electrification, and more and less carbon-intensive generation.[30] By 2050, they find, an electric vehicle would account for 59 to 71 percent less climate pollution per mile than cars built to the forthcoming CAFE standards.[31]

The footprint of vehicle manufacture and disposal

Any comprehensive analysis of EV impacts must also account for the side-effects of EV manufacture and disposal. It turns out that those impacts are small in comparison to those from operating the vehicle during its useful lifetime, amounting to about 20 to 25 percent of the car's emissions over its life-cycle.[32]

More importantly for this discussion, the climate impact of building an EV isn't much larger than for manufacturing an internal-combustion auto, amounting to a difference of just 35 to 40 grams CO_2-equivalent per mile, spread out over the lifetime of the car. For comparison, operating a contemporary gasoline vehicle is responsible for about 400 grams per mile of CO_2-equivalent emissions, falling to about 300 grams for a gasoline hybrid-electric vehicle[33]—nearly an order of magnitude more than the difference in manufacturing footprints.

In the DOE analysis cited here, the climate impact per mile attributed to car manufacture is sensitive to the assumed lifetime of the car (110,000 miles for a 70-mile-range EV, versus 160,000 miles for a 210-mile model or a hydrocarbon car), as well as the size of the battery bank for EVs. Longer range requires bigger batteries, which mean greater impacts from manufacture, an effect counterbalanced somewhat by the shorter assumed useful life of the short-range EV.

Like the climate impacts of the operation of an EV, the greenhouse gas emissions from the manufacture of EV batteries can decline over time as the power used at battery factories becomes greener. For instance, the Tesla "gigafactory" under construction in Nevada will generate all of its electricity renewably, and will not be supplied with natural gas, forcing plant designers to rely on that zero-emissions electricity for all the facility's energy needs. EVs using batteries from such a factory will thus leave a smaller climate footprint from their manufacture.[34] Over time, as EVs and their batteries are retired, the embodied energy in the next generation's batteries will decline as they are made partly from recycled materials.

How does this picture change if EVs are adopted in large numbers?

The analysis above takes a simplified view by focusing on the climate impact of a single electric vehicle. But it's important to examine whether the impacts would be qualitatively different if EVs were adopted at large scale. These potential differences arise mainly from an increase in electric demand to charge large numbers of EVs, which could change the mix of resources used to generate electricity, and thus the amount of extra carbon pollution that can be ascribed to each EV.

It turns out that large-scale adoption of EVs would result in only a modest bump in electricity consumption, all other factors being equal.

Using Federal Highway Administration figures on vehicle-miles traveled in each state broken down by vehicle type,[35] it is possible to estimate the electricity consumption by EVs at various rates of market penetration. Passenger cars traveled a total of 20 billion vehicle-miles in Oregon in 2013, and 34 billion vehicle-miles in Washington. (Other vehicle types can be electrified, but this thought experiment is confined just to passenger cars.) If, in the medium term, 10 percent of those miles were to be driven under battery power, electricity use would increase by about 0.6 billion kWh in Oregon and 1.0 billion kWh in Washington,[36] representing an increase of 1.2 percent and 1.1 percent respectively over current consumption.[37]

Even if the vast majority of passenger vehicles were electrified over the span of, say, two decades while production capacity ramped up and hydrocarbon-powered vehicles were retired at the end of their useful lifetimes, the total increase in demand would be on the order of 10 percent—a manageable increase over such a long period.

Such a scenario is described in a report by the Electric Power Research Institute, prepared in collaboration with the Natural Resources Defense Council. In the report's "electrification scenario," half of all new vehicles sold by the early 2030s are electrified (including a small proportion of plug-in hybrid vehicles), a figure that rises to 67 percent by 2045.[38] As a result, electric energy consumption would increase by 5 percent in 2030 and 13 percent by 2050[39]—an elaborately modeled conclusion that parallels the back-of-the-envelope estimates derived above for Oregon and Washington. With proper planning and policy incentives, this increase in electricity demand could be served with renewable sources of generation.

