Electric and Advanced Mobility
Board Learning Paper

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Preface

This paper is part of a series that describes a variety of topics identified by the Energy Trust of Oregon's Board of Directors as potentially influential to the organization during the time period of its next strategic plan (2020 – 2024). This series of papers will educate and inform the Board about the potential impact of these topics and enable its Directors to better to assess risk, identify opportunity and guide the direction and goals of Energy Trust.

Remaining current on potentially significant and influential developments in the clean energy industry is critical to the fundamental role of the Board. These topics have been identified because of their potential to influence, impact or otherwise affect Energy Trust's ability to serve the ratepayers of Oregon and Southwest Washington. **These papers should not be interpreted as policy proposals or recommendations for roles in which Energy Trust intends or desires to be directly involved.**

Introduction

Energy efficiency is the cleanest, cheapest and most important resource for the utilities and ratepayers of Oregon, and Energy Trust is the prime organization delivering that resource. Transportation is a topic pertinent to Energy Trust because transportation is the largest source of energy use and greenhouse gas emissions in Oregon[1],and is undergoing dramatic transformations that hold the promise of dramatic efficiency increases.

Transportation consumes an extraordinary amount of energy in Oregon. In 2017, Oregon's roughly 3.2 million passenger vehicles travelled about 36 billion total miles. That travel consumed approximately 1.4 billion gallons (170 trillion BTUs) of gasoline in 2015. To put this in perspective, that is the equivalent of 49.8 billion kWh or 5,685 aMW. For context, Energy Trust of Oregon-supported projects saved and generated 728 aMW from 2002-2016. Other forms of transportation, such as trucking, freight and aviation, consumed additional energy. Overall, in 2015 transportation emitted about 37 percent of Oregon's carbon dioxide emissions.[2] Americans spend about $1.4 billion per day on gasoline and diesel for on-road use (versus $1 billion per day on electricity). Oregon drivers spend over $3.8 billion per year for gasoline.[3]

Internal combustion vehicles are only about 25 percent efficient in translating the energy content of gasoline into motion. An electric vehicle (EV) is about 60 percent efficient, consuming 70-80 percent less energy per mile.[4] According to the Northwest Energy Coalition, “EVs can be thought of as just another energy-efficient appliance, like an LED bulb or a heat pump.”[5] Electric and advanced mobility offer dramatic efficiency opportunities. As illustrated in Figure 1, even a five to ten percent adoption rate of EVs could save more energy than current regional electricity conservation plans. Electric vehicles also offer the potential to accept excess renewable energy off peak, feed that energy back to the grid at peak times and offer other grid services.

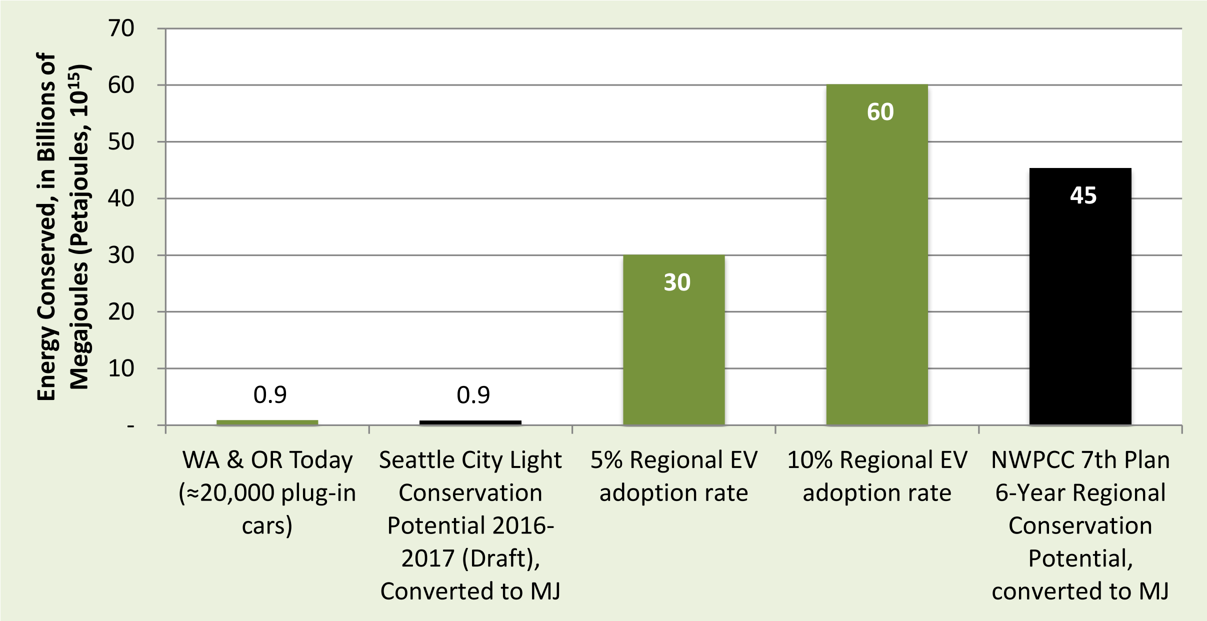

Figure 1: Relative Conservation Potentials (in Joules) From EVs and Current Utility Sector Conservation Programs[6]

Transportation electrification has the potential to be one of the most the most significant societal energy changes, but there are other autonomous, connected, electric and shared technologies (often referred to as “ACES”) that could dramatically reduce energy use and carbon pollution from transportation. For example, the average American car today is parked over 90 percent of the time, and has an average occupancy of just 1.08 people when it is driven, yielding a “capacity factor” of well under 2 percent.[7] ACES technologies could allow vehicles to be used more hours in a day, carrying more passengers per trip, increasing vehicle capacity factors and reducing energy consumed per passenger per mile.

The transformation underway in mobility creates significant energy opportunities, and brings utilities and the transportation sector together in new and disruptive ways. This paper briefly discusses these disruptive trends and technologies; describes the current and projected future deployment of these technologies in Oregon; and identifies opportunities where coordinated interventions by stakeholders will be required to ensure positive outcomes for energy efficiency and society at large.

Transportation Electrification and Electric Utilities

Transportation electrification will have impacts on electric utilities. Utilities can expect a 13 percent to 40 percent increase in electricity consumption among households that own an EV that is charged at home and driven 5,000 to 15,000 miles a year.[8] Over 75 percent of charging happens at home overnight, which can benefit utilities by flattening the load curve. Conversely, EVs also could increase afternoon peak loads as drivers come home and plug in. However, unlike lights or air conditioning, EV drivers have little preference about when energy is flowing to the car, as long as charging is complete by a certain time. All vehicles, and most chargers, offer options for delaying or managing the time of charging.

Studies also have shown that widespread EV adoption will have little to no effect on generation, transmission or distribution systems. For example, a report by Southern California Edison, home to 12 percent of the nation's EVs, found that grid impacts in its service territory were modest (only one percent of upgrade work), despite the fact EVs may tend to cluster in specific neighborhoods.[9]

In fact, most evaluations related to the rate impacts of EVs show that increased EV adoption will put downward pressure on rates by increasing the utilization of the system and spreading fixed costs. As shown in Figure 2, a modeling study in California found that additional revenue from EV charging exceeded the marginal costs to deliver electricity to the customer, providing positive net revenues of several thousand dollars per car.[10] Studies in Washington State found similar, yet more modest, benefits. A national study recently completed by MJ Bradley & Associates for CERES found a payback of more than three-to-one to customers for utility investments in transportation electrification.[11]

Overall, electric utilities have much to gain from transportation electrification. Consumers also expect utilities to be involved in this space. A survey of consumers conducted by the Edison Electric Institute found that almost two-thirds wanted their electric utility to take a leadership role in encouraging a shift toward electric transportation.[12]

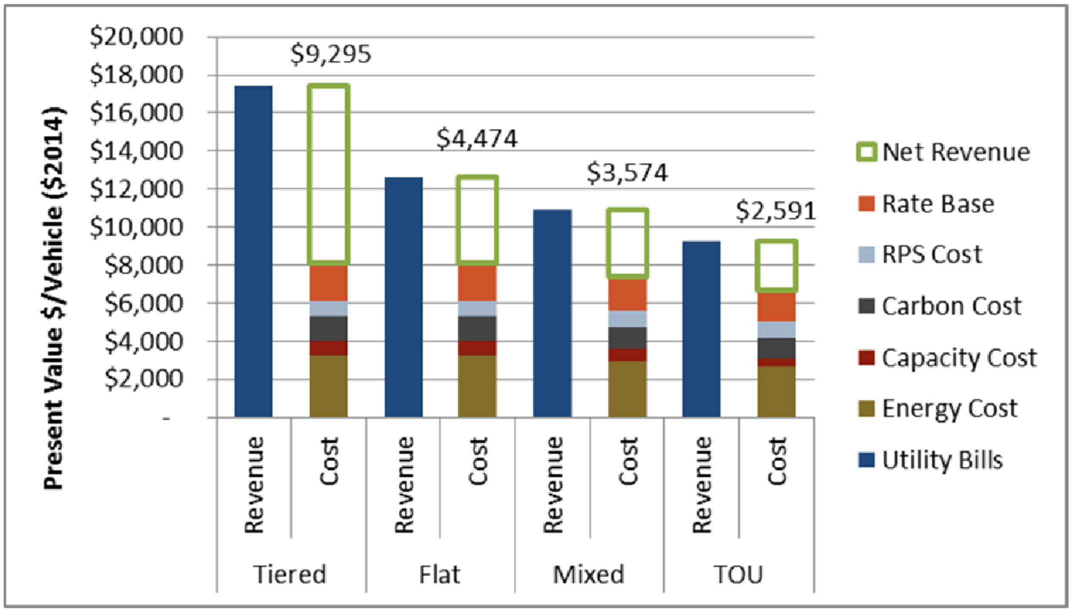

Figure 2: Ratepayer Costs and Benefits in Several Rate Scenarios in Present Value per Vehicle[13]