Such a shift toward clean power would be aligned with current trends. Of the net change in U.S. generating capacity for the 12 months ending in November 2015 (the most recent figures available), 6.7 GW of additions came from natural gas and 11.4 GW from wind, solar, and other renewables; meanwhile, coal capacity dropped by 13.7 GW.[40] The joint EPRI-NRDC study projected two scenarios for the mix of new generating resources that would be needed to power the electrified fleet they envision: a base case and a lower-greenhouse-gas-emissions case. Both rely on wind, solar, and gas, with some coal generation (equipped with carbon capture and storage) entering the mix in the 2040s.[41] If EV adoption increases as a result of public policy and consumer preference, utility resource planning can accommodate the new load with low-carbon generating capacity, depending on the incentives embodied in state-level Renewable Portfolio Standards, for instance.

On a decentralized scale, consumers and businesses can install solar arrays on rooftops and parking-lot canopies with which to charge their EVs. (In contrast, it would be hard to imagine maintaining one's own oil well and micro-refinery, or for large numbers of people to prepare and store their own supplies of biofuel.) Two studies by researchers at the University of California at Davis found that renewable energy and EV ownership were a synergistic combination in the minds of new or prospective EV owners.[42]

Even in cloudy Seattle, less than 300 square feet of rooftop solar panels would supply enough electricity to power an EV over the course of a year.

These trends in the generation mix supplied on the U.S. grid suggest that the climate impact of operating an EV will decrease over time, making electrified transportation an even more attractive approach to decarbonizing our economy than it is today.

Through this discussion of carbon emissions from power generation to charge EVs, it is critical to keep in mind that electrifying the light-duty fleet would bring about a much greater countervailing reduction in carbon pollution from petroleum that wouldn't be burned in internal combustion vehicles. The joint EPRI-NRDC study found that 35 years from now, high rates of transportation electrification would reduce national greenhouse gas pollution by an additional 10 to 14 percent of 2015 levels, depending on the mix of generating resources connected to the grid.[43] That reduction amounts to over half a billion tons of CO2 annually across the entire United States.

What about the increase in home electricity consumption?

Another way to assess EV energy demand is to estimate how much an EV would boost a family's monthly electricity consumption. Average Oregon and Washington residences consume 930 and 1,005 kWh per month respectively.[44] By comparison, an EV driven 12,000 miles annually (slightly more than the average US passenger car)[45] would add about 300 kWh to the household's monthly electricity usage, an increase of about 30 percent.

From the standpoint of controlling electric load growth due to transportation electrification, consider that switching from electric resistance heat to a heat pump at the mid-range of typical efficiencies (Heating Season Performance Factor of 8.5) would reduce electricity use for heating by about 60 percent.[46] According to a recent survey of how homes use energy in the Northwest, homes heated with electric resistance use 5 to 7 kWh of energy per square foot over the course of a year.[47] A 1,500-square-foot house would therefore use about 7,500 to 10,500 kWh of electricity for heating per year, which could be reduced by 60 percent (4,500 to 6,300 kWh per year) where feasible by switching from baseboard or electric furnace heating to a heat-pump system—more than enough to offset the increased electricity used by an EV.

Alternatively, a household could provide for an EV's electricity demands by installing additional solar panels as part of a rooftop or community solar array. Even at a low capacity factor of 15 percent (appropriate to western Washington's notoriously overcast skies), it would take less than 3 kW of solar panels to supply as much electricity as an EV would consume in a year.[48] That much solar capacity could be provided by less than 300 square feet of solar panels,[49] about the size of a typical living room.

From the perspective of the household finances, EVs promise a significant saving in fuel costs. The increase in the household's annual electric bill for those 12,000 miles of electrified driving would be more than offset by the decrease in its spending for hydrocarbon fuel. At average Oregon rates of 10.68 cents per kWh,[50] EV charging would cost $385, while in Washington (average price 9.36 cents) it would cost $337. By comparison, at the September 2015 price of $2.39 per gallon of unleaded regular[51] and a fuel economy of 35 mpg, an internal-combustion car would consume $821 worth of fuel.

On the Level: Different speeds of EV charging

Level 1: Uses a standard 120-volt plug from a regular household outlet, no installation required. It draws about 1.8 kW and recharges a 2015 Leaf overnight to its 80-mile range.

Level 2: This is a 240-volt specialized charging station on its own breaker, drawing about 3.5-7 kW. It can recharge a Leaf in about four hours. EV owners who own their own single-family residences often install these at home. They are also commonly found at EV-only public parking spots.

Level 3: Also known as DC fast charging, these chargers supply 480-volt DC charging current and can recharge a Nissan Leaf to 80 percent of its approximately 80-mile range in under half an hour. Different manufacturers have different plug designs and charging rates, which vary from about 50 kW for the Leaf standard to upwards of 100 kW for the Tesla.

How would the widespread adoption of EVs affect the grid?

Apart from the increased electric energy to charge EVs, the large-scale adoption of electrified transportation could also affect the peak power demands on the grid and the infrastructure—generating capacity, transmission lines, and distribution networks—needed to supply it.

Significant distribution upgrades are not yet needed, according to two recent California studies, but could be on the horizon within a decade and a half. With nearly 100,000 EVs on the road in late 2014, the three principal California investor-owned utilities found that just 0.1 percent of EVs had necessitated an upgrade to the service or distribution line.[52] A projection of where EVs will be adopted most rapidly showed that in neighborhoods where residents had a high likelihood of choosing EVs, distribution feeders would likely have to be upgraded by 2030 if most electrical refueling continues to occur at night in residential neighborhoods.[53]

Unlike the energy demands of EVs, which are simply a function of the vehicles' efficiency and the distance driven, the additional strain on utility infrastructure depends on how and when the EVs are charged—choices that can be modified with drivers' cooperation.

In a worst-case scenario for the utility, EV drivers returning home would plug in their cars in the early evening, just as household demand for other uses is ramping up as well. If EV penetration grew, most homes were equipped with Level 2 chargers that draw 7 kW apiece,[54] and neighborhood residents all began charging their cars in early evening, the additional demand could noticeably raise the utility's peak power demand.

Fortunately, it is possible to create incentives to charge EVs during periods of lower demand, and most EVs are already able to use software that dictates when and how quickly a car will imbibe its electric charge.

Basic time-of-use incentives—cheaper kilowatt-hours at times of lower demand—can shift charging into the late night hours, when utility infrastructure is under-utilized. It would be a terrific match with utilities that have a surplus of night-time wind generation; one Texas power company has already offered its customers free electricity between 9 pm and 6 am.[55] Pilot studies,[56] including a program with 430 Leaf owners in the San Diego area,[57] have shown that EV drivers are easily induced to schedule charging in order to take advantage of cheaper rates.

As the grid absorbs larger quantities of solar power, it may become advantageous to shift charging to the morning and middle of the day instead, as a way of flattening the belly of the famous "duck curve" of hourly power demand,[58] in which load on fossil generators drops in the morning and middle of the day and then ramps up quickly in the evening as the sun fades.[59]

EV adoption by car-buyers is lagging for two principal kinds of reasons: technological and institutional.

For EV drivers who commute by car to daytime jobs, taking advantage of that prospective surplus of PV generation would require them to charge at or near their workplaces and reverse their thinking about needing a charge to get from home to work and back. Instead, they could think in terms of charging their car to get from work to home and back to work the next day.

This scenario is one possible outcome of smart charging, in which "customers can charge their EVs in response to more granular price signals from the utility and so can sync with lower-cost times," as Rocky Mountain Institute succinctly defines it.[60] Those price signals sent by the grid's system operator would reflect real-time grid conditions, such as the imminent need to fire up an expensive peaker plant if load increased, or the availability of surplus wind or solar power.

In these programs, EV drivers set their recharging parameters, so they can be sure of having accumulated enough range for the driving they anticipate by the time they unplug.