Transportation Electrification is Evolving Quickly

Electric vehicles offer dramatic energy and environmental benefits for both electric utilities and society. They produce no tailpipe air pollution, thus improving air quality in population centers. Depending upon the generation resource used to charge them, EVs can also dramatically lower carbon pollution compared to gasoline cars. The Union of Concerned Scientists estimates that electric vehicles powered by Pacific Northwest utility electricity achieve the equivalent of driving a gasoline car that gets 75 miles per gallon – if such a thing existed. EVs also produce fewer contaminants (oil, coolant, etc.) thereby reducing pollution in storm water runoff.[14]

While they are currently more capital-intensive, electric vehicles are far cheaper to operate. For example, powering a car with electricity in Oregon is roughly equivalent to buying gas for $0.97 a gallon.[15] Driving on domestically produced electricity reduces spending on foreign oil. On average, a dollar saved at the gas pump and spent on the other goods and services that households want creates 16 times more jobs.[16]

Modern EVs only became widely available in 2011, but sales have been increasing rapidly. Cumulative U.S. EV sales hit 500,000 in August 2016, with over 16,000 electric vehicles registered in Oregon. Worldwide EV adoption rates are projected to climb steadily, and Morgan Stanley expects EVs to account for between 10 and 15 percent of the American new car market by 2025. These bullish EV adoption projections are driven, in part, by a dramatic fall in the cost of lithium-ion batteries used to power EVs.

In Oregon, EV sales are poised to double by 2020 aided by state and federal investments and policies. For example, SB 1547, passed in 2016, requires Oregon's investor-owned utilities to develop transportation electrification plans. Both Portland General Electric and Pacific Power have developed and submitted modest initial plans and have reached proposed settlement agreements that would inject approximately $9 million into charging and other EV programs over the next three to five years. Oregon also passed legislation in 2017 that will create a $2,500 point-of-purchase rebate for new EVs, and an additional $2,500 for lower income drivers that can be applied to used EVs.

Research shows that offering a point of purchase rebate is the best way to motivate consumers to purchase EVs[17] and sales are expected to climb when the rebates take effect in 2018. Oregon and California are among eight states that have adopted a binding Zero-Emission Vehicle mandate that requires automakers to sell increasing numbers of electric vehicles. Oregon Governor Brown has set a goal that all new vehicles sold will be electric by 2050. Additional investments in electric vehicle charging are coming to Oregon through Volkswagen's diesel settlements. Those settlements commit Volkswagen to invest $2 billion nationally over the next ten years in EV charging infrastructure[18] and distribute $72 million to Oregon for clean air projects including transportation electrification.

Autonomous, Connected, Electric and Shared (ACES)

The electric vehicle revolution is coming simultaneously with two other revolutions in mobility: autonomous and connected vehicles, and shared mobility. Figure 3 illustrates these possible scenarios. These ACES technologies are attracting billions in investment from major automakers and from technology firms like Alphabet (Google's parent company) and Uber. A recent UC-Davis report projects a limited rollout of driverless vehicles through the early 2020s, followed by mass-market rollouts in 2025.[19] Although there are many uncertainties, if all three of these technical revolutions are embraced, the initiatives could cut global energy use from urban passenger transportation by more than 70 percent and reduce the number of vehicles by up to 99 percent.[20]

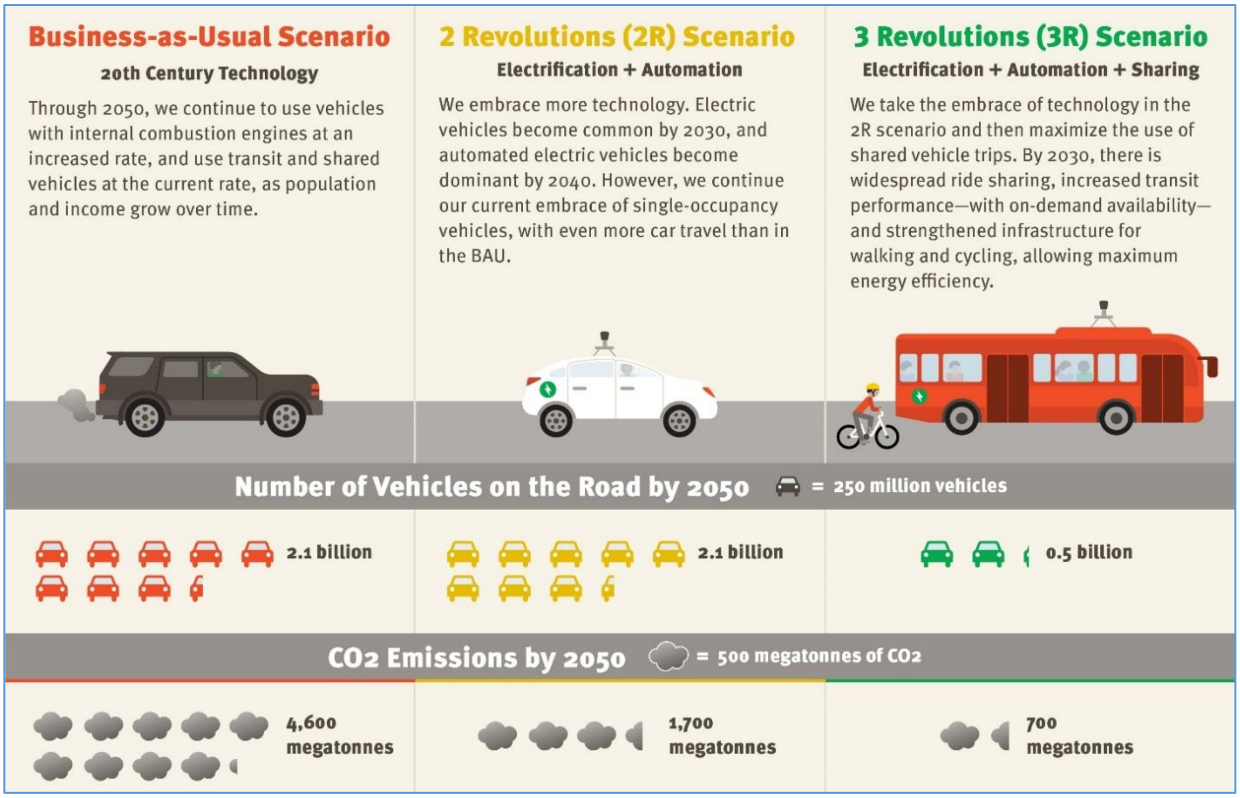

Figure 3: Potential Impact of Electrification + Automation + Sharing "Revolution" [21]

Transportation Electrification Opportunities

There are many stakeholders in the EV market, as outlined in Figure 4, and there are many areas where market intervention will be required to maximize public benefits. In most cases, it is not clear which stakeholders will own these key areas of work. Several of these areas are of particular relevance to the Energy Trust of Oregon.

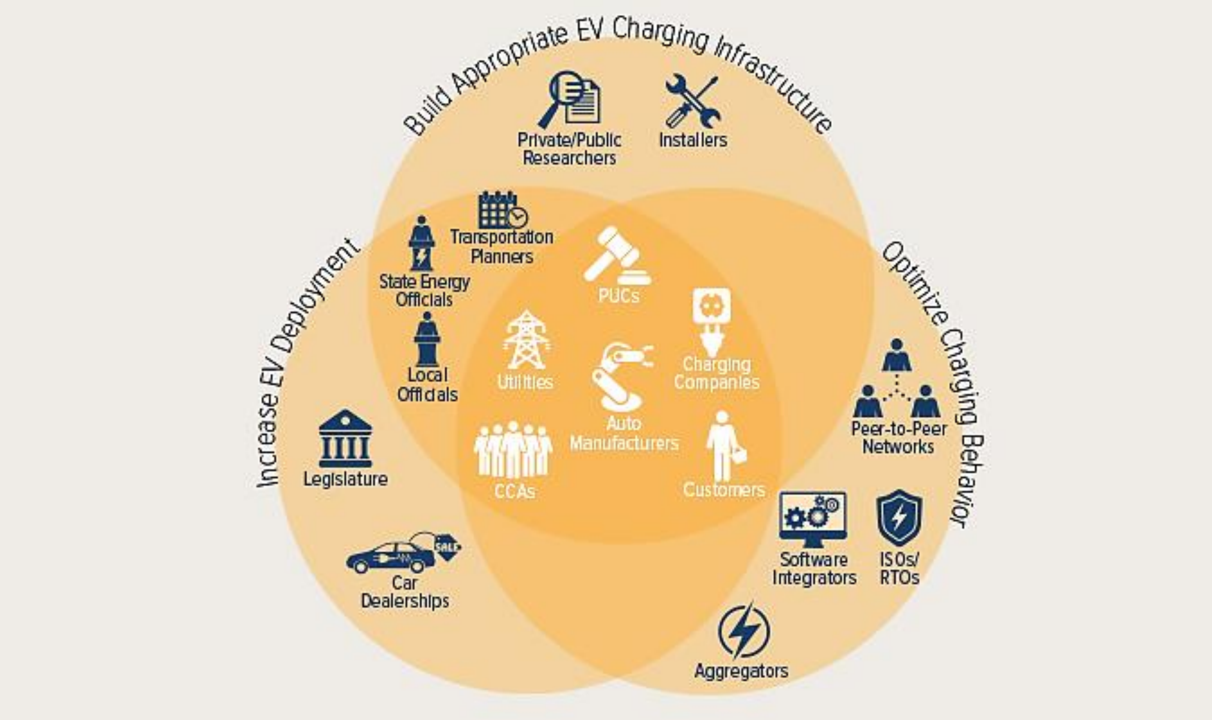

Figure 4: Areas of Intervention in the EV Market and Key Stakeholders[22]

I. Integrating EVs into Existing Efficiency and Renewable Programs

Many existing energy efficiency and renewable energy programs address transportation electrification and appeal to similar markets and consumers. Over time, these programs could better integrate transportation and electric vehicles in several ways. For example, some charging equipment is more energy efficient, and the ENERGY STAR® program has recently begun evaluating chargers. Because electricians and technicians are already on site upgrading and installing other systems, the best and least expensive time to add EV charging is during new construction or renovation. Implementing energy efficiency measures, can also free up capacity in existing homes or buildings for EV charging. Existing energy efficiency programs could leverage the opportunity to educate and better inform customers about EVs, and how best to integrate charging into home and energy improvement projects. For solar installers, this is also an opportunity to “upsize” the solar system, sell additional equipment and create cross-marketing opportunities among market actors.