Sacramento Municipal Utility District tested three different time-of-use and demand reduction programs, including one in which the utility can dial back the EV's charging rate to 1.4 kW during times of peak demand, and had no trouble finding volunteers to test that arrangement.[61] Siemens has also debuted a wi-fi-enabled charge controller, which can adjust charging rates based on utility data and user instructions.[62]

Utilities have already tested programs in which customers allow grid managers to curtail the power to specific appliances (air-conditioners and pool pumps) during peak demand events, in return for a fixed monthly fee.[63] Similar programs could be designed for EV charging, as long as BEV drivers had the opportunity to override the utility's instructions; PHEVs could be interrupted to optimize grid conditions without inconveniencing drivers.

While the advantage of smart charging is measured in dollars and cents for EV owners, it can be also be measured in megawatts of shifted demand for the utility. If the utility can dial thousands of EVs' charging rates up or down to suit the needs of the grid, that would amount to a substantial resource for system operators matching instantaneous supply and demand.

Consider, for instance, the Klamath Peaking plant on the Oregon-California border, composed of four simple-cycle natural-gas turbines with a combined output of 100 MW, or 25 MW each.[64] A Level 2 charger draws about 7 kW; if grid operators could delay the Level 2 charging of roughly 3,600 EVs, that would be enough to avoid the dispatch of one of those turbines.

The rise of electrified vehicles is already over-determined by trends in technology, price, and societal pressure to reduce carbon pollution.

In Washington, 21,000 EVs charging at Level 2 would equal the 147-MW Frederickson Generating Station, a Puget Sound Energy peaker plant in Pierce County.[65] Because those single-cycle peaker plants are less efficient than combined-cycle natural gas generation, time-shifting demand from peaker plants to combined-cycle natural gas reduces carbon pollution. While that number of EVs is large compared to current EV registrations in Washington state (approximately 13,000 in mid-2015),[66] it is small compared to the number of passenger cars on the road—4.6 million.[67] So if EVs came to comprise even 10 percent of the on-road auto fleet, their smart charging capabilities could become a significant grid resource.

At that level, the aggregate energy storable in EV batteries would also provide a useful resource for the grid. Using that same benchmark of 10 percent of the Washington passenger car fleet, and making the conservative assumption that the battery capacity were similar to a 2015 Leaf (24 kWh), the combined storage in those 460,000 cars would amount to 11 million kWh, or about nine hours' output of Bonneville Dam at maximum capacity.[68]

Of course, by the time EVs came to comprise 10 percent of the cars on the road, that would be an underestimate. Declining battery prices and consumers' "range anxiety" are leading manufacturers to build EVs with greater battery capacity. Nissan, for example, is offering a 107-mile version of its Leaf in 2016 with a 30-kWh battery pack, and is expected to produce a 200-mile version in 2017 or 2018.[69] As EV-makers and owners gain more experience with battery life, experiments with the use of EV batteries to send energy back to the grid may go from the pilot stage, where they are now,[70] to widespread use.

So what's the hold-up?

Electric vehicles might sound like the best innovation in human transportation since the saddle, but they still represent a tiny fraction of the cars that US consumers are buying–less than 1 percent of US auto sales in 2014,[71] counting all cars that accept a charge from the grid, including those with gasoline engines on board (plug-in hybrids such as the Toyota Prius, Ford C-Max, and Chevy Volt).[72]

EV adoption by car-buyers is lagging for two principal kinds of reasons: technological and institutional. On the engineering front, battery capacity has been limited by the cost of lithium-ion batteries—a handicap that is easing as battery makers progress up the learning curve and achieve economies of mass production. Battery prices fell 14 percent per year from 2007 to 2014, and are projected to drop even further.[73]

The barriers impeding access to vehicle charging are significant, but not insurmountable.

At a cost of $300 per kWh, the 24-kWh battery pack in a Leaf represents about one-fourth of its retail price. As those prices come down, manufacturers can begin to equip their EVs with battery packs that provide longer range, alleviating the "range anxiety" that arises when EV drivers run up against the limits of their on-board batteries.

Despite the barriers described below, the rise of electrified vehicles is already over-determined by trends in technology, price, and societal pressure to reduce carbon pollution. As advances in EV engineering reduce the cost of manufacturing and increase the range, the proportion of EVs in the auto fleet is bound to increase. What's still up for grabs is whether fuel-cell vehicles will eventually give battery-powered EVs a run for their money as the hydrogen-based technology matures; how quickly car purchasers choose electric-drive vehicles over internal combustion models; and how equitably the benefits of vehicle electrification will be shared among people of different income levels. The next section looks briefly at the social innovations that will be required to make EVs a viable choice for people across the spectrum of financial resources and life circumstances.

Institutional barriers

The urban infrastructure for personal automobiles has been built around the premise of fueling at gas stations, a process that takes five minutes or so for every few hundred miles of driving. In contrast, EVs have to be connected to the grid for several hours to charge at a Level 2 charger (installed cost: $1,200 or so,[74] with some regional utilities offering rebates that will cover nearly half of that cost).[75] This suggests the need to re-power EVs at locations where drivers spend a lot of time: home or work.

For some drivers, that needn't represent a significant impediment—for example, if they own their own home with off-street covered parking, and can consider the cost of charger installation as part of the cost of acquiring their first EV. However, many segments of the population would not find it so simple. Tenants would be reluctant to make that kind of investment, even if their landlords were amenable.

Many residents of urban areas don't have designated private parking spots; in multi-family residences, the landlords may not perceive an incentive to install chargers unless they are trying to market their apartments to EV drivers, while the tenants would not have the incentive to invest in a lasting improvement to the building. Finally, even in parts of Seattle and other Northwest cities where private alley parking is available, some of the garages have been repurposed as in-law apartments and home offices. All of these situations make it hard for large parts of the population to gain access to electricity for use as a transportation fuel.

These barriers are significant, but not insurmountable. Utilities and third-party providers of charging services could establish charging stations that are open to the public, accessible by either membership or card-swipe. However, utility involvement raises concerns about vertical integration and the utilities' use of their monopoly power to outcompete other charging providers.

A bigger question involves the allocation of the municipal right-of-way for private use, or to a restricted subset of drivers, at a time when access to parking spots is at a premium. Perhaps one way to think about it is by analogy to Zipcar, which has been allocated parking spots because it is believed that the public benefit of car-sharing is ample justification for the allotment of public resources (parking) to a private firm. The analogy is imperfect, however, as obtaining a Zipcar membership is much easier than acquiring an EV.

Conclusion

The electric vehicle stands on the brink of a breakthrough in feasibility and customer appeal. Ten auto manufacturers offered an all-electric four- or five-seat vehicle to the U.S. market in the 2015 model year,[76] up from three in 2011.[77] The batteries powering these cars are a far cry from the half-ton of lead-acid batteries that propelled the General Motors EV-1 when it was first released in 1996.[78] Electric cars have won praise for the quality of the driving experience they provide, as well as their efficiency and inexpensive maintenance.[79]

Even more significantly for societal goals of clean air and a stable climate, EVs have progressed to the point where they provide an off-ramp from dependence on petroleum for personal mobility. (With the advent of electric buses, this is true for public transit as well as private automobiles.[80])

Given the current mix of electric generating resources on the Northwest's grid, EVs account for only as much carbon dioxide per mile as a 94-mpg car. As coal plants retire and are replaced with lower-carbon resources, those emissions will only decline. Adopted at scale, EVs will add a significant amount of energy storage to the electrical system, which will facilitate the uptake of greater quantities of wind and solar power, whose output fluctuates with weather conditions. Making use of existing transmission and distribution infrastructure, they can attack the Northwest's largest source of climate pollution, while requiring only a modest, manageable increase in electricity supply, and one which can be offset at least in part by increases in end-use efficiency.

EVs can provide a financial benefit to their drivers as well, because electricity as a transportation fuel is cheaper than petroleum. For these benefits of electrified transportation to be broadly shared among all segments of society, however, new policies will need to be adopted at the local and state levels. Electricity for use as a transportation fuel must be available at a reasonable price to all drivers, regardless of whether they have access to private off-street parking of their own.