A PV solar system can also enhance EV benefits by decarbonizing the electric charging resource and helping to flatten the vehicle’s demand curve. Consumers that add electric vehicles may reap more benefits (and a faster payback) from their solar array, and utilities could reduce costs for net-metered systems if customers consume more electricity on-site.

II. Making Charging Smarter

Promoting charging at off-peak times is the best way to maximize financial and grid benefits to electric utilities. Managed or “smart” charging programs are designed to control the times and associated rates when customers charge. Additionally, smart charging may include having vehicle batteries that serve as a dynamic demand response asset, that discharge energy back to the grid (Vehicle-To-Grid or VTG), or that provide other ancillary grid services such as frequency regulation. Managed or smart charging may use a combination of consumer education and marketing, time of use rates and even “gamification” strategies. These programs can even include real-time pricing transactions by customers, the utility, the charging provider or an automated system to better integrate renewables and maximize grid benefits. However, managing charging first requires a basic understanding of the different types of charging available to EV drivers.

Simply plugging the EV in to a standard 120V wall socket and using the vehicle’s built-in converter is called “Level 1” charging. Level 1 charging takes eight hours or more to charge a fairly small-capacity EV battery. More than 75 percent of charging takes place at home, and roughly half of EV drivers manage with Level 1 charging. That share also is increasing. The fact that Level 1 charging is easy, cheap and available nearly everywhere can help convince consumers to try electric vehicles. However, Level 1 charging is less energy efficient and makes smart or managed charging more difficult.

Dedicated charging equipment using a 240V outlet is referred to as “Level 2” charging. Residential Level 2 chargers on average cost about $600 and provide a reasonably fast charging option. However, many drivers are discouraged from upgrading to Level 2 charging by the soft costs of choosing equipment, finding a qualified electrician, getting an installation estimate, etc. Some utilities are working to streamline the process for customers by creating lists of approved equipment and trusted installers, but these efforts are slow and scattered.

Direct Current Fast Charging is limited to public and commercial settings, because installations can cost $100,000 or more. These fast chargers generally operate at 50kW currently and give EV drivers the ability to charge quickly while on a longer trip, or if daily plans change. Direct Current Fast Charging is critical for the industry to achieve a number of milestones, including increasing consumer confidence, enabling drivers to travel long distances, and the ability to use EVs in shared applications such as taxis or Uber rides. However, these installations represent a substantial power draw and will not be profitable until substantial numbers of EVs are using them. Historically, demand charges alone constituted well over half the cost of operating a fast charger. (The mismatch between charging and vehicles is a broader concern, sometimes referred to as the “hot dog and bun” dilemma.[23]) Close coordination with utilities can help reduce the need for transmission and distribution investments, reduce other soft costs and manage demand charges and other rate issues.

EV charging is poised to get smarter in the coming years, in line with broader trends towards demand response and a smarter grid. Vehicle-To-Grid technologies designed to enable the bidirectional flow of energy between the EV and the grid have already been proven in several small pilot projects. This grid interaction could support utility demand response and provide ancillary services to a grid operator, such as frequency regulation. There are also demonstration projects underway that deploy used EV batteries to store renewable energy and provide grid services. These technologies are constrained mostly by programmatic issues, such as automaker battery warranties and utilities that see more immediate demand response opportunities rather than by technical limitations. It will take a combination of stakeholders to identify and overcome these barriers to ensure that EVs and charging infrastructure is ready for the future.

III. Leveraging Public Fast-Charging Installations

As it becomes increasingly clear that drivers expect to be able to fully charge their EVs quickly and conveniently, fast-charging installations are getting faster, larger and more complex. As opposed to early installations that might have a single 50kW plug, newer fast-charging installations are expected to provide 150kw or even 350kw capacity and include a half-dozen plugs. These fast-charging installations more often are incorporating on-site solar or wind generation and battery storage, primarily to reduce utility demand charges.

These large fast-charging installations with 1MW+ of load, onsite generation and integrated storage increasingly resemble micro grids that could provide a range of benefits beyond charging electric vehicles. These installations could provide grid benefits and strengthen the resilience of local communities during emergencies. For example, these installations could be used to charge emergency vehicles, pump liquid fuel, support key infrastructure like hospitals or for other critical needs. However, current market participants generally are not pursuing these opportunities. More work needs to be done to identify and document the benefits of these fast-charging “micro grids.” Some combination of stakeholders then will need to work together to plan and implement strategies to maximize these benefits.