If utilities become involved in providing car-charging services, regulators will need to ensure that they do not use their position as the supplier of the electricity to reap an improper advantage over other providers. Regulators must also see to it that tariffs for electricity used to charge EVs fairly reflect the cost of providing that service, without discrimination in comparison to prices charged to other ratepayers. For municipal utilities and co-ops to become involved in increasing the availability of charging services, they may need clarification of their legal authority to use ratepayer dollars to promote its availability.

These details are important for the equitable adoption of EVs, and to maximize the climate benefits of this technology. By broadening the spectrum of people who can make use of EVs, tackling these issues will speed the penetration of EVs into the auto fleet, and hasten the day when our region realizes the full benefits of a shift to electrified transportation—a shift that will be good for the Earth's climate and the region's prosperity alike.

Endnotes

[1] Estimated by quintupling the calculations for a 10 percent penetration rate for electrified vehicle-miles, described below on page 9, drawing on the sources in notes 36 and 37.

[2] Calculated from figures in "Monthly Energy Review June 2015" (Washington, D.C.: U.S. Energy Information Administration, June 25, 2015), Tables 2.2 and 2.3, https://www.eia.gov/totalenergy/data/monthly/archive/00351506.pdf.

[3] Ibid., Table 2.6.

[4] "Monthly Energy Review November 2015" (Washington, D.C.: U.S. Energy Information Administration, November 24, 2015), https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf. Calculated from figures in Table 12.6 (Carbon Dioxide Emissions From Energy Consumption: Electric Power Sector) and Table 7.2b. (Electricity Net Generation: Electric Power Sector).

[5] Ibid., Table 1.8 (Motor Vehicle Mileage, Fuel Consumption, and Fuel Economy), p. 19.

[6] Bill Vlasic, "U.S. Sets Much Higher Fuel Efficiency Standards," The New York Times, August 28, 2012, http://www.nytimes.com/2012/08/29/business/energy-environment/obama-unveils-tighter-fuel-efficiency-standards.html.

[7] Transportation was responsible for 42.5 million metric tons of CO2 emissions, of which 41.7 million tons were from petroleum-derived fuels, out of total CO2 emissions of 78 million tons of CO2. In addition, another 14 million tons of CO2-equivalent were discharged into the atmosphere from other sources, such as methane from ruminant digestion and CO2 from cement production. Petroleum for transportation thus accounts for 45 percent of the state's total climate pollution. "Washington State Total Annual Greenhouse Gas (GHG) Emissions," Washington State Greenhouse Gas Emissions Inventory 2011-2012 (Washington State Department of Ecology), accessed November 30, 2015, http://www.ecy.wa.gov/climatechange/docs/2012CO2e_table.pdf.

[8] "Biennial Report to the Legislature 2015" (Oregon Global Warming Commission, 2015), http://www.keeporegoncool.org/sites/default/files/ogwc-standard-documents/OGWC_Rpt_Leg_2015_final.pdf. Total climate pollution was nearly 61 million metric tons of CO2-equivalent, with 50 million coming from the combustion of fossil fuels. (Table 7, p. 58.) Of those, 22.3 million, or 45 percent, came from petroleum products burned in transportation. (Table 8, p. 59.)

[9] "Washington State Total Annual Greenhouse Gas (GHG) Emissions."

[10] "Oregon Greenhouse Gas Emissions: Updated Inventories," Report to Oregon Global Warming Commission (Oregon Department of Environmental Quality, April 2015), http://www.keeporegoncool.org/sites/default/files/meeting-supporting-files/OGWC%20inventory%20update%20April%2021.pdf.

[11] This figure excludes the denaturant added to make the ethanol undrinkable. "Monthly Energy Review November 2015," Table 10.3, 155.

[12] Ibid., Table 10.4, 156.

[13] Ibid., Table 2.5, 37.