IV. Engaging Consumers

Cost competitiveness alone will not be enough to drive consumers to shift to a dramatically new product, particularly with an emotionally charged purchase like a car. It will take a range of dedicated marketing and educational initiatives, from traditional marketing to social media to providing convenient opportunities to test-drive EVs. At a minimum, consumers need credible information about electric vehicles and electric vehicle charging. Recent research shows that most consumers – even in high penetration markets like California – are unaware of the growing number of EV makes and models or the increasing availability of public charging facilities.[24]

No single entity currently owns the responsibility for this educational work, or for rigorous analysis of which interventions are most cost-effective. Individual automakers are focused on selling their own models, and EVs are not yet profitable. Some argue that electric utilities are in the best position to motivate massive numbers of consumers. This argument is based on the belief that electric utilities have much to gain from increased electricity sales, and because, as previously noted, utility customers want them to take a leadership role in encouraging a shift toward electric transportation.[25] However, dozens of utilities in Oregon acting independently and across service territories are unlikely to produce a collaborative communication strategy. Therefore, public-private partnerships will be critical to accelerate market transformation.

V. Encouraging Heavy-Duty Electrification

Electrification and ACES disruptions also are impacting a range of transportation modes and vehicles beyond private passenger cars. Electric transit buses increasingly are cost-competitive, for example, and systems in Los Angeles, Seattle and ten other global cites have pledged to go 100 percent electric with their transit fleets.[26] Electric school buses currently are being tested in several districts around the country, and like transit buses, are quickly reaching price parity. Forklifts, yard haulers, bucket trucks and other kinds of industrial equipment increasingly are being electrified to capture fuel savings, reduce health and environmental impacts and promote safety (for example, quiet electric motors safeguard against miscommunication between workers). More recently, Daimler Trucks and other companies have launched initiatives to compete with Tesla for producing electric, automated long-haul trucks.

Heavy-duty electric vehicles tend to use far more electricity than passenger cars, to operate on more predictable duty cycles, and to be managed by a smaller number of commercial or industrial enterprises. These characteristics make them even more attractive than passenger cars for the kind of managed or smart charging programs discussed previously. These vehicles also create opportunities to broaden economic and other benefits of transportation electrification to reach more communities. For example, electric mining and industrial equipment can reduce manufacturing costs; electrified and semi-autonomous agricultural equipment can reduce cost for labor-intensive agricultural producers like nurseries; and electrifying buses can improve health outcomes for low-income populations.

So far, both public policy and utility programs in Oregon have focused more on passenger vehicles than on heavy-duty vehicles.[27] More work is needed to promote and support investment in heavy-duty electrification, to evaluate the return on investment, to develop and promote financing tools, and to share the results of pilots with others.

VI. Fostering Equity

Electric and advanced mobility technologies will tend to flow first toward their most profitable applications, not necessarily toward the ones where they are most needed, will save the most energy or yield the most utility system benefits. Low income and traditionally underserved communities tend to suffer the most from the health impacts of air pollution, as well as the economic impacts of limited mobility options. For most families, transportation is the second highest household expense. For rural and low-income families, it is often the first. Furthermore, low-income families tend to rely on older, less efficient vehicles and often live further from job opportunities. Low income consumers also face multiple barriers to adopting new technology, from limited access to credit, higher likelihood of living in apartments or remote locations where charging is difficult, and a lack of culturally appropriate marketing.

Electric vehicles could save more energy, and provide social and utility benefits, if low-income consumers can gain access to them. However, it is not clear how different stakeholders will work together to achieve this goal. For example, many utility regulatory filings simply agree that 10 to 20 percent of charging installations must be placed in low-income communities and neighborhoods. That is inefficient and can even be counterproductive, by simply speeding gentrification without benefit to current residents. A number of pilot projects are demonstrating models that could be replicated, but these all rely on third party financing (e.g. from state carbon offset funds in California, or foundation funds in Oregon) and are generally driven by nonprofit organizations.

Hydrogen Fuel Cell Electric Vehicles

Fuel cell buses have been available for some time, and fuel cell cars have become available for individual purchase in California and select other markets in the past few years. Fuel cell electric vehicles can be thought of as a specialized form of electric vehicle that uses hydrogen (rather than a battery) for energy storage.[28] Hydrogen has the advantage of providing more energy density and range, but hydrogen-fueling infrastructure is expensive (several million dollars per station) and presents an even larger challenge than electric car charging, since there are no options for home fueling.

Just as the technology used to produce electricity has a substantial impact on the net energy and climate benefits of battery electric cars, the methods used to produce hydrogen are key to evaluating fuel cell vehicles. Much of the current hydrogen being used for vehicles is produced from natural gas, with few efficiency benefits. Longer term, however, hydrogen could be produced from otherwise surplus renewables, or from renewable natural gas. [29] This could potentially be stored directly in the natural gas infrastructure. Pilots are underway in Germany, California and Ontario, with early work underway to develop a pilot in the Pacific Northwest.