[14] According to a brochure from the Department of Energy, 0.78 million BTU of fossil energy are consumed to produce 1 million BTU of ethanol, versus 1.23 million BTU of fossil energy that are used in the production of 1 million BTU of gasoline. "Ethanol: The Complete Energy Life Cycle Picture" (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, March 2007), http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/ethanol_brochure_color.pdf. 0.78 ÷ 1.23 = 63%

[15] Fossil energy used for ethanol: 1.11 Q x 0.78 = 0.866 Q. Fossil energy avoided: 1.11 x 1.23 = 1.365 Q . Fossil energy saved: 1.365 – 0.866 = 0.499 Q (Factors 0.78 and 1.23 from note 14 above.)

[16] The fossil ratio of 5.5 is calculated in: A. Pradhan et al., "Energy Life-Cycle Assessment of Soybean Biodiesel Revisited," American Society of Agricultural and Biological Engineers 54, no. 3 (2011): 1031–1039.:15

[17] "Monthly Energy Review November 2015," Table 7.2a, 109.

[18] "California Renewable Portfolio Standard (RPS)," California Public Utilities Commission, October 7, 2015, http://www.cpuc.ca.gov/PUC/energy/Renewables/.

[19] Data and generation vs. consumption figures here: "State Electricity Profiles 2013," U.S. Energy Information Administration, July 8, 2015, http://www.eia.gov/electricity/state/.; data for Oregon and Washington in Table 5, Electric Power Industry Generation by Primary Energy Source, http://www.eia.

gov/electricity/state/oregon/xls/sept05or.xls and http://www.eia.gov/electricity/state/washington/xls/sept05wa.xls

[20] "Oregon Clean Fuel Standard for Gasoline and Gasoline Substitutes," Division 253 Clean Fuels Program (Oregon Administrative Rules), Table 1, accessed November 30, 2015, http://arcweb.sos.state.or.us/pages/rules/oars_300/oar_340/_340_tables/340-253-8010_1-7-15.pdf.

[21] Donella Meadows, "A Thousand Miles Per Gallon," Donella Meadows Institute, September 29, 1994, http://www.donellameadows.org/archives/a-thousand-miles-per-gallon/.

[22] With respect to criteria air pollutants such as nitrogen oxides, particulates, and ground-level ozone, "elsewhere emissions" can be a positive development. Displacing emissions out of urban areas where pollution standards are routinely violated can provide a significant public health benefit, though one which lies outside the scope of the climate focus of this paper.

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[25] "Electric Power Annual 2013" (US Energy Information Administration, March 2015), http://www.eia.gov/electricity/annual/pdf/epa.pdf, calculated from Table 5.4.D (8,813 trillion BTU of natural gas burned for electricity generation in the US), Table 3.1.A (1,125 million MWh of electricity generated with natural gas, or 1,125 billion kWh), Table 1.3 (line losses of 244 out of 4,135 million MWh, or 5.9%), and an emissions factor of 117.0 lb of CO2 per million BTU (cited in this US EIA FAQ document, "How much carbon dioxide is produced when different fuels are burned?" http://www.eia.gov/tools/faqs/faq.cfm?id=73&t=11). 8,813 trillion BTU ÷ 1,125 billion kWh ÷ (1 – 0.059) x 117 lb / million BTU = 0.976 lb/kWh.

[26] Although the manufacturer spells the car's name in all capital letters (LEAF), in this paper it is written with just an initial capital 'L' for consistency with other automotive brands.

[27] 30 kWh per 100 miles, or 3.3 miles / kWh. "2016 Nissan Leaf (24 kW-Hr Battery Pack)," Energy Efficiency & Renewable Energy, U.S. Department of Energy, accessed December 1, 2015, http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=37066.