Many automakers view fuel cells as part of the long-term strategy for fully decarbonizing transportation, and some are more bullish on the technology. However, dropping battery prices has made battery-electric and plug-in hybrid vehicles the frontrunner technologies in the short term. Automakers are prepared to bring hydrogen vehicles to Oregon as soon as the fueling infrastructure is available. However, no entity yet has stepped forward to invest in that infrastructure, and therefore the path forward remains unclear.

Natural Gas Vehicles

Natural gas, typically in compressed form, is another prominent alternative to gasoline or diesel. For some time, compressed natural gas has been the best alternative fuel for heavier or medium duty vehicles, which would otherwise burn large quantities of diesel. Natural gas has been quite cost-competitive recently due to relatively low prices, and can reduce greenhouse gas emissions and air pollution substantially. The currently available Cummins Westport "Near Zero" engine reduces air pollution by 90 percent compared to diesel, for example. Like electric vehicles, natural gas vehicles also offer resiliency benefits to fleets and local communities, and tend to keep more resources circulating in local economies.

While the infrastructure to compress natural gas and fuel vehicles has been slow to develop, and has served as a barrier to wider adoption, recent innovations have created disruption and opportunity. First, Oregon startup company Onboard Dynamics has developed a portable compressor that reduces costs[30] and produces renewable natural gas as a byproduct of organic sources (e.g. from digesters at waste water treatment plants, dairy farms, food waste, etc.). This example offers a promise of carbon-negative emissions. Furthermore, this fall, the Oregon Department of Energy is expected to release a study evaluating the quantity of renewable natural gas available, barriers to its development, and recommendations for the future. On the policy front, gas utilities such as NW Natural and utility regulators have begun to engage more significantly to support adoption of natural gas vehicles.

About Energy Trust of Oregon

Energy Trust of Oregon is an independent nonprofit organization dedicated to helping utility customers benefit from saving energy and generating renewable power. Our services, cash incentives and energy solutions have helped participating customers of Portland General Electric, Pacific Power, NW Natural, Cascade Natural Gas and Avista save on energy bills. Our work helps keep energy costs as low as possible, creates jobs and builds a sustainable energy future.

Terminology and Definitions

ACES- Autonomous, connected, electric, and shared vehicles.

EV – Electric Vehicle. A vehicle that uses one or more electric motors for propulsion.

BEV - Battery Electric Vehicle—also referred to as an all-electric vehicle. A vehicle that solely uses an electric engine for propulsion.

PHEV - Plug-in Hybrid Electric Vehicle. A vehicle that contains both an ICE engine and an electric engine, which can be recharged by plugging it into an external power source.

ICE – Internal Combustion Engine. An engine that heats a fuel with air to cause a reaction that creates a force that moves a vehicle over a distance. A traditional gas-powered car is considered an ICE vehicle.

ZEV – Zero-Emissions Vehicle. A vehicle that emits no emissions - which are generally carbon dioxide, water and nitrogen. A BEV, like the Nissan Leaf, would be considered a ZEV.

Fuel Cell Electric Vehicle (FCEV) – A type of electric vehicle that uses fuel cell technology. Fuel cells convert chemical energy from a fuel into electricity (usually from a reaction of Hydrogen with Oxygen.)

Level 1 AC Charging – The slowest form of charging, which uses a plug to connect the vehicle to a standard household 120V outlet at 1.4 or 1.9 kW and uses the on-board vehicle charger to convert AC to DC power to charge the car battery.

Level 2 AC Charging –Uses EVSE to provide power using a 240V outlet up to 19.2 kW and uses the on-board vehicle charger to convert AC to DC power to charge the car battery.

DCFC – Direct Current Fast Charge –also called Level 3 charging. This is the fastest form of charging, as it bypasses on-board charging. Not available for residential use.

EVSE - Electric vehicle supply equipment. A unit that supplies electricity to recharge an EV. (Also called a charger, although this is a misnomer as it is truly just a means by which electricity flows from the outlet to the EV.)

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[1] Oregon Global Warming Commission. *Oregon Global Warming Commission Biennial Report to the Legislature 2017.* https://www.eia.gov/state/?sid=OR#tabs-2

Energy Information Administration, *Oregon State Profile and Energy Estimates* https://www.eia.gov/state/?sid=OR#tabs-2

[2] Oregon Global Warming Commission. *Oregon Global Warming Commission Biennial Report to the Legislature 2017,* https://www.eia.gov/state/?sid=OR#tabs-2

[3] http://www.ktvz.com/news/oregonians-have-few-complaints-about-the-gas-they-buy/694859648

[4] January 25, 2016. Northwest Energy Coalition. Building "Good Load" to Reduce Carbon Emissions: Getting Northwest Utilities More Involved in Widespread Transportation Electrification. http://nwenergy.org/featured/nw-energy-coalition-issue-paper-weighs-benefits-and-opportunities-for-vehicle-electrification/