[28] For a gallon of purely fossil gasoline, the figure is 19.64 pounds. For motor fuel containing 10% ethanol, the figure used in greenhouse inventories is 17.68 pounds, since biofuel is not counted as having any greenhouse impact. However, to make the accounting properly parallel to the climate reckoning of an EV, the emissions from producing the ethanol must be accounted for. As cited above, corn-based ethanol—the bulk of the ethanol mixed into the US motor fuel supply—accounts for 37 percent less fossil-fuel energy than the energy it releases when burned, so each gallon of E10 gasoline accounts for the emission of about 18.9 pounds of CO2. 3.3 miles/kWh x 18.9 pounds / gal ÷ 0.976 pounds / kWh = 64 miles / gal. "FAQ - How Much Carbon Dioxide Is Produced by Burning Gasoline and Diesel Fuel?," U.S. Energy Information Administration, July 7, 2015, http://www.eia.gov/tools/faqs/faq.cfm?id=307&t=11.

[29] "Clean Power Plan for Existing Power Plants," Policies and Guidance (U.S. Environmental Protection Agency), accessed November 30, 2015, http://www2.epa.gov/cleanpowerplan/clean-power-plan-existing-power-plants.

[30] "Environmental Assessment of a Full Electric Transportation Portfolio, Volume 1: Background, Methodology, and Best Practices" (Palo Alto, CA: Electric Power Research Institute (EPRI), 2015), See, in particular, 4–1 to 4–13, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?productId=000000003002006875.

[31] Luke Tonachel, "Study: Electric Vehicles Can Dramatically Reduce Carbon Pollution from Transportation, and Improve Air Quality," Switchboard: Natural Resources Defense Council Staff Blog, September 17, 2015, http://switchboard.nrdc.org/blogs/ltonachel/study_electric_vehicles_can_dr.html.

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[33] Joseck and Ward, "Cradle to Grave Lifecycle Analysis of Vehicle and Fuel Pathways." p. 11

[34] Kyle Field, "Tesla Gigafactory Will Indeed Be 100% Renewable Powered," EV Obsession, November 12, 2015, http://evobsession.com/tesla-gigafactory-will-indeed-be-100-renewable-powered/.

[35] "Functional System Travel, Annual Vehicle-Miles," Highway Statistics 2013 (Federal Highway Administration Office of Highway Policy Information, October 2014), Table VM–2, https://www.fhwa.dot.gov/

policyinformation/statistics/2013/vm2.cfm; “Distribution of Annual Vehicle Distance Traveled - Percentage by Vehicle Type,” Highway Statistics 2013 (Federal Highway Administration Office of Highway Policy Information, November 2014), Table VM–4, https://www.fhwa.dot.gov/policyinformation/statistics/2013/vm4.cfm.

[36] This approximation, for 2 billion vehicle-miles in OR and 3.4 billion in Washington, is based on a fuel economy of 0.3 kWh/mile: not as good as a BMW i3 or Chevrolet Spark, equivalent to the Nissan Leaf, and better than the Tesla Model X. As experience with EV design increases, electricity consumption can be expected to decrease. “Compare Side-by-Side,” Energy Efficiency & Renewable Energy, U.S. Department of Energy, accessed December 1, 2015, http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=37066&id=36979&id=36996&id=36016.

[37] Total electricity consumption from US EIA figures: 48.23 billion kWh in Oregon, including 589 million kWh of direct use, and 94.1 billion kWh in Washington. “Oregon Electricity Profile 2013,” U.S. Energy Information Administration, July 8, 2015, http://www.eia.gov/electricity/state/Oregon/; “Washington Electricity Profile 2013,” U.S. Energy Information Administration, July 8, 2015, http://www.eia.gov/electricity/state/Washington/.

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[39] Ibid., 4-12.

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[42] Max Baumhefner, Ed Pike, and Andreas Klugescheid, “Plugging Vehicles into Clean Energy,” Electricity Journal 26, no. 1 (April 2013): 72–80.

[43] In the baseline generating mix scenario, electrification makes the difference between a 31 and 41 percent reduction in GHG emissions. For their high-renewables case, the difference is between a 48 and 62 percent cut. “Environmental Assessment of a Full Electric Transportation Portfolio: Volume 2: Greenhouse Gas Emissions.,” 8–1 to 8–4.

[44] “2014 Average Monthly Bill- Residential” (U.S. Energy Information Administration), accessed November 30, 2015, http://www.eia.gov/electricity/sales_revenue_price/xls/table5_a.xls.

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