[5] January 25, 2016. Northwest Energy Coalition. Building "Good Load" to Reduce Carbon Emissions: Getting Northwest Utilities More Involved in Widespread Transportation Electrification. http://nwenergy.org/featured/nw-energy-coalition-issue-paper-weighs-benefits-and-opportunities-for-vehicle-electrification/

[7] See e.g. Morgan Stanley analysis at http://linkback.morganstanley.com/web/sendlink/webapp/BMServlet?file=e72626n0-3pka-g002-b8c7-005056013600&store=0&d=1&user=ded82hm7bu07c-2&__gda__=1601757194_55d7b23ee93236041c022c4c70eacdf9#0001&ded82hm7bu07c-0&1601757194_c1c3530231514a8ac2e1c78bdf76871f&0011&ded82hm7bu07c-1&1601757194_45a5104d280513428eb57e473a5220c0

[8] *May, 2015.* National Rural Electric Cooperative Association (NRECA). *Managing the Financial and Grid Impacts of Plug-In Electric Vehicles. https://www.cooperative.com/public/bts/energy-efficiency/Documents/Managing%20the%20Financial%20and%20Grid%20Impacts%20of%20Plug-In%20Electric%20Vehicles%20%E2%80%93%20May%202015.pdf*

[9] *August, 2013.* Southern California Edison. *Charged Up: Southern California Edison's Key Learnings about Electric Vehicles, Customers, and Grid Reliability. http://newsroom.edison.com/internal_redirect/cms.ipressroom.com.s3.amazonaws.com/166/files/20136/SCE-EVWhitePaper2013.pdf*

[10] October, 2014. California Transportation Electrification Coalition (CalETC). *California Transportation Electrification Assessment; Phase 2: Grid Impacts.* http://www.caletc.com/wp-content/uploads/2016/08/CalETC_TEA_Phase_2_Final_10-23-14.pdf

[11] November, 2017. Ceres. Accelerating Investment in Electric Vehicle Charging Infrastructure. https://www.ceres.org/resources/reports/accelerating-investment-electric-vehicle-charging-infrastructure

[12] November, 2011. Edison Electric Institute (EEI). *The Utility Guide to Plug-in Electric Vehicle Readiness.* http://www.eei.org/issuesandpolicy/electrictransportation/Documents/EVReadinessGuide_web_final.pdf

[13] October, 2014. California Transportation Electrification Coalition (CalETC). *California Transportation Electrification Assessment; Phase 2: Grid Impacts.* http://www.caletc.com/wp-content/uploads/2016/08/CalETC_TEA_Phase_2_Final_10-23-14.pdf

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[14] 2014. Washington State Department of Transportation. Washington EV Action Plan. http://www.wsdot.wa.gov/NR/rdonlyres/28559EF4-CD9D-4CFA-9886-105A30FD58C4/0/WAEVActionPlan2014.pdf

[15] Department of Energy. E Gallon. https://energy.gov/maps/egallon

[16] September 2012. Plug-in Electric Vehicle Deployment in California: An Economic Jobs Assessment. http://www.caletc.com/wp-content/uploads/2016/08/Economic-Jobs-Assessment-Exec-Summary.pdf

[17] See e.g. September 2017, Driving the Market for Plug-in Vehicles - Understanding Financial Purchase Incentives. https://phev.ucdavis.edu/wp-content/uploads/2017/10/Purchase-Incentives-Policy-Guide-No-CW-Logo.pdf

[18] Electrify America, https://www.electrifyamerica.com/our-plan

[19] May 3, 2017. Institute for Transportation and Development Policy. Three Revolutions in Urban Transportation https://www.itdp.org/publication/3rs-in-urban-transport/

[20] http://www.detroitchamber.com/wp-content/uploads/2012/09/AutofactsAnalystNoteUSFeb2013FINAL.pdf

[21] May 3, 2017. Institute for Transportation and Development Policy. Three Revolutions in Urban Transportation https://www.itdp.org/publication/3rs-in-urban-transport/

[22] October, 2016. Rocky Mountain Institute. Driving Integration. https://www.rmi.org/wp-content/uploads/2017/04/eLab_driving_integration.pdf

[23] Green Car Reports, http://www.greencarreports.com/news/1112362_electric-cars-and-public-charging-hot-dog-and-bun-not-chicken-or-egg

[24] UC Davis, https://its.ucdavis.edu/blog-post/automakers-policymakers-on-path-to-electric-vehicles-consumers-are-not/

[26] October, 2017. Electrek. 12 major cities pledge to only buy all-electric buses starting in 2025. https://electrek.co/2017/10/23/electric-buses-12-major-cities-pledge-2025/

[27] With the exception of at least one of PGE's proposals under Senate Bill 1547, which is with TriMet. (E. Prause, Oregon Public Utility Commission, personal communication, February 14, 2018)

[28] General information on fuel cell vehicles at https://www.afdc.energy.gov/fuels/hydrogen_stations.html and https://cafcp.org/

[29] Department of Energy. H2@Scale. https://energy.gov/eere/fuelcells/h2-scale

[30] https://www.onboarddynamics.com/